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MANUAL

For Welding Inspectors

Fourth Edition

American Welding Society

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Preface

In 1976, the American Welding Society (AWS) introduced a much-needed certification program, specifically for those individuals who perform visual welding inspection. Shortly thereafter, the AWS Qualification and Certification Committee initiated the development of a publication that could serve as a valid reference for those individuals interested in becoming a Certified Welding Inspector. Prior to the initial publication of the *Certification Manual for Welding Inspectors* in 1977, relevant information on the subject could be found scattered among various documents.

Numerous changes have occurred both in the AWS Certified Welding Inspector program and examination and in the technology related to welding inspection. Consequently, AWS sought to update the information contained in the Certification Manual. Much of the information contained herein is drawn from other AWS publications, including *Welding Inspection*, Second Edition, *Welding Inspection Technology*, AWS B1.11, *Guide for the Visual Examination of Welds*, and AWS B1.10, *Guide for the Nondestructive Examination of Welds*. The reader is encouraged to review these and other documents for even more detailed descriptions of much of the information contained in this new edition.

Welding inspectors are employed in a variety of industries. As a result, their duties will differ somewhat from one situation to the next. This book has been developed under the assumption that a welding inspector will be performing quality control duties of a general nature. Some inspectors, for example, may be working at a field construction site where they are in charge of overall welding quality. At the other extreme, in a large organization, a quality assurance department may make many of the decisions that the manual assigns solely to the inspector. The welding inspector will always perform a key role. The individual inspector's specific role in the quality control activity must, therefore, mesh with many other activities and personnel, as outlined in the pages which follow.

In this fourth edition, there has been an attempt to update the technical information, where appropriate. One of the areas where readers of previous editions will note changes is in the terminology used for describing various weld characteristics. There is an ongoing effort to use standard terminology when talking about welding operations and related weld characteristics. Questions appear at the end of each chapter. The questions have been included to provide those individuals who are preparing for the CWI examination with numerous examples of the types of questions that appear on the test. The questions appear in the same format (multiple choice with five options) as the questions on the CWI examination. While this is intended to specifically aid those studying for the test, it should also be beneficial to others from the standpoint of improving their comprehension of the information presented in the text. An Answer Key for all chapters appears in Annex C.

I hope this presentation will prove helpful to those interested in becoming welding inspectors and eventually becoming an AWS Certified Welding Inspector. The job of welding inspector is a tremendously challenging and important one, and those seeking the CWI qualification should be commended and encouraged. My desire is that this book will assist in reaching that goal.

Eugene G. Hornberger
Welding Consultant

CHAPTER 1

The Welding Inspector

Contents

Chapter 1—The Welding Inspector

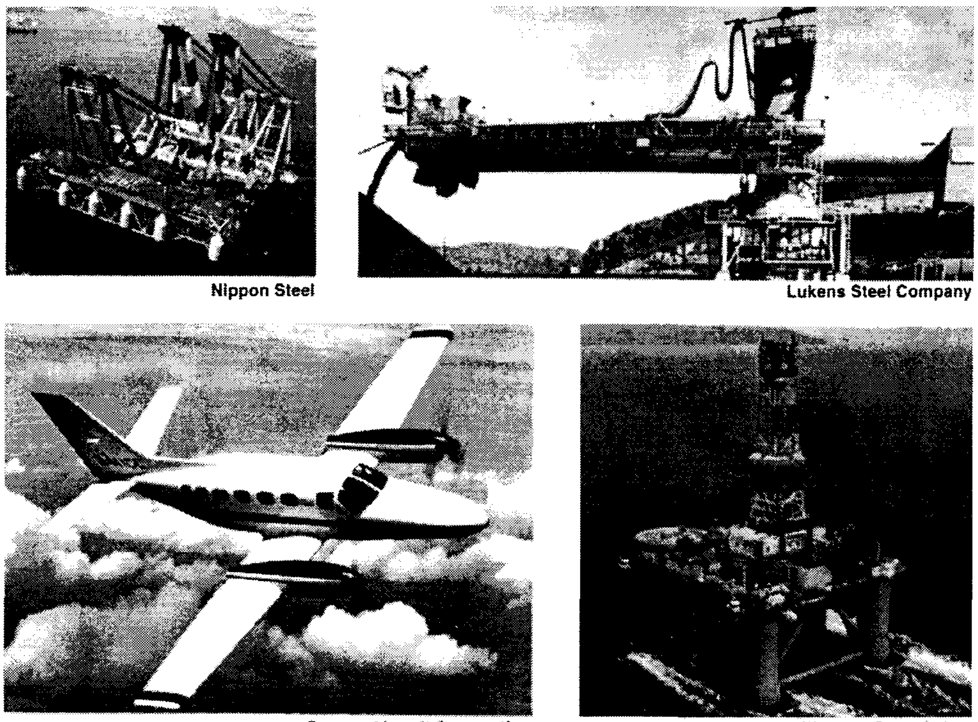
Introduction

Welding inspectors function as quality representatives of organizations that may be a manufacturer, purchaser, insurance company, or government agency. The inspector is responsible for judging the acceptability of a product according to a written specification. The inspector must understand both the limitations and intent of the specification. The goal of the welding inspector is to strive for the required quality, but not to delay completion and delivery schedules without proper cause.

Welding inspectors find themselves working in dozens of different industries, with each situation having slightly different job responsibilities. Among those industries employing welding inspectors are energy production, chemical processing, petroleum product refining and distribution, transportation, and bridge and building construction (see Figure 1.1).

The welding inspector is a composite person—a highly qualified specialist in the field of welding. Welding inspectors can be classified as:

- Code or governing agency inspector



Nippon Steel

Lukens Steel Company

Cessna Aircraft Corporation

Western Oceanic Inc.

Figure 1.1—Industries Utilizing Welding Inspectors

- Purchaser's, customer's, or owner's inspector
- Fabricator's, manufacturer's, or contractor's inspector
- Architect's or engineer's inspector

Inspectors working in small welding fabrication, construction, or erection shops are often required to be more versatile than those working in larger industries. An inspector working in a small shop may be the receiving inspector, in process inspector, and final inspector. In fact, the inspector may be a one-man Quality Control Department. An inspector working in these situations must be knowledgeable in all facets of welding inspection.

Even though the in-house inspector may have different duties from the outside inspector, only a single inclusive category of inspector is considered within this manual. The content of this manual may sometimes apply to all the categories above or be limited to one or more of them. In all cases, however, the inspector has the necessary qualifications and is competent to make the examinations appropriate for the type of weldment being inspected.

Important Qualifications for the Welding Inspector

For a person to become a welding inspector, there are a number of important qualifications. Any person who wishes to do their inspection job conscientiously and professionally must take these qualifications seriously.

Physical Condition

A welding inspector must be active and in good physical condition. Inspection requires examination before, during, and after fabrication; therefore, climbing around large fixtures and assemblies may be a job requirement. Inspection conditions are frequently difficult, since work may be positioned for the convenience of welders and welding operators, but not necessarily for the inspector.

Short of unnecessary endangerment, the inspector must be able to see the weld to perform the visual inspection. Inspecting completed welds in the shortest possible time requires the same means of access to the weld that the welder had.

Vision

Good vision is vital. The ability to examine weld surface conditions and judge their acceptability according to written quality requirements are the primary functions of a welding inspector. An American Welding Society (AWS) Certified Welding Inspector (CWI) is required to have 20/40 vision, as determined by corrective eye charts, and Jaeger J-2, at 12 in. near-vision acuity, with or without corrective lenses. The required eye examination may also include a color perception test for red/green and blue/yellow differentiation; however, color perception for most visual welding inspection jobs is not a requirement. According to AWS QC1, *Standard for AWS Certification of Welding Inspectors*, *"It is the employer's responsibility to determine and enforce any color perception requirement."*

Professional Attitude

It is extremely important that the welding inspector maintain a professional attitude. Attitude determines the degree of success or failure. Success will be dependent upon the cooperation of associates in all departments, and the welding inspector must have their respect to obtain their help. It is important that the welding inspector strive to remain impartial and be consistent in all decisions. The inspector should develop a definite system for inspection procedures, and maintain an attitude of being neither stubborn nor readily swayed by arguments. Under no circumstances may the welding inspector seek favor or incur obligation through personal or pending decisions.

Knowledge of Welding and Inspection Terminology

The improper use of welding terminology by a welding inspector could create an embarrassing situation if such use became apparent to others in job-related conversations. Consequently, the welding inspector must know and correctly communicate the language of welding. The job of welding inspector requires communication of findings to the shop personnel who create the welds and make repairs, and the engineers who plan the work and accept the final structure. The vocabulary used in speaking and writing must be in terms understandable to all levels of personnel involved.

Inspectors should review the latest edition of AWS A3.0, *Standard Welding Terms and Definitions*, which provides AWS-approved terminology used to describe the various aspects of welding. It is advisable that welding inspectors study and consult this standard until the terms become part of their natural vocabulary.

This manual describes the types of joints and welds, parts of welds, and weld application terminology (Chapter 5); terminology related to destructive testing (Chapter 8) and nondestructive examination (Chapter 12); names and descriptions of weld and base metal discontinuities (Chapter 11); terms related to welding metallurgy (Chapter 7); and terminology related to various welding processes (Chapter 10).

Knowledge of Drawings and Specifications

An inspector must be familiar with engineering drawings and able to understand specifications. Welding inspectors must be able to read and understand blueprints and drawings and must know welding and nondestructive examination symbols. It is not necessary to memorize the various standards and specifications that may be in effect; however, the welding inspector should be familiar with the contents of these documents so that information can be quickly referenced.

Knowledge of Testing Methods

Numerous destructive and nondestructive examination methods are available for use in determining whether a base metal, weld metal, and/or a weldment meets certain specification requirements. Although others may perform the testing, the welding inspector must be aware of test basics, including: application technique, obtainable information, and the advantages and limitations of the method.

The welding inspector must also be certain that the technicians performing nondestructive examination (NDE) have the proper credentials, and the inspector must be familiar enough with the method to determine if the test results obtained meet prescribed requirements.

Ability to Produce and Maintain Records

A welding inspector should be able to develop and maintain inspection records and write concise, accurate reports. The reports should be simple and understandable to anyone familiar with the project. At the same time, reports should be thorough enough so that the reasoning behind decisions will remain clear months or years after completion of the project. It is important to remember that well-known facts at the time of the writing often are not remembered as clearly, completely, or accurately at a later date. Records should include not only all results of inspections and tests, but also supporting records relating to welding procedures, welder qualifications, drawing or specification revisions, etc. Good records also protect the welding inspector's reputation.

Knowledge of Welding Processes

Since the welding inspector spends the major portion of his time evaluating welds, knowledge of the various welding processes is essential. Further, actual experience as a welder or welding operator is valuable to a welding inspector, but is not mandatory. Welding experience broadens the inspector's welding knowledge, commands respect, and gives his opinions more credibility when weld quality is being evaluated. Some employers require actual welding experience as a prerequisite to becoming a welding inspector; however, welding experience is not a prerequisite to certification as an AWS Senior Certified Welding Inspector (SCWI), Certified Welding Inspector (CWI), or Certified Associate Welding Inspector (CAWI). The inspector who is familiar with the advantages and limitations of the various welding processes is able to identify problems when, or even before, they occur.

Ability to be Trained

To be considered effective, welding inspectors are expected to possess expertise in a number of different areas, and the ability to be trained in areas of unfamiliarity. Many employers select potential welding inspectors based on their ability to study and gain the necessary knowledge. Training in fundamental engineering can be applied as partial satisfaction of the experience requirements for becoming a CWI. AWS QC1 outlines these limits for the CWI program.

Inspection Experience

The attitude and point of view of a good inspector is acquired only through inspection experience. Even experience in inspecting non-welded materials is extremely helpful in the inspection of weldments, since a good inspector has developed a distinct way of thinking and working. Those "learning the ropes" should observe the behavior and techniques of experienced inspectors.

To comply with the experience requirement for AWS certification, the welding inspector must show evidence of having performed the functions of a welding inspector. Other job functions that have a close relationship to welding inspection also provide this evidence. Periods of qualifying experience are counted by the actual number of calendar months employed at jobs (not the number of employers). The jobs must have a close relationship to fabrication of weldments according to a code, standard, or specification, and directly involve one or more of the following:

- **Design.** Preparation of plans and drawings for weldment construction/fabrication.
- **Production.** Planning and control of welding materials, welding procedures, and welding operations for weldment fabrication.
- **Construction.** Fabrication and/or erection of weldments.

- **Inspection.** Detection and measurement of weld discontinuities; verification of fabrication requirements.
- **Repair.** Repair of defective welds.

Section 5 of AWS QC1 contains the requirements for the three levels of certification: SCWI, CWI, and CAWI.

Ethical Requirements for the Welding Inspector

Introduction

This manual describes the technical methods, procedures, processes, and functions of the welding inspector. However, effective weld inspection requires not only the performance of duties consistent with the specification requirements, but also the practice of professional conduct and ethical principles. What follows is the "Code of Ethics" for welding inspectors, which is included in AWS QC1. Consult the latest edition for the most recent requirements.

Preamble

To safeguard the public's health and well-being and to maintain integrity and high standards of skills, practice, and conduct in the occupation of welding inspection, the AWS SCWIs, CWIs, and CAWIs shall be cognizant of the following principles and the scope to which they apply, with the understanding that any unauthorized practice is subject to the AWS Qualification and Certification Committee's review and may result in suspension, reprimand, or revocation of certification.

Integrity

The SCWI, CWI, and CAWI shall act with complete integrity (honesty) in professional matters and be forthright and candid with the Committee or its representatives on matters pertaining to AWS QC1.

Responsibility to the Public

The SCWI, CWI, and CAWI shall act to preserve the health and well-being of the public by performing the required weld inspection duties in a conscientious and impartial manner, to the full extent of the inspector's moral and civic responsibility and qualification. Accordingly, the SCWI, CWI, and CAWI shall:

- Undertake and perform assignments only when qualified by training, experience and capability.
- Present credentials upon request.
- Neither falsely represent current status nor seek to misrepresent certification level (SCWI/CWI/CAWI) by modifying certification documents or giving false verbal or written testimony of current level or status.
- Be completely objective, thorough, and factual in any written report, statement or testimony of the work and include all relevant or pertinent testimony in such communiqués or testimonials.
- Sign only for work the inspector has inspected or has personal knowledge of through direct supervision.
- Neither associate with nor knowingly participate in a fraudulent or dishonest venture.

Public Statements

The SCWI, CWI, or CAWI shall issue no statements, criticisms, or arguments on weld inspection matters connected with public policy that are inspired or paid for by an interested party, or parties, without first identifying the party and speaker, and disclosing any possible financial interest.

The SCWI, CWI, or CAWI shall publicly express no opinion on welding inspection subjects, unless such opinion is founded upon adequate knowledge of the facts in issue, possession of a background of technical competence pertinent to the subject, and having an honest conviction as to the accuracy and propriety of the statement.

Conflict of Interest

The SCWI, CWI, or CAWI shall avoid conflict of interest with the employer or client and will disclose any business association or circumstance that might be so considered.

The SCWI, CWI, or CAWI shall not accept compensation, financial or otherwise, from more than one party for services on the same project, or for services pertaining to the same project, unless the circumstances are fully disclosed and agreed to by all interested parties or their authorized agents.

The SCWI, CWI, or CAWI shall not solicit or accept gratuities, directly or indirectly, from any party or parties dealing with the client or employer in connection with the SCWI's, CWI's, and CAWI's work.

The SCWI, CWI, or CAWI shall, while serving in the capacity of an elected, retained, or employed public official, neither inspect, review, nor approve work in the capacity of SCWI, CWI, or CAWI on projects also subject to the inspector's administrative jurisdiction as a public official, unless this practice is expressly dictated by a job description and/or specification, and all effected parties to the action are in agreement.

The Solicitation of Employment

The SCWI, CWI, or CAWI shall neither pay, solicit, or offer, directly or indirectly, any bribe or commission for professional employment, with the exception of the usual commission required from licensed employment agencies.

The SCWI, CWI, or CAWI shall neither falsify, exaggerate, nor indulge in the misinterpretation of personal academic and professional qualifications, past assignments, accomplishments, and responsibilities, or those of the inspector's associates. Misrepresentation of current SCWI/CWI/CAWI certification status at the time of, or subsequent to, submission of requested employment information or in the solicitation of business contracts wherein current certification is either required or inherently beneficial (advertisements for training courses, consulting services, etc.) shall be a violation of this section.

The SCWI, CWI, or CAWI credentials may only be used for the field of welding inspection. AWS has not qualified those individuals for non-welding inspection.

CAUTION

Although the CWI may have established excellent credentials, certification alone may not legally qualify the inspector to provide inspection services to the public. Contract documents, building or jurisdiction laws may require that inspection be performed under the direction and responsibility of others, such as a registered Professional Engineer (P.E.).

Unauthorized Practice

Any violation of any part of the standard of conduct prescribed by AWS QC1 if related to a SCWI's, CWI's, or CAWI's occupation, including any violation of the Code of Ethics contained in AWS QC1, shall constitute an unauthorized practice that is subject to the imposition of sanctions.

Establishing Lines of Communication

The welding inspector must possess the physical, technical, and ethical qualifications mentioned above, as well as the skill of a communicator (see Figures 1.2 and 1.3). The welding inspector's success will be affected by the ability to convey information to others, as well as the ability to understand what others are trying to explain.

Communication can occur in numerous forms, including spoken or written words, pictures, numbers, or gestures. Each provides an effective means of conveying information; however, the inspector should always be cautious regarding verbal communication. It is often important to have verbal communication supported by written information, especially when it relates to changes in the inspection requirements or results.

Any form of communication should be a continuous loop. That is, the receiver should have the opportunity to respond to the sender. Effective communication must be considered as a two-way proposition.

The welding inspector is often the central figure in many fabrication situations; consequently, the inspector must be capable of communicating effectively with many individuals involved in the project. The welding inspector must be able to establish lines of communication with a varied number of associates to accomplish the necessary tasks and responsibilities efficiently and professionally. For example, the associates of a fabricator's inspector will often include the personnel listed below.

Reporting Supervisor

Virtually all welding inspectors report to someone; in some cases, it is the chief inspector. In other situations, it could be the project engineer, a plant manager, an architect, or government official. Regardless of who this individual is, the welding inspector should be able to refer

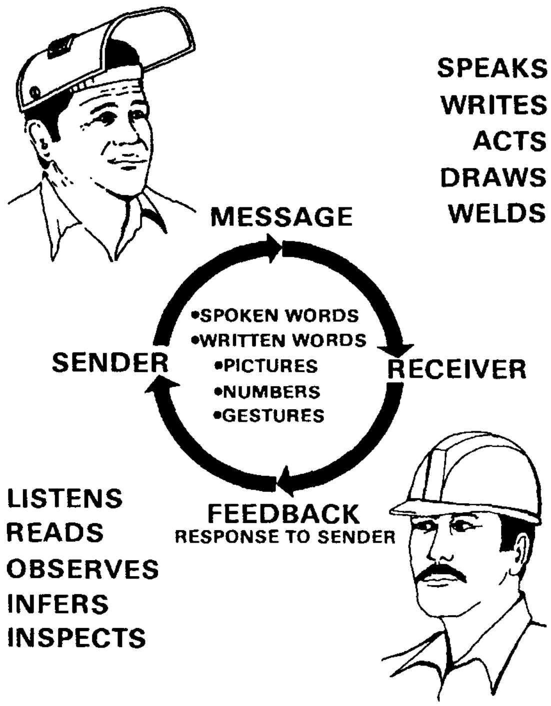


Figure 1.2—The Welding Inspector—A Communicator

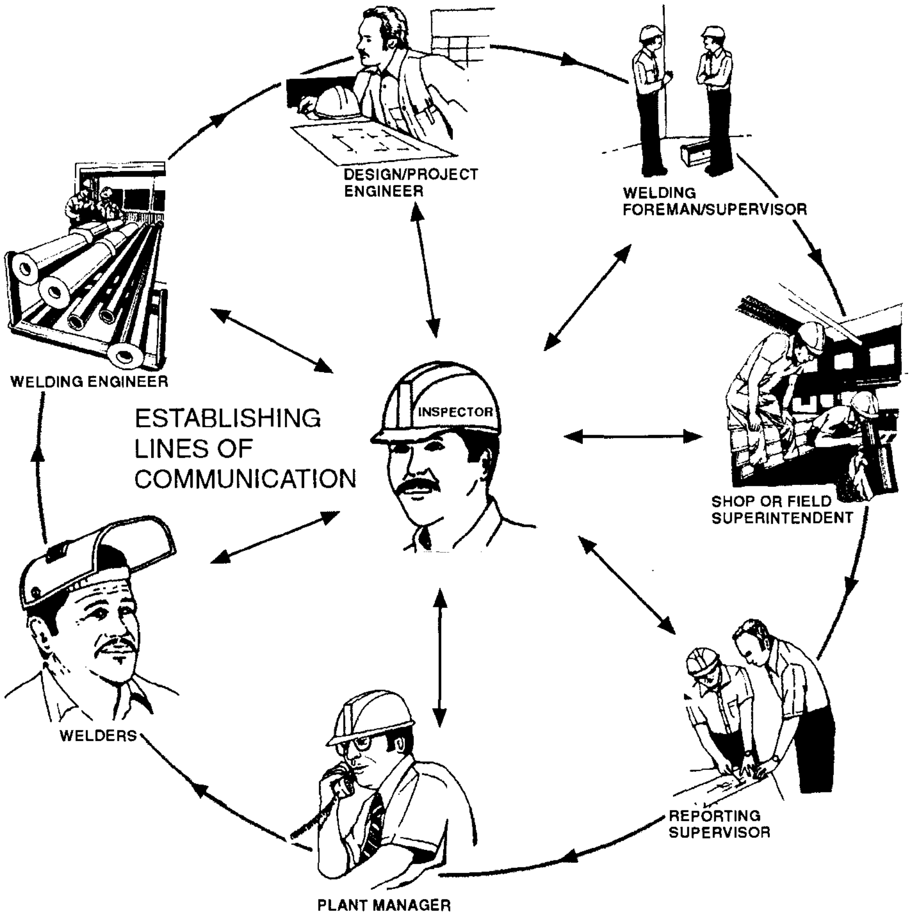


Figure 1.3—Establishing Lines of Communication

questions or job difficulties to their supervisor for answers or guidance. Through direct communication, the supervisor should be able to help the inspector become more knowledgeable about the job and, therefore, more effective.

Welders

The relationship between the inspector and the welder is of utmost importance. The welder often knows which welds are of borderline quality, or where the joint fitup was improper or not as specified. A welder who regards the inspector as an enemy will not be concentrating on making each weld a good one. At any rate, the welder will not be trying to make the inspector's job any easier. In most cases, good rapport between the welder and inspector results in improved quality and higher efficiency, because problems are identified and corrected as they occur, instead of later when repair is costly.

Welding Foremen or Supervisors

The welding foreman or supervisor is highly important to the inspector. When assigned a group of welders who are equally qualified to meet specifications, the foreman will decide which welder is best-suited for the more difficult welding jobs. Both the welding inspector and the foreman should be in agreement as to which welders are considered qualified to produce satisfactory welds.

At times, the fabricator's representative may suggest that the welding inspector tell the welder what the fabricator wants; however, this would make the welding inspector a party to the operation, and perhaps eliminate the fabricator's responsibility to meet the specification requirements. It is important to remember that the inspector's authority extends only to the determination as to whether the weld is acceptable or rejectable. Volunteering unsolicited information may overstep an inspector's responsibility and should, therefore, be limited.

Since supervisors are also concerned with production, some communication must occur to indicate when parts or assemblies will be ready for inspection. After that inspection, the supervisor will need to know if the welding has been found to be acceptable. If rejects are noted, then more communication will be necessary to describe and locate the defect, so that repairs can be accomplished.

Shop or Field Superintendent

It may also be necessary to discuss weld quality matters with the shop or field superintendent, as a result of some aspect of the welding quality having an effect on the overall production schedule of a project. In other cases, the welding inspector may simply have encountered some problem that is beyond the responsibility of the welding foreman or supervisor.

Plant Manager

Communication with the plant manager is much the same as that with the shop or field superintendent. Since plant managers are responsible for production, as well as product quality, they are very concerned about learning what the status of some part may be when it is subjected to inspection. A single rejected weld could result in delays for the entire project. The welding inspector needs to keep the plant manager informed and aware of the acceptability or rejectability of certain items, so that appropriate scheduling can be accomplished.

> A weldment is an assembly whose component parts are joined by welding. A weldment may consist of many pieces and welds or it can be fairly simple with few parts and welds.

Design/Project Engineers

The design engineer is responsible for the details of any welded fabrication. Their intentions are communicated through drawings and specifications. The project engineer is then responsible for the interpretation of these requirements when the work is being performed. The welding inspector may need to communicate with either or both of these individuals regarding these welding requirements. An overview of the job in consultation with the project engineer will reveal any fabrication or inspection tasks that may require additional planning. For example, in a massive, complex weldment, weld sequencing may be necessary to ensure weld soundness and minimized distortion; or modification of some design detail may be needed to facilitate successful fabrication and inspection.

Welding Engineer

The welding inspector should have access to the welding engineer, welding technician, or welding specialist so that possible welding-related construction problems can be brought to the engineer's attention before they become inspection problems. The welding inspector can be thought of as the welding engineer's "eyes" while the welding is being performed. When such an arrangement exists, the welding inspector can communicate with the welding engineer to describe fabrication problems, so that corrective action can be instituted.

Proper communication is important to the inspection process. The welding inspector's primary function is to inspect the fabricator's work to see that it meets the requirements of the contract. The quality of work being accomplished is the substance of the welding inspector's reports. Whether the fabricator takes advantage of this information may depend upon how clearly it has been presented in the report. The fabricator still has full responsibility for the quality of the final product.

Proper communication will allow the welding inspector to keep in touch with the activities of the production organization. Early correction of a fault results in producing a satisfactory product instead of one that would otherwise have to be rejected and subsequently repaired.

Summary

The job of welding inspector requires a wide variety of talents and physical capabilities. The individual must be both mentally and physically prepared for the many tasks at hand. The inspector's day-to-day existence dictates that with proper knowledge and training, the inspector can submit accurate reports, maintain that information for future reference, and act in an ethical manner.

Good welding inspectors are invaluable to a company. When permitted to act as specified by an effective quality control system, the welding inspector often can save a company money by identifying problems when or before they occur, to minimize correction costs.

Review—Chapter 1—The Welding Inspector

Q1-1 Of the following, which is considered an important duty of the welding inspector?
- a. it is a welding inspector's responsibility to judge the quality of the product in relation to some form of written specification
- b. it is a welding inspector's responsibility to monitor welding operations
- c. a welding inspector must be able to interpret the specification requirements
- d. all of the above
- e. none of the above

Q1-2 Of the following, which is not considered an important attribute of a welding inspector?
- a. welding experience
- b. inspection experience
- c. professional attitude
- d. engineering experience
- e. ability to be trained

Q1-3 What document describes the important requirements of the AWS Certified Welding Inspector program?
- a. AWS D1.1
- b. AWS A5.1
- c. AWS QC1
- d. AWS D14.1
- e. none of the above

Q1-4 As a welding inspector, must you know how to weld?
- a. yes, according to AWS D1.1
- b. yes, according to AWS QC1
- c. yes, if inspecting highway bridges
- d. no, according to AWS D1.1
- e. not mandatory, according to AWS QC1

Q1-5 Which of the following are important ethical requirements for the welding inspector?
- a. integrity
- b. professional ability
- c. good physical condition
- d. volunteering public statements regarding an inspection for personal exposure
- e. all of the above

Q1-6 Of those attributes considered to be important in the welding inspector, which is probably most influential in their gaining the cooperation and respect of others with whom they work?
- a. ability to be trained
- b. professional attitude
- c. ability to complete and maintain inspection records
- d. good physical condition
- e. ability to interpret drawings and specifications

Q1-7 The welding inspector is likely to work in which of the following industries?
- a. shipbuilding
- b. automotive
- c. bridge construction
- d. pressure vessel construction
- e. all of the above

Q1-8 According to the requirements of the AWS CWI program, what is the necessary visual acuity of a welding inspector?
- a. 20/20 natural vision
- b. 20/20 corrected vision
- c. 20/40 natural vision
- d. 20/40 corrected vision
- e. 20/40 natural or corrected vision

Q1-9 Which of the following could be considered essential knowledge for a welding inspector?
- a. nondestructive testing
- b. welding symbols
- c. welding processes
- d. destructive testing
- e. all of the above

Q1-10 When a weld requires repair due to some deficiency, to whom should your inspection report be directed?
- a. to the welder whose mark is on the weld
- b. to another welder, better trained
- c. to the project engineer
- d. to the welding engineer
- e. to the welding foreman or supervisor

Q1-11 What professional attributes are most helpful in performing inspection duties?
- a. being informed, impartial, and consistent in your decisions
- b. being close friends with welders and superiors
- c. being a former welder
- d. being a non-union employee
- e. being a nondestructive examination technician (NDE) as well as a CWI

Q1-12 With whom may the welding inspector communicate during the performance of his or her inspection responsibilities?
- a. welding engineer
- b. welding foreman
- c. welders
- d. inspection supervisor
- e. all of the above

Q1-13 What document defines the proper terminology for use by the CWI?
- a. AWS QC1
- b. AWS A3.0
- c. AWS D1.1
- d. AWS A5.1
- e. none of the above

Q1-14 With regard to drawings and specifications, the CWI must:
- a. be familiar with engineering drawings and able to understand specifications
- b. memorize the content
- c. memorize those portions of these documents applicable to a particular job
- d. all of the above
- e. none of the above

CHAPTER 2

Welding Inspector Responsibilities

Contents

Chapter 2—Welding Inspector Responsibilities

Introduction

The welding inspector holds a position of responsibility that requires a professional attitude, good character, ability, and common sense. Since a welding inspector works at various fabrication plants and job sites, strict observance of all rules and regulations—especially those pertaining to personal conduct, safety, and security—is mandatory. The welding inspector should never consider himself entitled to special privileges. In dealing with the fabricating organization, the welding inspector should be impartial, render decisions promptly, and be tolerant of the opinion of others during communications. It is important to remember to rely on the facts when making decisions, and to carefully evaluate differing opinions.

To effectively perform visual inspection, it is necessary to observe as many individual stages of fabrication as possible. Consequently, the various responsibilities of the welding inspector are categorized by *when* they occur; specifically, before, during, and after welding. An example of typical inspection requirements is listed below.

Inspection Responsibilities Before Welding

- Review all applicable drawings and standards.
- Check purchase orders to ensure that base and filler materials are properly specified.
- Check and identify materials as they are received against the purchase specifications.
- Check the chemical compositions and mechanical properties shown on mill test reports against specified requirements.
- Check the condition and storage of filler metals.
- Check the condition and adequacy of equipment to be used.
- Check weld joint edge geometries.
- Check joint fit.
- Check joint cleanliness.
- Check the welding procedures and welder qualifications.
- Check preheat temperature.

Inspection Responsibilities During Welding

- Check welding parameters and techniques for compliance with welding procedure.
- Check quality of individual weld passes.
- Check interpass cleaning.
- Check interpass temperature.
- Verify that in-process nondestructive examination (NDE) is performed, if required.

Inspection Responsibilities After Welding

- Check finished weld appearance.
- Check finished weld sizes and lengths.
- Check dimensional accuracy of completed weldment.
- Select production test samples.
- Evaluate test results.
- Verify that additional NDE has been performed, if required.
- Verify that postweld heat treatment has been done satisfactorily, if required.
- Prepare and maintain inspection reports.

Inspection Responsibilities Before Welding

Knowledge of Drawings and Standards

Drawings, designs, standards, contracts, etc., should be studied in advance so that the welding inspector is aware of the construction details, the proposed use of subassemblies, and the specifics of the welding operation (see Figure 2.1). Note which materials are to be used in the welded structure and whether any of them require special treatment for satisfactory welding. This information should be clearly stated in the standards or welding procedures. If not, the project engineer should be contacted for clarification.

Lincoln Electric Company

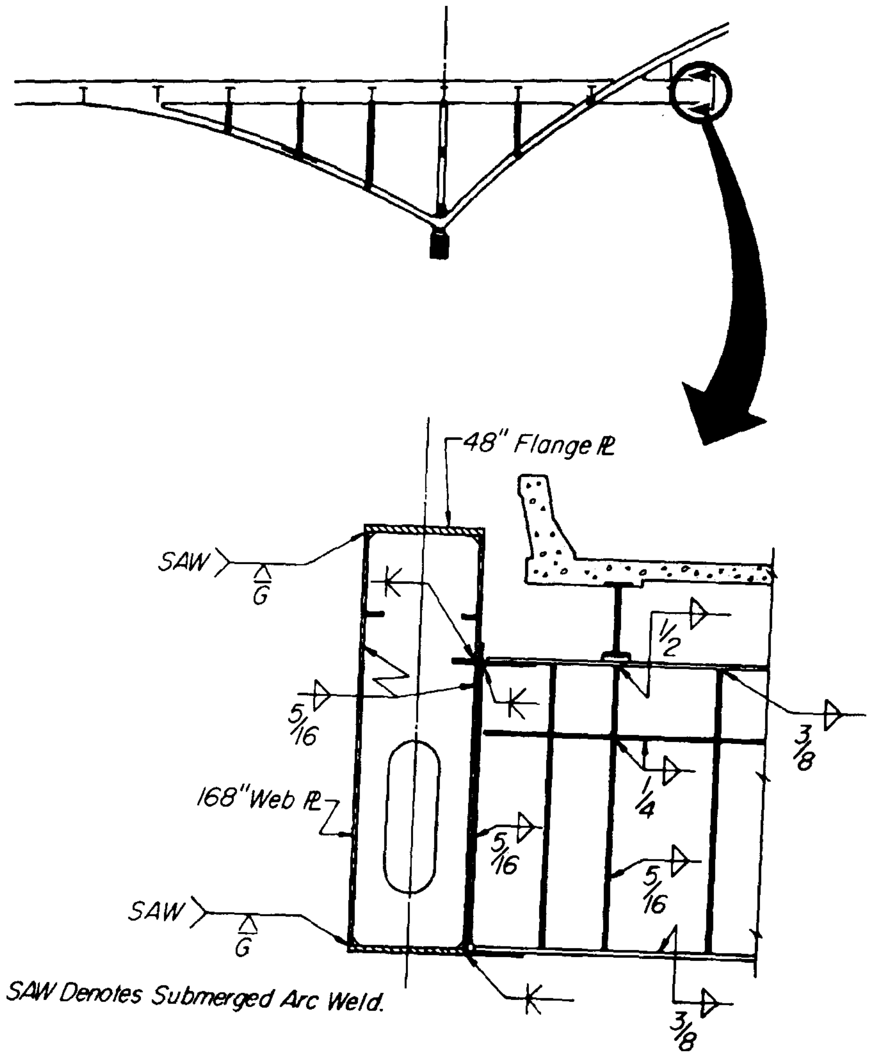


Figure 2.1—Knowledge of Drawings and Standards is Important

The term "Standard" applies collectively to codes, specifications, recommended practices, classifications, methods, and guides that have been prepared by a sponsoring organization and approved in accordance with established procedures. Standards for welding are published in cooperation with the American National Standards Institute (ANSI).

During fabrication of a welded structure or component, the welding inspector may be called upon to interpret drawings or standards on the spot. Prior study of the drawings and design requirements will enhance the inspector's ability to make clear and concise decisions, which in turn, will speed completion of the work under contract, increase the inspector's professional image, and greatly aid in exercising authority.

When situations that require a deviation from the drawing or detailed procedure arise during the fabrication of any structure, it is the welding inspector's responsibility to alert the project engineer or quality assurance (QA) personnel, who will decide whether the deviation in question should be permitted or rejected.

Sometimes, acceptance or rejection of a large welded structure will be involved. It may be the inspector's duty, after careful study, to recommend whether the error can be corrected and whether the method of correction to be used will still ensure a satisfactorily completed product in accordance with the drawings and standards. In all cases, extreme caution should be exercised in accepting deviations. Deviations from drawings should be referred to the design agency for approval. Their approval should be received "*in writing*."

It is not always possible to write an all-inclusive standard containing all the detailed information needed to provide an answer for any question that might arise. If parts of the standard have requirements that are not fully defined, the inspector is often responsible for determining the meaning and intent of that document. Communication with engineering and design personnel may be necessary before responding to a fabricator.

Purchase Specifications Check

The specifications for the job should identify all the materials that will be used, including all consumable material, such as welding electrodes, welding or brazing fluxes, shielding gases, consumable inserts, and backing bars or rings. The inspector should review the purchase order or contract to see that the materials ordered meet the specification requirements. For example, commercial specifications for steel, such as ASTM A 572, frequently include more than one grade of the product, which must be individually identified on the purchase order to obtain the correct grade.

As another example, specifications for welding electrodes, such as AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, cover a dozen or more electrode classifications in one document. In A5.1, the six E70XX electrodes are all equivalent in strength, but they are not interchangeable when low-hydrogen grades are required. If low-hydrogen types are required, either E7015, E7016, E7018, or E7028 must be called out on the purchase order.

Job Material Verification

Since many metals look alike, the potential exists for inadvertent mixups. To prevent mistakes such as these, the inspector must verify upon receipt that the materials supplied match the applicable purchase order, and the material test reports (MTRs) must be checked against the applicable specification (see Figure 2.2). In some cases, additional requirements specify that the proper identification be visibly marked on each piece, preferably at multiple locations. For example, identification will be lost for the rest of the plate, if the first slice cut off by the shop removes the labeled end displaying the grade stamp. Good practice calls for re-marking remnants produced in cutting operations prior to the actual cutting, while the identity is still verifiable.

Identification of low-hydrogen welding electrodes becomes impossible when stockroom clerks prematurely remove electrodes from their containers for storage in holding ovens. The individual electrodes will still bear classification numbers on their coverings (at the stub end); however, the manufacturer's control number appears only on the now-discarded container. In critical work, the manufacturer's control number may be needed for each weld. If this is a requirement, the preferred container for a welding electrode is its original unopened package. An alternative is storage in an electrode oven with an oven map posted on the front of the oven or in another suitable location.

Chemical Analysis and Mechanical Properties Tests

Confirming tests of incoming materials are desirable for many reasons. The number of tests required will depend on the inspector's judgment and past experience, unless everything is specified under quality assurance procedure requirements. The inspector should request tests on representative samples of questionable incoming

CERTIFICATION OF TESTS

RECEIVED MAY 19 1999

AML Q. M.

CUSTOMER TECNIWELD, INC.

PURCHASE ORDER 4563 **DATE SHIPPED** 5-14-99

DESCRIPTION 1 3/4" THK., 10 PCS. 39-1/2 O. D. X 9-5/8 I. D. TEMP
2
3
4

SPECIFICATION: ASTM-A-516 GR. 70 PVQ - FINE GRAIN

PROPERTIES	1	2	3	4
HEAT NO.	91E060			
C	.22			
MN	1.05			
P	.009			
S	.022			
SI	.23			
NI	.02			
CR	.02			
MO	.005			
CU	.02			
V	.004			
YIELD PSI	48.2 KSI			
TENSILE PSI	76.3 KSI			
%ELONGATION	8" = 25.0			
% RED OF AREA				
BEND TEST				

WE HEREBY CERTIFY THAT THE ABOVE MATERIALS HAVE BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATION AND THAT THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THIS COMPANY.

SWORN TO AND SUBSCRIBED BEFORE ME THIS ________ DAY OF ________ 19 ____

NOTARY PUBLIC

JANE DOE
Notary Public, State of Ohio
Recorded in Cuyahoga County
My Commission Expires 2/22/2001

GENERAL STEEL SHEET & PLATE, INC.
ANYTOWN, U.S.A.
By I. B. Manager

Figure 2.2—Typical Example of a Mill Test Report

materials to verify chemical composition and mechanical properties. Where material test reports from reliable suppliers (that is, suppliers accredited through an approved quality assurance program) give assurance of conformance, the welding inspector should ask for check tests when errors are strongly suspected.

Base Metal Defects Investigation

The quality of mill products supplied for a job must equal or exceed the quality specified for the final weldment or structure. Base metals almost always contain many small discontinuities, the impact of which depends on the thickness of the metal, the type of loading, and the criticality of the design. In some instances, these discontinuities may be cause for rejection; while in other similar situations, they may not.

> A discontinuity is an interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.

The welding inspector has the responsibility to see that discontinuities in the base metal are detected, identified, evaluated, and properly repaired, where necessary, so that they will not be incorporated into the welded product. This requires that the inspector be aware of the acceptable limits for these discontinuities. At times, there may be a need to communicate with the responsible engineer in deciding what to do about a major discontinuity.

Some specifications may require that a defective piece be rejected and replaced, unless it can be repaired. In fact, some defects may require rejecting the piece altogether. On the other hand, the specification may permit minor restoration, such as flame straightening of members accidentally bent in shipping or handling. As another example, the presence of laminations will rule out placing a particular plate where it must withstand tensile stresses in the through thickness direction; however, the same plate may be used in a different location with complete safety. Engineering should make that decision. The welding inspector must then inspect any replacement materials.

Condition and Storage of Filler Materials Check

The welding inspector should check the condition of filler metals to be used, especially in the case of shielded metal arc welding (SMAW) electrodes having a flux coating that can be easily damaged. Other types of filler metals that are stored out in the open can also deteriorate with time. For example, solid wire and flux cored electrodes can develop rust, which could then result in the production of porosity in the weld.

After removal from their shipping containers, low-hydrogen-type SMAW electrodes must be stored in electrically heated, vented, and thermostatically controlled storage ovens to maintain their low moisture content (see Figure 2.3).

In addition to these filler metals, some fluxes and flux cored electrodes also require special protection from moisture, such as rain or high humidity. Some submerged arc fluxes even require heated storage containers.

Welding Equipment Check

All welding equipment, including that to be used for testing, should be checked periodically for operational capability, calibration, and safety. For example, always check the ammeters and voltmeters on welding machines, because due to mishandling, shop contamination, and overloads, these meters may not always be accurate. Periodic calibration is recommended.

The equipment should also be checked to make certain it has the necessary output capacity to satisfy the welding procedure requirements. Welding leads, gas hoses, and wire feed apparatus must also be examined to ensure good condition and operability.

Weld Joint Edge Geometry Check

Specific tolerances for weld joint edge geometries are listed in various codes and specifications. The prequalified joints found in AWS D1.1, *Structural Welding Code—Steel*, are typical examples. Inspection responsibilities include examination of the unwelded joint for edge geometry, including root face dimensions and

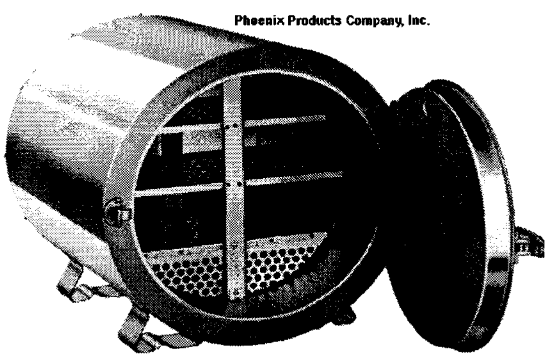


Figure 2.3—Electrode Oven

groove angles. The suitability of the joint for the welding process to be used will be discussed in greater detail in Chapter 6.

Weld Joint Fit Check

When examining the unwelded joint, the welding inspector should also observe the fit of the parts. For butt joints, alignment and root opening are important. It is important to remember that prestressing or cambering may be needed for welds that will be subject to distortion as a result of weld shrinkage stresses. The fabricator should not attempt such welds without the necessary knowledge. Procedure modifications may produce an acceptable weld; however, the welding inspector should offer suggestions to the project engineer, not to the foreman. If the foreman later says, "You told me to do it this way," the inspector may find it difficult to reject an unacceptable weld.

The fit of backing preparations needs particular attention, i.e., backing bars and rings should fit tightly against the pieces to be joined.

Transverse joints between segments of a backing material are undesirable, because they induce cracking in the root pass. For this reason, when welding is performed in accordance with AWS D1.1, steel backing on groove welds is required to be made continuous for the entire length of that backing member.

Weld Joint Cleanliness Check

In welding, the cleanliness of the base metal surfaces in and adjacent to the joint is a critical factor. Welding over contamination such as oil, grease, paint, moisture, rust, etc., will likely result in porosity in the completed weld. In many cases, this contamination could also lead to the occurrence of incomplete fusion, or even cracking. Consequently, it is imperative that the welding inspector check the cleanliness of the weld zone prior to welding.

Welding Procedure Qualification Check

The fabricator must prescribe the details of the welding procedure that will be followed in producing weldments. Welded joints should be produced with acceptable mechanical properties, as required by the particular specification or code. Chapter 9 of this manual describes the basic elements of a welding procedure specification, the reasons for its use, its qualification, and the responsibilities of the welding inspector in verifying proper application of the welding procedure on the job.

Welder Qualification Check

Codes and specifications that apply to the fabrication of weldments usually require qualification of all welders and welding operators. It is the welding inspector's duty to verify that every welder and welding operator who works under the code or specification has been properly qualified in accordance with those requirements. Verification can be made either by witnessing each test, or by reviewing verified test results. It is important for the welding inspector to monitor the welders and welding operators, to ensure that they are working within the scope of their qualifications with respect to such variables as base metal type and thickness, position of welding, welding process, electrode type and size, etc.

Welding codes and specifications generally do not require requalification of procedures, welders, or welding operators for each new contract or design. The welding inspector should review the requirements of the contract specification or code to make this determination. It is important to remember that the main objective of qualification checking is to ensure that procedures and welders or welding operators are adequate for the intended purpose. To be fair to the fabricator and purchaser, the inspector should make every effort to avoid unnecessary qualification tests.

Preheat Temperature Check

Most codes and specifications require that certain materials be preheated prior to welding. In Chapter 6, there is a discussion of reasons why preheat is necessary. For carbon steels, preheat will be required as the base metal alloy content or thickness increases. Most often, preheat temperature is verified using temperature-indicating crayons that are formulated to melt at the temperature noted on their coatings (see Figure 2.4). However, digital contact pyrometers are an effective alternative.

Since preheat is necessary to prevent degradation of the base metal properties during the welding operation, the preheat temperature should be measured 3 in. from the edge of the weld preparation.

Normally, the temperature should be maintained during all welding of the joint. For most carbon steels, the preheat is specified as a minimum. However, for some types of steels, such as quenched and tempered, the preheat temperature is expressed as a range of temperatures having a minimum and maximum value.

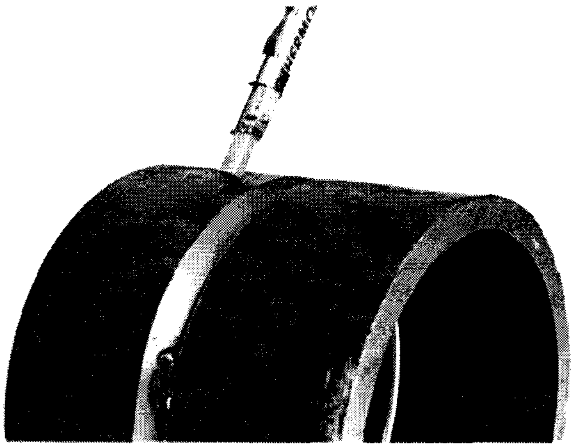


Figure 2.4—Temperature-Sensitive Crayon for Measuring Metal Temperature

Welding Inspector Responsibilities During Welding

To continue ongoing welding quality control, the welding inspector has numerous items to check as the welding process is actually being performed. As was the case for inspections performed prior to welding, checks performed during welding can help to detect problems as they occur, making them easier to correct. During this phase of the fabrication process, the inspector's knowledge of welding is extremely beneficial, since part of the inspection involves evaluation of the actual welding technique, as well as the resulting weld quality. It is unrealistic to expect the welding inspector to observe the deposition of each and every weld pass; therefore, the experienced welding inspector should be able to select those aspects of the welding sequence that are considered to be critical enough to warrant his presence.

Following are some aspects of the visual welding inspection phase.

Check Production Welding for Compliance with Welding Procedure

When conducting inspection during production welding, the inspector must rely on the welding procedure to guide that inspection. This document will specify all important aspects of the welding operation, including welding process, materials, specific technique, preheat and interpass temperature, plus any additional information that describes how the production welding should be performed.

The welding inspector's job is to monitor the production welding to ensure that it is being performed in accordance with the appropriate procedure (see Figure 2.5).

Check the Quality of Individual Passes

One aspect of inspection during production welding is visual examination of the individual weld passes as they are deposited. If necessary, any surface discontinuities can be detected and corrected at this time. It is also important to note any weld profile irregularities that may hinder subsequent welding, e.g., during the welding of a multipass groove weld. If one of the intermediate passes exhibits a very convex profile when deposited—creating a deep notch at its toe—this configuration may prevent a subsequent pass from properly fusing at that location. If noted, the welding inspector could request that grinding be performed at this point, to ensure that thorough fusion is attained on the next pass.

Checking in-process quality is especially critical in the case of root bead. In most situations, this portion of the weld cross section represents the most difficult welding condition, especially in the case of an open root joint.

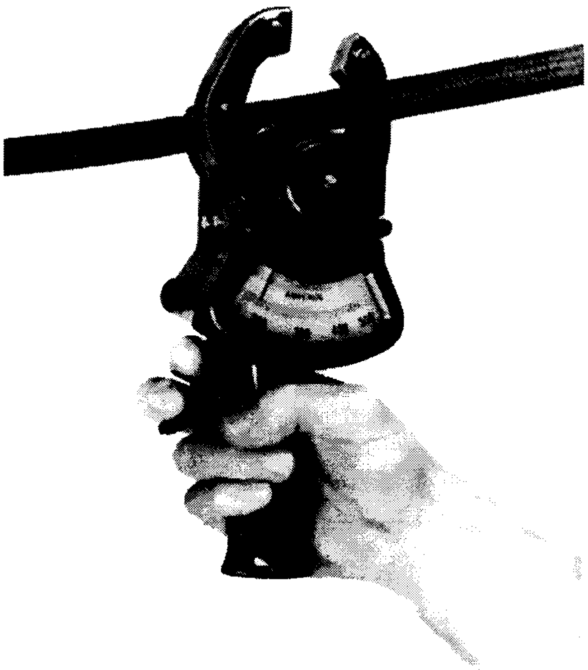


Figure 2.5—Tong Test Ammeter

In conditions of high restraint, the shrinkage stresses from welding may result in fracture if the root pass is not thick enough to resist those stresses. The welding inspector should be aware of these problems and thoroughly check the root pass prior to any additional welding, so that any irregularities can be found and corrected as they occur.

Check Interpass Cleaning

Another aspect that should be evaluated during the welding operation is the cleanliness of intermediate weld passes. If the welder fails to thoroughly clean the weld deposit between individual passes, there is a possibility that slag inclusions and/or incomplete fusion could result (see Figures 2.6 and 2.7). This is especially critical when using a welding process that uses a flux for protective shielding. Careful interpass cleaning is also recommended for those processes using gas shielding. Proper cleaning may be hindered when the deposited weld exhibits a convex profile that prevents sufficient access to the slag coating. As discussed above, additional grinding to remove the objectionable profile and facilitate proper cleaning may then be necessary.

Check Interpass Temperature

The welding inspector may also need to monitor welding procedures requiring interpass temperature control. As with preheat, the interpass temperature can be specified as a minimum, maximum or both. The interpass temperature is also measured on the base metal surface near the weld zone. Devices such as temperature-indicating crayons and surface contact pyrometers are used for these measurements.

Confusion sometimes exists as to where preheat and interpass temperatures should be measured. Preheat is measured 3 in. away from the weld joint along the entire length of the joint—regardless of the length of the joint. On pipe joints, preheat is measured along the entire circumference. The preheat should also be measured both on the topside of the joint and the back side to ensure preheat has soaked through the material being welded. Interpass temperatures are measured 1 in. from the joint, before beginning the next pass or layer—not at starts and stops of beads in a single pass or layer. On a fixed pipe joint, interpass is measured when the welder changes direction.

In-Process Nondestructive Examination (NDE)

At various stages during production, some welds may require a type of nondestructive examination other than visual examination. For example, it is common for the root pass to be evaluated using magnetic particle or penetrant testing to ensure that it is free of surface discontinuities or cracking (see Figure 2.8). Problems discovered at this time will result in a relatively easy and inexpensive repair, compared to that required if the problem is not detected until the weld is completed.

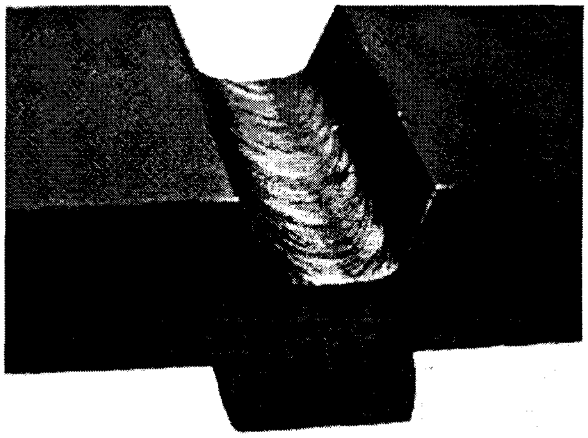


Figure 2.6—Proper Cleaning Between Weld Passes

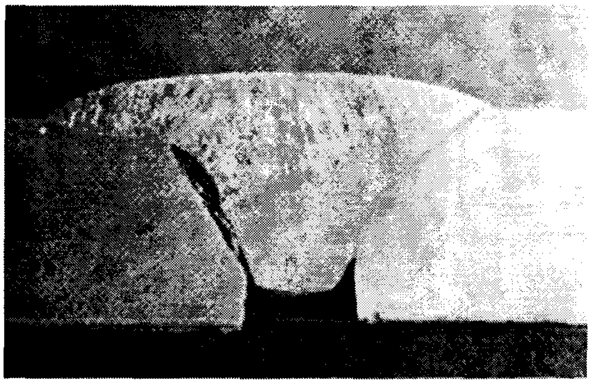


Figure 2.7—Cross Section of a Partial Penetration Groove Weld with Heavy Slag Inclusion

Figure 2.8—Magnetic Particle Testing of a Partially Filled Groove Weld

Nondestructive examination operations shall be performed by an individual qualified in accordance with the recommendations of ASNT's SNT-TC-1A, or equivalent. If qualified, the welding inspector can perform this inspection, as well as the visual examination; however, a separate NDE technician will usually perform the examination. The welding inspector is required to verify that the proper test has been administered and the results have been properly recorded.

Welding Inspector Responsibilities After Welding

Upon completion of a weld, the welding inspector must examine the finished product to ensure that all preceding steps have been performed to produce a quality weld. If all of the preliminary steps have been performed as required, the postweld inspection should simply confirm that the weld is of sufficient quality and size. Since the codes specify the required attributes of the finished weld, however, the welding inspector must visually examine the weld to determine if those requirements have been met. Some of the important aspects of postweld inspection are discussed below.

Check Final Weld Appearance

In general, visual inspection after welding consists of looking at the appearance of the finished weld. This visual examination will detect surface discontinuities in the weld and adjacent base metal. Of special importance during this aspect of the welding inspection is the evaluation of the weld's profile. Sharp surface irregularities could result in premature failure of a component during service or difficulty in film interpretation if the weld is to be radiographed. These visible features are evaluated in accordance with the applicable code that describes the permissible amount of certain types of discontinuity.

Check Final Weld Sizes and Lengths

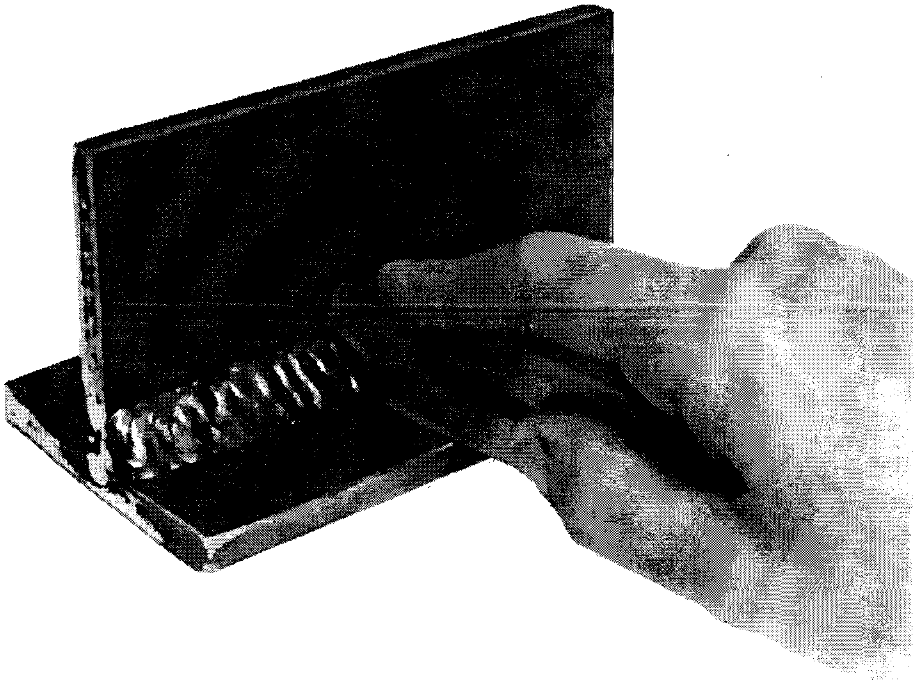
During visual examination, the weld should be measured to determine that it is of sufficient size, as specified on the drawing. For example, a primary concern for a groove weld is whether or not the groove is filled flush with the base metal surfaces, or has the required reinforcement. Any underfill that is present must be corrected by the deposit of additional weld metal. Excessive weld reinforcement must be removed to maintain the specified height and blend smoothly with adjacent base metal.

For fillet welds, size determination is normally accomplished with the aid of a fillet weld gauge (see Figure 2.9). Although this measurement could be determined using standard measuring devices, fillet weld gauges facilitate accurate gauging of the fillet weld size. Numerous types of fillet weld gauges are available, including gauges or templates that are specially made for a particular fillet weld configuration.

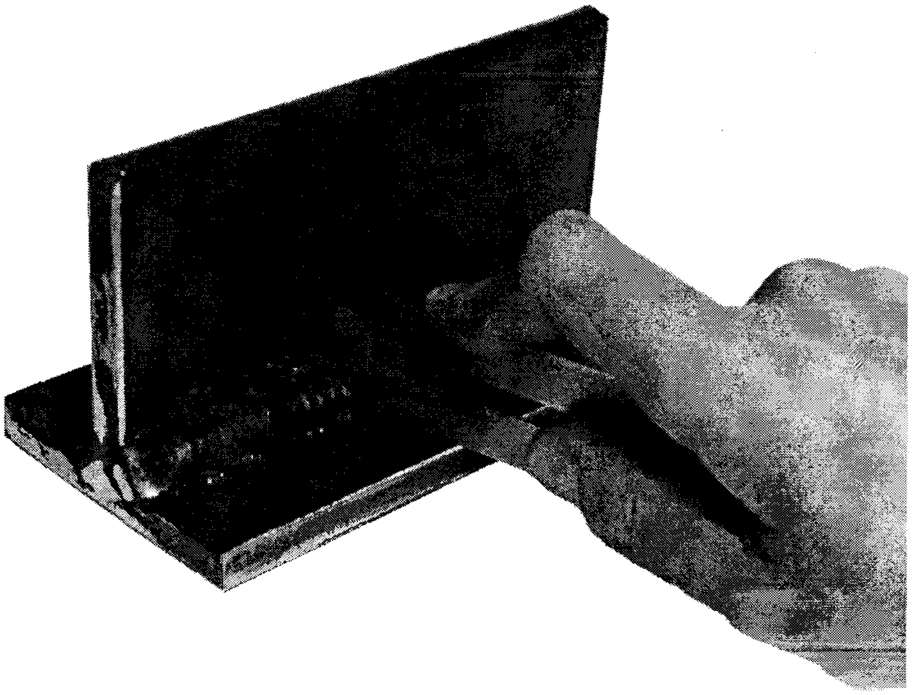
Since fillet weld sizes are designated as nominal dimensions, some tolerance should be applied to their measurement. Commercially available gauges are typically graduated in 1/16 in. increments; therefore, it is reasonable to gauge fillet weld sizes to the closest 1/32 in. Conditions warranting such an approach include the difficulty in properly positioning the eyes to view the gauge, the fact that weld sizes cannot be thought of in terms of machining precision, gauge inaccuracies, base and weld metal surface irregularities, and the difficulty in determining the exact location of the toe of a convex fillet weld.

Once a weld has been determined to be of sufficient size, the welding inspector must then evaluate the length to ensure that enough weld metal was deposited to satisfy the requirements (see Figure 2.10). This is particularly important in cases where intermittent fillet welds have been specified. Each segment should be measured, as well as their center-to-center, or pitch, distances.

Continuous groove or fillet welds are considered to be of sufficient length only if they are filled to their full cross section, for the entire length of the shorter of the two members being joined. Normally, minimum lengths are specified; therefore, the presence of extra fillet weld length is not considered rejectable. However, in some cases, excessive weld lengths may be unacceptable.

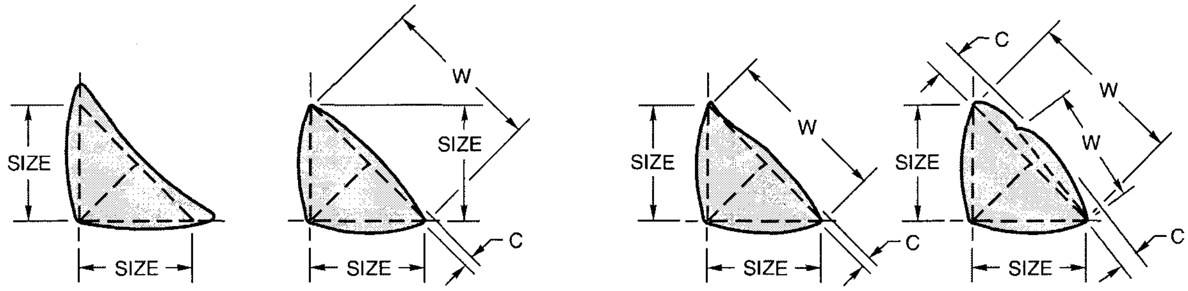


(A) CONVEX FILLET WELD



(B) CONCAVE FILLET WELD

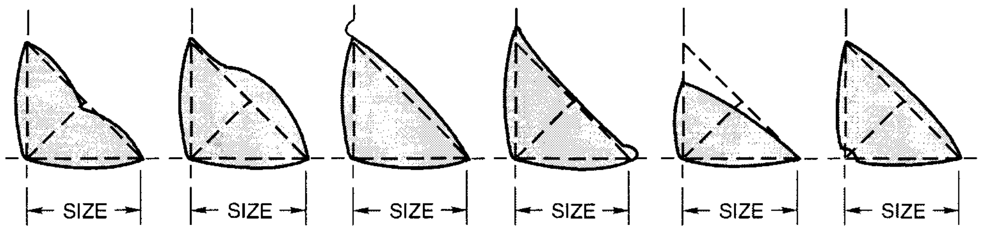
Figure 2.9—Evaluating Size with a Fillet Weld Gauge



(A) DESIRABLE FILLET WELD PROFILES **(B) ACCEPTABLE FILLET WELD PROFILES**

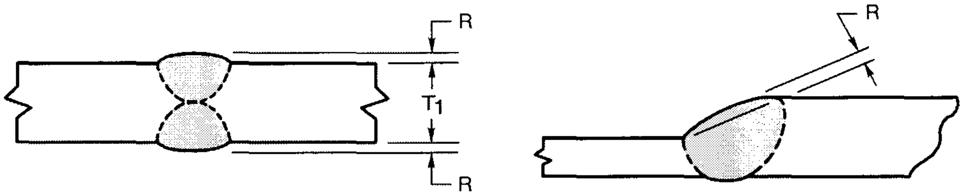
NOTE: CONVEXITY, C, OF A WELD OR INDIVIDUAL SURFACE BEAD WITH DIMENSION W SHALL NOT EXCEED THE VALUE OF THE FOLLOWING TABLE:

WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W	MAX CONVEXITY, C
W ≤ 5/16 in. (8 mm)	1/16 in. (2 mm)
W > 5/16 in. (8 mm) TO W < 1 in. (25 mm)	1/8 in. (3 mm)
W ≥ 1 in. (25 mm)	3/16 in. (5 mm)



INSUFFICIENT THROAT | EXCESSIVE CONVEXITY | EXCESSIVE UNDERCUT | OVERLAP | INSUFFICIENT LEG | INCOMPLETE FUSION

(C) UNACCEPTABLE FILLET WELD PROFILES

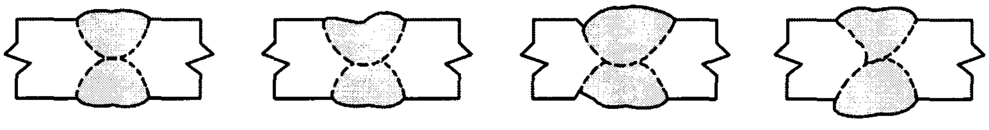


BUTT JOINT—
EQUAL THICKNESS PLATE

BUTT JOINT (TRANSITION)—
UNEQUAL THICKNESS PLATE

NOTE: REINFORCEMENT R SHALL NOT EXCEED 1/8 in. (3 mm). SEE 5.24.4.

(D) ACCEPTABLE GROOVE WELD PROFILE IN BUTT JOINT



EXCESSIVE CONVEXITY | INSUFFICIENT THROAT | EXCESSIVE UNDERCUT | OVERLAP

(E) UNACCEPTABLE GROOVE WELD PROFILES IN BUTT JOINTS

Figure 2.10—Acceptable and Unacceptable Weld Profiles

Check Dimensional Accuracy of Completed Weldment

Other measurements are required to evaluate the overall dimensional accuracy of the completed weldment, since the shrinkage stresses from welding may have caused the size of the part to change. For example, a weld deposited around the outside of a machined bore may cause the diameter of that bore to be reduced, necessitating further machining to provide the appropriate bore size. Dimensional evaluation will also determine whether any distortion resulted from welding. The localized heat of welding could cause members to be distorted or misaligned, with respect to other parts of the weldment. These measurements will determine if the amount of distortion that is present is enough to cause the part to be rejected or unusable.

Selection of Production Test Samples

In welded assemblies, inspection of the product may be performed on samples taken from the production line. These samples may be selected at random, or according to an established order. In either case, witnessing sample selection and testing is one of the welding inspector's important duties. Selection of samples is sometimes left to the inspector's judgment and discretion; however, it is not necessary to take more samples than required to determine conformance. Typical tests include radiography and other nondestructive examinations, hydrostatic tests, chemical analysis, metallurgical examinations, and destructive mechanical testing. It is important to ensure that such work is properly carried out. Various sampling plans, test processes, and inspection methods are described in Chapters 7 and 10.

Evaluation of Test Results

It is impractical to expect that a welding inspector will witness all tests; however, enough tests should be witnessed to satisfy the inspector that tests are being performed in the proper manner and results are being accurately reported. It is important to ascertain that the testing equipment calibration is documented. When the tests have been performed, the inspector must evaluate the results and decide whether the product meets the specifications.

Final Nondestructive Examination

Some welds must also be examined upon completion using other nondestructive examination in addition to visual inspection. This testing may be performed by the welding inspector or other NDE technician. In either case, the individual performing the test shall be properly qualified.

A CWI certification does not qualify an individual to perform nondestructive examinations. If an individual other than the welding inspector performs the examination, the inspector is required to verify that the NDE was performed by qualified personnel in the specified manner. In this case, the welding inspector's primary responsibility is to review the information to ensure that the results are complete. The welding inspector is then responsible for the maintenance of those records.

Maintaining Records and Reports

Code work always requires record keeping. Whether specified or not, complete records (i.e., detailed notes or formal inspection reports) should be kept by every inspector.

The welding inspector should check official records for completeness and accuracy and make certain that the records are available. Records that require the fabricator's signature should be prepared by the fabricator, not by the inspector. Records should be as detailed as necessary and entries should be in ink. Errors are to be crossed out with a single line and not erased; otherwise, record tampering may be suspected. The final report should comment on the general character of the work, how well it stayed within prescribed tolerances, difficulties that occurred, and any defects that were noted. Repairs should be explained. Reports describing the presence of weld defects should be accompanied by reports describing acceptance of subsequent repairs. Copies of reports should be distributed to all involved parties, and the welding inspector should maintain a copy for his records should some question later arise. Chapter 13 provides a detailed description of this aspect of the welding inspector's responsibilities.

Review—Chapter 2—Welding Inspector Responsibility

Q2-1 Which of the following is an acceptable way to correct an error on an inspection report?

a. draw a line through the incorrect portion of the report
b. erase the incorrect word or words
c. throw away the report
d. line out the error, make the correction, and initial and date the correction
e. none of the above

Q2-2 What records should you keep as a CWI?

a. copies of reports of all inspections you perform
b. copies of reports relevant to your areas of responsibility (material test reports, welder qualification paperwork, procedure qualification paperwork, etc.) even though you didn't prepare them
c. copies of sales literature describing welding equipment
d. a and b above
e. all of the above

Q2-3 When a particular type of weld is consistently marginal, with rejects occurring, what action would be appropriate for you as the inspector?

a. tell the welder what you want
b. bring the problem to the attention of production personnel in order for corrective action to be taken, if possible
c. simply continue to accept or reject the welds according to specified criteria (no more action is appropriate for inspectors)
d. all of the above
e. none of the above

Q2-4 A specification for a weld joint that must be immediately accepted or rejected lacks detailed information about that particular joint. Who should rule on the meaning and intent of the specification?

a. the designer
b. the welding engineer
c. the project engineer or quality assurance personnel (if their approval is required by contract)
d. you, as the CWI
e. none of the above

Q2-5 How can you identify an individual low-hydrogen electrode that a welder is already consuming to make a weld?

a. read the classification numbers painted on the covering near the stub end of the electrode
b. ask the welder what it is
c. ask the welding foreman
d. look at the completed weld and identify the type of electrode by the visual appearance of the weld deposit
e. look on the drawing or specification to determine what type of electrode is required for that weld

Q2-6 How should low-hydrogen electrodes be stored before use?

a. in their original unopened containers
b. in ovens held at a temperature that ensures the maintenance of their low moisture content
c. in tool room cribs, properly labeled, ready for quick distribution
d. a or b above
e. all of the above

Q2-7 What joint fit should you insist on?

a. within tolerances specified on drawings or specifications
b. groove welds should have minimal root openings to reduce distortion
c. root openings greater than 1/8 in. to ensure complete penetration
d. fillet welds should have root openings so that the resulting weld's effective throat will be greater
e. none of the above

Q2-8 Which welders are allowed to work on a "code" job?
- a. only those with certification papers from former jobs
- b. only those tested by the fabricator for this particular job
- c. only those qualified in accordance with job specifications
- d. only those you have requalified for this job
- e. all of the above

Q2-9 How should low-hydrogen electrodes out of their original containers be stored?
- a. in their original resealed containers
- b. in vented electric storage ovens
- c. in open tool crib shelves
- d. in individual welders' electrode pouches
- e. none of the above

Q2-10 How can a CWI verify that the specified material is used on the job?
- a. for code jobs, each piece of material must be correctly marked with its identity
- b. perform a quick carbon analysis with a field test kit
- c. material must be scrapped if no identification is evident
- d. once the material leaves the storage area, the CWI no longer has to verify it
- e. none of the above

Q2-11 If a mill product has imperfections such as splits, tears, or surface irregularities, what action should you as the inspector take?
- a. reject any imperfect materials
- b. judge whether or not the imperfections meet acceptance criteria according to applicable job specifications
- c. ignore the irregularities, if not in the immediate vicinity of the weld joint
- d. wait until the welder finishes the weld to see if any cracking occurs, before making any judgment
- e. none of the above

Q2-12 Which of the following is a welding inspector's responsibility prior to welding?
- a. check joint fit
- b. check preheat temperature
- c. check interpass temperature
- d. a and b above
- e. b and c above

Q2-13 A 1/4 in. fillet weld is specified on the drawing. When the CWI inspects the weld, it is measured to be 3/8 in. What should be done?
- a. reject the weld for being oversize
- b. accept the weld if no weld size tolerances are specified
- c. ask for an engineering review of the design
- d. b and c above
- e. none of the above

Q2-14 Fillet welds may be measured using a tolerance of:
- a. +1/16 in.
- b. +1/32 in.
- c. −1/16 in.
- d. −1/32 in.
- e. no tolerance

CHAPTER 3
Safety

Contents

Chapter 3—Safety

Introduction

Since welding inspectors frequently work in the same environment as the welder, they can be exposed to many potential safety hazards, i.e., electric shock, falling, radiation, eye hazards such as ultraviolet (UV) light, and particulate matter in the air, smoke and fumes, and falling objects. Safety is not to be taken lightly, even though the welding inspector may be exposed to these conditions only momentarily. The welding inspector should strive to observe all safety precautions, such as the use of safety glasses, hard hats, protective clothing, or any other appropriate apparatus. For a detailed look at recommended safety precautions, refer to ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes.*

Management's Responsibility

Safety is an important consideration in all welding, cutting, and related work. The most important components of an effective safety and health program are leadership, support, and direction. Management must clearly state objectives and show its commitment to safety and health by consistent support of safe practices. Management must designate approved safe areas for conducting cutting and welding operations (see Figure 3.1). When these operations are done in other than designated areas, management must ensure that a proper procedure is established and followed to protect personnel and property. Management must also be certain that only approved welding, cutting, and allied equipment such as torches, regulators, welding machines, electrode holders, and personal protective devices are used.

Adequate training is mandated under provisions of the *U.S. Occupational Safety and Health Act (OSHA)*. Thorough and effective training is a key aspect of any safety and health program, since welders and other equipment operators work most safely when they are properly trained in the performance of their job. Proper training includes instruction in both the safe use of equipment and processes, and the safety rules that must be followed.

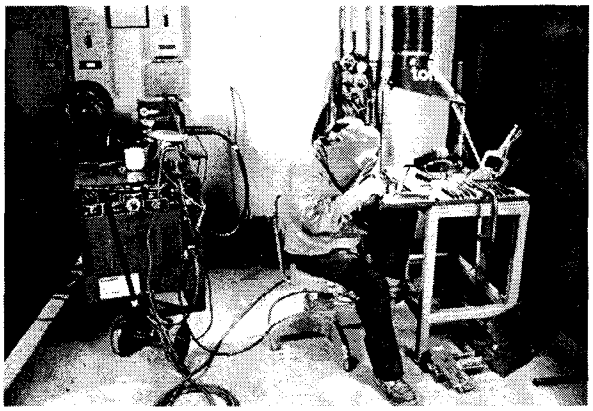


Figure 3.1—Designated Welding Area

Personnel need to know and understand the rules and the consequences of failing to comply with them.

The Working Environment

Good housekeeping is essential to avoid injuries. For example, a welder's vision is often restricted by necessary eye protection, and workers passing by a welding station frequently must shield their eyes from the flame or arc radiation. In both cases, limited vision increases the probability of tripping over objects left on the floor; therefore, shop personnel must ensure that the area is clear of potential hazards. The production area should be designed so that gas hoses, cables, mechanical assemblies, and other equipment does not obstruct walkways or interfere with routine tasks.

When work is performed aboveground or at floor level, safety rails or lines must be provided to prevent falls. Safety lines and harnesses can help restrict workers to safe areas and catch them in case of a fall. Since unexpected events, such as fume releases, fire, and explosions can and do occur in industrial environments, all escape routes should be identified and kept clear so that orderly, rapid, and safe evacuation of an area can take place. Employees must be trained in evacuation procedures. Storage of goods and equipment in evacuation routes should be avoided.

To avoid a safety hazard, equipment, machines, cables, hoses, and other apparatus should never be placed in passageways, on ladders, or on stairways. Warning signs specifying that eye protection must be worn should be prominently posted in all welding areas. Occasionally, a "firewatch" employee must be assigned to maintain safety during cutting or welding.

Personnel in areas adjacent to welding and cutting operations must be protected from radiant energy and hot spatter by the use of flame-resistant screens or shields, suitable eye and face protection, and by wearing protective clothing. If feasible, work stations should be separated by noncombustible screens or shields, which allow air circulation both at floor level and above the screen.

In most welding and cutting processes, a high-temperature heat source is present. Open flames, electric arcs, hot metal, sparks, and spatter are ready sources of ignition. Most fires are started by sparks, which can travel horizontally up to 35 ft from their source and fall even greater distances. Sparks can pass through or lodge in cracks, holes, and small openings on floors and walls.

The risk of fire is also increased by the presence of combustibles in the work area, or by welding or cutting too close to unshielded combustibles. Flammable gases, vapors, and dust—when mixed with certain proportions of air and oxygen—may also present explosion and fire dangers. Welding, brazing, soldering, cutting, or operating equipment capable of producing heat or sparks, must not be performed in atmospheres containing flammable gases, vapors, or dust.

Eye and Face Protection

Welding helmets or handshields containing appropriate filter and cover plates must be used by welders, welding operators, and nearby personnel when viewing an arc. Safety spectacles, goggles, or other types of suitable eye protection must also be worn during other types of welding and cutting operations (see Figure 3.2). Such devices must have full-conforming side shields, when worn in areas where there is danger of exposure to injurious rays or flying particles from grinding or chipping operations. Spectacles and goggles may have clear or colored lenses. Shading depends on the intensity of the radiation emitted from adjacent welding or cutting operations when the welding helmet is raised or removed (see Table 3.1). Number 2 filter plates are recommended for general purpose protection.

Figure 3.2—Eye, Ear, and Face Protective Equipment

> When wearing welding shields, welders frequently neglect to wear safety glasses under the hood, which is not a good practice. The welding shield does not protect the eyes from stray sparks and grinding particles. Any worker who has performed welding, particularly out-of-position welding, can attest to the number of sparks that enter and bounce around the helmet. These sparks can easily enter the eye; therefore, it is good practice to wear safety glasses with side shields under the welding shield.

Oxyfuel Gas Welding, Cutting, Brazing, Soldering, and Submerged Arc Welding

Safety goggles with filter plates and full-conforming side shields must be worn while performing oxyfuel gas welding and cutting. During submerged arc welding, the arc is covered by flux and not readily visible; therefore, an arc welding helmet is not needed. Because the arc occasionally flashes through the flux, however, the operator should wear tinted safety glasses. During torch brazing and soldering, a bright yellow flame may be visible. An appropriate tinted safety glass is recommended.

Protective Clothing

Sturdy shoes or boots and heavy clothing should be worn to protect the whole body from flying sparks, spatter, and radiation burns. Woolen clothing is preferable to cotton clothing, because it is not so readily ignited. Cotton clothing, if used, should be chemically treated to reduce its combustibility. Clothing treated with nondurable

Table 3.1
Lens Shade Selector

Operation	Shade Number
Soldering	2
Torch Brazing	3 or 4
Oxygen Cutting	
Up to 25.4 mm (1 in.)	3 or 4
25.4 mm to 152.4 mm (1 to 6 in.)	4 or 5
152.4 mm (6 in.) and over	5 or 6
Gas Welding	
Up to 3.2 mm (1/8 in.)	4 or 5
3.2 mm to 12.7 mm (1/8 in. to 1/2 in.)	5 or 6
12.7 mm (1/2 in.) and over	6 or 8
Shielded Metal Arc Welding 1.6 mm (1/16 in.), 2.4 mm (3/32 in.), 3.2 mm (1/8 in.), 4.0 mm (5/32 in.) electrodes	10
Gas Tungsten Arc Welding (Nonferrous) Gas Metal Arc Welding (Nonferrous) 1.6 mm (1/16 in.), 2.4 mm (3/32 in.), 3.2 mm (1/8 in.), 4.0 mm (5/32 in.) electrodes	11
Gas Tungsten Arc Welding (Ferrous) Gas Metal Arc Welding (Ferrous) 1.6 mm (1/16 in.), 2.4 mm (3/32 in.), 3.2 mm (1/8 in.), 4.0 mm (5/32 in.) electrodes	12
Shielded Metal Arc Welding	
4.7 mm (3/16 in.), 5/6 mm (7/32 in.), 6.4 mm (1/4 in.) electrodes	12
7.9 mm (5/16 in.), 9.5 mm (3/8 in.) electrodes	14
Atomic Hydrogen Welding	10 to 14
Carbon Arc Welding	14

flame retardants must be treated again after each washing or cleaning. Polyester clothes, which can melt and cause severe burns, should not be used. Frayed denim will burn as if dipped in gasoline. Outer clothing should be kept free of oil and grease.

Cuffless pants and covered pockets should be worn to avoid spatter or spark entrapment. Pockets should be emptied of flammable material that can be ignited by sparks or weld spatter and cause severe burns. Pants should be worn on the outside of shoes. Protection of the head is also recommended. Flammable hair preparations should not be used.

Durable gloves of leather or other suitable material should be worn, because gloves not only protect the hands from burns or abrasion, they also provide insulation from electrical shock.

Ear Protection

Sparks or hot spatter in the ears can be serious and particularly painful. Properly fitted, flame-resistant ear plugs or ear muffs should be worn whenever operations pose such risks. Excessive noise, particularly continuous noise at high levels, can severely damage hearing. In welding, cutting, and allied operations, noise may be generated by the process, the equipment, or both. Hearing protection devices are required for some operations. Additional information is presented in the AWS publication, *Arc Welding and Cutting Noise*. Air carbon arc and plasma arc cutting are processes with high noise levels. Engine-driven generators sometimes emit a high noise level, as do some high-frequency and induction power sources.

Fumes and Gases

Welders, welding operators, and other personnel in the area must be protected from overexposure to fumes and gases produced during welding brazing, soldering, and cutting operations. Fumes and gases are usually a greater concern in arc welding than in oxyfuel gas welding, cutting, or brazing. A welding arc may generate a larger volume of fume and gas, and a greater variety of materials. Protection from excess exposure is usually accomplished by ventilation. Proper ventilation can significantly reduce fume amounts in the work area, and the welder's exposure to them. Ventilation may be local, where the fumes are extracted near the point of welding, or general, where the shop air is changed or filtered (see Figure 3.3).

The single most important factor influencing exposure to fume is the position of the welder's head, with respect to the plume. When the head is in such a position that the fume envelops the face or helmet, exposures can be very high. Therefore, welders must be trained to keep their heads to one side of the fume plume. The size of the welding or cutting enclosure is important, because it affects the background fume level. Fume exposure in a tank, pressure vessel, or other confined space will be higher than in a high-bay fabrication area.

Confined Spaces

Special consideration must be given to the safety and health of welders and other workers in confined spaces. See the latest edition of ANSI Publication Z117.1, *Safety Requirements for Working in Tanks and Other Confined Spaces*, for further precautions. Gas cylinders must be located outside the confined space, to avoid possible contamination of the space with leaking gases or volatiles. Welding power sources should also be located outside, to reduce danger of engine exhaust and electric shock. Lighting inside the work area should be low voltage, i.e., 12 V. If 110 V is required, the circuit must be protected by an approved ground fault circuit interrupter.

In case of emergency, a means of removing workers quickly has to be provided. Safety belts and lifelines, when used, should be attached to the worker's body in such a way to avoid the possibility of becoming jammed

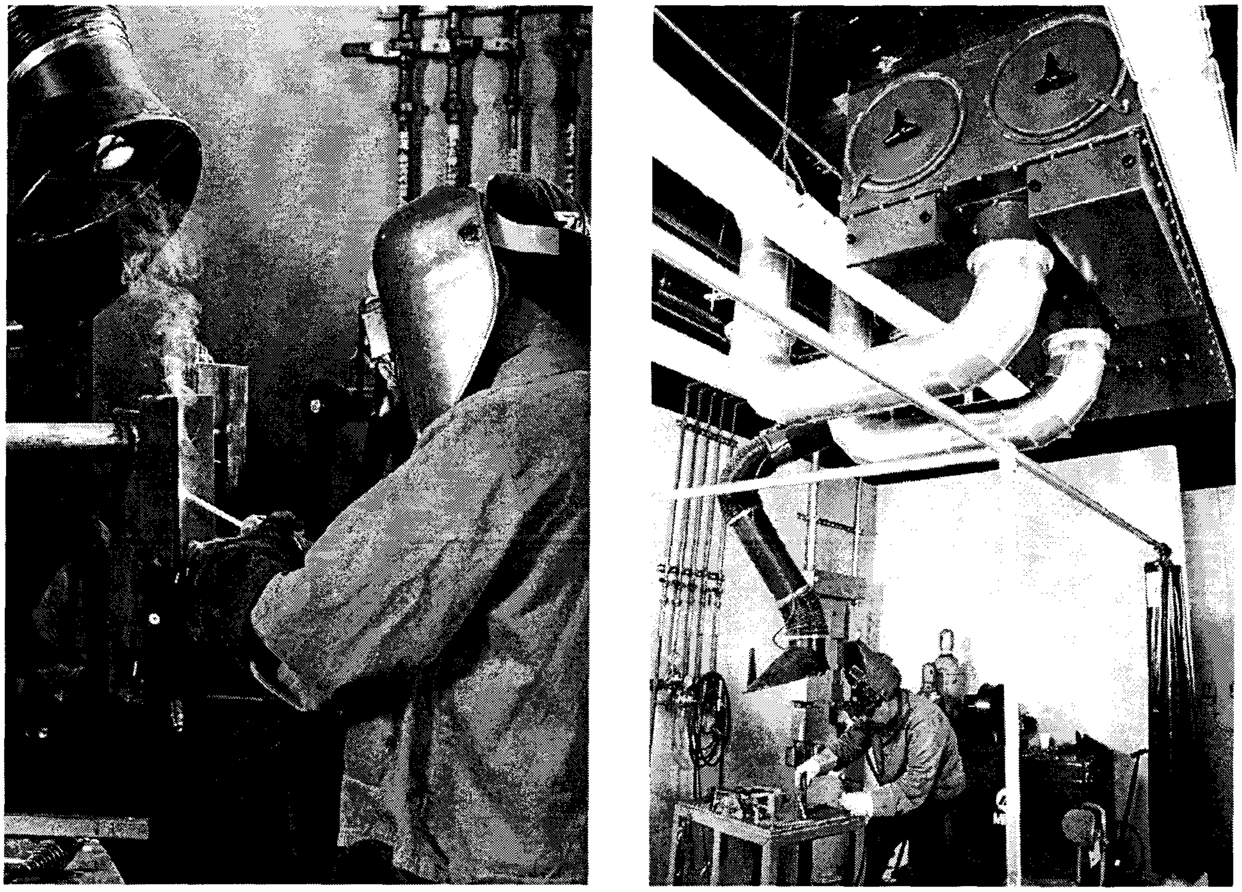


Figure 3.3—Movable Fume Extractor Positioned Near the Welding Arc

in the exit. A trained helper should be stationed outside the confined space with a preplanned emergency rescue procedure.

In addition to keeping airborne contaminants in breathing atmospheres at or below recommended limits, ventilation in confined spaces must (1) ensure adequate oxygen for life support, (2) prevent accumulation of an oxygen-enriched atmosphere, and (3) prevent accumulation of flammable mixtures. Before a worker enters a confined space, the space should be tested for toxic or flammable gases and vapors and adequate or excess oxygen.

Heavier-than-air gases, such as argon (Ar), methylacetylene propadiene (MAPP) (also referred to as methylacetylene propadiene stabilized or MPS gas), propane, and carbon dioxide (CO_2) may accumulate in pits, tank bottoms, low areas, and near floors. Lighter-than-air gases, such as helium and hydrogen, may accumulate in tank tops, high areas, and near ceilings. The same precautions apply as for confined spaces. If practical, a continuous monitoring system with audible alarms should be used for work in confined spaces.

Handling of Compressed Gases

Gases used in welding and cutting operations are packaged in containers called cylinders. Only those cylinders designed and maintained in accordance with specifications of the U.S. Department of Transportation (DOT) may be used in the United States.

When handling cylinders, the following general safety precautions should be taken:

- Gas cylinders must not be welded.
- Cylinders must not be allowed to become part of an electric circuit, because arcing may result.
- Cylinders must not be used as work rests or rollers.
- Cylinders should be protected from bumps, falling objects, and weather; they should not be dropped.
- Cylinders should be kept in areas where temperatures do not fall below –0°F, or exceed 130°F.
- Proper cradles or cradle slings should be used to secure cylinders for hoisting.
- Electromagnets should not be used when handling cylinders.
- Cylinders must always be secured by the user against falling during either use or storage.
- Acetylene and liquefied gas cylinders should be stored and used in the upright position.

Before using gas from a cylinder, the contents should be identified only by the label on the cylinder. Any other means of identification, such as cylinder color, banding, or shape (which may vary among manufacturer, geographical area, or product line) may be completely misleading and should not be used. If a cylinder has no label, the contents should not be used and the cylinder should be returned to the supplier.

A valve protection cap is provided on the cylinder, to protect the cylinder valve. This cap should always remain in place, unless the cylinder is in use. The cylinder should never be lifted manually or hoisted by the valve protection cap. Gas cylinders and other containers must be stored in accordance with all state and local regulations and the appropriate standards of OSHA and the National Fire Protection Association (NFPA). Safe handling and storage procedures are discussed in the *Handbook of Compressed Gases*, published by the Compressed Gas Association (CGA).

Appropriate pressure-reducing regulators should be used to withdraw gases from cylinders; however, such regulations must be used only for the gas and pressure given on the label. Cylinders containing high-pressure gases must be opened slowly, to prevent rapid pressurization of the regulator. Once high-pressure cylinders are opened, the tank valve should be opened all the way to "back seat" the valve. Tank valves on cylinders containing fuel gases should not be opened more than one turn. When not in use, the tank valves should be closed, the lines purged, and the pressure-regulating screw backed out.

Gases

Oxygen

Oxygen is nonflammable, but it supports the combustion of flammable materials. It can initiate combustion and vigorously accelerate it. Oxygen cylinders should not be stored near combustibles, or with cylinders of fuel gas. Oxygen should never be used as a substitute for compressed air. Oil, grease, and combustible dusts may spontaneously ignite on contact with oxygen. All systems and apparatus for oxygen service must be kept free of any combustibles. Oxygen valves, regulators, and apparatus should never be lubricated with oil. Oxygen must never be used to power compressed air tools. Similarly, oxygen must not be used to blow dirt from work and clothing, which are often contaminated with oil, grease, or combustible dust.

Fuel Gases

Fuel gases commonly used in oxyfuel gas welding (OFW) and oxyfuel gas cutting (OFC) are acetylene, methylacetylene propadiene, natural gas, propane, and propylene. Acetylene in cylinders is dissolved in a solvent, so that it can be safely stored under pressure. In its free state, acetylene should never be used at pressures over 15 psi, because it can dissociate with explosive violence at higher pressures. Acetylene and MAPP should never be used in contact with silver, mercury, or alloys containing 70% or more copper, because the gases react with these metals to form unstable compounds that may detonate under shock or heat.

Fuel Gas Fires

The best procedure for avoiding fuel gas fires from a fuel gas or a liquid is to prevent leaks, which will keep the fire contained within the system. All fuel gas systems should be checked carefully for leaks upon assembly, and at frequent intervals after that. Fuel gas cylinders should be examined for leaks, especially at fuse plugs, safety devices, and valve packing.

One common source of fire is the ignition of leaking fuel by flying sparks or spatter. In case of a fuel fire, an effective means for controlling the fire is to shut off the fuel valve, if accessible. A fuel gas valve should not be opened more than one turn, because in this way, it can be shut off quickly in an emergency.

Most fuel gases in cylinders are in liquid form or dissolved in liquids; therefore, the cylinders should always be used in the upright position to prevent liquid surges into the system.

Shielding Gases

In some welding processes, argon, helium, carbon dioxide, and nitrogen are used for shielding. All except carbon dioxide are used as brazing atmospheres. These gases are odorless and colorless, and can displace air needed for breathing.

Before being entered by personnel, confined spaces containing these gases must be well ventilated. If there is any question regarding safety, the space should first be checked for adequate oxygen concentration with an oxygen analyzer. If an oxygen analyzer is not available, an air-supplied respirator should be worn by personnel entering the space.

Electric Shock

Most welding and cutting operations employ some type of electrical equipment. To protect workers from fatalities and injuries caused by electric shock in welding and cutting operations, proper safety precautions should be followed.

Electric shock occurs when an electric current of sufficient amount to create an adverse effect passes through the body. The severity of the shock depends on the amount of current, the duration and path of the flow, and the state of health of the victim at the time of receiving the shock. The current is caused to flow by the applied voltage. The amount of current depends upon the applied voltage and the resistance of the body path. The frequency of the current may also be a factor when alternating current is involved.

Currents greater than about 6 milliamperes (mA) are considered *primary shock currents*, because they can cause direct physiological harm. Steady-state currents between 0.5 and 6 mA are considered *secondary shock currents*. Secondary shock currents can cause involuntary muscular reactions, normally without causing direct physiological harm. The 0.5 mA level is called the *perception threshold*, because it is the point at which most people just begin to feel the tingle from the current.

In welding and cutting work, electrical equipment is generally powered from ac sources of between 115 and 575 V, or by engine-driven generators. Most welding is done with less than 100 arc volts. Electric shock in the welding industry usually occurs as a result of accidental contact with bare or poorly insulated conductors operating at such voltages. Therefore, welders must take precautions against contacting bare elements, in welding and primary circuits.

Electrical resistance is usually reduced in the presence of water or moisture. To prevent electric shock when performing arc welding or cutting under damp or wet conditions, including when perspiring heavily, the inspector must wear dry gloves and clothing in good condition. The welding inspector should be protected from electrically conductive surfaces, including the ground. Minimal protection can be afforded by rubber-soled shoes; however, an insulating layer, such as a rubber mat or a dry wooden board, is preferable. Similar precautions against accidental contact with electrically conductive surfaces must be taken by the welding inspector, especially when working in cramped kneeling, sitting, or prone positions. Rings and jewelry should be removed before welding, to decrease the possibility of electric shock.

Electric shock hazards are reduced by proper equipment installation and maintenance, good operator practice, proper clothing and body protection, and use of equipment designed for the job and situation. Equipment should meet applicable National Electrical Manufacturers' Association (NEMA) or ANSI standards, such as ANSI/UL 551, *Safety Standard for Transformer Type Arc Welding Machines*.

Equipment should be installed in a clean, dry area. When this is not possible, equipment should be adequately protected from dirt and moisture. Installation—including disconnects, fusing, and certain types of incoming power lines—must be performed in accordance with the requirements of ANSI/NFPA 70, *National Electric Code*, and local codes. Electrical connections must be tightly installed, and should be periodically checked thereafter.

Review Chapter 3—Safety

Q3-1 The welding inspector is exposed to which of the following safety hazards?
a. radiation
b. falling objects
c. electrical shock
d. eye hazards
e. all of the above

Q3-2 A document that covers safety in welding and cutting is:
a. AWS D1.1
b. API 1104
c. ANSI Z49.1
d. ASME Section IX
e. ASME B31.1

Q3-3 Eye hazards found in welding operations include:
a. grinding dust
b. weld spatter
c. radiation
d. smoke and fumes
e. all the above

Q3-4 In avoiding fumes during welding, the most important factor is:
a. the type of base metal
b. the position of the welder's head
c. the type of welding process
d. the position of the welding machine
e. the type of filler metal

Q3-5 Acetylene becomes unstable above what pressure?
a. 5 psi
b. 10 psi
c. 15 psi
d. 25 psi
e. none of the above

Q3-6 Electric currents above approximately 6 milliamperes (mA) are considered:
a. secondary currents
b. primary currents
c. harmful
d. b and c above
e. not harmful

Q3-7 When operating gas cylinders, the cylinder valve should be opened:
a. all the way on the acetylene cylinder
b. one turn on an oxygen cylinder
c. one turn or less on an acetylene cylinder, all the way on the oxygen cylinder
d. whatever is convenient
e. none of the above

Q3-8 Proper handling of compressed gas cylinders includes:
a. not welding on cylinders
b. not including the cylinders in the ground or electrical circuit
c. securing them properly
d. identifying the gas prior to use
e. all of the above

Q3-9 The most important component of an effective safety and health program is:
- a. safety rules
- b. safety procedures
- c. management support
- d. welding helmet
- e. protective equipment

Q3-10 Safety training is mandated under provisions of:
- a. AWS *Safe Practices*
- b. OSHA
- c. ASME code
- d. AWS *Welding Handbook*, Volume 2
- e. none of the above

Q3-11 Protective equipment suitable for eye protection from welding radiation includes:
- a. welding helmets with filter lens
- b. clear safety glasses
- c. safety goggles with filter plates
- d. protective screens
- e. all of the above

Q3-12 Suitable clothing materials for welding and cutting are:
- a. 65% cotton, 35% polyester
- b. wool
- c. chemically treated cotton
- d. b and c above
- e. none of the above

CHAPTER 4

Standards, Including Codes and Specifications

Contents

Chapter 4—Standards, Including Codes and Specifications

Introduction

The responsibility associated with inspection is quite large. People who inspect for a living must have a critical eye, knowledge of their field, and the ability to exercise judgment.

Some welding applications are more critical than others; however, all welding inspections are important, no matter how critical the weld or the application. The importance of welding inspection activities is underscored by the array of standards that inspectors must use.

There are many approaches to inspection. Today's growing technical demands by purchasers and the cost of product liability rule out casual inspection. However, there are still areas of interpretation; i.e., when selecting the level of and severity of inspection. Where life and safety are involved, the quantity and quality of welding inspection usually must conform to a code, standard, or specification. The welding inspector frequently inspects work in accordance to a particular code. Several organizations, including AWS and ASME, have developed codes for various areas of concern.

Requirements of Standards, Codes, and Specifications

The term "standard" applies to numerous types of documents, including codes and specifications. Other types of documents considered to be standards are procedures, recommended practices, groups of graphic symbols, classifications, and definitions of terms. So, once a "standard" has been specified, you as an inspector must then judge the adequacy of product based upon how it compares with that established standard. Standards can be considered mandatory, such as a code, or nonmandatory, as is the case for a recommended practice. Nonmandatory standards use the words "should" and "could" in place of "shall" and "will." Nonmandatory standards become mandatory when referenced by a code. For example, the American Society for Nondestructive Testing's (ASNT) Recommended Practice No. SNT-TC-1A establishes guidelines for the qualification and certification of NDT personnel. Because Section 6 of AWS D1.1 requires that NDT personnel be qualified in accordance with SNT-TC-1A, the practice becomes mandatory.

The term standard applies collectively to codes, specifications, recommended practices, classifications, methods and guides that have been prepared by a sponsoring organization, and approved in accordance with established procedures. Standards for welding are published in cooperation with the American National Standards Institute (ANSI).

The code may come from a government agency or a private agency such as an engineering society. A code is defined as "a body of laws, as of a nation, city, etc., arranged systematically for easy reference." For example, cities have "building codes" that describe the construction requirements for structures in that municipality. Since a code consists of rules having legal status, the code is also considered mandatory, and text in the code will contain words such as "shall" and "will." A specific code includes conditions and specifications for the item in question. The code frequently will include descriptions of methods to determine if those conditions and requirements have been achieved.

During the execution of any inspection, the welding inspector must constantly refer to the codes, standards, specifications, or a combination of the three, to learn many important requirements for the fabrication or construction taking place. A number of these documents, which relate to some aspect of weld quality, are primarily produced by national professional organizations or government agencies. The type of weldment being constructed will determine the requirements to be enforced.

The following discussion includes descriptions of these various welding codes, standards and specifications and their areas of coverage.

A code is a standard consisting of a set of conditions and requirements relating to a particular subject, and indicating appropriate procedures by which it can be determined that the requirements have been met. It is a standard that is suitable for adoption by a governmental authority as a part of a law or regulation, or as specified by other mandatory documents. A code is intended to be mandatory, and it should be used when so required by a governmental authority or specified by other mandatory documents. Other mandatory documents could be documents issued by agencies such as purchasing departments, trade associations, or insurance companies.

Codes Important to Welding

Structural Welding Code—Steel (AWS D1.1)

AWS D1.1, *Structural Welding Code—Steel*, is published by the American Welding Society, with new editions scheduled for publication every other year. AWS D1.1 describes the welding requirements for steel structures, including statically loaded, dynamically loaded, and tubular structures.

The following is a listing of the various sections of AWS D1.1 and their areas of coverage:

(1) General Requirements
(2) Design of Welded Connections
  Part A—Common Requirements of Nontubular and Tubular Connections
  Part B—Specific Requirements for Nontubular Connections (Statically or Cyclically Loaded)
  Part C—Specific Requirements for Cyclically Loaded Nontubular Connections
  Part D—Specific Requirements for Tubular Connections
(3) Prequalification of WPSs
(4) Qualifications
  Part A—General Requirements
  Part B—Welding Procedure Specifications (WPS)
  Part C—Performance Qualification
(5) Fabrication
(6) Inspection
  Part A—General Requirements
  Part B—Contractor Responsibilities
  Part C—Acceptance Criteria
  Part D—Nondestructive Testing Procedures
  Part E—Radiographic Testing
  Part F—Ultrasonic Testing of Groove Welds
  Part G—Other Examination Methods
(7) Stud Welding
(8) Strengthening and Repairing Existing Structures
Annexes—Mandatory Information
Annexes—Nonmandatory Information
Commentary

Section 6 of AWS D1.1 describes two categories of welding inspectors: fabrication/erection and verification. *Fabrication/erection* inspection and testing is the responsibility of the contractor, unless otherwise stated in the contract; while *verification* inspection and testing is the responsibility of the owner or engineer. AWS D1.1 does make this distinction, however, the requirements of the code are intended to apply equally to the work of both parties.

Subsections 6.1 through 6.5 describe the welding inspector's duties and responsibilities, and 6.6 details the contractor's responsibilities in satisfying the requirements of inspection personnel. Beginning at 6.9, the methods for nondestructive examination in accordance with AWS D1.1 are listed. For information pertaining to the various NDE methods, refer to Table 4.1.

Other AWS Structural Welding Codes (D1.2, D1.3, D1.4, D1.5, and D1.6)

In addition to D1.1, AWS has developed five other codes dealing with structural welding requirements:

(1) D1.2, *Structural Welding Code—Aluminum*
(2) D1.3, *Structural Welding Code—Sheet Steel*
(3) D1.4, *Structural Welding Code—Reinforcing Steel*
(4) D1.5, *Bridge Welding Code*
(5) D1.6, *Structural Welding Code—Stainless Steel*

Table 4.1
Nondestructive Testing Methods—D1.1 Code Reference

Test Method	Applicable Code References
Radiographic	Section 6, Part E
Ultrasonic	Section 6, Part F
Magnetic Particle	Section 6, ASTM E 709
Liquid Penetrant	Section 6
NDT Personnel Qualification	6.14.6.1 (SNT-TC-1A)

The acceptance criteria for both the visual inspection and nondestructive examination are found in the following code locations, depending upon the type of structure being constructed.

Type of Structure	Weld Acceptance Criteria Reference
Statically Loaded, Dynamically Loaded, and Tubular Structures	Section 6

All five codes follow the general format of AWS D1.1; however, because each refers to a specific type of structure, the welding requirements differ slightly.

ASME Boiler and Pressure Vessel Code (PVC)

The ASME *Boiler and Pressure Vessel Code* covers requirements for the design and construction of pressure-containing components, the care and operation of heating and power boilers, and both fossil and nuclear power equipment. The ASME code offers a wide range of coverage contained in several different sections. Table 4.2 lists the various areas of coverage for these code sections.

Table 4.2
ASME Boiler and Pressure Vessel—Code Reference

ASME Section	Topic
I	Power Boilers
II	Material Specifications Part A: Ferrous Materials Part B: Nonferrous Materials Part C: Welding Filler Materials Part D: Properties
III	Nuclear Components
IV	Heating Boilers
V	Nondestructive Examination
VI	Care and Operation of Heating Boilers
VII	Care of Power Boilers
VIII	Unfired Pressure Vessels
IX	Welding and Brazing Qualification
X	Fiberglass-Reinforced Plastic Pressure Vessels
XI	Inservice Inspection of Nuclear Components

When performing an inspection in accordance with the ASME code, the welding inspector must refer to several of the different sections, because they contain different types of requirements. As an example, for an unfired pressure vessel constructed from steel in accordance with the ASME code, the various sections which apply are:

Section	Information Provided
II, Part A	Description, including chemical and mechanical properties, of the steel base metals to be used.
II, Part C	Description, including chemical and mechanical properties, of the welding filler materials.
II, Part D	Material properties
V	Methods for performing various required nondestructive examinations.
VIII	Design, fabrication and inspection requirements for unfired pressure vessels, including weld acceptance criteria.
IX	Requirements for the qualification of welding procedures and welders.

Definition of Inspector

There are welding inspectors who work within the quality control department, on behalf of the fabricator. Under the ASME code, an inspector who has bottom-line responsibility and signs off on the Data Report is referred to as an *Authorized Inspector*. The Authorized Inspector is employed by:

(1) A state or municipality of the U.S. or a province of Canada

(2) An insurance company authorized to write boiler and pressure vessel insurance

(3) A company having vessels made for its exclusive use and not for sale (applies to Section VIII, Division I, only)

An Authorized Inspector is not hired by the fabricator; rather, such inspectors are third-party inspectors who are usually employed by an insurance company. Qualification of a National Board-commissioned Authorized Inspector is by written examination prepared by the National Board of Boiler and Pressure Vessel Inspectors and administered by a city, state, or province. The CWI is not an Authorized Inspector, because this position requires separate certification.

Codes and Materials

The welding inspector must be sure that the specified materials are ordered, received, and used. Most codes require the ability to trace the material to a specific heat number and be accompanied with an actual mill test report. This mill test report must be checked against the appropriate ASTM standard, to verify that the materials conform to the chemical and mechanical requirements. The inspector must verify that the filler materials were ordered to the correct specification, received, and used. Most codes require that filler metals be ordered to an AWS filler metal specification; however, actual material test reports are rarely required on filler metals. If Certificates of Conformance (COC) are required, they are readily available from the filler metal supplier.

Codes and Procedures

It must be verified that the welding procedures have been qualified. Evidence of this qualification can be found by reviewing a written Welding Procedure Specification (WPS). AWS D1.1 allows the use of some prequalified WPSs; however, these WPSs must still be checked for conformance to code requirements. In some cases, AWS D1.1 and most other codes do not allow prequalified procedures. In such cases, the inspector would review a WPS, accompanied by its Procedure Qualification Record (PQR).

Codes and Personnel

All welders, tack welders, welding operators, brazers, and brazing operators working on code work must be qualified.

Codes and Nondestructive Examination (NDE)

You must ensure that nondestructive examinations and tests are carried out by qualified personnel, to the extent specified by the code.

ASTM Standards

Numerous standards of the American Society for Testing and Materials (ASTM) are referenced in the ASME, AWS, and other codes, most commonly as the specifications for materials. However, for ASME code fabrication, the designations for ASTM standards are assigned the prefix "S." Hence, ASTM A 285 steel is specified as SA 285 for ASME applications. However, when accepted by ASME, the information found in both is identical.

API Standards

The American Petroleum Institute (API) publishes three important standards that deal with welded pipelines and vessels:

(1) API 1104, *Standard for Welding Pipeline and Related Facilities*

(2) API 620, *Recommended Rules for Design and Construction of Large Welded Low-Pressure Storage Tanks*

(3) API 650, *Standard for Welded Steel Tank for Oil Storage*

API 1104 contains requirements for qualification of procedures and welders, qualification of radiographers, radiographic techniques, and weld quality requirements for production welding.

For procedure and welder qualification, test coupons are subjected to various destructive tests, including tensile, nick break, root bend, face bend, and side bend. Fillet welds are examined by the nick break test. However, as in AWS D1.1 and ASME Section IX, API 1104 permits the qualification of welders by using radiographic testing in lieu of destructive tests (see specific code for requirements).

API 620 is intended to apply to the design and construction of large, welded, low-pressure, carbon steel, above-ground storage tanks that have a single vertical axis of revolution. These tanks may be operated at temperatures up to 200°F and pressures up to 15 psi. API 650 applies to the material, design, fabrication, erection, and testing requirements for vertical cylindrical aboveground, closed, and open-top, welded steel storage tanks in various sizes and capacities for internal pressures approximating atmospheric pressures, except that a small internal pressure is permitted when the additional requirements of Appendix F are met. API 650 applies only to nonrefrigerated service.

Military Standards

The United States Department of Defense (DOD) produces a comprehensive quantity of military standards. For a complete list of all military specifications, refer to the *Index to Military Specifications and Standards* that may be available at companies producing products under a military contract. A few examples of military standards are as follows.

Welding electrode specifications have the identifying letter "E" and a multi-digit number, such as MIL-E-22200/1 for "Electrodes, covered low-alloy steel"; MIL-E-22200/2 for covered stainless steel electrodes; MIL-E-19933D for bare stainless steel electrode wires; and MIL-E-16053L for bare aluminum electrode wires. Other important filler metal specifications include MIL-R-17131B for "Rods, bare hard surfacing alloys for GTA welding" and MIL-I-23413B for "Inserts, consumable."

ANSI Standards

The American National Standards Institute (ANSI) is a private organization responsible for coordinating national standards for use within the United States. ANSI does not actually prepare standards. Instead, it forms national interest review groups to determine whether proposed standards are in the public interest. Each group is composed of persons from various organizations concerned with the scope and provisions of a particular document. If there is consensus regarding the general value of a particular standard, then it may be adopted as an American National Standard. Adoption of a standard by

ANSI does not, of itself, give it mandatory status. However, if the standard is cited by a governmental rule or regulation, it may then be backed by force of law.

Specifications

Another standard that is important to the welding inspector is the "specification." The specification differs from the code in that it describes the requirements for a particular object, material, service, etc., while the code describes a much larger scope of construction or fabrication. A specification describes a specific part or material that may become an integral part of a product fabricated in accordance with some code. Companies often develop in-house specifications describing the necessary attributes of a material or process used in their manufacturing operation. The specification may be used entirely within the company, or it may be sent to suppliers to detail exactly what the company wants to purchase. Almost all codes and standards require written welding procedure specifications (WPSs). These specifications provide the welder and inspector with valuable details about the welding processes to be applied. The WPS is a "recipe" for a welded joint.

AWS Filler Metal Specifications

Thirty different specifications for filler materials are published by AWS. Reference to the AWS filler metal specifications is made in ASME and AWS codes, and indirectly in the API Standards. Certain of these specifications are reviewed and adopted by ASME, adding the letters "SF" preceding the AWS designation.

A specification is a standard that clearly and accurately describes the essential technical requirements for a material, product, system or service. It indicates the procedures, methods, qualifications or equipment by which it can be determined that the requirements have been met. A specification is intended to be mandatory when referenced by other mandatory documents, such as those for procurement purposes, or when mutually agreed upon by the parties involved.

The AWS filler metal specifications are shown in Tables 4.3 and 4.4.

Table 4.3
Alphabetic Index to
AWS Filler Metal Specifications

Type	AWS Specification
Aluminum	A5.3, A5.10
Brazing	A5.8, A5.31
Carbon Steel	A5.1, A5.17, A5.18, A5.20, A5.25, A5.26
Cast Iron	A5.15
Consumable Inserts	A5.30
Copper	A5.6, A5.7
Corrosion Resistance	A5.4, A5.9, A5.22
Electrogas	A5.26
Electroslag	A5.25
Flux Cored	A5.20, A5.22, A5.29
Gas Shielded Arc	A5.18, A5.28
Low-Alloy Steel	A5.5, A5.23, A5.25, A5.26, A5.28
Magnesium	A5.19
Nickel	A5.11, A5.14
Stainless Steel	A5.4, A5.9, A5.22
Submerged Arc	A5.17, A5.23
Surfacing	A5.13, A5.21
Titanium	A5.16
Tungsten	A5.12
Zirconium	A5.24

Summary

A welding inspector is required to work under the guidance and requirements of certain codes, standards, and specifications. These documents should describe all of the necessary information, including:

- what to inspect,
- where to inspect,
- how to inspect,
- the extent of inspection, and
- the acceptance criteria to be used during these evaluations.

Various organizations are responsible for the development and maintenance of these codes, standards, and specifications. As required by contract documents, the welding inspector will refer to those documents that will be in effect for the inspector's portion of the inspection.

A number of different codes, standards, and specifications exist for different types of fabrication and construction. Their requirements differ, depending on the specific needs of that particular industry.

Table 4.4
Numeric Index to AWS Filler Metal Specifications

AWS Designation	Type	Title
A5.1	Carbon Steel	Carbon Steel Electrodes for Shielded Metal Arc Welding
A5.2	Carbon Steel	Carbon and Low Alloy Steel Rods for Oxyfuel Gas Welding
A5.3/M	Aluminum	Aluminum and Aluminum Alloy Electrodes for Shielded Metal Arc Welding
A5.4	Stainless Steel	Stainless Steel Electrodes for Shielded Metal Arc Welding
A5.5	Low Alloy Steel	Low Alloy Steel Electrodes for Shielded Metal Arc Welding
A5.6	Copper Alloys and Brazing Materials	Covered Copper and Copper Alloy Arc Welding Electrodes
A5.7	Copper Alloys and Brazing Materials	Copper and Copper Alloy Bare Welding Rods and Electrodes
A5.8	Copper Alloys and Brazing Materials	Filler Metals for Brazing and Braze Welding
A5.9	Stainless Steel	Bare Stainless Steel Welding Electrodes and Rods
A5.10	Aluminum	Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods
A5.11/M	Nickel	Nickel and Nickel Alloy Welding Electrodes for Shielded Metal Arc Welding
A5.12/M	Tungsten (non-consumable)	Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting
A5.13	Surfacing Rods and Electrodes	Solid Surfacing Welding Rods and Electrodes
A5.14/M	Nickel	Nickel and Nickel Alloy Bare Welding Electrodes and Rods
A5.15	Cast Iron	Welding Electrodes and Rods for Cast Irons
A5.16	Titanium	Titanium and Titanium Alloy Welding Electrodes and Rods
A5.17/M	Carbon Steel	Carbon Steel Electrodes and Fluxes for Submerged Arc Welding
A5.18	Carbon Steel	Carbon Steel Filler Metals for Gas Shielded Arc Welding
A5.19	Magnesium	Magnesium Alloy Welding Electrodes and Rods
A5.20	Carbon Steel	Carbon Steel Electrodes for Flux Cored Arc Welding
A5.21	Surfacing Rods and Electrodes	Composite Surfacing Welding Rods and Electrodes
A5.22	Stainless Steel	Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding
A5.23/M	Low Alloy Steel	Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding
A5.24	Zirconium	Zirconium and Zirconium Alloy Welding Electrodes and Rods
A5.25/M	Carbon Steel	Carbon and Low Alloy Steel Electrodes and Fluxes for Electroslag Welding
A5.26/M	Carbon Steel	Carbon and Low Alloy Steel Electrodes for Electrogas Welding
A5.28	Low Alloy Steel	Low Alloy Steel Electrodes for Gas Metal Arc Welding
A5.29	Low Alloy Steel	Low Alloy Steel Electrodes for Flux Cored Arc Welding
A5.30	Consumables	Consumable Inserts
A5.31	Copper Alloys and Brazing Materials	Fluxes for Brazing and Braze Welding
A5.32/M	Shielding Gases	Welding Shielding Gases

NOTE: "M" in the order code means the document incorporates rational metric and customary U.S. units.

Review—Chapter 4—Standards, Including Codes and Specifications

Q4-1 Job quality requirements can be found in all but which of the following?
- a. codes
- b. standards
- c. specifications
- d. text books
- e. a and b only

Q4-2 Of the following documents, which may be considered a "standard"?
- a. codes
- b. specifications
- c. recommended practices
- d. a and b above
- e. all of the above

Q4-3 The type of document that has legal status is:
- a. code
- b. standard
- c. specification
- d. both a and b above
- e. all of the above

Q4-4 That type of document that describes the requirements for a particular object or component is referred to as:
- a. code
- b. standard
- c. specification
- d. a and b above
- e. b and c above

Q4-5 Of the following types of documents, which is the more general type? (In fact, the other documents could be considered as more specific types of this classification.)
- a. codes
- b. standards
- c. specifications
- d. drawings
- e. none of the above

Q4-6 The code that covers the welding of steel structures is:
- a. ASME Section IX
- b. ASME B31.1
- c. API 1104
- d. AWS D1.1
- e. none of the above

Q4-7 The code that covers the design and fabrication of unfired pressure vessels is:
- a. ASME Section IX
- b. ASME Section VIII
- c. ASME Section III
- d. API 1104
- e. AWS D1.1

Q4-8 The specification covering the requirements for welding electrodes are designated as:
a. AWS D1.X
b. AWS D14.X
c. AWS A5.X
d. ASTM A 53
e. ASTM A 36

Q4-9 The standard describing the requirements for welding of cross-country pipelines is:
a. AWS D1.1
b. ASME Section VIII
c. ASME Section IX
d. API 1104
e. none of the above

CHAPTER **5**

Weld Geometry and Welding Terminology

Contents

Chapter 5—Weld Joint Geometry and Welding Terminology

Introduction

One of the more important aspects of the welding inspector's job is the ability to communicate with others involved in the fabrication of a weldment. The inspector needs to effectively state inspection findings to others and understand their responses or questions. This does not imply that all communication must be oral, however, it can also be in the form of written or graphic explanations.

Another part of the welding inspector's job is to review and interpret various documents relating to the welded fabrication. All aspects of this communication require that the individual have a full understanding of the proper terms and definitions used.

AWS has long realized the need for standardized terms and definitions for use by those actively involved in the fabrication of welded products. In answer to this need, AWS has published A3.0, *Standard Welding Terms and Definitions*. This document was developed by the Committee on Definitions and Symbols to aid in the communication of welding information. The standard terms and definitions published in AWS A3.0 should be used in the oral and written language of welding. While these are the standard, or preferred terms, they are by no means the only terms used to describe various situations. Other commonly used welding terms will be mentioned in this document, even though they are not preferred terminology. When these common or nonstandard terms are mentioned, they will appear in parentheses after the preferred words.

While most of the terms used apply to the actual welding operation, it is important for the welding inspector to understand other definitions that apply to related operations. For example, the welding inspector should understand how to describe the various weld joint configurations and elements of the fitting process. After welding is completed, the welding inspector may need to describe the location of some welding discontinuity that has been discovered. If such a discontinuity requires further attention, it is important that the inspector accurately describe the location of the problem, so that the welder will know where the repair is to be made.

Types of Joints

Before welding begins, the welding inspector may be required to examine the weld joint configuration and fit. This is one of the most important aspects of welding inspection, because potential problems that are discovered at this stage can be corrected more economically.

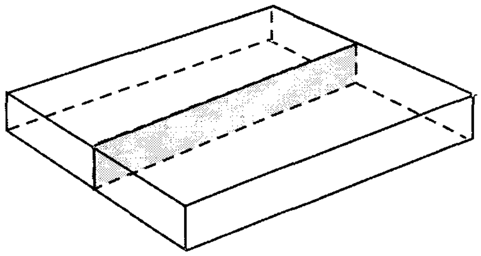
When performing a joint inspection, the welding inspector needs to know the differences between the various types of weld joints. A *joint* is "the junction of members or edges of members that are to be joined or have been joined." The five basic types of joints are butt, corner, T-, lap, and edge (see Figure 5.1).

These five joint types derive their names from their basic configurations. The butt joint describes the configuration when two members to be joined are aligned in the same plane and are connected at their edges.

With a corner joint, the two members to be joined are aligned in perpendicular planes and their edges are connected. The T-joint is similar in that the two members are aligned in perpendicular planes, except the edge of one member is joined to the planar surface of the other. In a lap joint, the two members are aligned in parallel planes, but not the same plane. The joint occurs where the two members overlap each other to form a double thickness region. The final joint configuration, the edge, also has the two members lying in parallel planes, but the two members are aligned with their planar surfaces in contact, so that the actual welding occurs around the perimeter, or outside, of the joint.

Parts of the Weld Joint

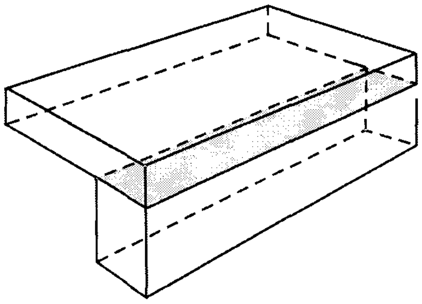
Once the type of joint has been identified, further description of the exact configuration may be required; therefore, the welding inspector must be capable of naming the various features of that particular joint. Some of these elements include joint root, groove face, root face, root edge, root opening, bevel, bevel angle, groove angle, and groove radius. Depending upon the particular type of



APPLICABLE WELDS

BEVEL GROOVE
FLARE BEVEL GROOVE
FLARE V-GROOVE
J-GROOVE
SQUARE GROOVE
U-GROOVE
V-GROOVE
EDGE FLANGE
BRAZE

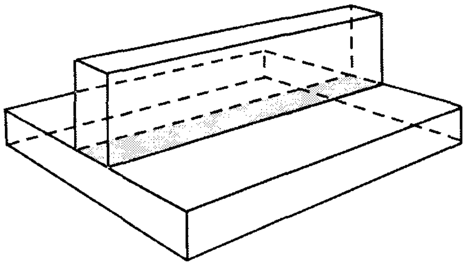
(A) BUTT JOINT



APPLICABLE WELDS

FILLET
BEVEL GROOVE
FLARE BEVEL GROOVE
FLARE V-GROOVE
J-GROOVE
SQUARE GROOVE
U-GROOVE
V-GROOVE
CORNER FLANGE
EDGE FLANGE
PLUG
SLOT
SPOT
SEAM
PROJECTION
BRAZE

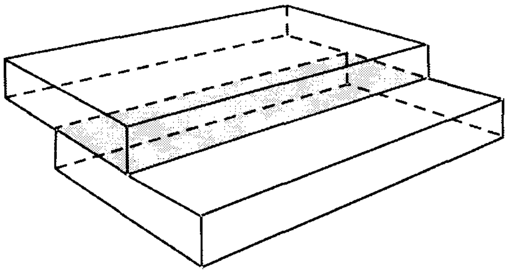
(B) CORNER JOINT



APPLICABLE WELDS

FILLET
BEVEL GROOVE
FLARE BEVEL GROOVE
J-GROOVE
SQUARE GROOVE
PLUG
SLOT
SPOT
SEAM
PROJECTION
BRAZE

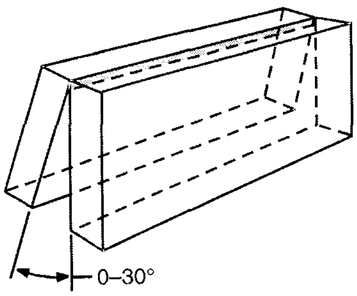
(C) T-JOINT



APPLICABLE WELDS

FILLET
BEVEL GROOVE
FLARE BEVEL GROOVE
FLARE V-GROOVE
J-GROOVE
PLUG
SLOT
SPOT
SEAM
PROJECTION
BRAZE

(D) LAP JOINT



APPLICABLE WELDS

BEVEL GROOVE
FLARE BEVEL GROOVE
FLARE V-GROOVE
J-GROOVE
SQUARE GROOVE
U-GROOVE
V-GROOVE
EDGE
CORNER FLANGE
EDGE FLANGE
SEAM

(E) EDGE JOINT

Figure 5.1—Joint Types

joint configuration, these features may assume slightly different shapes (see Figure 5.2).

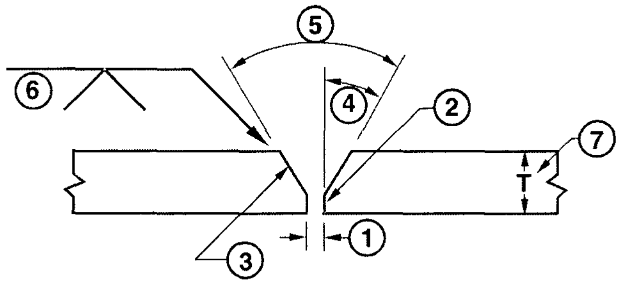
A perfect example of this is the *joint root*, or "that portion of a joint to be welded where the members approach closest to each other. In cross section, the joint root may be either a point, line, or an area."

Some other related terms are groove face, root face, and root edge. By definition, *groove face* is "that surface of a member included in the groove." The *root face* (also commonly called the land, nose, or flat) is "that portion of the groove face adjacent to the joint root." The *root edge* is defined as "a root face of zero width."

Terms describing actual shapes and dimensions are some of the other features that the welding inspector may be required to describe. Because these elements are often essential variables for welding procedure specifications, the welding inspector may be required to actually measure the elements to judge their compliance with applicable drawings or other documents.

The ASME code lists three types of variables for welding procedure specifications (WPSs). *Essential variables* are those in which change is considered to affect mechanical properties of the weld joint or weldment. For example, a change in the base metal, welding process, filler metal, preheat, or postweld heat treatment. *Supplementary essential variables* are variables in which change is considered to affect the notch toughness of the weld metal or the heat-affected zone. A change in the welding process, vertical up or down welding, heat input, and/or preheat are examples of supplementary essential variables. A change in either essential or supplementary essential variables require that the WPS be requalified. Nonessential variables are those in which a change may be made in the WPS without the need for requalification. AWS D1.1 lists essential variables requiring WPS requalification for the SMAW, SAW, GMAW, FCAW, and GTAW processes.

The *root opening* (gap) is described as "a separation between the workpieces at the joint root." The *bevel* (also referred to as chamfer) is "an angular edge slope." The *bevel angle* is defined as "the angle between the bevel of a joint member and a plane perpendicular to the surface of the member." The *groove angle* is "the total included angle of the groove between workpieces." For a single-bevel-groove weld, the bevel angle and the groove angle are equal. The final term, *groove radius*, applies only to J- and U-groove welds and is described as "the radius used to form the shape of a J- or U-groove weld." Normally, a



1. ROOT OPENING:	A separation at the joint root between the workpieces.
2. ROOT FACE:	That portion of the groove face adjacent to the joint root.
3. GROOVE FACE:	The surface of a joint member included in the groove.
4. BEVEL ANGLE:	The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.
5. GROOVE ANGLE:	The total included angle of the groove between workpieces.
6. GROOVE WELD SIZE:	The joint penetration of a groove weld.
7. PLATE THICKNESS (T):	Thickness of the base metals to be welded.

Figure 5.2—Groove Weld

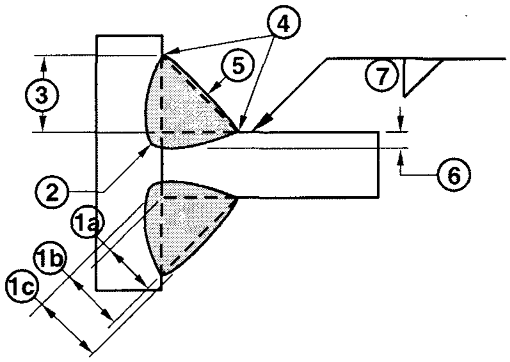
J- or U-groove weld configuration is specified by both a bevel (or groove) angle and a groove radius.

Figure 5.3 illustrates the various parts of a fillet weld.

Types of Welds

There are numerous welds that can be applied to the various types of joints. According to AWS A3.0, there are 18 basic types of welds used in arc welding:

(1) Square-groove weld
(2) Bevel-groove weld
(3) V-groove weld
(4) J-groove weld
(5) U-groove weld
(6) Flare-bevel-groove weld
(7) Flare-V-groove weld
(8) Fillet weld
(9) Edge weld
(10) Edge-flange weld
(11) Corner-flange weld
(12) Spot weld
(13) Seam weld
(14) Plug weld
(15) Slot weld
(16) Surfacing weld
(17) Back weld
(18) Backing weld

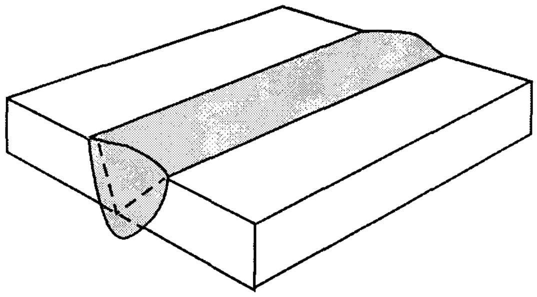


1. FILLET WELD THROAT
   a. THEORETICAL THROAT: The distance from the beginning of the joint root perpendicular to the hypotenuse of the Largest right triangle that can be inscribed within the cross section of a fillet weld. This dimension is based on the assumption that the root opening is equal to zero.
   b. EFFECTIVE THROAT: The minimum distance minus any convexity between the weld root and the face of a fillet weld.
   c. ACTUAL THROAT: The shortest distance between the weld root and the face of the fillet weld.
2. WELD ROOT: The points, shown in a cross section, at which the root surface intersects the base metal surfaces.
3. FILLET WELD LEG: The distance from the joint root to the toe of the fillet weld.
4. WELD TOE: The junction of the weld face and the base metal.
5. WELD FACE: The exposed surface of a weld on the side from which welding was done.
6. DEPTH OF FUSION: The distance that fusion extends into the base metal or previous bead from the surface melted during welding.
7. FILLET WELD SIZE: For equal leg fillet welds, the lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed with the fillet weld cross section.

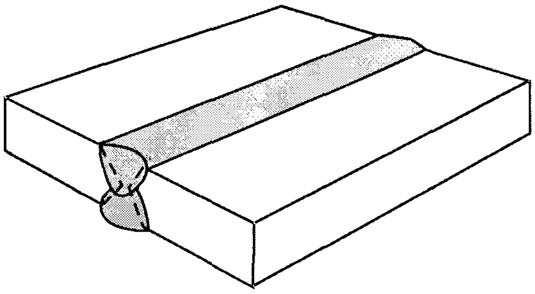
Figure 5.3—Fillet Weld

With this variety of weld geometries available, the welding fabricator can choose the one that best suits the specifications. This choice could be based on considerations such as accessibility, type of welding process being used, method of joint preparation, and adaptation to particular designs of the structure being fabricated. Figure 1, which shows the various types of weld joints, also indicates which of the previous welds can be applied to each of the five types of weld joints.

The first seven types of welds refer to different groove configurations. Their names imply what the actual configurations look like when viewed in cross section. All of these groove weld types can be applied to joints that are welded from a single side or both sides. A *single-welded joint* is "a joint that is welded from one side only," while a *double-welded joint* is "a joint that is welded from both sides" (see Figure 5.4).



SINGLE V-GROOVE WELD



DOUBLE V-GROOVE WELD

Figure 5.4—Groove Welds

The next category of weld is the *fillet weld*, defined by AWS A3.0 as "a weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, T-joint, or corner joint." The fillet weld is possibly the most commonly used type of weld. *NOTE: A fillet weld is not a type of joint; rather, it is a particular type of weld that can be applied to a lap, T-, or corner joint.*

An *edge weld* is described as "a weld in an edge joint (see Figure 5.5).

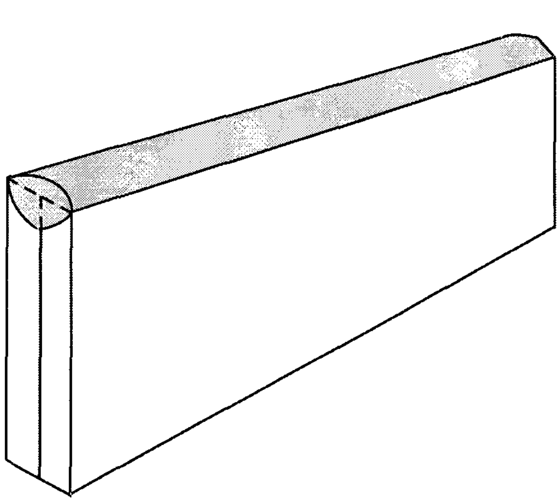
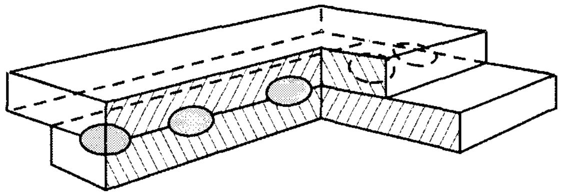


Figure 5.5—Edge Weld

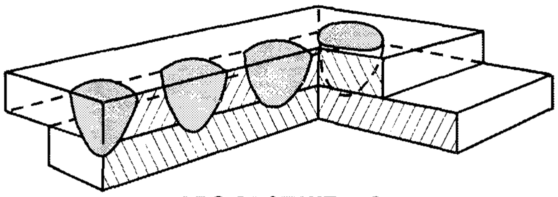
The next type of weld to be discussed is the *spot weld*, which is defined as "a weld made between or upon overlapping members in which coalescence (the act of combining or uniting) may start and occur on the faying surfaces or may proceed from the outer surface of one member. The weld cross section (plan view) is approximately circular" (see Figure 5.6). Spot welds are most commonly associated with resistance welding, which is used extensively in the automotive and aerospace industries. However, a very effective way to join a lap joint configuration is through the use of an arc spot weld. A *faying surface* is "the mating surface of a member that is in contact with or in close proximity to another member to which it is joined." In the case of arc spot welding, the weld is accomplished by melting through the top member using one of the arc welding processes, so that fusion occurs between it and the member which it overlaps.

A similar type of weld is the *seam weld*, which is defined as "a continuous weld made between or upon overlapping members, in which coalescence may start and occur on the faying surfaces, or may have proceeded from the outer surface of one member." Instead of being applied in a single spot, the seam weld forms a continuous weld having some length (see Figure 5.7). As was the case for spot welds, seam welds can be accomplished using resistance or arc welding methods. The continuous weld may consist of a single weld bead or a series of overlapping spot welds. Like the arc spot weld, the arc seam weld extends through one member to provide fusion to the member that is overlapped.

Two other types of welds that are used for joining overlapping members are plug and slot welds. These two

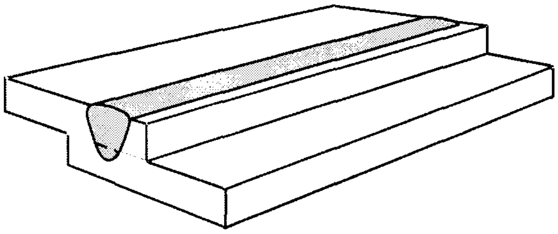


RESISTANCE SPOT WELDS

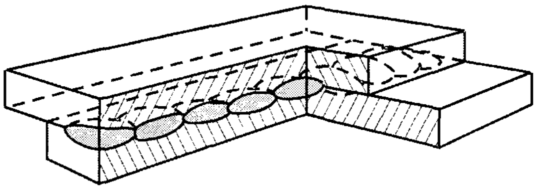


ARC SPOT WELDS

Figure 5.6—Spot Welds



ARC SEAM WELD



RESISTANCE SEAM WELDS

Figure 5.7—Seam Welds

welds differ from spot and seam welds, in that the near side member has a hole or slot cut to provide access to the member that it overlaps. A *plug weld* is defined as "a weld made in a circular hole in one member of a joint fusing that member to another member. A fillet welded hole is not to be construed as conforming to this definition."

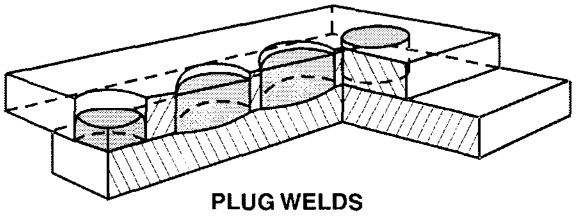
Similarly, a *slot weld* is "a weld made in an elongated hole in one member of a joint fusing that member to another member." The hole may be open at one end. A fillet welded slot is not to be construed as conforming to this definition" In either case, the hole or slot is normally filled flush with the top surface. A fillet weld applied in a circular hole or slot is not considered to be either a plug or slot weld (see Figure 5.8).

The next weld type is the *surfacing weld*, which is defined as "a weld applied to a surface, as opposed to making a joint, to obtain desired properties or dimensions." Normally, the primary reason for this application is to provide a barrier against abrasion or corrosion. Often, this approach is more economical than using the full thickness of a more expensive material (see Figure 5.9).

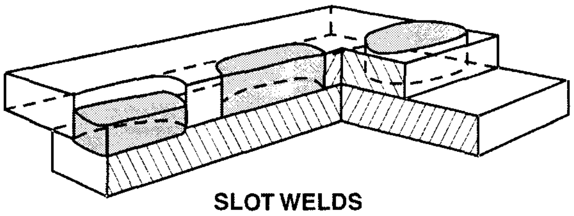
The final weld types to be discussed are called back and backing welds. These welds are applied to the back side of a weld joint. Although they are applied to the same location, backing welds differ depending upon when they are deposited. AWS A3.0 describes a *back weld* as "a weld made at the back of a single groove weld," and a *backing weld* as "backing in the form of a weld." A back weld is applied after the front side has already been welded, while the backing weld is deposited prior to the welding of the front side.

Parts of Completed Welds

The discussion thus far has been limited to descriptions of weld joints and types of weld configurations. However, the welding inspector must also be aware of terms used to describe conditions or features of completed welds. When a completed weld is being inspected, the inspector should describe the conditions that exist when reporting inspection findings. Groove welds have



PLUG WELDS



SLOT WELDS

Figure 5.8—Plug and Slot Welds

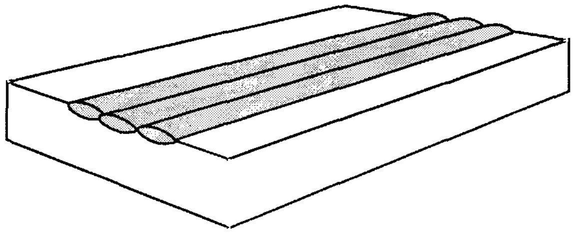


Figure 5.9—Surfacing Weld

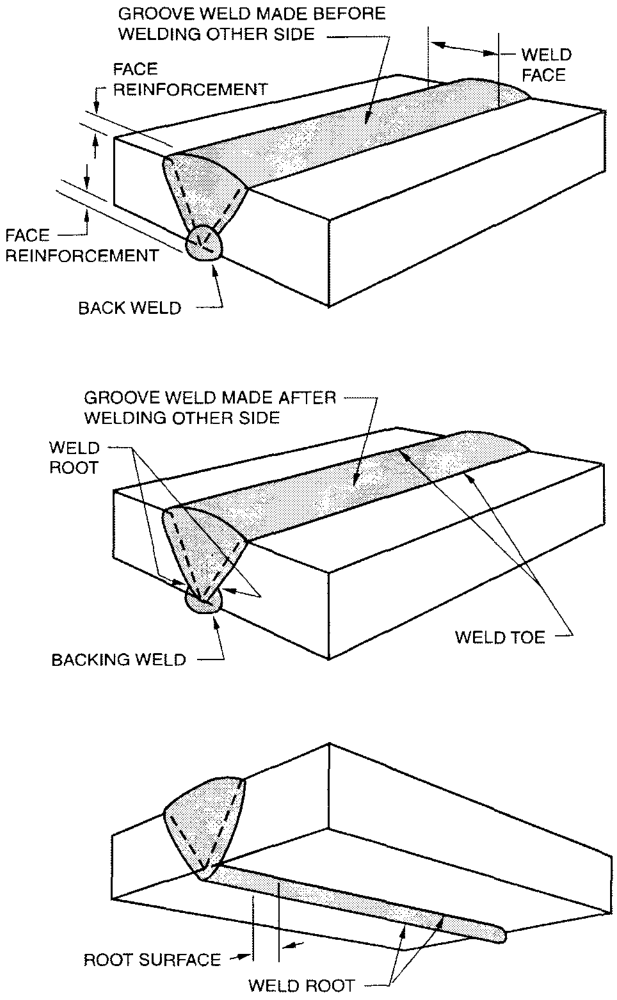


Figure 5.10—Parts of a Weld

several primary components. The first part, the *weld face*, is "the exposed surface of a weld on the side from which welding was done." "The junction of the weld face and the base metal" is referred to as the *weld toe*. Opposite the weld face is the *weld root*, which is defined as "the points, shown in cross section, at which the root surface intersects the base metal surfaces." The *root surface* is "the exposed surface of the weld opposite the side from which welding was done." Therefore, the root surface is bounded by the weld root on either side.

Other terms relate to *weld reinforcement*, "the weld metal in excess of the quantity required to fill a joint." The *face reinforcement* (also commonly called weld crown) is "weld reinforcement on the side of the joint from which welding was done." Conversely, the *root reinforcement* is "weld reinforcement opposite the side from which welding was done." In both cases, this represents that portion of the weld metal that extends beyond the surface of the base metal (see Figure 5.10).

The previous explanations assume a single-welded joint, or all welding was performed from one side. In the case of a double-welded joint, both sides of the joint will have a weld face, and the amount of reinforcement present on each side will be referred to as the face reinforcement. This is illustrated in Figure 5.10, showing the use of a back weld.

Just as groove welds have names for various parts, standard terminology exists for parts of fillet welds. As with the groove weld, the surface of the weld that the inspector will evaluate is referred to as the weld face. The junctions of the weld face with the base metal are the weld toes. The furthest penetration of the weld metal into the joint is the weld root.

The distance from the weld toe to the joint root is called the fillet weld leg. One other feature of a fillet weld is the *weld throat*, generally the shortest distance through the cross section of the weld. Various types of fillet weld throats will be discussed in more detail under the topic of sizing convex and concave fillet welds (see Figure 5.11).

> It is important to use correct terminology when writing inspection reports, specifications, and other documents related to code inspections. However, wide variations in the use of correct welding terms still exist throughout the industry. Welders will make reference to "stingers" "whips" (electrode holders), "ground clamps" (work leads), "nose," "land or landing" (root faces), "heat," "temperature" (amperage), etc. While it may be necessary to use these terms to be understood by the welder, the inspection report should contain the correct terminology. Correct terminology should be emphasized in any training program.

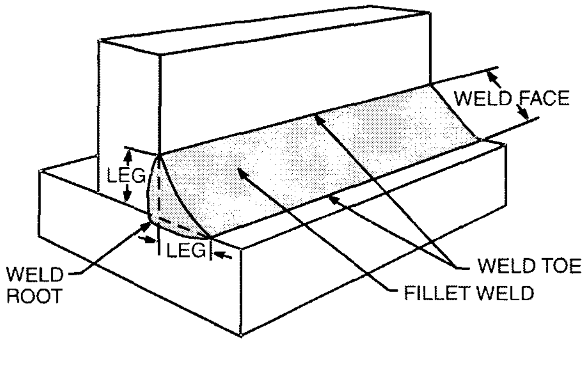


Figure 5.11—Parts of a Weld

Fusion and Penetration Terminology

There are also terms relating to the fusion and penetration of the weld metal into the base metal. These features are difficult for the visual inspector to check without further destructive or nondestructive examination; however, it is still important to understand what the various terms mean.

In general, *fusion* refers to the actual melting together of the filler metal and base metal, or of the base metal only. *Penetration* relates to the distance that the weld metal has progressed into the joint. The degree of penetration achieved has a direct effect on the strength of the joint and is, therefore, related to the weld size.

Numerous terms exist that describe the degree or location of either fusion or penetration. During the welding operation, the original groove face is melted so that the final boundary of the weld metal is deeper than the original surface. The groove face is referred to as the *fusion face*, because it will be melted during welding. The boundary between the weld metal and base metal is referred to as the *weld interface*. The depth of fusion is the distance from the fusion face to the weld interface. The depth of fusion is always measured perpendicular to the fusion face. These terms are applied similarly for other types of welds, such as fillet and surfacing welds (see Figure 5.12).

There are also several terms that refer to penetration of the weld. *Root penetration* is "the distance that the weld metal extends into the joint root." The *joint penetration* is "the distance the weld metal extends from the weld face into a joint, exclusive of any weld reinforcement." For groove welds, this same length is also referred to as the *weld size* (sometimes improperly referred to as effective throat) (see Figure 5.13).

Another related term is *heat-affected zone* (HAZ), the region defined as "the portion of the base metal whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, or thermal cutting" (see Figure 5.14).

Weld Size Terminology

The previous discussion described joint penetration and the weld size for single-groove weld configurations. For a double-groove weld configuration where the joint penetration is less than complete, the weld size is equal to the sum of the joint penetrations from both sides.

For a complete penetration groove weld, the weld size will be equal to the thickness of the thinner of the two members joined, because there is no credit given for any weld reinforcement present (see Figure 5.15).

To determine the size of a fillet weld, first establish whether the final weld configuration is convex or concave. The weld profile is convex if the weld face exhibits some buildup, causing it to appear slightly curved outwardly. This is referred to as the amount of convexity. Convexity in a fillet weld is analogous with weld reinforcement in a groove weld. If the weld face is "dished in," the profile is determined to be concave.

For either configuration, the fillet weld size for equal leg fillet welds is described as "the leg lengths of the largest isosceles (two legs of equal length) right triangle which can be inscribed within the fillet weld cross section" (see Figure 5.16).

These inscribed isosceles right triangles are shown with dotted lines in Figure 5.17; therefore, for the convex fillet weld, the leg, and size are equal. However, the size of a concave fillet weld is slightly less than its leg length. For unequal leg fillet welds, the fillet weld size is defined as "the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross section."

The additional notations on these illustrations refer to the three different types of fillet weld throat as follows:

(1) The *theoretical throat* is described as "the distance from the beginning of the joint root perpendicular to the hypotenuse (side of the triangle opposite the right angle) of the largest right triangle that can be inscribed within the cross section of a fillet weld. This dimension is based on the assumption that the root opening is equal to zero." This is the minimum amount of weld considered when the designer originally specifies a weld size.

(2) The *effective throat* can be defined as "the minimum distance minus any convexity between the weld root and the face of a fillet weld." The effective throat takes into account any additional joint penetration which may be present.

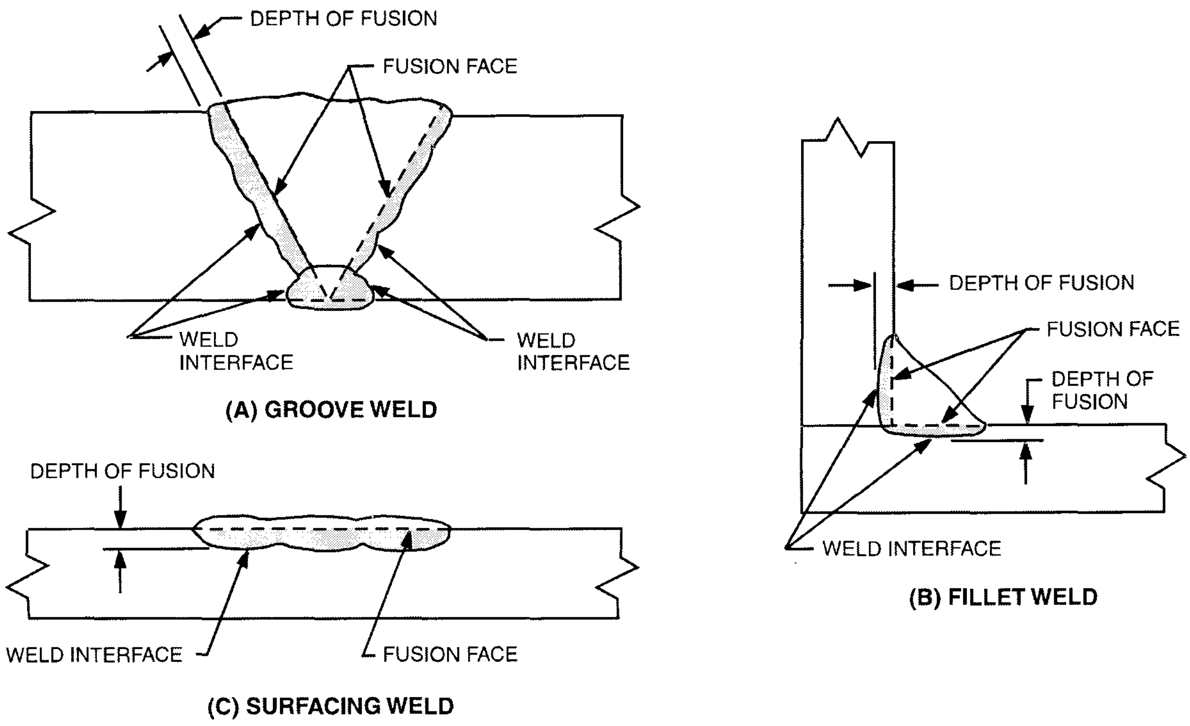


Figure 5.12—Fusion Welds

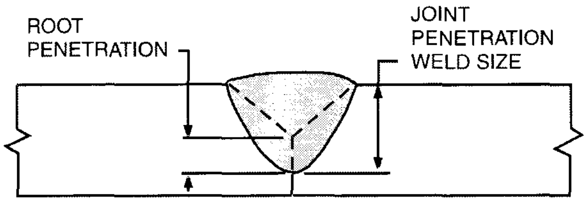


Figure 5.13—Incomplete Joint Penetration or Partial Joint Penetration

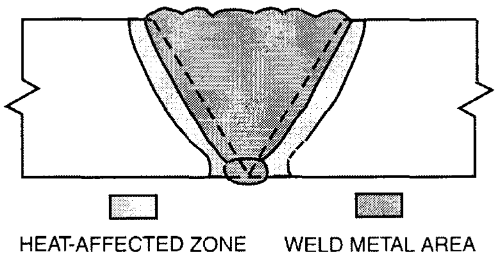


Figure 5.14—Heat-Affected Zone

(3) The *actual throat* is described as "the shortest distance between the weld root and the face of a fillet weld." The actual throat, takes into account both the joint penetration and any additional convexity present at the weld face. For a concave fillet weld, the effective throat and actual throat are equal, since there is no convexity present (see Figure 5.17).

The welding inspector may also be asked to determine the sizes of other types of welds, for example, a spot or seam weld, where the weld size is equal to the actual spot diameter or seam width (see Figure 5.18). For an edge or flange weld, the weld size is equal to the total thickness of the weld from the weld root to the weld face.

Weld Application Terminology

To complete this discussion of welding terms and definitions, it seems appropriate to mention some of the terminology associated with the actual application of welds. Since some welding procedures refer to these details, the welding inspector should be familiar with their meanings. The first aspect is the difference among the terms

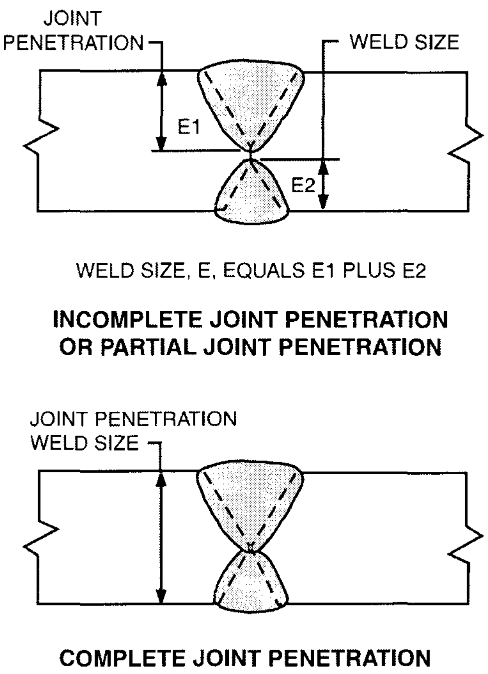


Figure 5.15—Joint Penetration

weld pass, weld bead, and weld layer. A *weld pass* is "a single progression of welding along a joint. The result of a pass is a *weld bead* or *weld layer*, which is defined as "a stratum of weld metal consisting of one or more weld beads." A weld layer may consist of a single bead or multiple beads (see Figure 5.19).

When a weld bead is deposited, it can have a different name, depending upon the technique used by the welder. A type of weld bead made without appreciable weaving motion is referred to as a *stringer bead.* A *weave bead*, which is defined as "a type of weld bead made with transverse oscillation," results when the welder manipulates the electrode laterally, or side to side, as the weld is deposited along the joint. The weave bead is typically wider than the stringer bead. Due to the amount of lateral motion used, the travel speed (as measured along the longitudinal axis of the weld) is less than would be the case for a stringer bead (see Figure 5.20).

There are several terms that describe the actual sequence in which the welding is to be done. This is commonly done to reduce the amount of distortion caused by welding. Three common techniques, backstep sequence, block sequence, and cascade sequence, are defined as follows:

(1) A *backstep sequence* is "a longitudinal sequence in which weld passes are made in the direction opposite to the progress of welding."

(2) A *block sequence* is "a combined longitudinal and cross-sectional sequence for a continuous multiple pass weld in which separated increments are completely or partially welded before intervening increments are welded." With the block sequence, it is important that each subsequent layer is slightly shorter than the previous one so that the end of the block has a gentle slope. This will provide the best chance of obtaining adequate fusion when the adjacent block is filled in later.

(3) A *cascade sequence* is "a combined longitudinal and cross-sectional sequence in which weld passes are made in overlapping layers." This method differs from the block sequence in that each subsequent pass is longer than the previous one (see Figure 5.21).

When fillet welds are required, occasionally the design will not warrant the use of continuous welds; therefore, the designer may specify intermittent fillet welds. If there are intermittent fillet welds specified on both sides of a particular joint, they can be detailed as either chain intermittent or staggered intermittent fillet welds. The *chain intermittent fillet weld* is defined as "having an intermittent weld on both sides of a joint in which the weld increments on one side are approximately opposite to those on the other side."

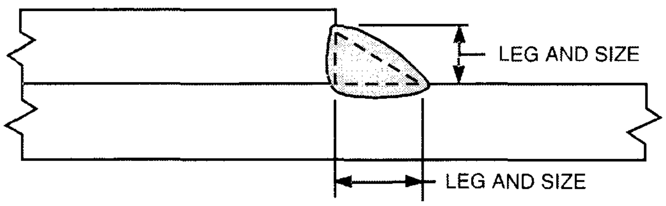
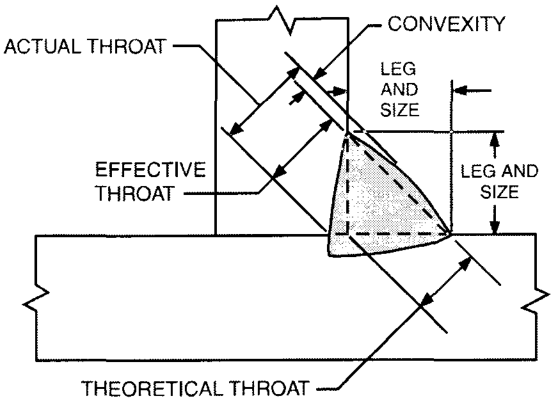
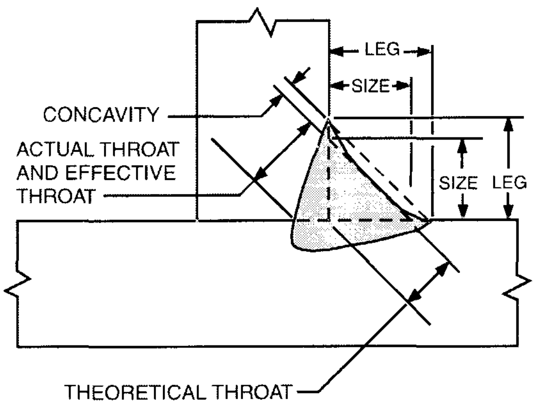


Figure 5.16—Unequal Leg Fillet Weld



CONVEX FILLET WELD



CONCAVE FILLET WELD

Figure 5.17—Fillet Welds

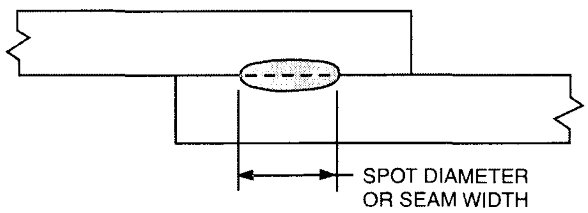
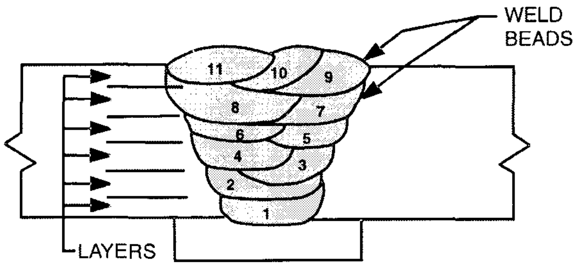


Figure 5.18—Size of Seam or Spot Weld



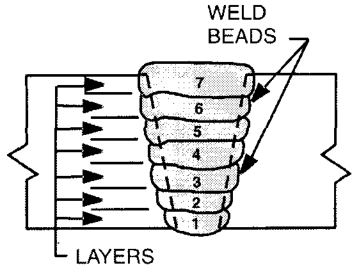
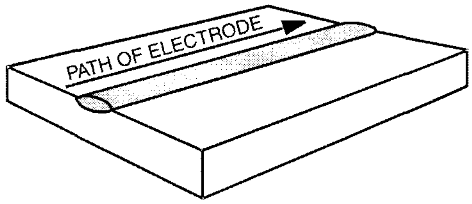
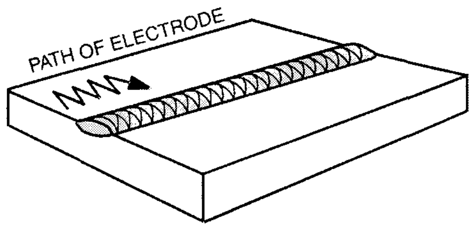


Figure 5.19—Cross-Sectional Welding Sequence



STRINGER BEAD



WEAVE BEAD

Figure 5.20—Weld Beads

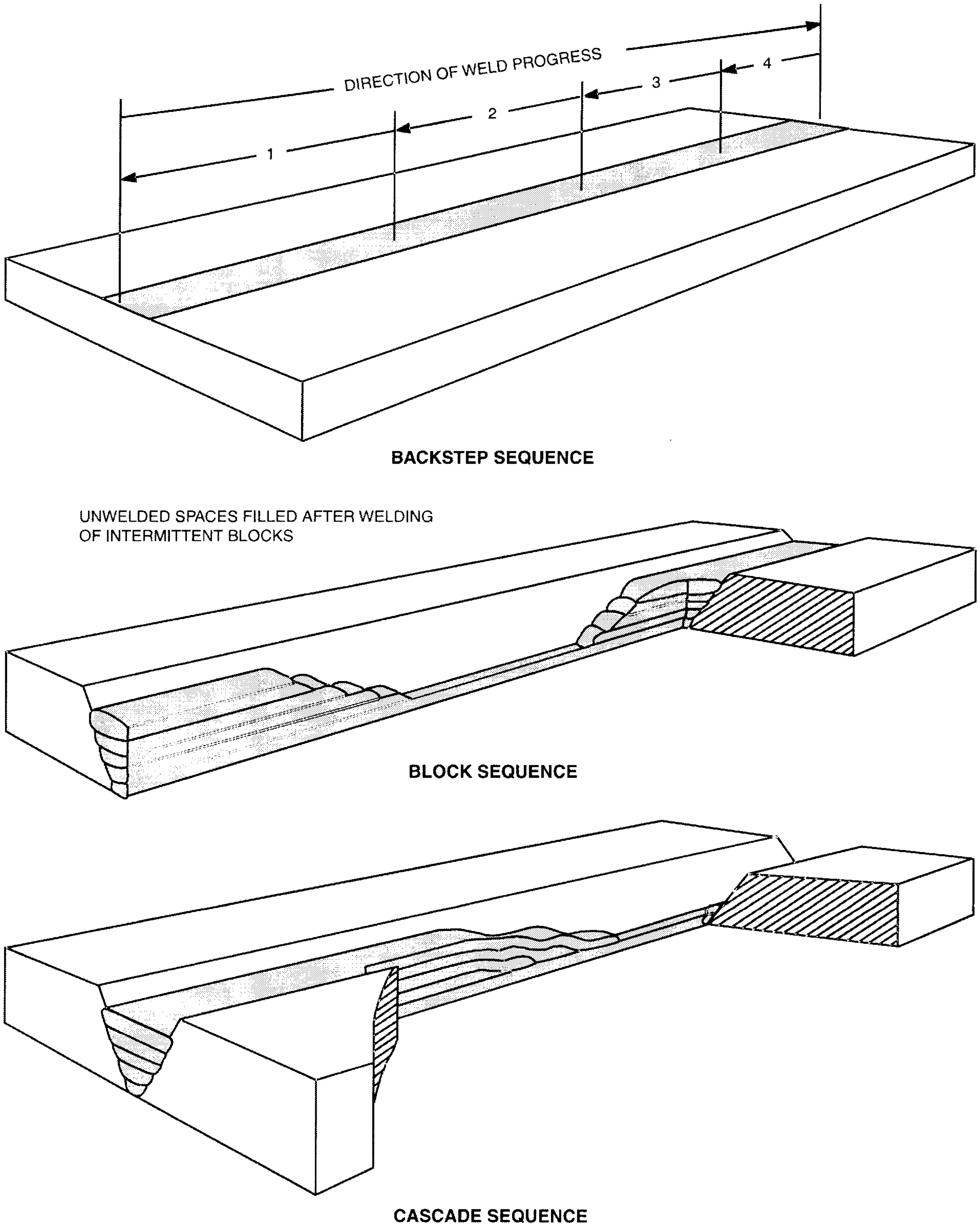


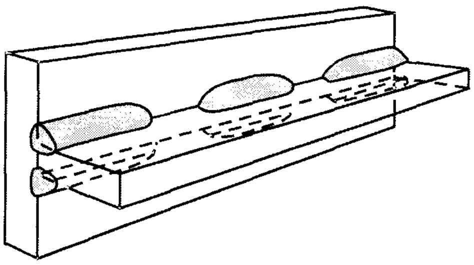
Figure 5.21—Welding Sequences

Similarly, a *staggered intermittent fillet weld* is defined as "an intermittent fillet weld on both sides of a joint in which the weld increments on one side are alternated with respect to those on the other side" (see Figure 5.22).

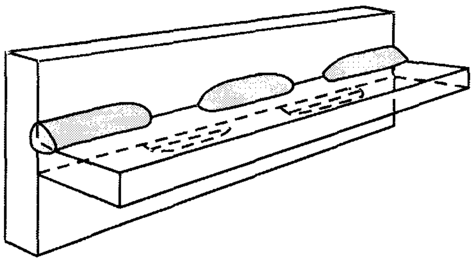
One final term related to the actual welding operation is *boxing* (commonly referred to as "end returning"), which is defined as "the continuation of a fillet weld around a corner of a member as an extension of the principal weld" (see Figure 5.23).

Summary

Although numerous terms have been discussed, these are not the only terms that are applied to welding; however, they provide a basis upon which the inspector can begin to understand how to describe a weld or some feature of that weld. These written explanations and illustrations are simply a beginning. With experience, the welding inspector will learn to correlate these "textbook" terms with actual physical characteristics. Only after working with and using these terms will the inspector gain full understanding of how to describe various welding attributes.



CHAIN INTERMITTENT FILLET WELD



STAGGERED INTERMITTENT FILLET WELD

Figure 5.22—Intermittent Fillet Welds

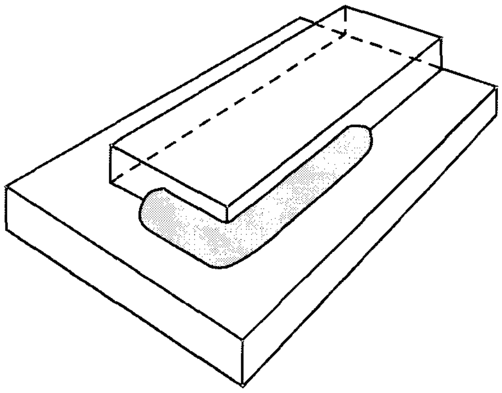


Figure 5.23—Boxing

Review—Chapter 5—Weld Joint Geometry and Welding Terminology

Q5-1 Which of the following is not considered a type of joint?
- a. butt
- b. T
- c. fillet
- d. corner
- e. edge

Q5-2 The type of joint formed when the two pieces to be joined are aligned in parallel planes and their edges overlap is called:
- a. corner
- b. T
- c. edge
- d. lap
- e. butt

Q5-3 That portion of the joint where the two pieces to be joined come closest together is referred to as the:
- a. bevel
- b. joint root
- c. groove angle
- d. root face
- e. both b and d

Q5-4 In a single-V-groove weld, the sloped surfaces against which the weld metal is applied are called:
- a. root face
- b. joint root
- c. groove face
- d. groove angle
- e. bevel angle

Q5-5 The type of weld produced by filling an elongated hole in an overlapping member, fusing it to the member beneath is called a:
- a. plug weld
- b. spot weld
- c. seam weld
- d. slot weld
- e. none of the above

Q5-6 The type of weld having a generally triangular cross section and which is applied to either a T-, corner, or lap joint is called a:
- a. flange weld
- b. flare weld
- c. fillet weld
- d. slot weld
- e. spot weld

Q5-7 The type of weld used to build up thinned surfaces, provide a layer of corrosion protection, provide a layer of abrasion-resistant material, etc. is referred to as a:
- a. edge weld
- b. flare weld
- c. flange weld
- d. slot weld
- e. surfacing weld

Q5-8 The type of weld applied to the opposite side of a joint before a single-V-groove weld is completed on the near side of a joint is called a:

a. melt-through weld
b. backing weld
c. back weld
d. root weld
e. none of the above

Q5-9 In a completed groove weld, the surface of the weld on the side from which the welding was done is called the:

a. crown
b. weld reinforcement
c. weld face
d. root
e. none of the above

Q5-10 In a completed weld, the junction between the weld face and the base metal is called the:

a. root
b. weld edge
c. weld reinforcement
d. leg
e. weld toe

Q5-11 The height of the weld above the base metal in a groove weld is called the:

a. crown
b. buildup
c. face
d. weld reinforcement
e. none of the above

Q5-12 In a fillet weld, the leg and size are the same for what type of configuration?

a. equal leg
b. concave
c. convex
d. unequal leg
e. oversize

Q5-13 When looking at the cross section of a completed groove weld, the difference between the fusion face and the weld interface is called the:

a. depth of fusion
b. depth of penetration
c. root penetration
d. joint penetration
e. effective throat

Q5-14 For a concave fillet weld, which throat dimensions are the same?

a. theoretical and effective
b. actual and effective
c. theoretical and actual
d. all of the above
e. none of the above

Q5-15 In a partial penetration single-V-groove weld, the dimension measured from the joint root to the weld root is called the:

a. joint penetration
b. effective throat
c. root penetration
d. depth of fusion
e. weld interface

Q5-16 The size of a spot weld is determined by its:

a. depth of fusion
b. spot diameter
c. depth of penetration
d. thickness
e. none of the above

Q5-17 In the performance of a vertical position weld, the type of weld progression having a side-to-side motion is called:

a. stringer bead technique
b. stagger bead technique
c. weave bead technique
d. unacceptable
e. none of the above

Q5-18 The technique used to control distortion of a long joint where individual passes are applied in a direction opposite the general progression of welding in the joint is called:

a. backstepping
b. boxing
c. staggering
d. cascading
e. blocking

Q5-19 A technique used in a multiple layer weld deposit where each successive layer is longer than the previous one is called:

a. block sequence
b. box sequence
c. cascade sequence
d. backstep sequence
e. stagger sequence

Questions **Q5-20** through **Q5-27** refer to Figure 1 below:

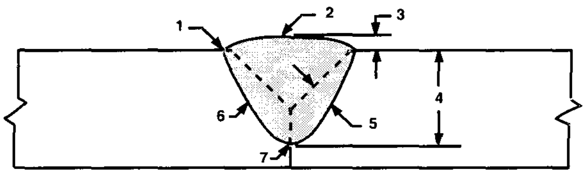


FIGURE 1

Q5-20 The weld face shown in Figure 1 is labeled:

a. 1
b. 2
c. 3
d. 6
e. 7

Q5-21 The weld root shown in Figure 1 is labeled:

a. 1
b. 2
c. 3
d. 6
e. 7

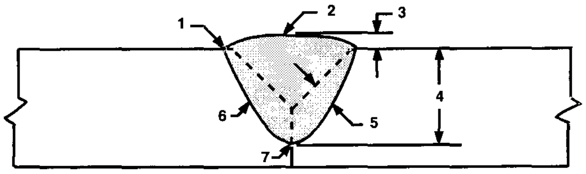


FIGURE 1

Q5-22 The type of weld shown in Figure 1 is a:
- a. double-bevel-groove
- b. single-bevel-groove
- c. double-V-groove
- d. single-V-groove
- e. none of the above

Q5-23 The weld reinforcement height shown in Figure 1 is labeled:
- a. 1
- b. 2
- c. 3
- d. 6
- e. 7

Q5-24 The weld toe shown in Figure 1 is labeled:
- a. 1
- b. 2
- c. 3
- d. 6
- e. 7

Q5-25 Number 6 shown in Figure 1 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-26 Number 5 (between arrows) shown in Figure 1 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-27 Number 4 shown in Figure 1 is the:
- a. weld size
- b. joint penetration
- c. actual throat
- d. theoretical throat
- e. a and b above

Questions **Q5-28** through **Q5-39** refer to Figure 2 below:

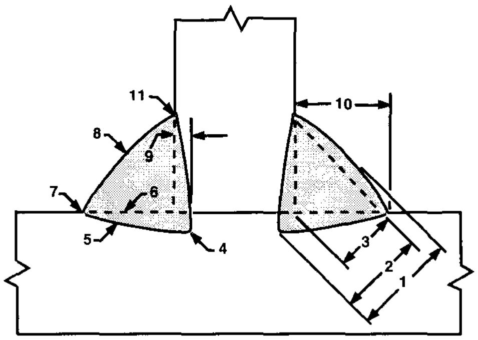


FIGURE 2

Q5-28 The weld face shown in Figure 2 is labeled:
- a. 7
- b. 8
- c. 6
- d. 11
- e. 10

Q5-29 The weld root shown in Figure 2 is labeled:
- a. 6
- b. 4
- c. 5
- d. 9
- e. 3

Q5-30 The welds shown in Figure 2 are:
- a. concave fillets
- b. conical fillets
- c. convex fillets
- d. T-fillets
- e. fillet of fish

Q5-31 The actual throat shown in Figure 2 is labeled:
- a. 1
- b. 2
- c. 3
- d. 10
- e. 9

Q5-32 The weld toe shown in Figure 2 is labeled:
- a. 11
- b. 8
- c. 10
- d. 7
- e. both a and d

Q5-33 Number 6 shown in Figure 2 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-34 Number 9 shown in Figure 2 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-35 Number 5 shown in Figure 2 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-36 Number 4 shown in Figure 2 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-37 Number 2 shown in Figure 2 is the:
- a. weld size
- b. effective throat
- c. actual throat
- d. theoretical throat
- e. a and b above

Q5-38 Number 3 shown in Figure 2 is the:
- a. weld size
- b. effective throat
- c. actual throat
- d. theoretical throat
- e. a and b above

Q5-39 Number 10 shown in Figure 2 is the:
- a. weld size and leg size
- b. weld size
- c. leg
- d. theoretical throat
- e. actual throat

Questions **Q5-40** through **Q5-44** refer to Figure 3 below:

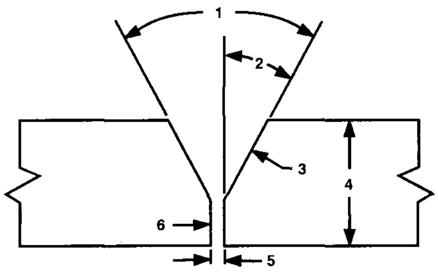


FIGURE 3

Q5-40 The groove angle shown in Figure 3 is labeled:
- a. 1
- b. 2
- c. 3
- d. 4
- e. 5

Q5-41 The bevel angle shown in Figure 3 is labeled:
- a. 1
- b. 2
- c. 3
- d. 4
- e. 5

Q5-42 Number 3 shown in Figure 3 is the:
- a. groove angle
- b. bevel angle
- c. groove face
- d. fusion face
- e. both c and d above

Q5-43 Number 6 shown in Figure 3 is the:
- a. groove face
- b. fusion face
- c. bevel face
- d. root face
- e. bevel

Q5-44 Number 5 shown in Figure 3 is the:
- a. fusion face
- b. groove face
- c. root opening
- d. root face
- e. weld root

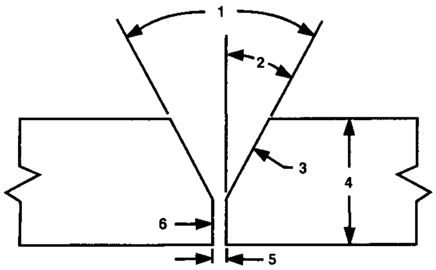


FIGURE 3

Questions **Q5-45** through **Q5-53** refer to Figure 4 below:

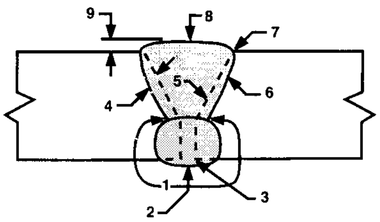


FIGURE 4

Q5-45 The weld faces shown in Figure 4 are labeled:
- a. 8 and 2
- b. 9 and 7
- c. 7 and 4
- d. 1 and 6
- e. 3 and 9

Q5-46 The weld root shown in Figure 4 is labeled:
- a. 1
- b. 2
- c. 3
- d. 7
- e. a and c above

Q5-47 The weld shown in Figure 4 includes a:
- a. backing weld
- b. back weld
- c. double-V-groove
- d. double-bevel-groove
- e. none of the above

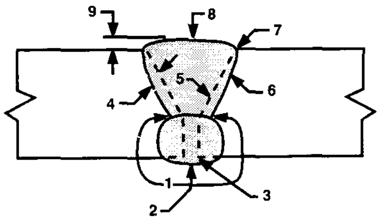


FIGURE 4

Q5-48 The weld size shown in Figure 4 is labeled:
- a. 9
- b. 8
- c. 7
- d. 2
- e. none of the above

Q5-49 The weld toe shown in Figure 4 is labeled:
- a. 1
- b. 2
- c. 3
- d. 6
- e. 7

Q5-50 Number 6 shown in Figure 4 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-51 Number 5 shown in Figure 4 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-52 Number 4 (between arrows) shown in Figure 4 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-53 Number 2 shown in Figure 4 is the:
- a. root surface
- b. fusion face
- c. weld face
- d. weld interface
- e. depth of fusion

Questions **Q5-54** through **Q5-57** refer to Figure 5 below:

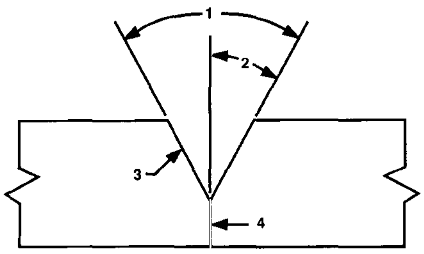


FIGURE 5

Q5-54 The bevel angle shown in Figure 5 is labeled:
- a. 1
- b. 2
- c. 3
- d. 4
- e. both c and d above

Q5-55 The joint root shown in Figure 5 is labeled:
- a. 1
- b. 2
- c. 3
- d. 4
- e. none of the above

Q5-56 The groove face shown in Figure 5 is labeled:
- a. 1
- b. 2
- c. 3
- d. 4
- e. both c and d above

Q5-57 The root face shown in Figure 5 is labeled:
- a. 1
- b. 2
- c. 3
- d. 4
- e. none of the above

Questions **Q5-58** through **Q5-65** refer to Figure 6 below:

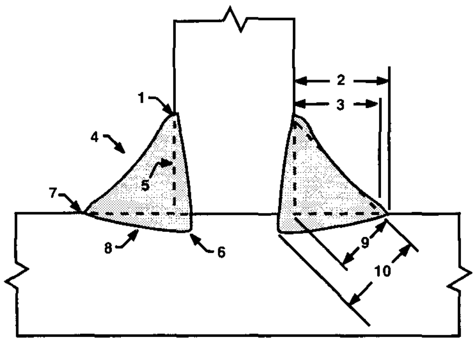


FIGURE 6

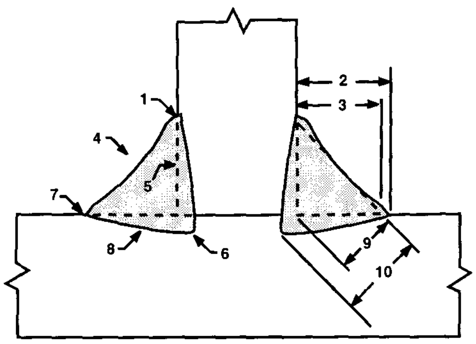


FIGURE 6

Q5-58 The weld face shown in Figure 6 is labeled:
- a. 1
- b. 4
- c. 7
- d. 3
- e. 2

Q5-59 The weld root shown in Figure 6 is labeled:
- a. 6
- b. 4
- c. 5
- d. 9
- e. 10

Q5-60 The welds shown in Figure 6 are:
- a. concave fillets
- b. conical fillets
- c. convex fillets
- d. T-fillets
- e. fillets of fish

Q5-61 The actual throat shown in Figure 6 is labeled:
- a. 9
- b. 10
- c. 3
- d. 2
- e. 5

Q5-62 The weld toe shown in Figure 6 is labeled:
- a. 1
- b. 8
- c. 10
- d. 7
- e. both a and d above

Q5-63 Number 6 shown in Figure 6 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-64 Number 8 shown in Figure 6 is the:
- a. weld root
- b. fusion face
- c. groove face
- d. weld interface
- e. depth of fusion

Q5-65 Number 2 shown in Figure 6 is the:
- a. weld size
- b. leg size
- c. leg and weld size
- d. theoretical throat
- e. actual throat

CHAPTER 6

Welding and Nondestructive Examination Symbols

Contents

Chapter 6—Welding and Nondestructive Examination Symbols

Introduction

The previous chapters discussed the importance of effective communication between the welding inspector and others involved in the fabrication of welded products. Much of this communication is achieved through the use of various types of documents that describe what attributes such products must exhibit. While these documents provide the basis for performing the inspection, the confusion can occur if there is a tremendous amount of material involved. Spending a great deal of time studying this information may detract from the welding inspector's actual inspection.

One method for reducing the mass of information contained in documents (especially drawings) is through the practice of using symbols. This practice replaces written words and detailed graphic illustrations with specific symbols to convey the same information in an abbreviated manner. To provide continuity, AWS has developed a standard, AWS A2.4, *Standard Symbols for Welding and Nondestructive Examination*, which describes the construction and interpretation of all types of welding and nondestructive examination symbols, and details all requirements relating to the use of these symbols.

Welding and nondestructive examination symbols are a "shorthand" method for conveying pertinent information. This system provides a simple, yet powerful method of describing detailed information. For example, by using symbols the designer can easily communicate a vast amount of information regarding numerous aspects of the welding project to both fabrication and inspection personnel.

Welding or examination symbols can provide a great deal of information; however, they must be used properly to be effective. If misapplied or misinterpreted, the symbols can cause confusion, rather than aid in the understanding of some welding or testing detail. For that reason, it is important to understand how the welding and nondestructive examination symbols are used.

There are numerous elements of a symbol that have specific meaning, due to their location with respect to other parts of that symbol. Once it is understood how a symbol is constructed, that information can be applied in reverse to gain insight as to what is actually required for a weld to be in compliance with a symbol. The following is a detailed description of the steps used in the construction of a welding or nondestructive examination symbol.

Elements of the Welding Symbol

It is important to understand some of the terminology relating to symbols, before describing the various parts of a welding symbol. A basic distinction is the difference between the terms weld symbol and welding symbol. As stated in AWS A2.4, the *weld symbol* "indicates the type of weld, and when used, is a part of the welding symbol."

The *welding symbol* is defined as "a graphical representation of a weld." It is a method of representing the weld symbol on drawings, and includes supplementary information and consists of the following eight elements. *NOTE: It is not necessary to use all elements, unless required for clarity* (see Figure 6.1).

(1) Reference line (shown horizontally)
(2) Arrow
(3) Basic weld symbols
(4) Dimensions and other data
(5) Supplementary symbols
(6) Finish symbols
(7) Tail
(8) Specification, process, or other reference

Reference Line

In the construction of a welding symbol, the primary element that is always included is the *reference line*, which is simply a horizontal line segment that provides the basis for all other parts of the symbol. The reference line must appear on the drawing as a horizontal line, because it is significant whether information is positioned above or below the line.

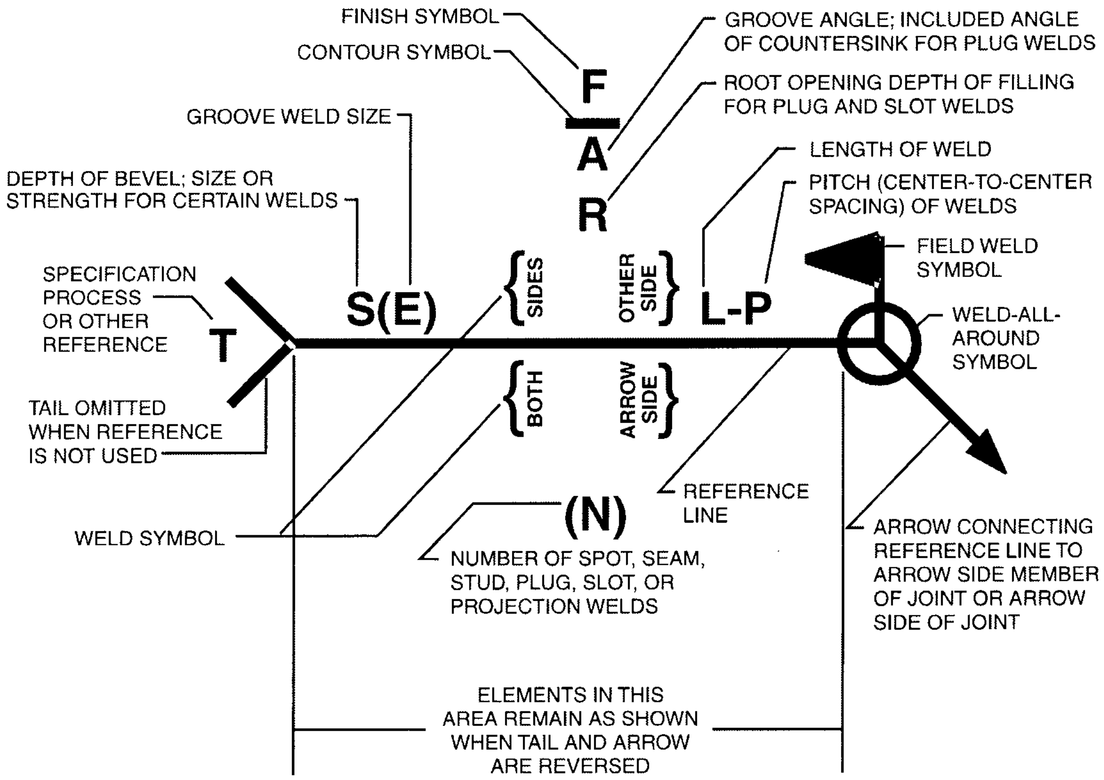


Figure 6.1—Standard Location of Elements of a Welding Symbol

Arrow

The next element of the welding symbol is the *arrow*, which is the line segment that connects to one end of the reference line and points to one side of the weld joint. The side to which the arrow points is referred to as the *arrow side*, while the opposite side is called the *other side*. Once the arrow side and other side have been determined by the placement of the arrow, information relating to either or both sides can then be specified (see Figure 6.2).

The AWS rule is that any information placed below the reference line relates to the arrow side of the joint, and that information above the reference line describes what will occur on the other side of the joint. No matter which end of the reference line is attached to the arrow or which direction the arrow may point, the rule remains the same. Even with the arrow oriented in different directions and at either end of the reference line, the operations will be performed on the side of the joint to which the arrow points.

Basic Weld Symbols

Once the reference line and arrow are in place, the weld symbol that describes what the actual weld configuration will be can be added. Weld symbols that depict arrow side welds will be positioned below the reference line and symbols referring to other side welds will be positioned above the reference line. Note that some weld symbols are placed so that the reference line splits them in half (e.g., spot, projection, and seam welds), which means that the weld has no side significance, and either side can be called the arrow side. *With the exception of the surfacing weld and the stud, which always appears as an arrow side weld,* all other types can be shown as arrow side, other side, or both sides.

Because most of the weld symbols resemble the actual weld configuration, it is easier to remember exactly what type of weld is specified by a particular weld symbol.

Note that for weld symbols that represent welds with only one of the two members prepared, *the perpendicular side of the symbol will always appear on the left side* (e.g.,

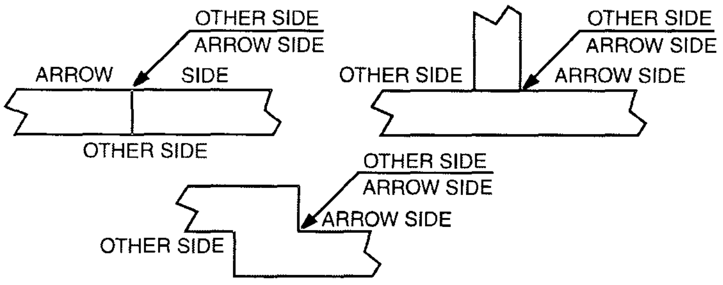


Figure 6.2—Arrow Location Significance

bevel, J- and flare-bevel grooves, fillet, and corner-flange welds). For these groove welds, the designer can designate which of the two members actually receives the preparation by using an arrow with a break in the line. *The rule is that the last segment of the arrow points to that member receiving the specified preparation* (see Figure 6.3).

Dimensions and Other Data

Groove Weld Detailing

After designating the type of groove weld required and determining at which side or sides of the joint the weld will be deposited, other data are necessary—primarily relating to dimensional requirements. Groove weld features that need dimensions include the joint configuration, weld size, and the extent of welding.

Some of the groove weld dimensions are placed within, or slightly outside, the weld symbol. A dimension within the weld symbol indicates the required root opening, while a dimension just outside (above or below) the weld symbol refers to the necessary groove angle. Another important dimension for the preparation of the groove is the depth of preparation. This dimension is always shown to the left of the groove weld symbol. This depth is measured from the base material surface. In each case, the specified depth of preparation is that dimension outside of the parentheses. In general, dimensions to the left of the weld symbol refer to the weld size required.

The dimensions (in parentheses) placed to the left of the symbol refer to the groove weld size (or joint penetration) required. For groove welds, absence of dimensions for depth of preparation or weld size implies that the required weld is to have complete joint penetration (see Figures 6.4–6.6). The final piece of dimensional information necessary for a groove weld is the required length. This detail is always shown on the welding symbol to the right of the weld symbol. If no dimension is shown, it is assumed that the specified weld is to be the entire length of the joint. A dimension to the right of the weld symbol refers to the length of groove weld segment required.

Fillet Weld Detailing

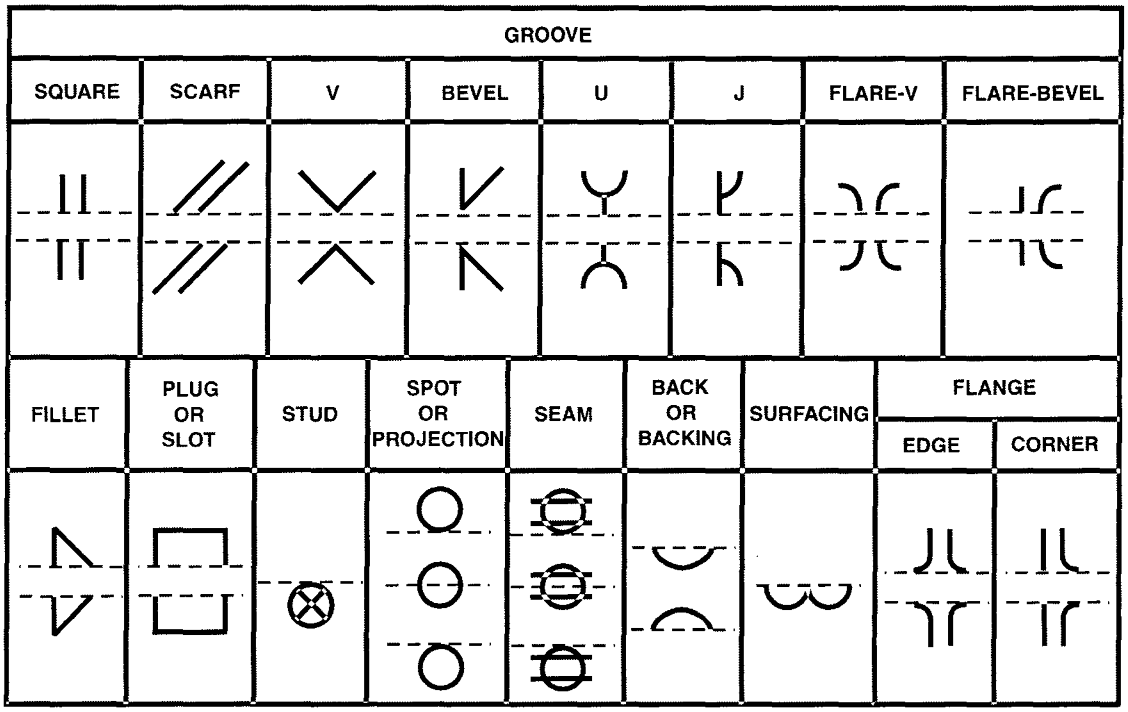
There is also dimensional information pertinent to fillet welds. As was the case for groove welds, the size of a fillet weld is dimensioned to the left of the weld symbol.

Another feature identical to the groove weld application is that the length of a fillet weld is dimensioned to the right of the weld symbol.

No dimension to the right of the fillet weld symbol indicates that the fillet weld is to be continuous for the entire length of the joint. A specific length of fillet weld is denoted by the single dimension to the right of the weld symbol. This dimension, however, does not indicate where the weld is to be placed. Such information must be provided elsewhere; for example, the tail, the drawing, etc. (see Figure 6.7).

A common welding practice is to use intermittent fillet welds instead of a continuous fillet weld to reduce distortion and the amount of time required for welding. The dimensions for intermittent fillet welds are shown as two numbers separated by a hyphen. The first number is the length of each individual weld segment and the second number refers to the center-to-center spacing of these weld segments. The spacing from one segment to the next is referred to as the *pitch*. The pitch is measured as the center-to-center distance of each adjacent length of fillet weld.

Intermittent fillet welds may be applied to both sides of a joint in one of two ways. If the individual segments are directly opposite each other, the application is referred to as *chain intermittent welding*. When the segments on either side of the joint coincide with spaces between individual segments on the other side of the joint, the application is referred to as *staggered intermittent welding*. In both types of intermittent welds, the



(NOTE: THE REFERENCE LINE IS SHOWN DASHED FOR ILLUSTRATIVE PURPOSES.)

Figure 6.3—Weld Symbols

pitch distance refers to the center-to-center spacing on that side of the joint only. The dimensions for either staggered or chain intermittent welding do not indicate where the weld is to begin; such information must be provided elsewhere (see Figure 6.8).

> **U.S. Customary and Metric Units**
> The same system that is the standard for the drawings shall be used on welding symbols. Dual units shall not be used on welding symbols. If it is desired to show conversions from metric to U.S. customary, or vice versa, a table of conversions may be included on the drawing. For guidance in drafting standards, reference is made to ANSI Y14, *Drafting Manual*. For guidance on the use of metric (SI) units, reference is made to AWS A1.1, *Metric Practice Guide for the Welding Industry*.

Plug and Slot Weld Detailing

The symbolization of plug and slot welds involves several different features, due to the uniqueness of their configurations. Both welds join overlapping members by filling a hole in the top member to connect it to the backing member. The symbol for both plug and slot welds is simply a rectangular box.

Dimensions for plug welds include plug weld size, depth of filling, pitch distances between adjacent plugs, and groove angle for tapered plug holes. The plug weld size dimension appears to the left of the weld symbol and indicates its diameter. If the hole is intended to be only partially filled, the required depth of filling is indicated within the plug weld symbol. Pitch distances are shown to the right of the plug weld symbol. If the hole is to be tapered to provide better root access, the angular dimension appears just outside (above or below) the weld symbol.

In general, the rules for plug welds also apply to the welding symbols for slot welds. A number to the left of the slot weld symbol indicates the width of the slot. If the hole is intended to be only partially filled, the required depth of filling is indicated within the slot weld symbol. The number to the right of the symbol specifies its length. If another number appears farther to the right, it indicates the pitch of the slot welds. A number directly above or below the symbol indicates the countersink, and a number above that in parenthesis specifies the number of slot welds (see Figure 6.9).

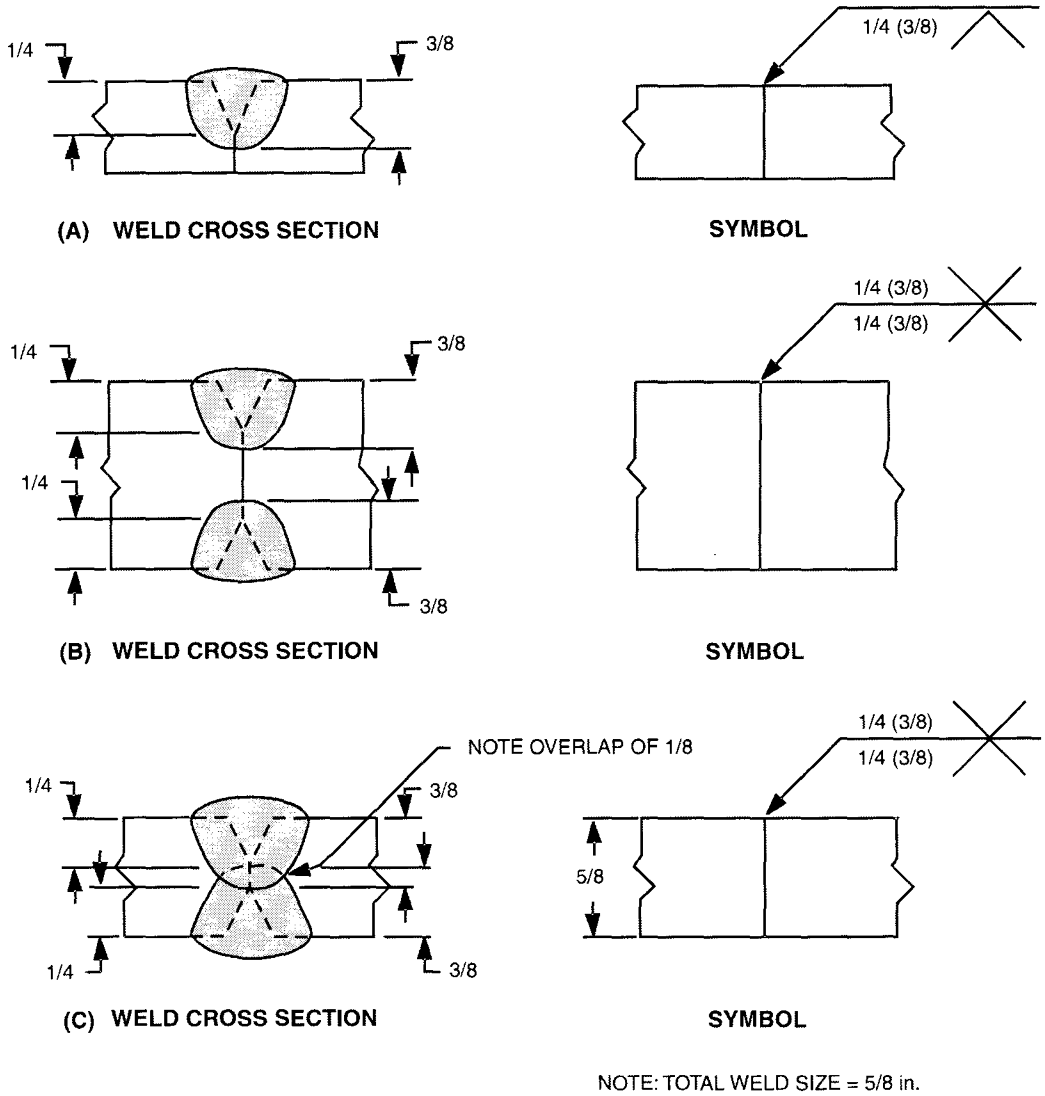


Figure 6.4—Specification of Groove Weld Size and Depth of Bevel

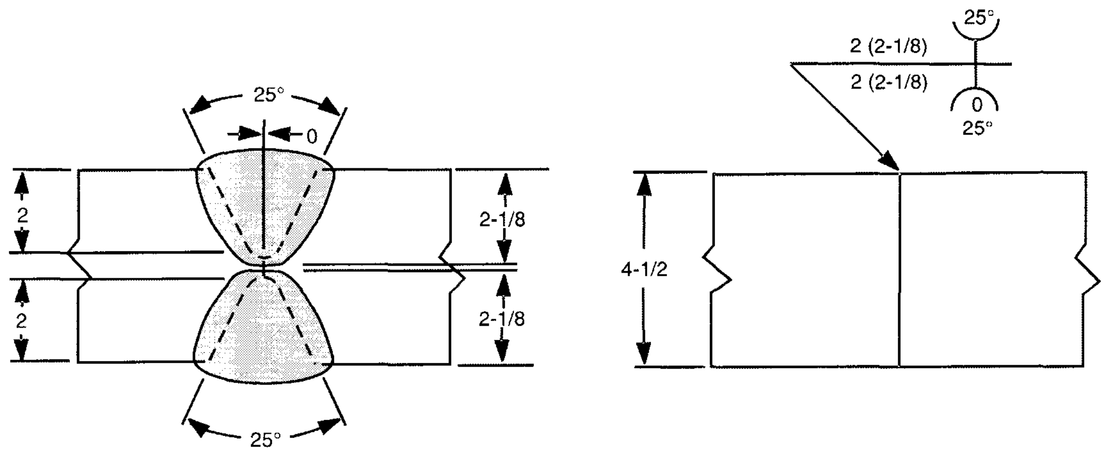
Spot and Seam Weld Detailing

Spot and seam welds can also be described by the use of welding symbols. The size dimension that refers to the diameter of the spot or width of the seam is shown to the left of the weld symbol. Another way to describe degree of welding is by specifying the required shear strength of the resulting spot weld or the shear strength per inch of weld for a seam weld.

The pitch distance of adjacent spot welds is shown in the same manner as for plug and slot welds. The required number of spots is shown by the number enclosed in parentheses just above or below the weld symbol. In seam welds, the first number to the right of the symbol is the length of the seam weld, while the second number is the pitch. The symbol does not indicate where the weld is to start; that information must be provided elsewhere (see Figure 6.10).

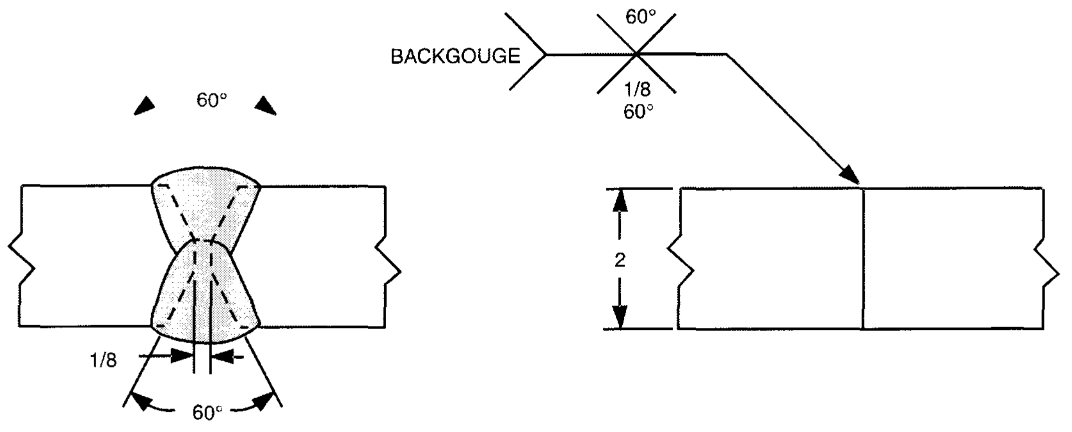
Back and Backing Weld Detailing

Two other types of welds are the back and backing welds. While both are represented by the same weld symbol, they differ in that the back weld is deposited after one side has been welded and the backing weld is deposited before depositing the opposite side. Some treatment,



WELD CROSS SECTION SYMBOL

Figure 6.5—Groove Weld Symbol with Combined Dimensions



WELD CROSS SECTION SYMBOL

Figure 6.6—Symmetrical Groove Welds with Backgouging

such as backgouging, may be required before application of a back weld and after the deposition of a backing weld. There are two ways to describe the sequencing of these welds. They can be differentiated by using a symbol with a note in the tail or by using multiple reference lines to show a sequence of operations (see Figure 6.11).

Surfacing Weld Detailing

The detailing of surface welds is quite simple—the primary information required is the thickness of the surfacing and the weld filler metal. The welding symbol must then indicate the region of the part requiring the surfacing treatment. The surfacing symbol appears only as an arrow side weld (see Figure 6.12).

Stud Weld Detailing

The stud weld symbol appears as a circle with an enclosed "X" and is only shown as an arrow side weld. A dimension to the left of the stud weld symbol refers to its required size. The number of studs required can be indicated by a number enclosed in parentheses just below the stud weld symbol. To indicate the spacing of adjacent studs, a number can be placed to the right of the stud weld symbol (see Figure 6.13).

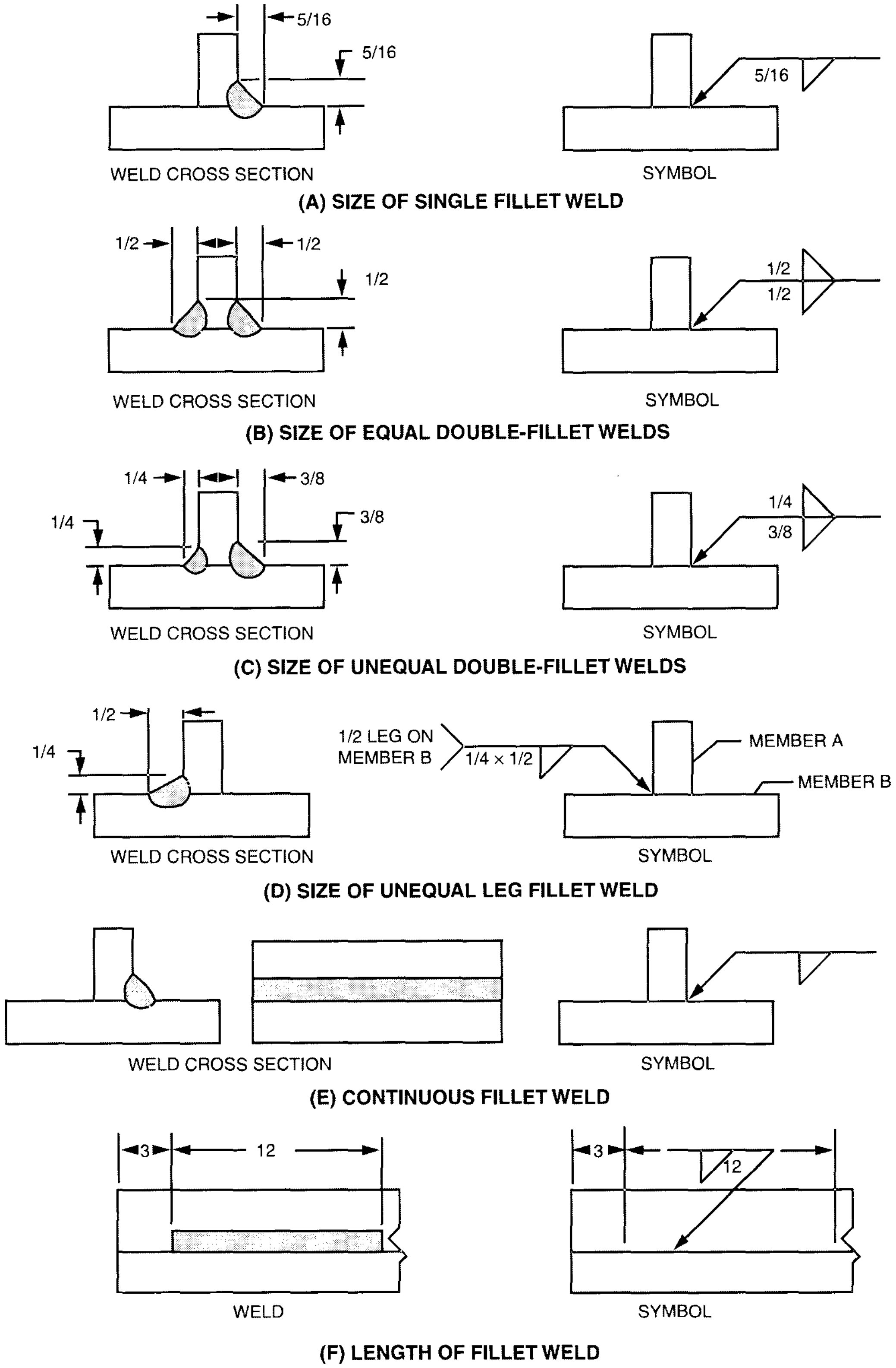
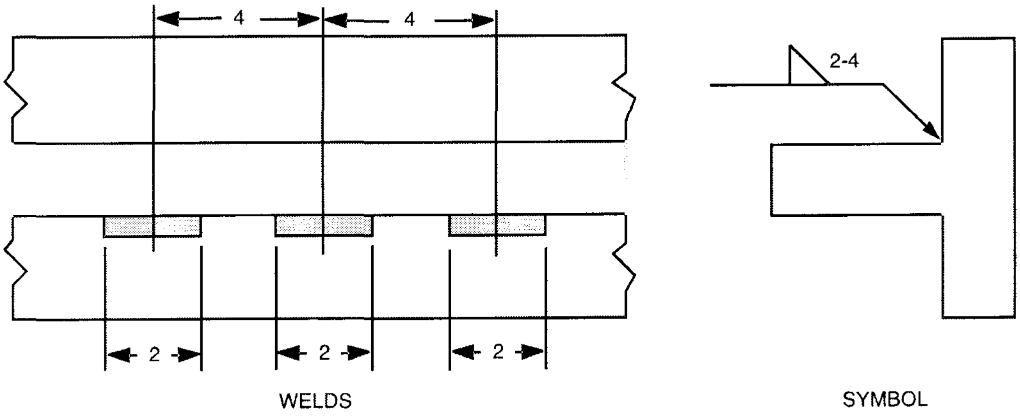
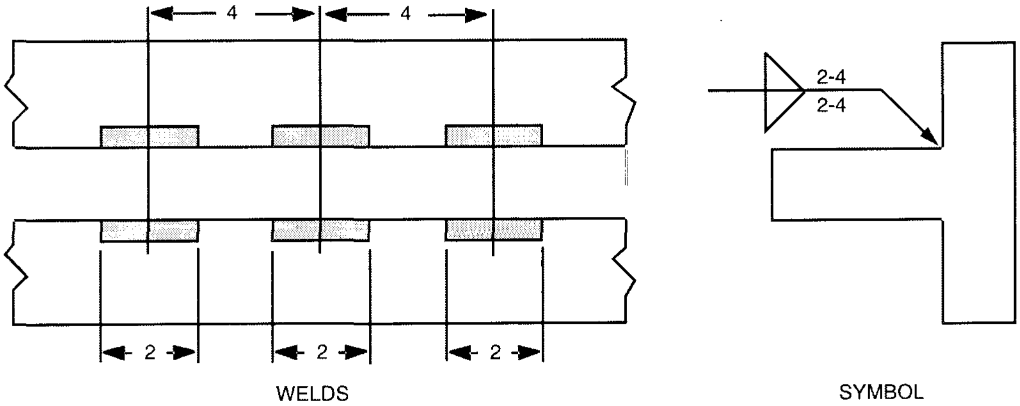


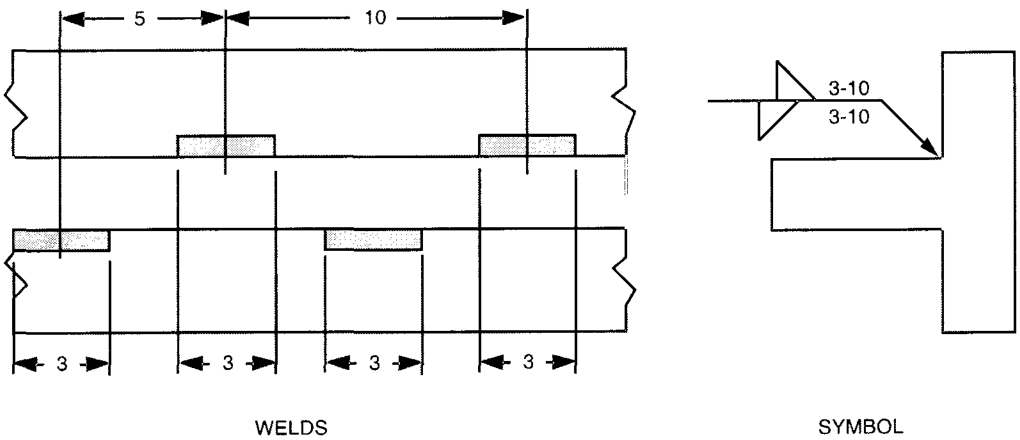
Figure 6.7—Specification of Size and Length of Fillet Welds



(A) LENGTH AND PITCH OF INTERMITTENT WELDS



(B) LENGTH AND PITCH OF CHAIN INTERMITTENT WELDS



(C) LENGTH AND PITCH OF STAGGERED INTERMITTENT WELDS

Figure 6.8—Applications of Intermittent Fillet Weld Symbols

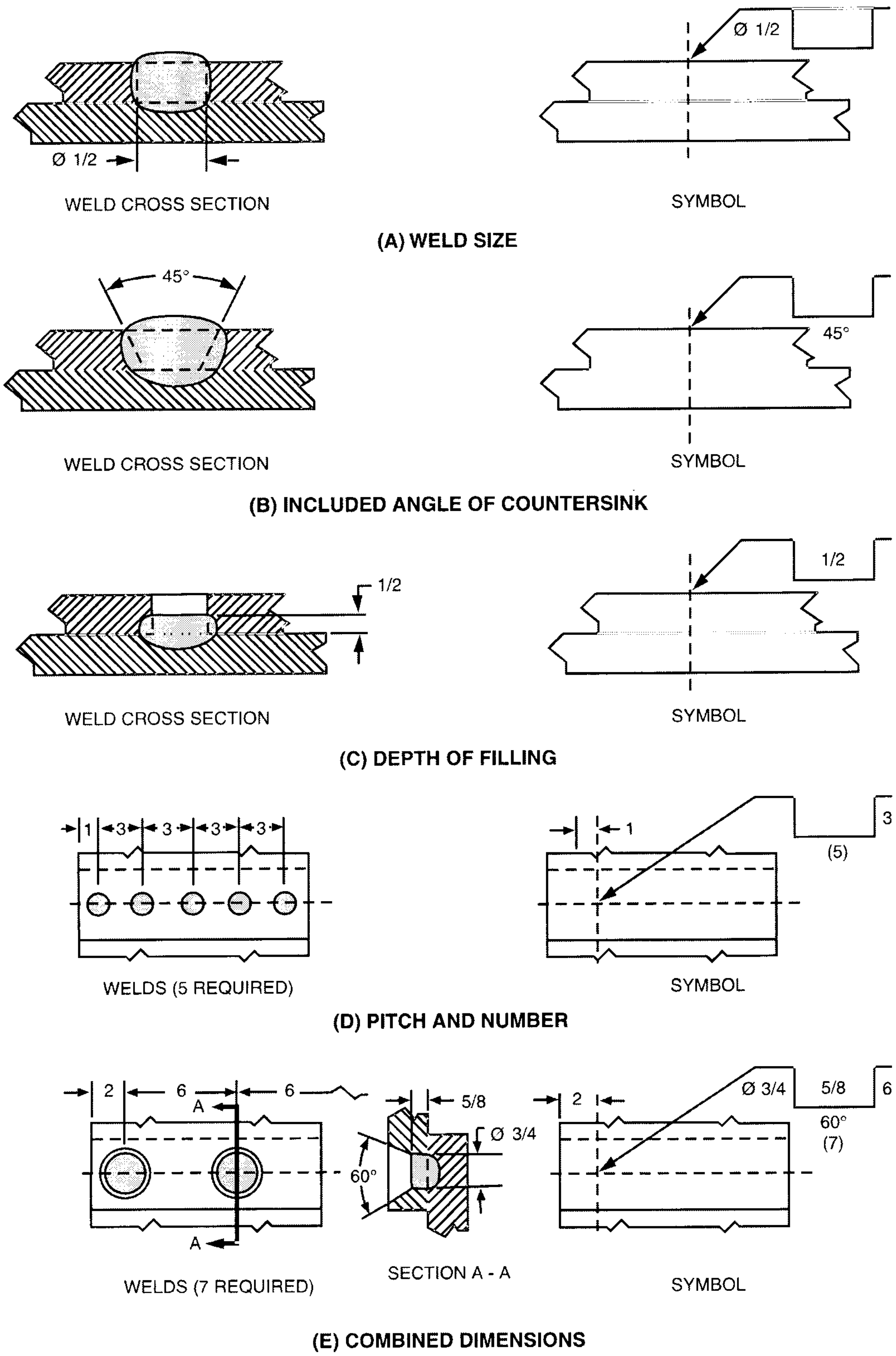


Figure 6.9—Applications of Information to Plug Weld Symbols

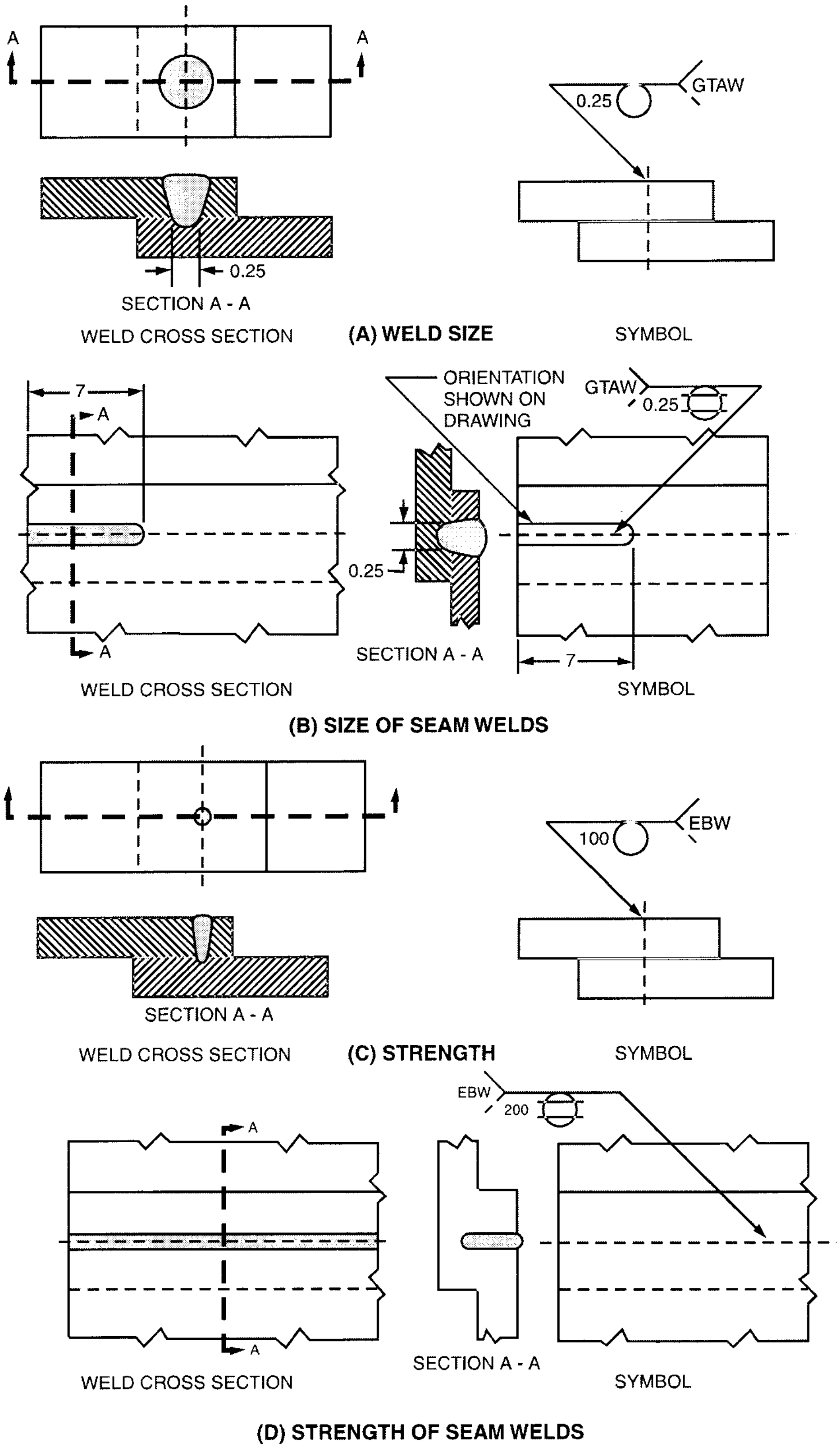
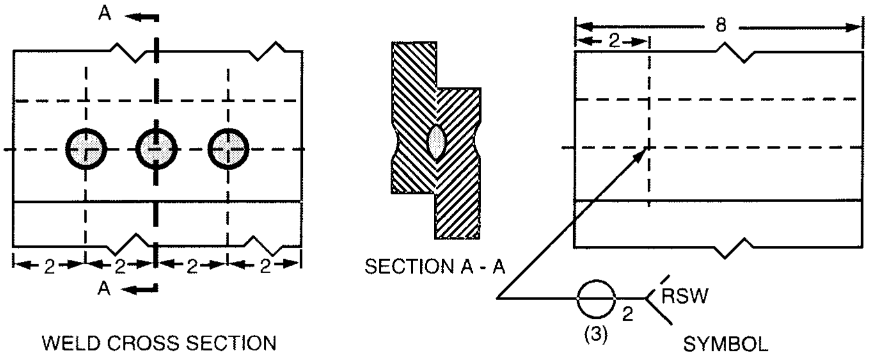
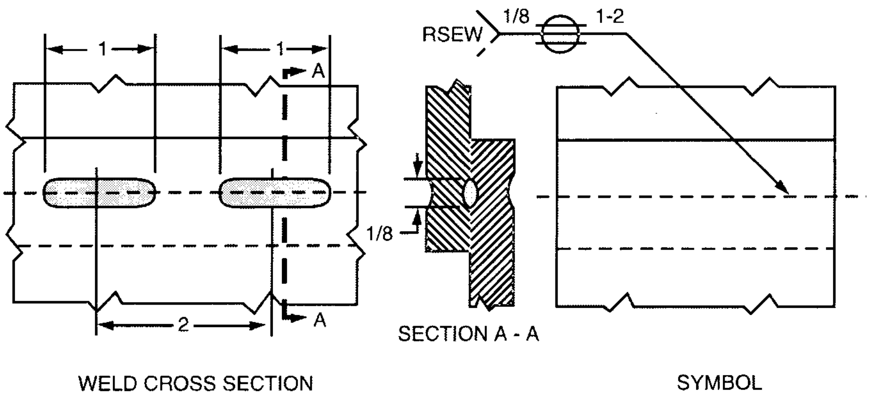


Figure 6.10—Applications of Information to Spot and Seam Weld Symbols



(E) NUMBER AND PITCH



(F) SIZE, LENGTH AND PITCH OF INTERMITTENT SEAM WELDS

Figure 6.10 (Continued)—Applications of Information to Spot and Seam Weld Symbols

Supplementary Symbols

The basic weld symbols can be supplemented with additional symbols to detail other important information. This group of symbols is referred to as *supplementary symbols*, because they can be combined with many of the basic weld symbols (see Figure 6.14).

The first of these symbols is the weld all around symbol. This symbol, consisting of a circle around the junction of the arrow and reference line, describes a weld that is to be continuous around the joint, despite abrupt changes in direction (see Figure 6.15). Another commonly used supplementary symbol is the field weld symbol. This symbol, shown as a flag at the junction of the arrow and reference line, defines welding in the field rather than in the shop. The field weld flag is placed at a right angle to, and on either side of, the reference line at the junction with the arrow (see Figure 6.16).

The next commonly used supplementary symbol is the melt-through symbol, which can be used to describe weld penetration beyond the back surface of the joint. The melt-through symbol itself appears as a darkened-in back/backing weld symbol. The amount of melt-through can be detailed by including a dimension to the left of the symbol (see Figure 6.17).

Another way to show the backside treatment of a weld is through the use of a symbol for backing or spacer material. If a weld requires some type of backing material or a spacer within the joint, it can be symbolized by placing a rectangular box opposite the groove weld symbol.

While this symbol appears similar to the plug weld symbol, it can be differentiated by the fact that the backing material symbol always appears in conjunction with some groove weld symbol. Details such as the material type and size can be noted in the tail.

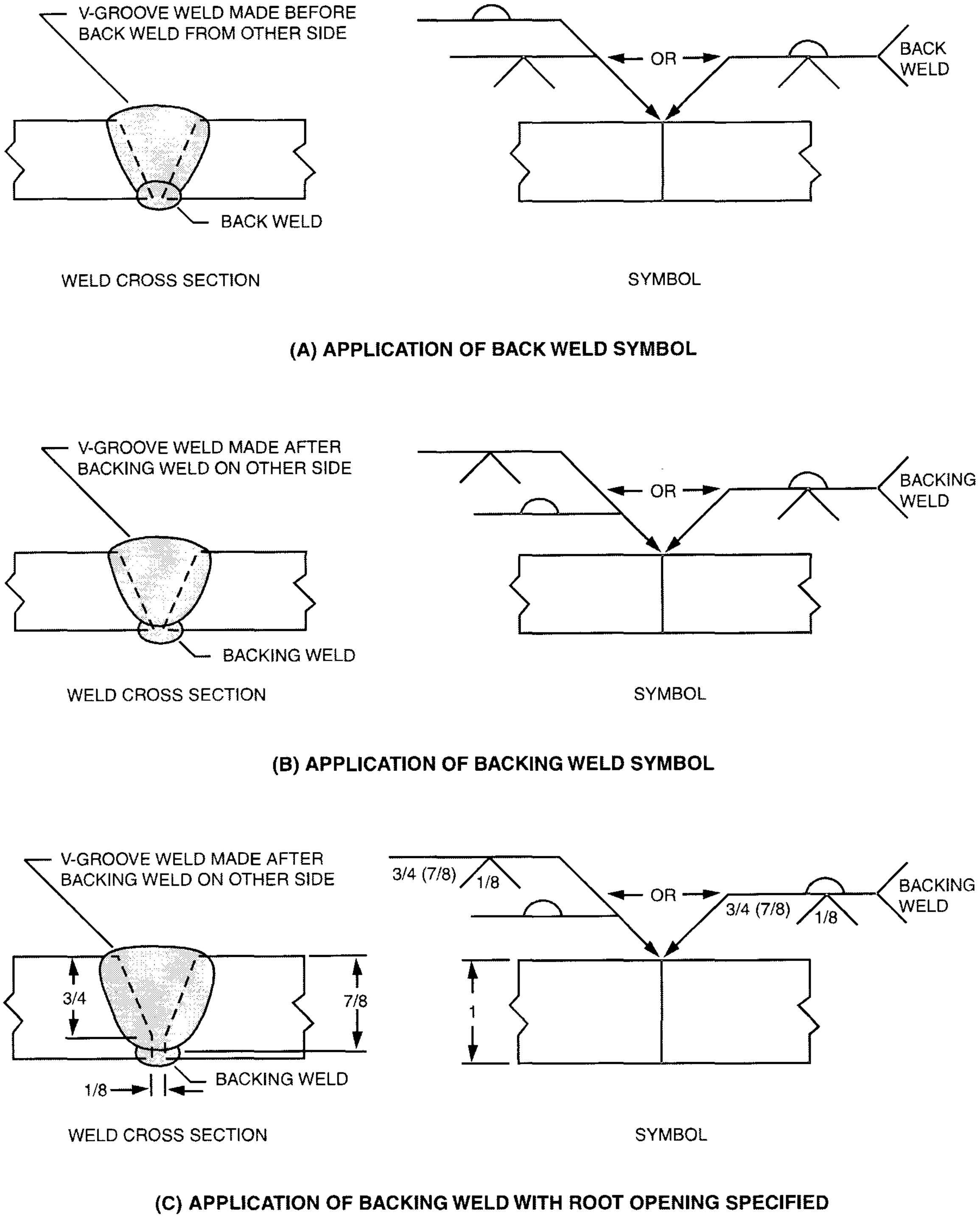


Figure 6.11—Applications of Back or Backing Weld Symbol

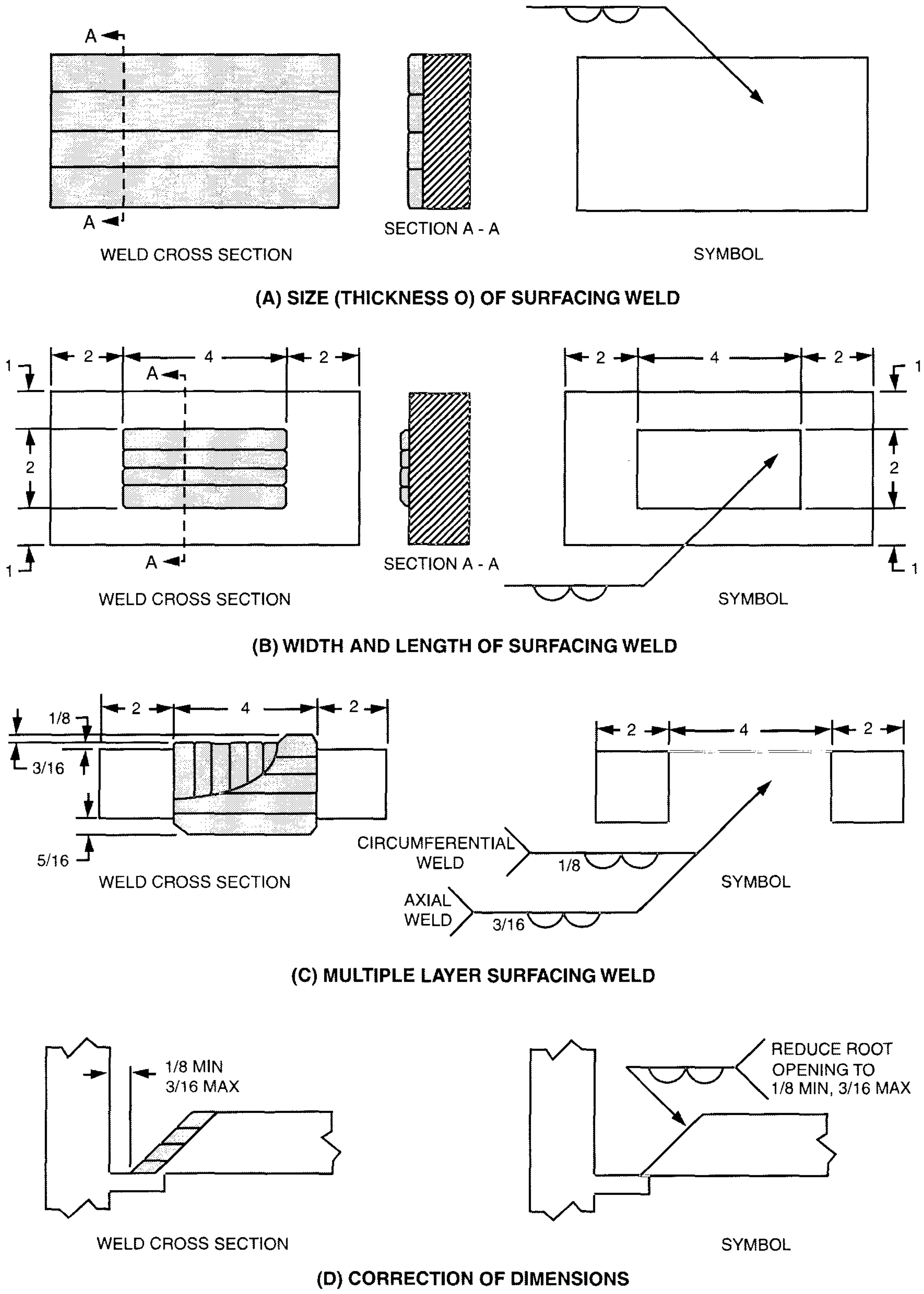
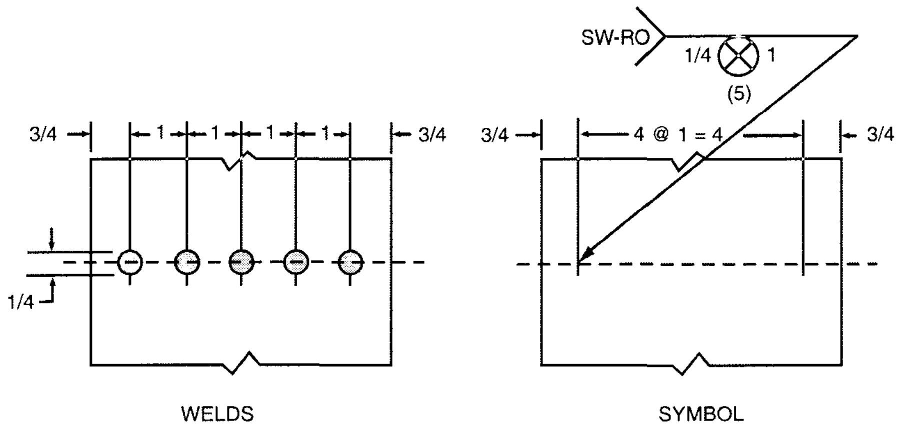
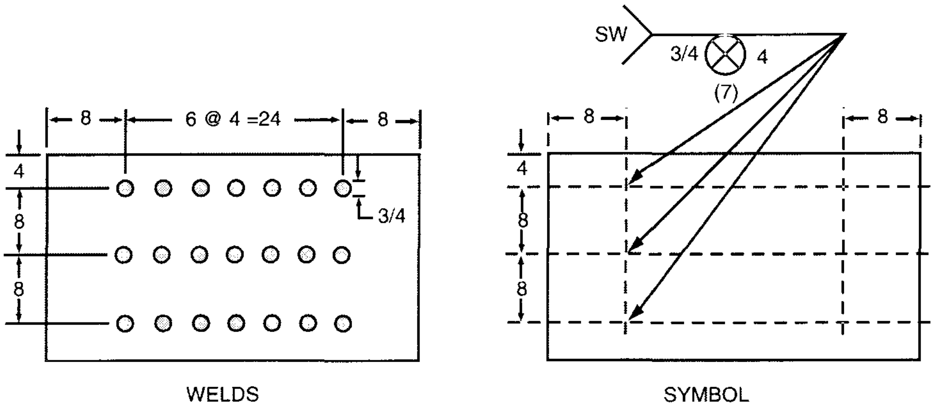


Figure 6.12—Applications of Surfacing Weld Symbol



(A) STUD WELD SYMBOL WITH COMBINED DIMENSIONS



(B) STUD WELD SYMBOL FOR MULTIPLE ROWS

Figure 6.13—Applications of Stud Weld Symbols

WELD-ALL-AROUND	FIELD WELD	MELT THROUGH	CONSUMABLE INSERT (SQUARE)	BACKING OR SPACER (RECTANGLE)	CONTOUR		
					FLUSH OR FLAT	CONVEX	CONCAVE

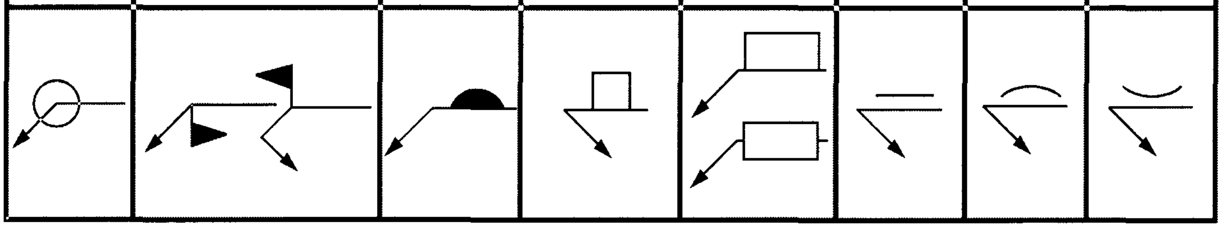


Figure 6.14—Supplementary Symbols

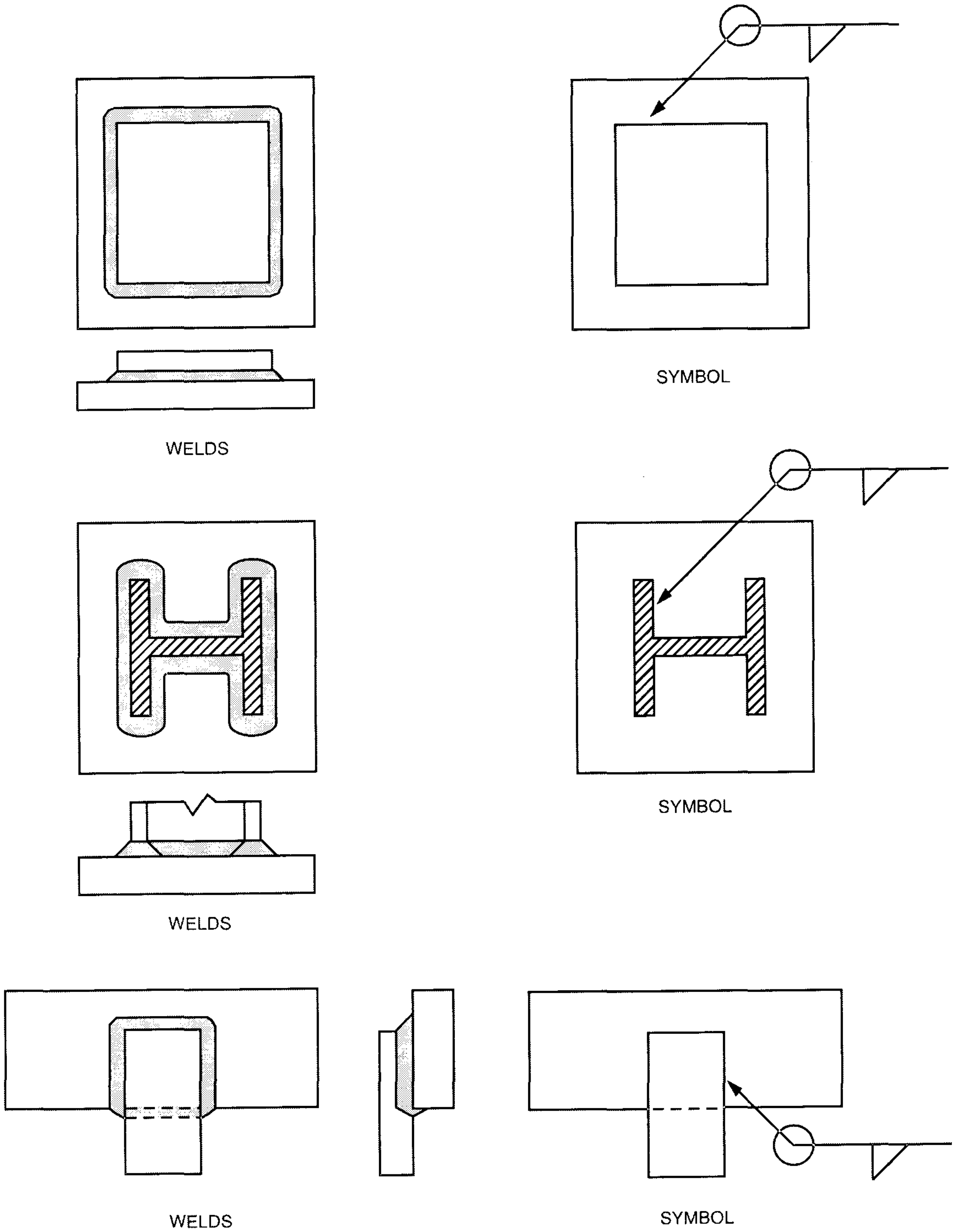


Figure 6.15—Applications of Weld-All-Around Symbol

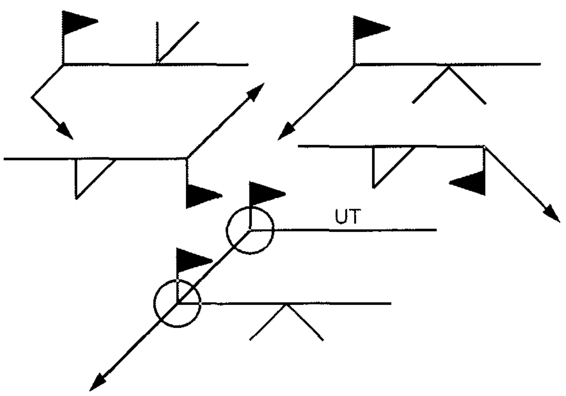


Figure 6.16—Applications of Field Weld Symbols

If some material is to be placed at the joint root for a double groove weld, it is referred to as a *spacer.* To depict the use of a spacer on a welding symbol, an open rectangular box is placed within the groove weld symbol at the diagrammatic joint root. Use of this symbol is identical to the backing material symbol (see Figure 6.18).

Another type of backing that is commonly used with the gas tungsten arc process is referred to as the *consumable insert,* which appears much like the backing material symbol except it is square instead of rectangular (see Figure 6.19).

Finish Symbols

The last group of supplementary symbols to be discussed describes the desired shape of the completed weld. Contour symbols for various configurations include flush, convex, and concave. The symbols for these contours correspond to the actual configurations desired.

The letters outside the contour symbols indicate the method of mechanical finishing to produce the desired contour. The letter designations for the various methods are as follows (see Figure 6.20 for use of "C" and "G"):

C = Chipping
G = Grinding
H = Hammering
M = Machining
R = Rolling

The Tail of the Symbol

The final element of the welding symbol is referred to as the *tail.* While not considered to be an essential element of a welding symbol, the tail can be used effectively to convey other important information that cannot be conveniently communicated elsewhere on the welding symbol. When used, the tail is placed on the end of the reference line opposite the arrow. Typical information to include in the tail is procedure number, process type, specification number, filler metal type, need for backgouging, reference to other drawing details, need for NDE, etc. (see Figure 6.21).

Specifications, Process, or Other Reference

Use of Multiple Reference Lines

Discussion thus far has dealt with using weld symbols and other elements to create a welding symbol that describes the requirements to weld a particular weld joint. Sometimes it is necessary to convey more detailed explanations of exactly how a weld is to be performed. For example, it is often convenient to describe the order, or sequence, of the entire welding operation, which is important if the weld joint in question requires measures to prevent excessive distortion or reduce the possibility of cracking due to high restraint.

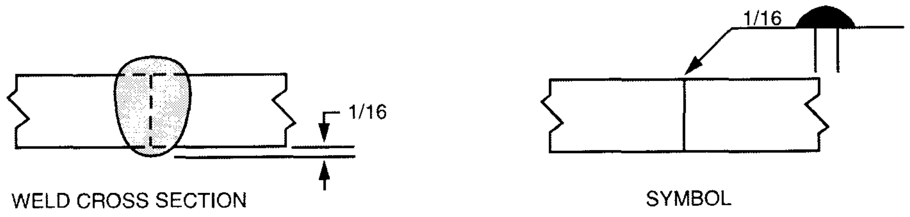
One way to describe this sequence of operations is to combine several individual reference lines on the same arrow, with each line containing information to be applied at a certain step in the welding operation. The convention is that the order of operations depends on the relative location of each reference line with respect to the arrow. That is, the first operation is described by the reference line closest to the arrow. Reference lines for subsequent operations will then appear in order, moving away from the arrow so that the last operation is described by the reference line furthest from the arrow (see Figure 6.22).

Brazing Symbols

With some minor changes, the use of welding symbols can also be applied to various brazing joints.

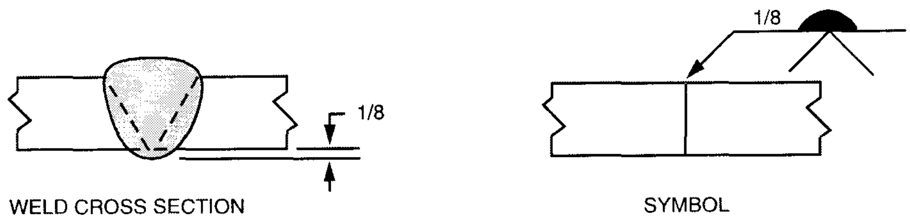
When a brazing symbol is used, certain dimensions should be specified to fully describe the important aspects of the braze joint. A dimension within the square-groove symbol describes the amount of clearance between the two members when fit up. The dimension to the right of the braze symbol refers to the amount of overlap, and the dimension to the left of the braze symbol indicates the size of the reinforcing fillet on the outside of the joint.

While the symbols for some of the braze joints are identical to those used for welding, the scarf groove is a joint design specifically used with brazing. For this type of joint, the angle of the scarf cut is shown as an angular dimension to the right of the braze symbol (see Figure 6.23).

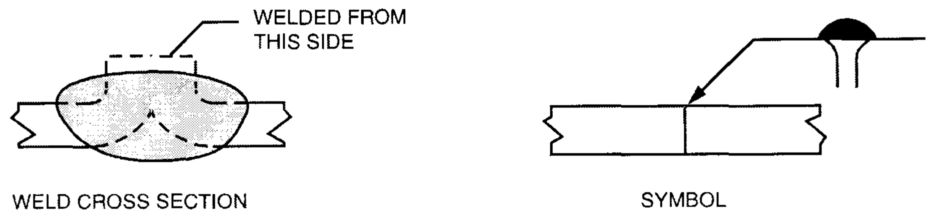


(A) SQUARE-GROOVE WELD

(B) SINGLE-BEVEL-GROOVE WELD



(C) SINGLE-V-GROOVE WELD



(D) EDGE-FLANGE WELD

Figure 6.17—Applications of Melt-Through Symbol

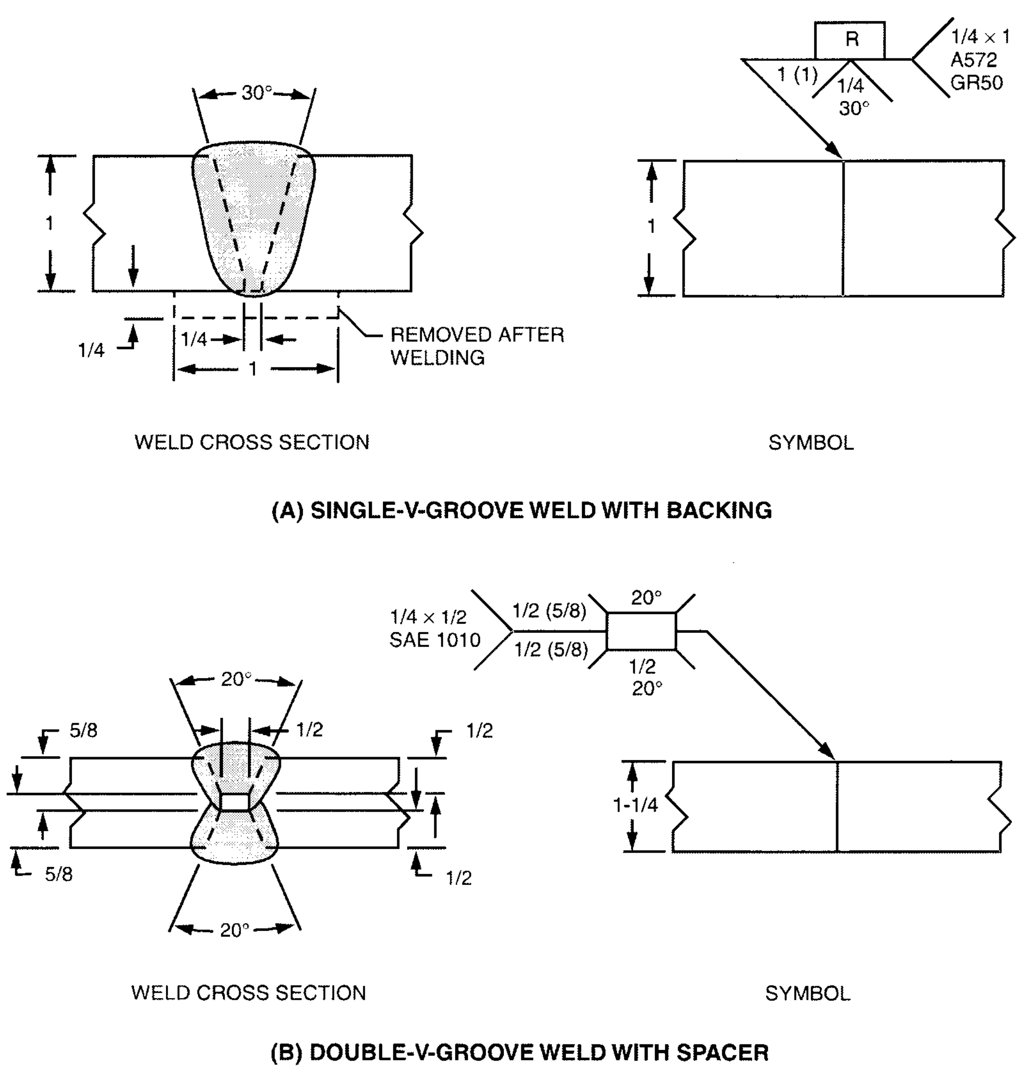


Figure 6.18—Joints with Backing or Spacers

Nondestructive Examination (NDE) Symbols

The preceding section described the methodology for the application of symbols to welding and brazing joints, to detail how members are to be joined. Once joined, those joints may need inspection to determine if the applicable quality requirements have been satisfied. As will be discussed in Chapter 11, there are numerous nondestructive examinations that can be performed to monitor the apparent weld quality. If required, those tests can be specified through the use of nondestructive examination symbols, which are constructed in a similar manner as the symbols described earlier.

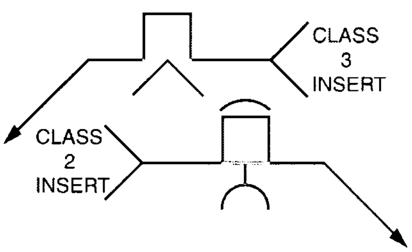
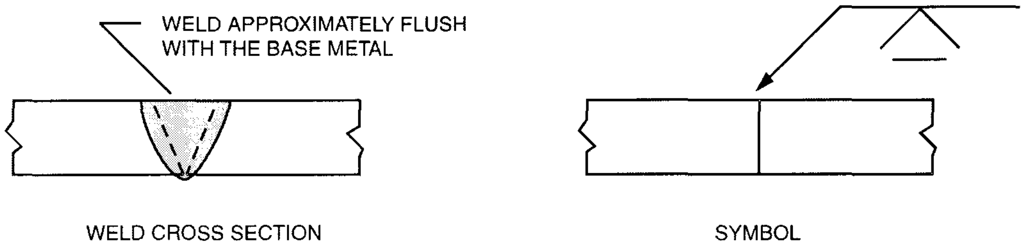
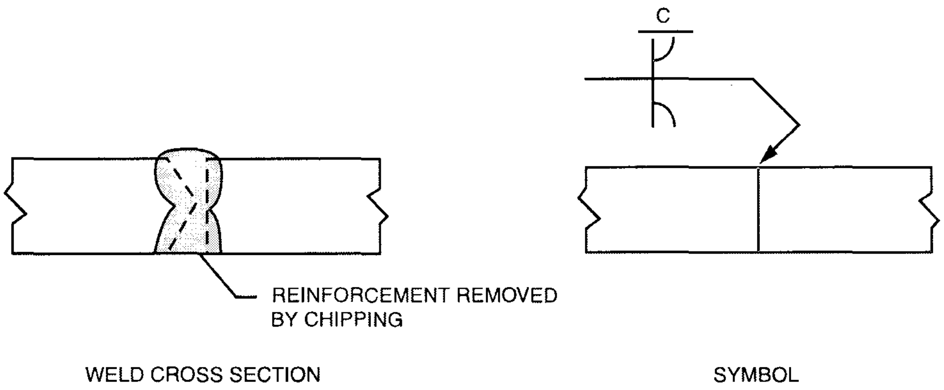


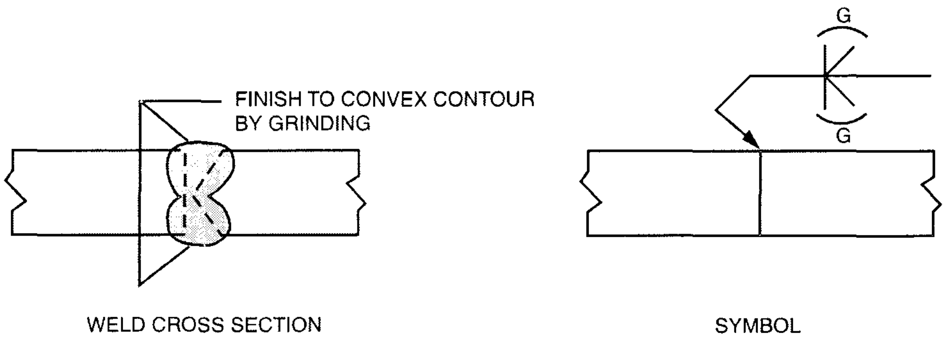
Figure 6.19—Consumable Insert Symbol



(A) ARROW-SIDE FLUSH CONTOUR SYMBOL



(B) OTHER-SIDE FLUSH CONTOUR SYMBOL



(C) BOTH SIDES CONVEX CONTOUR SYMBOL

Figure 6.20—Applications of Flush and Convex Contour Symbols

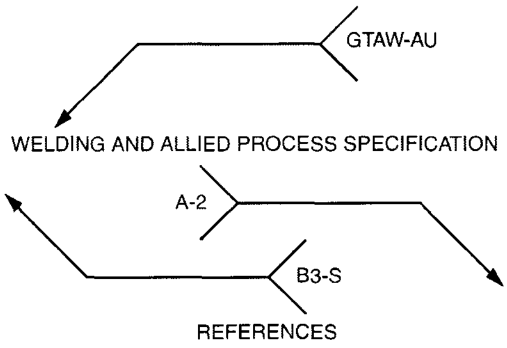


Figure 6.21—Supplementary Data Shown in the Tail of the Welding Symbol

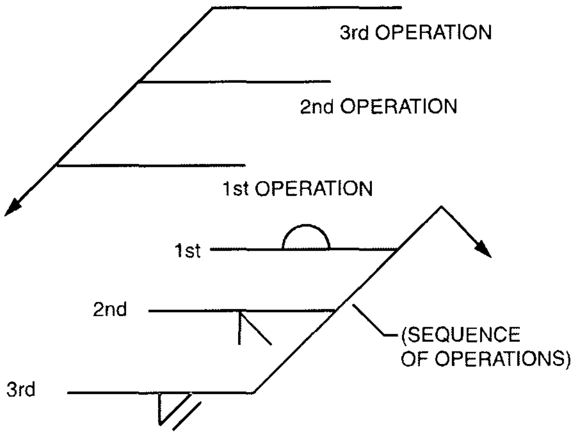


Figure 6.22—Multiple Reference Lines

As was the case for the welding symbol, information below the reference line refers to a testing operation performed on the arrow side of the joint and information above the line describes the treatment of the other side (see Figure 6.24). Instead of weld symbols, there are basic testing symbols that are letter designations for various testing processes, as shown in Table 6.1.

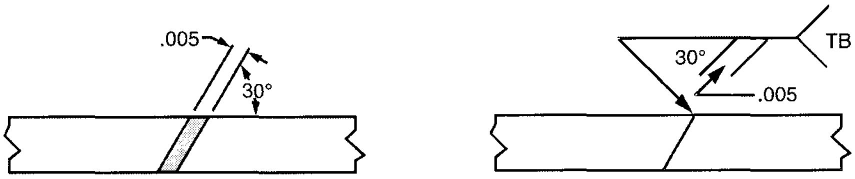
Table 6.1
Designations and Abbreviations of NDE Testing Processes

Designation	Abbreviation
Acoustic Emission	AET
Eddy Current	ET
Leak	LT
Magnetic Particle	MT
Neutron Radiographic	NRT
Penetrant	PT
Proof	PRT
Radiographic	RT
Ultrasonic	UT
Visual	VT

Summary

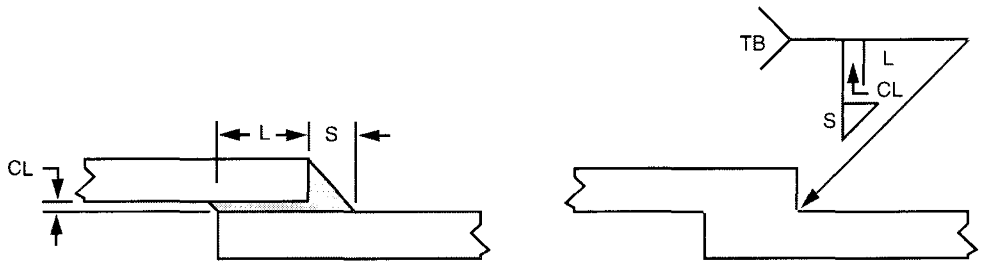
The welding inspector spends a great deal of time communicating with others involved in the welded fabrication of various structures and components. The use of welding and nondestructive examination symbols is an important part of that communication process, because symbols are the "shorthand" of welding and inspection that is used to convey information from the designer to those involved in the production and inspection of that product. The welding inspector, therefore, is expected to understand the many features of these symbols so that weld and inspection requirements can be determined.

Although generally straightforward, welding symbols can be confusing; therefore, the welding inspector must learn their meanings. To fully understand the meaning of welding and testing symbols, the inspector must know both the basic elements of the symbols and the significance of their relative locations with respect to the reference line. It is important to remember that even the most complicated symbol can be interpreted, if the meanings of individual parts of the symbol are understood and a combined determination can be made.

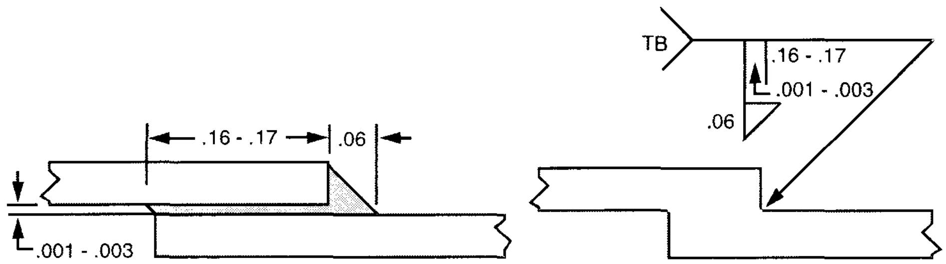


BRAZE CROSS SECTION SYMBOL

CL - CLEARANCE
L - LENGTH OF OVERLAP
S - FILLET SIZE



BRAZE CROSS SECTION SYMBOL



BRAZE CROSS SECTION SYMBOL

Figure 6.23—Applications of Brazing Symbols

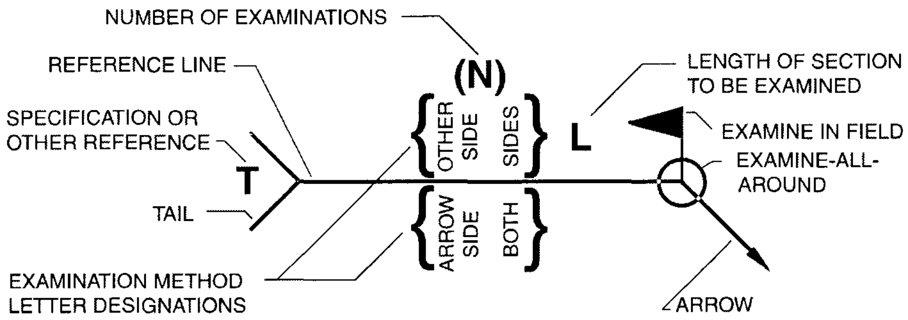


Figure 6.24—Location of Elements of a Nondestructive Examination Symbol

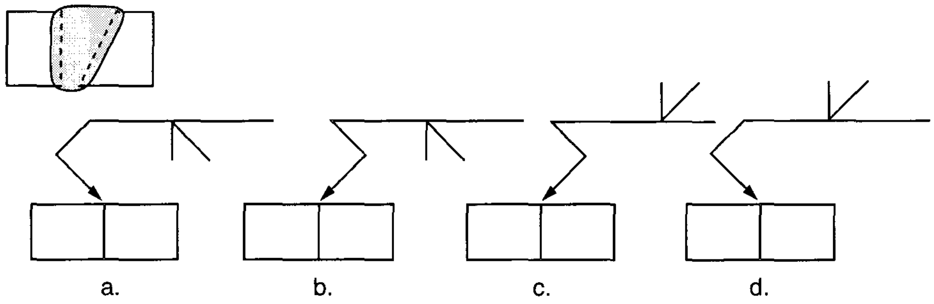
Review—Chapter 6—Welding and Nondestructive Examination Symbols

Q6-1 The primary element of any welding symbol is referred to as the:
a. tail
b. arrow
c. reference line
d. arrow side
e. weld symbol

Q6-2 Information appearing above the reference line refers to the:
a. near side
b. arrow side
c. far side
d. other side
e. none of the above

Q6-3 The graphical representation of the type of weld is called the:
a. tail
b. welding symbol
c. weld symbol
d. arrow
e. none of the above

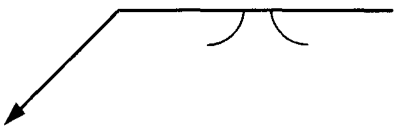
Q6-4 Which of the symbols below represents the weld shown?



e. none of the above

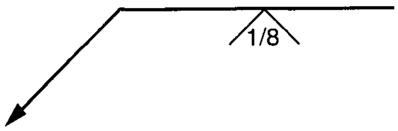
Q6-5 When a weld symbol is centered on the reference line, this indicates:
a. that the welder can put the weld on either side
b. that there is no side significance
c. that the designer doesn't know where the weld should go
d. that the welder should weld in whatever position the weld is in
e. none of the above

Q6-6 The symbol below depicts what type of weld?



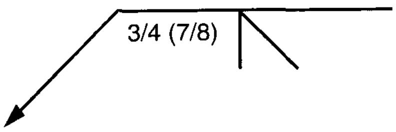
a. flare-V-groove
b. flare-bevel-groove
c. edge-flange
d. corner-flange
e. none of the above

Q6-7 In the symbol below, the 1/8 dimension refers to what?



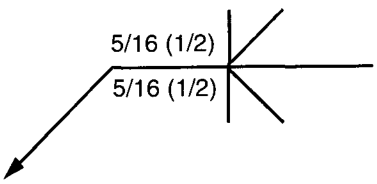
a. groove angle
b. root face
c. depth of preparation
d. weld size
e. root opening

Q6-8 In the symbol below, the 3/4 dimension refers to what?



a. weld size
b. effective throat
c. depth of preparation
d. root opening
e. none of the above

Q6-9 If applied to a 1 in. thick weld, the symbol below represents what type of weld?

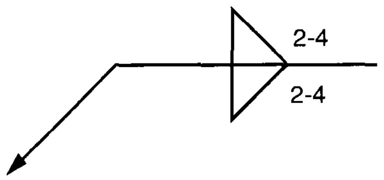


a. full penetration double-bevel-groove weld
b. full penetration double-V-groove weld
c. partial penetration double-bevel-groove weld
d. partial penetration double-V-groove weld
e. none of the above

Q6-10 Dimensions appearing to the left of the weld symbol generally refer to the:
a. weld length
b. weld size/depth of preparation
c. root opening
d. radius
e. none of the above

Q6-11 A triangular-shaped weld symbol represents what type of weld?
a. bevel-groove
b. flare-groove
c. flange-groove
d. V-groove
e. none of the above

Q6-12 The symbol below represents what type of weld?



a. staggered intermittent fillet weld
b. chain intermittent fillet weld
c. segmented fillet weld
d. intermittent fillet weld
e. none of the above

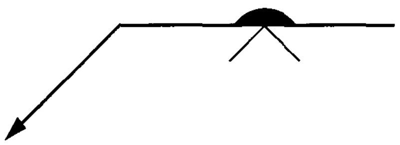
Q6-13 Dimensions appearing to the right of the weld symbol generally refer to the:
a. weld size
b. root opening
c. depth of preparation
d. weld length/pitch
e. none of the above

Q6-14 A weld symbolized by a rectangular box that contains a dimension represents a:
a. plug weld
b. slot weld
c. plug weld in beveled hole
d. partially filled plug weld
e. plug weld in hole having dimension shown

Q6-15 The required spot weld size can be shown as:
a. a dimension to the right of the symbol
b. a dimension of the required nugget diameter
c. a value for the required shear strength
d. both a and b above
e. both b and c above

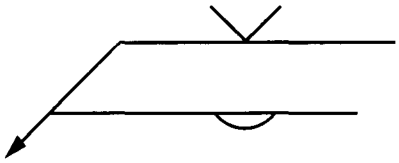
Q6-16 A number appearing to the right of the spot weld symbol refers to:
a. spot weld size
b. spot weld length
c. number of spots required
d. pitch distance between adjacent spots
e. none of the above

Q6-17 In the symbol below, the symbol shown on the other side represents:



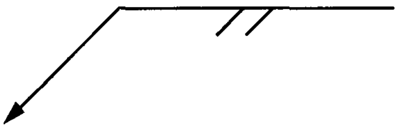
a. back weld
b. backing weld
c. melt-through weld
d. both a and b above
e. both b and c above

Q6-18 The symbol below shows the use of what type of weld?



a. single-bevel-groove weld
b. single-V-groove weld
c. backing weld
d. back weld
e. b and c above

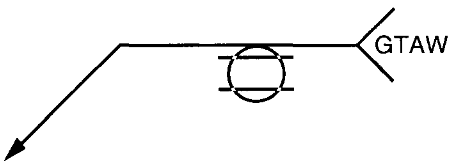
Q6-19 The symbol below shows what type of groove configuration?



a. square groove
b. skewed groove
c. sloped groove
d. scarf
e. none of the above

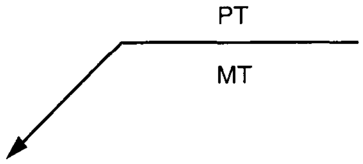
Q6-20 The part of the welding symbol which can be used to convey any additional information which cannot be shown otherwise is referred to as:
a. the weld symbol
b. the arrow
c. the reference line
d. the tail
e. none of the above

Q6-21 The symbol below shows what type of weld?



a. gas metal arc spot weld
b. resistance spot weld
c. gas tungsten arc seam weld
d. resistance seam weld
e. none of the above

Q6-22 What nondestructive examination method is to be applied to the arrow side?

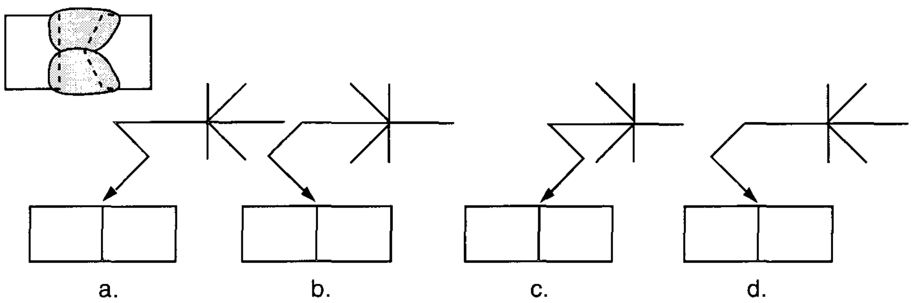


a. magnetic particle testing
b. eddy current testing
c. radiographic testing
d. penetrant testing
e. none of the above

Q6-23 A number in parentheses just outside a test symbol represents:
a. the length of weld to be tested
b. the extent of testing
c. the number of tests to perform
d. the type of test to perform
e. none of the above

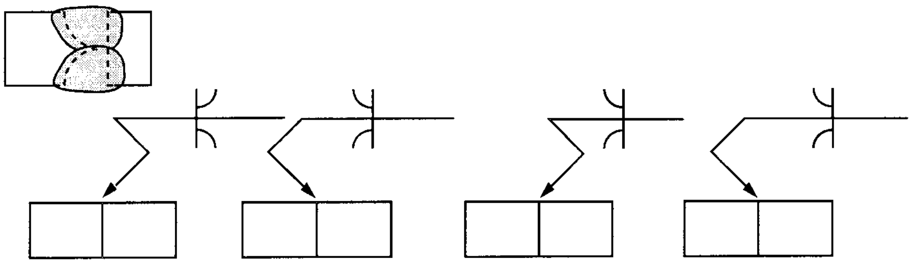
Q6-24 A number to the right of a nondestructive examination symbol refers to the:
a. number of tests to perform
b. the length of weld to be tested
c. the applicable quality standard
d. the test procedure to use
e. none of the above

Q6-25 Which of the symbols represents the weld shown below?



e. none of the above

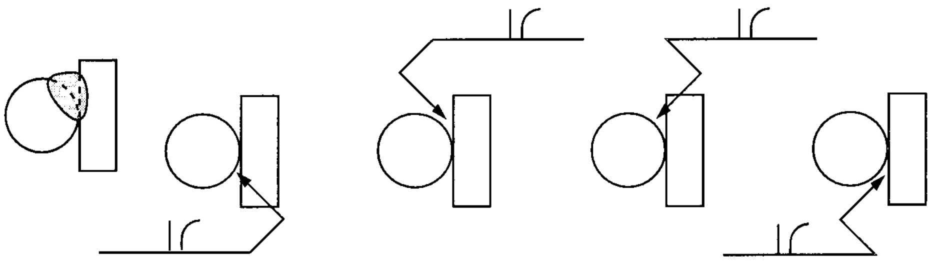
Q6-26 Which of the symbols represents the weld shown below?



a. b. c. d.

e. none of the above

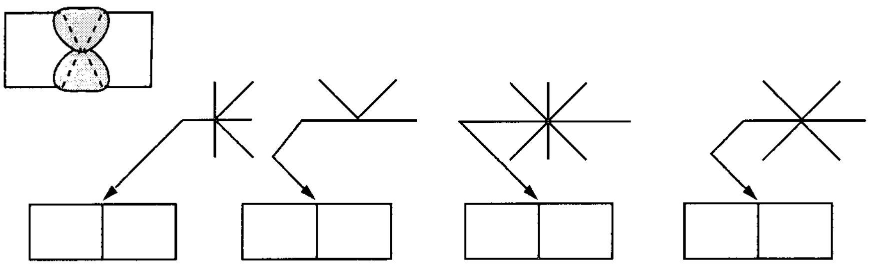
Q6-27 Which of the symbols represents the weld shown below?



a. b. c. d.

e. none of the above

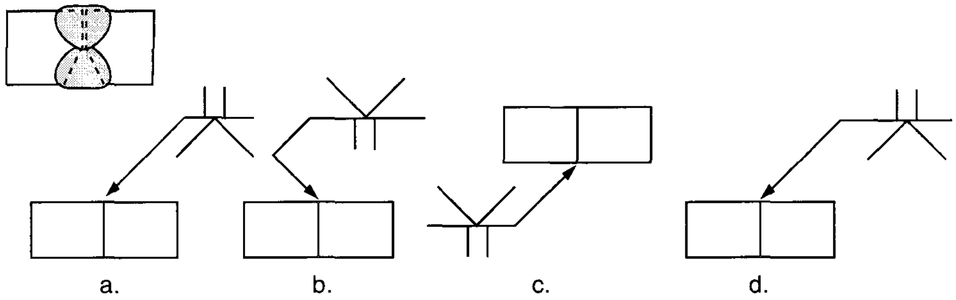
Q6-28 Which of the symbols represents the weld shown below?



a. b. c. d.

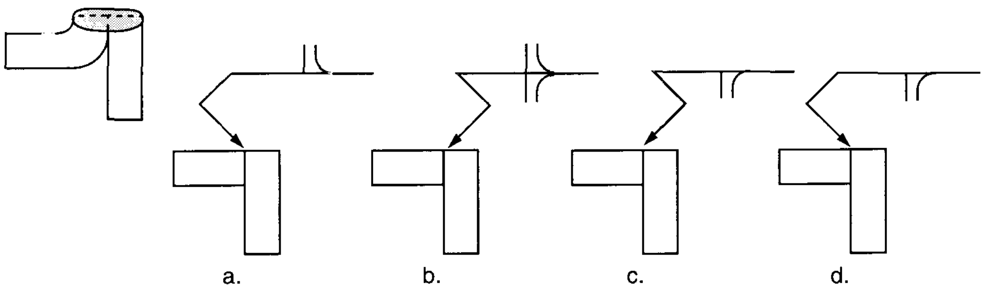
e. none of the above

Q6-29 Which of the symbols represents the weld shown below?



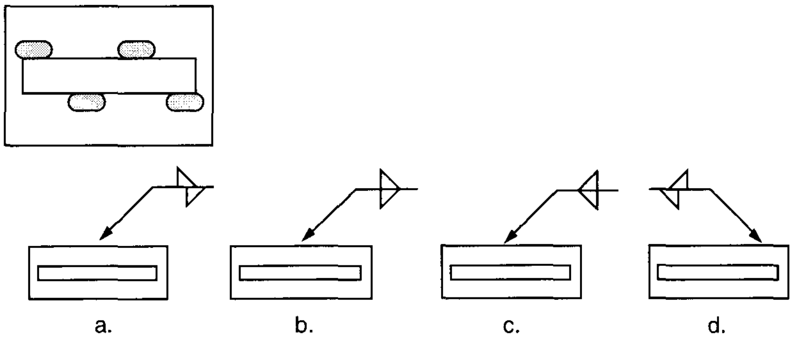
e. none of the above

Q6-30 Which of the symbols represents the weld shown below?



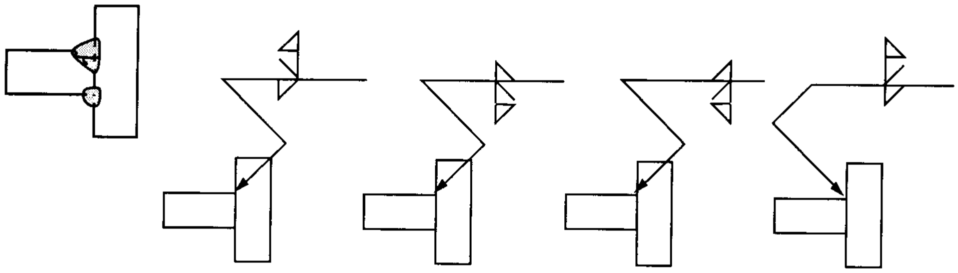
e. none of the above

Q6-31 Which of the symbols represents the weld shown below?



e. none of the above

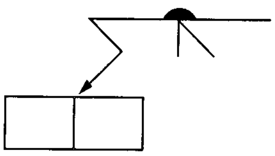
Q6-32 Which of the symbols represents the weld shown below?

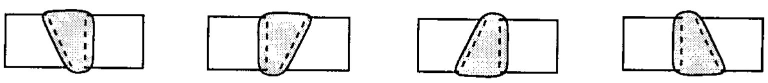


a. b. c. d.

e. none of the above

Q6-33 Which of the welds is represented by the symbol shown below?

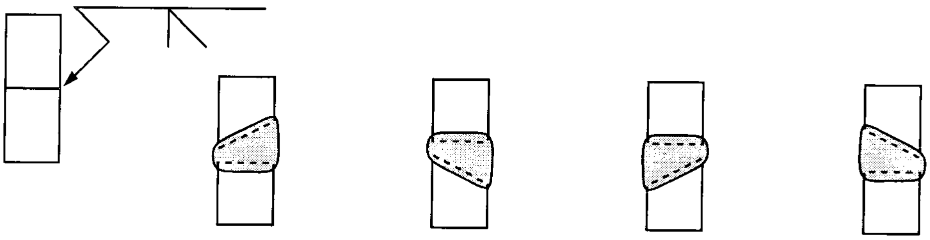




a. b. c. d.

e. none of the above

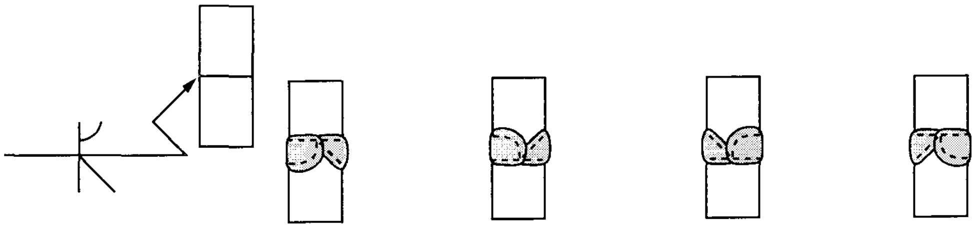
Q6-34 Which of the welds is represented by the symbol shown below?



a. b. c. d.

e. none of the above

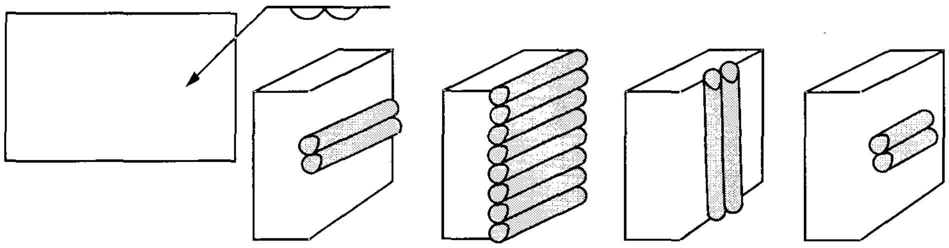
Q6-35 Which of the welds is represented by the symbol shown below?



a. b. c. d.

e. none of the above

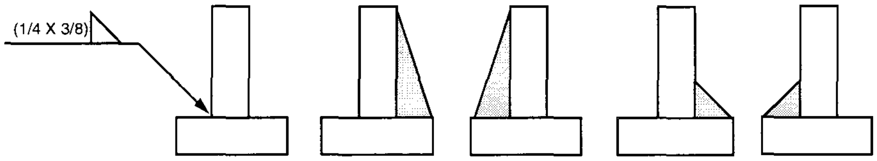
Q6-36 Which of the welds is represented by the symbol shown below?



a. b. c. d.

e. none of the above

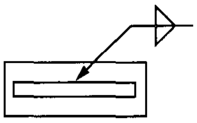
Q6-37 Which of the welds is represented by the symbol shown below?

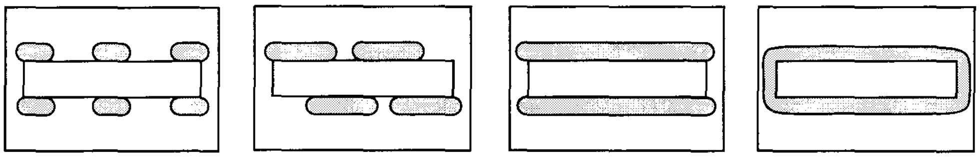


a. b. c. d.

e. insufficient reference or detailing

Q6-38 Which of the welds is represented by the symbol shown below?

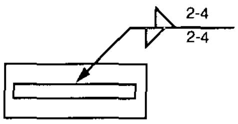


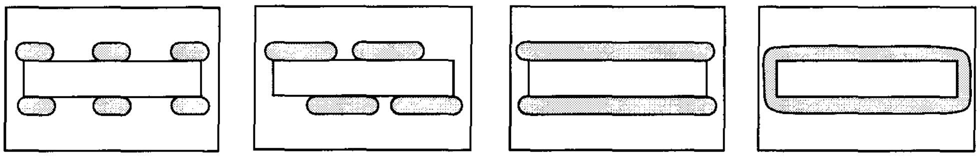


a. b. c. d.

e. none of the above

Q6-39 Which of the welds is represented by the symbol shown below?

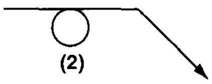




a. b. c. d.

e. none of the above

Q6-40 Which of the welds is represented by the symbol shown below?



a. b. c. d.

e. none of the above

Questions **Q6-41** through **Q6-45** refers to Figure 1 below:

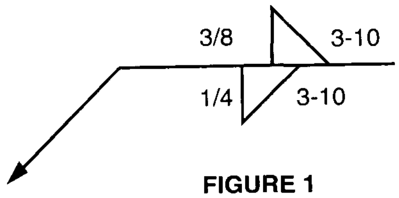


FIGURE 1

Q6-41 What is the weld length?
- a. 1/4 in.
- b. 3/8 in.
- c. 3 in.
- d. 10 in.
- e. none of the above

Q6-42 What is the pitch distance?
- a. 1/4 in.
- b. 3/8 in.
- c. 3 in.
- d. 10 in.
- e. none of the above

Q6-43 What is the size of the arrow side weld?
- a. 1/4 in.
- b. 3/8 in.
- c. 3 in.
- d. 10 in.
- e. none of the above

Q6-44 What is the size of the other side weld?
- a. 1/4 in.
- b. 3/8 in.
- c. 3 in.
- d. 10 in.
- e. none of the above

Q6-45 What does the symbol represent?
- a. fillet welds on both sides
- b. intermittent fillet welds
- c. chain intermittent fillet welds
- d. staggered intermittent fillet welds
- e. none of the above

Questions **Q6-46** through **Q6-50** refer to Figure 2 below:

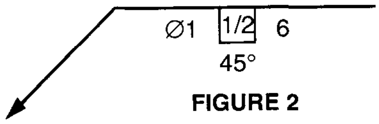


FIGURE 2

Q6-46 What is the pitch distance?
- a. 1 in.
- b. 1/2 in.
- c. 45 in.
- d. 6 in.
- e. none of the above

Q6-47 What is the angle of the countersink?
- a. 1°
- b. 1/2°
- c. 45°
- d. 6°
- e. none of the above

Q6-48 What is the depth of filling?
- a. 1 in.
- b. 1/2 in.
- c. 45 in.
- d. 6 in.
- e. none of the above

Q6-49 What is the weld size?
- a. 1 in.
- b. 1/2 in.
- c. 45 in.
- d. 6 in.
- e. none of the above

Q6-50 What weld is represented by the symbol?
- a. arrow side slot weld
- b. other side slot weld
- c. arrow side plug weld
- d. other side plug weld
- e. a or c above

Questions **Q6-51** through **Q6-55** refer to Figure 3 below:

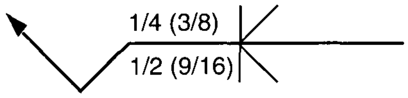


FIGURE 3

Q6-51 What is the arrow side depth of preparation?
- a. 1/4 in.
- b. 3/8 in.
- c. 1/2 in.
- d. 9/16 in.
- e. 15/16 in.

Q6-52 What is the other side depth of preparation?
- a. 1/4 in.
- b. 3/8 in.
- c. 1/2 in.
- d. 9/16 in.
- e. 15/16 in.

Q6-53 What is the other side weld size?
- a. 1/4 in.
- b. 3/8 in.
- c. 1/2 in.
- d. 9/16 in.
- e. 15/16 in.

Q6-54 What is the arrow side weld size?
- a. 1/4 in.
- b. 3/8 in.
- c. 1/2 in.
- d. 9/16 in.
- e. 15/16 in.

Q6-55 What is the total weld size?
- a. 1/4 in.
- b. 3/8 in.
- c. 1/2 in.
- d. 9/16 in.
- e. 15/16 in.

CHAPTER 7

Weldability, Welding Metallurgy, and Welding Chemistry

Contents

Chapter 7—Weldability, Welding Metallurgy, and Welding Chemistry

Introduction

A weld joint is the functional unit basic to any welded structure, and the key base metal property is weldability. The better the weldability of a metal, the easier the metal can be fabricated into a suitably designed structure that will perform satisfactorily. Weldability is determined by several factors, including:

- Welding metallurgy
- Welding chemistry
- Joint surface condition
- Joint geometry

Welding metallurgy deals with the changes that occur in a metal when acted upon by the various mechanical and thermal effects of a welding process. Welding metallurgy considers the basic atomic structure of metals and how that structure can be affected by forces and temperature. Metals' atomic structures have a pronounced effect on their resulting mechanical properties. Consequently, we will be able to establish relationships between the metallurgical treatments given to metals (preheat, postheat, stress relief, etc.) and the mechanical properties that result.

Welding chemistry deals with the chemical interaction between the base metals, filler metals, and other chemicals present at the joint during the welding process. The ability of the base metal and filler metal to fuse together without adverse chemical effects is an important factor in determining weldability.

The final factors affecting weldability are referred to as *joint surface condition* and *joint geometry*. The joint surface condition factor includes the effects of different amounts of surface roughness and cleanliness of the joint. The shape of the joint edge geometry will also have an effect on a metal's (or joint's) weldability. The amount of joint restraint can also have an effect on weldability.

Although weldability problems are usually solved by engineers, it may be the inspector who first recognizes that a weldability problem exists. In general, a poor weld is not made on purpose—welders usually strive to make good welds, and to correct faults. Whenever a rejection is encountered, the cause should be determined and corrections should be made. Defects that are not welder-related, or repetitive defects, should be noted and reported for corrective action.

The term "weldability" means the capacity of material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service. With an understanding of welding metallurgy and its chemistry, the inspector is more able to anticipate weldability problems and be on the look out for the telltale signs. In addition, armed with this foreknowledge, the inspector becomes a more valuable feedback source to the engineer or engineers responsible for the original designed welded structure. This feedback is particularly critical if the weldability problem is detected in weld after weld.

> Engineers should know the weldability of the metals they select; many problem alloys are listed in technical references on welding metallurgy. The topic of weldability for various steels is covered in the *Welding Handbook*, available through AWS. The AWS *Welding Journal* is also an excellent source for this type of information, because it includes many research papers on the subject of weldability.

An example of a code reference to the weldability of a metal is found in AWS D1.1, *Structural Welding Code—Steel*. This particular reference pertains to the welding of certain high-strength, low-alloy, quenched, and tempered steels (ASTM A 514 and ASTM A 517). The precaution clearly states that "final weld inspection of these materials must not occur until at least 48 hours after welding is completed and the base metal has cooled to room temperature." The reason for the precaution is that these steels are susceptible to underbead cracking, which is a delayed cracking problem that will not be discovered by premature inspection.

Welding Metallurgy

Metallurgy is the science that deals with the internal structure of metals and the relationship between those structures and the properties exhibited by metals. When referring to welding metallurgy, the real concerns are about the various changes that occur in metals when joined by welding. From a welding standpoint, there are several topics of concern to welding engineers:

(1) Properties of solids and liquids
(2) Melting and freezing
(3) Thermal expansion
(4) Thermal treatments (e.g., stress relief)
(5) Diffusion
(6) Solid solubility

Solids vs. Liquids

As it relates to welding, the following discussion refers to the solid (metallic) state, and the liquid (molten) state. The primary difference between these two states of matter in metals is the amount of energy contained in each. Liquid metal contains a much higher level of internal energy than solid metal. Structurally, the major difference is that for solid metals, the atoms are in a fixed position relative to each other, while in a liquid, the atoms are free to move in relation to each other (see Figure 7.1).

In the solid state, each atom has a specific "home" position with respect to all adjacent atoms. These atoms are aligned row upon row, layer upon layer, in a three-dimensional, symmetrical, crystalline structure, or pattern. These "fixed" atoms are held in place by the attracting and repelling forces of their neighboring atoms. Each atom nucleus has a cloud of encircling electrons to complete its atomic structure. This overall atomic configuration gives metals in the solid state their metallic luster and determines their physical, mechanical, chemical, and electrical properties (see Figure 7.2).

While occupying these "home" positions in the solid state, the atoms are vibrating (or oscillating) about their home position. The amount of atom movement is directly proportional to the metal's temperature. As the metal temperature increases, the movement of the atoms becomes larger and faster. Eventually, as temperature continues to increase, the internal energy increases to the point where the individual atoms break away from one another and move freely in the liquid state. This "breakaway" occurs at the melting point of the metal (see Figure 7.3).

Melting and Freezing

When a metal is heated to the liquid state, atoms move about very energetically with complete mixing. The mixing action is created by convection and conduction, which occur due to the flow of heat from hot areas to colder areas. In welding, the mixing action is also stimulated by magnetic forces, and by arc pressure, or pressure from a gas flame and movement of a welding electrode. The welder can observe this mixing action as the metal swirls beneath the heat source. The result is that the atoms from the base metal mix with the atoms from the metal being added.

Freezing of liquid metal cannot occur until the heat source is removed and the atoms lose enough energy to "settle down" into a metallic crystalline structure. The liquid's energy must be dissipated, in the form of heat

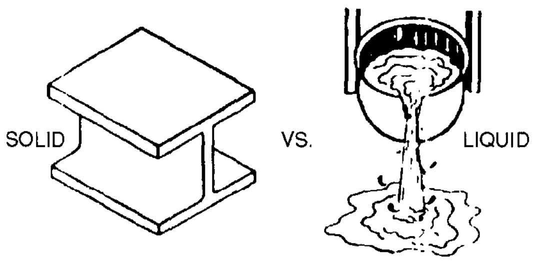


Figure 7.1—Solid State vs. Liquid State of Metals

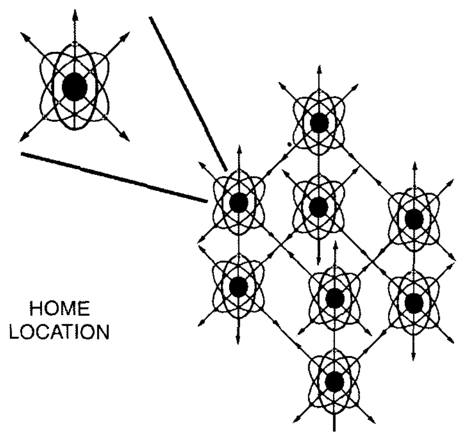


Figure 7.2—Position of Atoms in the Solid State

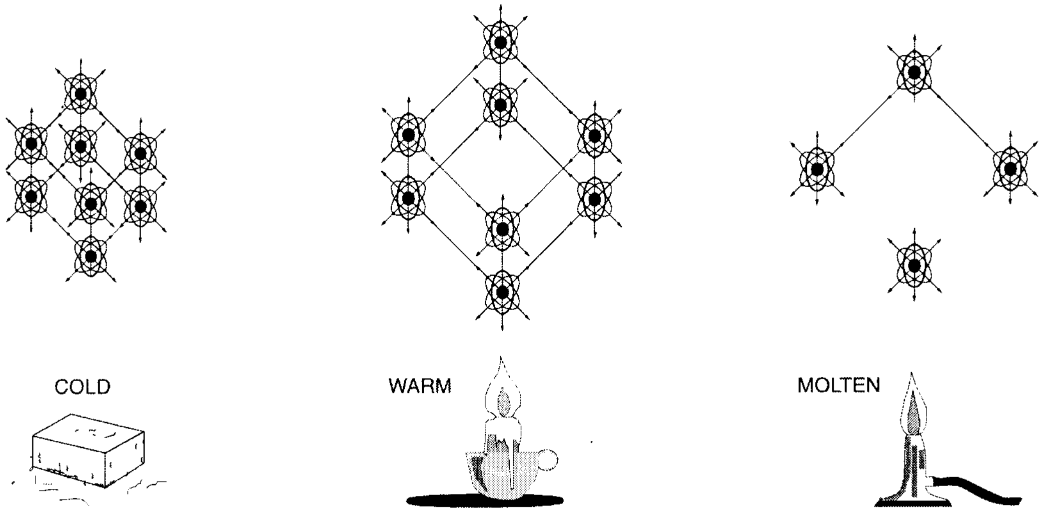


Figure 7.3—Increase in Temperature Causes Atom "Breakaway"

loss. Heat is quickly given to surrounding atoms already in the solid state. When this happens, the surrounding metal warms, and the liquid cools enough to solidify (see Figure 7.4).

The initial configuration of the crystalline structure as the weld solidifies is determined by the crystalline structure of the metal already existing in the solid state. Growth continues in the same pattern, if that is the natural pattern for the mix of atoms present. Atoms of a dissimilar weld composition may take their own preferred alignment shortly after the solidification has begun. Some atoms in a mixture may tend to segregate when solidifying, but in general, atoms mixed together as a liquid will form a homogeneous (consistent) weld. Segregation refers to the separation of like-atoms or phases resulting in a non-homogeneous structure.

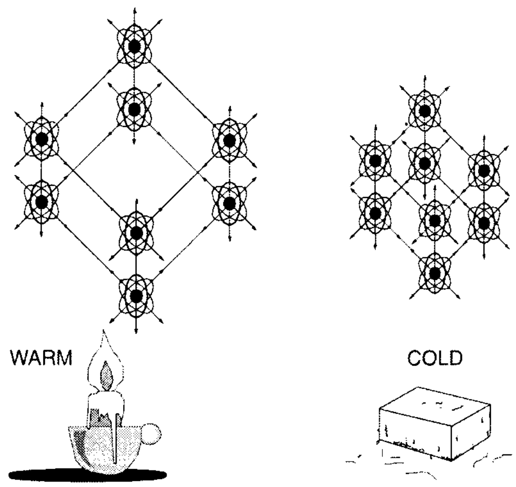


Figure 7.4—Heat Loss Causes Atoms to "Settle Down" and Liquid Metal to Solidify

Welds Under the Microscope

When properly prepared and examined under a metallurgical microscope, base metals and welds have a revealing structure that correlates with their mechanical properties. A brief review of the appearance of carbon steels as seen by the metallographer emphasizes the value that a metallographic study can bring to any welding discussion.

In a solid metal, the atoms tend to align themselves into orderly lines, rows, and layers to form three-dimensional crystalline structures. When a metal solidifies, it always does so in a crystalline pattern. The most common crystal structures, or phases, are body centered cubic (bcc), face centered cubic (fcc), and hexagonal close packed (hcp). Some metals, such as iron, exist as one solid phase at room temperature and as another phase at elevated temperatures.

The bcc cell can be described as a cube with an atom at each of the eight corners and a single atom in the center of the cell. Among the common bcc metals are iron, carbon steels, chromium, molybdenum, and tungsten.

The fcc unit cell can be described as a cube with atoms at each of the eight corners and with one atom at the center or each of the six faces. Among the common fcc metals are aluminum, copper, nickel, and austenitic stainless steels.

The hcp unit cell is a hexagonal prism that can be described as two hexagons (six sided shapes) forming the top and bottom of the prism. An atom is located at the center and at each point of the hexagon. Three atoms, one at each point of a triangle, are located between the top and bottom hexagons. Among the common hcp metals are zinc, cadmium, and magnesium.

Steels exist in several phases, typically austenite, ferrite, pearlite, bainite, and martensite (see Figures 7.5–7.7). At temperatures up about 1333°F (defined as the transformation temperature) a 0.30% C steel exists in the form of pearlite and ferrite. Above 1333°F the phases change to a mixture of austenite and ferrite, and above 1550°F the material changes entirely to austenite (see Figure 7.8). The steel will remain austenite until it reaches the melting point, at which there is no phase. The changes do not occur instantaneously and may require considerable time. The higher in the range the metal reaches, the more quickly and completely the changes will occur. As we get higher in the austenitic range, the change to austenite also occurs more quickly and the grains begin to consume each other and grow. By altering the cooling rate from the austenite range we can affect the phases of steel (see Figure 7.9).

The methods of cooling the steel in order from slowest to fastest is *furnace anneal, normalize, oil quench, water quench*, and *brine quench*. In furnace anneal the steel is taken to its austenitizing temperature, held for a period of time, and allowed to cool in the furnace. Annealing a steel results in placing it in its softest, weakest condition. In normalizing, the steel is taken to its austenitizing temperature, held for a period of time, and allowed to cool in still air. Normalizing forms new grains of ferrite and pearlite. Quenched steels are taken to the austenitizing temperature, held for a period of time, and quenched in oil, water, or brine.

Quenching the steel results in a martensitic structure. Slow cooling forms ferrite and pearlite and somewhat faster cooling forms bainite. A very rapid quench forms martensite. The critical cooling rate is governed by the carbon content, and for alloy steels, by their additional

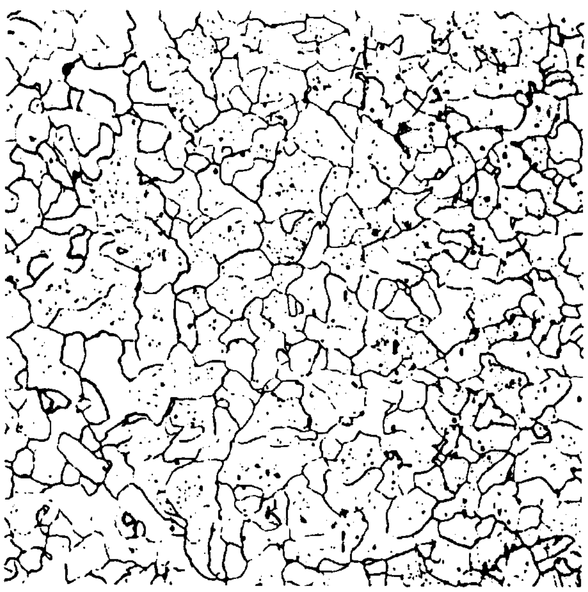


Figure 7.5—Photomicrograph of Commercially Pure Iron, Nominally Called Ferrite (No Carbides are Present, the Acid Etch Reveals Grain Boundaries, and the Dark Globules are Nonmetallic Inclusions)

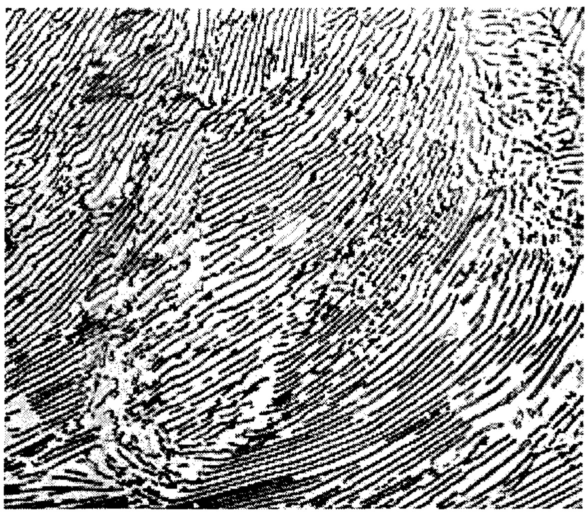


Figure 7.6—Typical Lamellar Appearance of Pearlite (1500X Etchant:Picral)

Figure 7.7—Quenched Martensite Showing Acicular Structure (500X Etched)

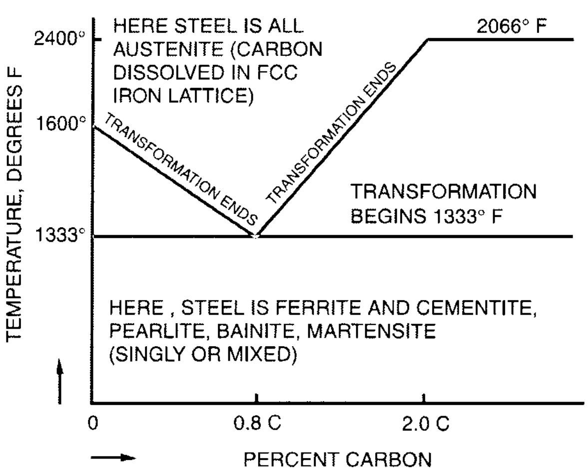


Figure 7.8—Transformation of Steels to Austenite on Heating

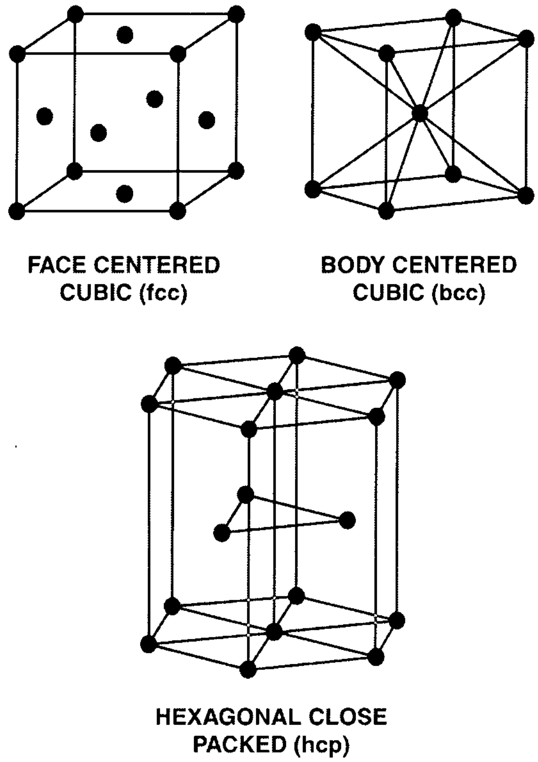


Figure 7.9—Common Crystalline Structures of Metals and Alloys

chemical composition (see Figure 7.10). Steels quenched to form martensite usually require a "tempering" heat treatment to lower their hardness and strength, and improve ductility and toughness.

Tempering is accomplished by heating the martensite to a temperature between 100°F and 1300°F to soften the steel. At the lower temperatures of tempering, no structural change can be seen on the microscope, but the strength and hardness are reduced and the ductility and toughness are increased. The changes are more or less proportional to the tempering temperature (see Figure 7.11).

In simple terms, for steels, the faster the cooling rate, the harder and less ductile the resulting structure. While the increased strength is often desirable, the accompanying low ductility will increase the steel's susceptibility to cracking.

When welding, the base metal directly adjacent to the molten weld metal will be subjected to the maximum cooling rate, because it is heated to a very high temperature and then rapidly quenched due to its contact with the massive, colder base metal. Progressing away from the weld into the base metal that has not been melted, areas that have been exposed to temperatures well above the transformation temperature can be found. Although the metal has not melted, it has been taken into the austenitizing range at various temperatures and for varying periods of time. This cooling rate also varies across this zone. This region, which has been affected by the heat of welding but has not been melted, is called the heat-affected zone (HAZ). The area immediately adjacent to

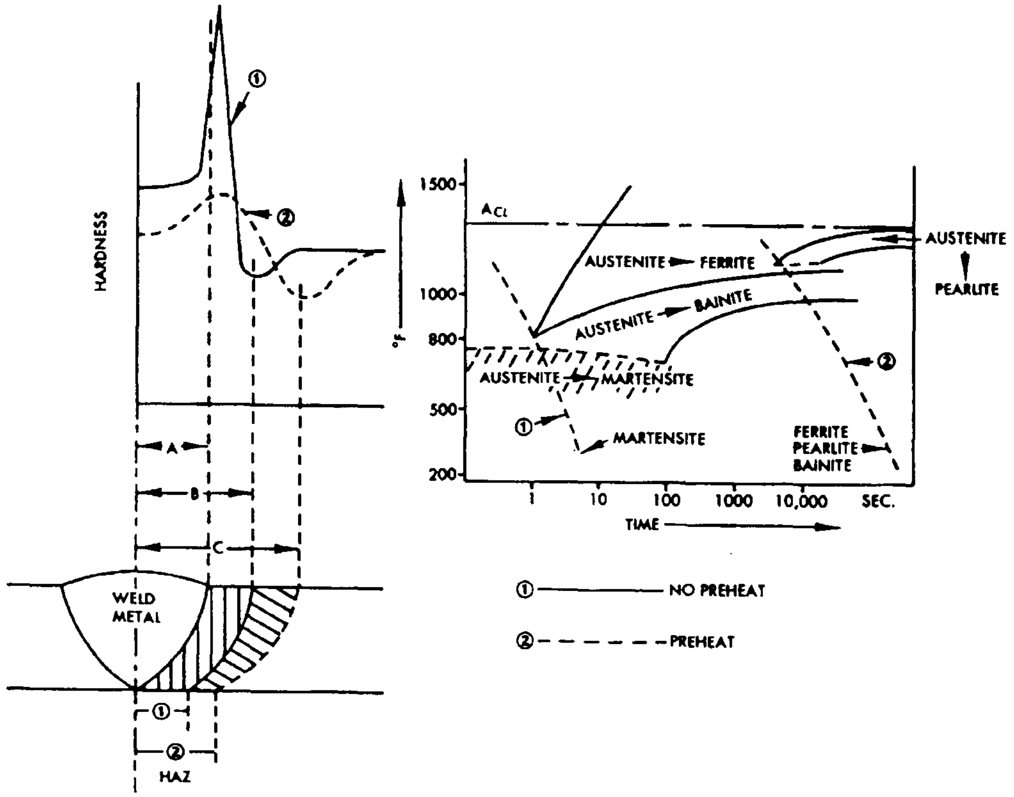


Figure 7.10—Variation of Cooling Conditions in a Weld as a Function of Preheat; Diagram Includes Some of the Property Changes Brought About by These Conditions (Also Shown is a CCT Diagram for a Steel, to Illustrate Why the Cooling Conditions Promote the Property Changes)

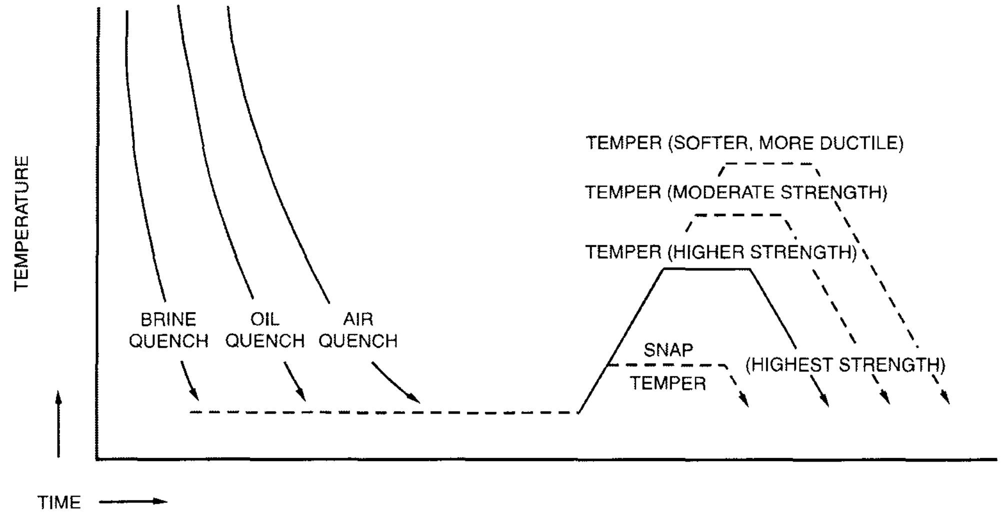


Figure 7.11—Effects of Tempering

the weld will have the largest grains, and depending upon its cooling rate, may have martensite. Progressing away from the weld, the grains get smaller and more phases within the steel can be found, until the unaffected base metal is reached (see Figure 7.12).

One of the more common heat treatments used to reduce the tendency for this high hardness and low ductility in the HAZ is referred to as *preheat*. By preheating the base metal prior to welding to a temperature of 150–700°F, the cooling rate will be effectively reduced. Therefore, time will be allowed for a more ductile microstructure than martensite to form, which, in turn, will result in a more ductile, less crack-sensitive weld and HAZ.

Another factor having an affect on the cooling rate of the weld zone is heat input or the amount of energy supplied by the welding arc to heat the base metal. As the heat input increases, the cooling rate decreases. Use of smaller diameter welding electrodes, lower welding currents and faster travel speeds will all tend to decrease the heat input and therefore increase the cooling rate. For arc welding processes, the heat input can be calculated using the formula shown. It is dependent only upon the welding current, arc voltage, and travel speed as measured along the longitudinal axis of the weld joint. The heat input formula is:

Heat input, joules/in. =

$$\frac{\text{welding current} \times \text{welding voltage} \times 60}{\text{travel speed, in./min.}}$$

Other Metallurgical Factors

(1) **Fatigue.** Any welds that are to be inspected will have to be designed to resist with elastic deformation all stresses up to the yield point of the steel, except for weldments subject to fatigue. Welds subject to cyclic stresses must be designed for lower applied stresses to avoid fatigue failures, because metals usually fail by fatigue at stresses below their yield point.

(2) **Surface Configuration.** Another important factor affecting a metal's resistance to fatigue stresses is its surface configuration. Sharp crevices or notches on the metal's

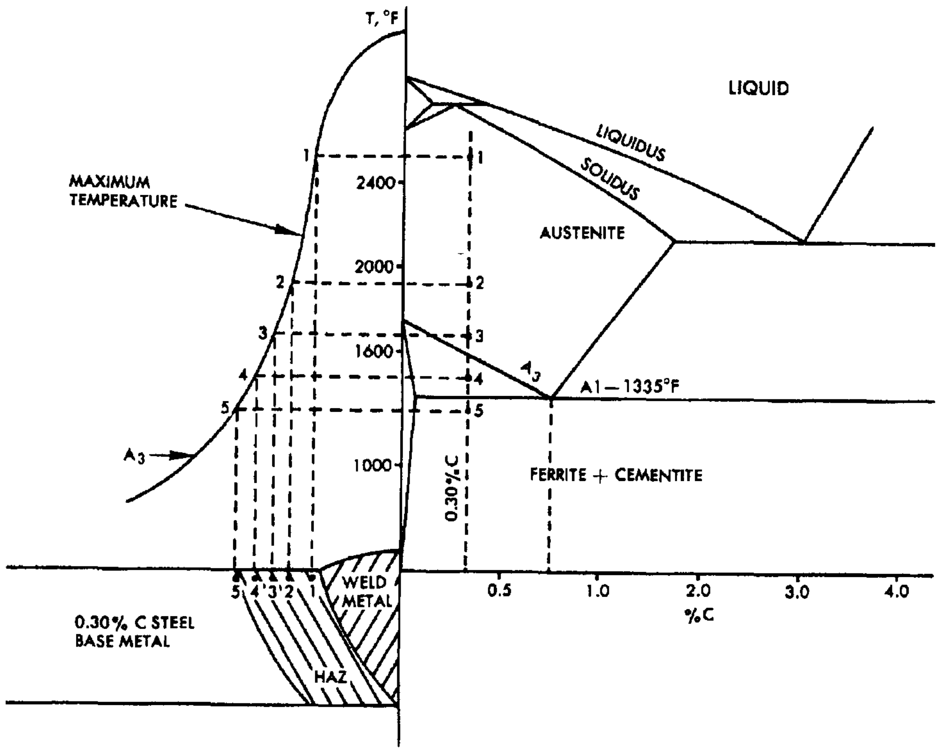


Figure 7.12—Relation Between the Peak Temperatures Experienced by Various Regions in a Weld, and How These Correlate with the Iron-Carbon Phase Diagram

surface result in creating a "stress riser," which can increase the actual applied load to much higher levels of stress. Typically, engineers have determined that applied stresses can be multiplied by factors from 1 to 10, depending on the nature and shape of the "notch." A crack, with its very sharp end conditions, can multiply the applied stress by as much as 10. Undercut can multiply the applied stress by a factor of 3–5, and weld ripples can increase the applied stress by a factor of 2–3.

The allowable stresses for bridge welds are defined in special tables that impose higher than normal factors of safety to account for fatigue loading. Safety factors normally are 3 or 4; bridges often have safety factors of 5 or even higher. The design engineer translates these higher factors of safety into larger fillet welds, longer welds, heavier beams, etc., so the bridge will be able to handle the applied cyclic stresses. The welding inspector should be aware of these design differences and inspect accordingly.

The previous information clarifies why surface discontinuities such as excessive weld reinforcement, undercut, overlap, and excess convexity, can cause stress risers, or notches, which can significantly reduce the component's fatigue strength. For that reason, fatigue-loaded structures may have their weld surfaces ground to remove surface irregularities. An example of this is found in AWS D1.5, *Bridge Welding Code*, which states that the allowable depth of undercut for bridges is significantly less than for some other structures. Many fabricated structures are subject to some level of fatigue loading; in fact, it is difficult to find a complex structure that has not had some aspect of its design modified to account for dynamic fatigue loading.

(3) **Internal structure.** When alloys are melted in the steel mill and cast into large ingots, they have a cast structure. These large ingots are formed into the required shapes by a combination of hot working and cold working of the metal. This "working" changes the internal structure of the metal, however, metallurgical discontinuities such as segregation of elements, laminations, seams and laps may remain in the finished product. These discontinuities can become "planes of weakness" in the finished product. Metals have a grain. They have their highest mechanical properties in the direction of rolling, are significantly weaker in the direction transverse to the rolling direction, and have little strength (and virtually no ductility) in the through-thickness direction. The designer and welding engineer must take these factors into account in the design and fabrication of a structure. The inspector should be aware of these conditions, which relate to inspection responsibilities.

Thermal Expansion

Metals expand and contract upon heating and cooling, because of the effects of energy on the atomic oscillations. Heating the metal puts more energy into the oscillations, which tends to move the atoms further apart. As a result, the metal expands. When the metal cools, this process is reversed and the metal contracts, or shrinks (see Figure 7.13).

When heat is uniformly applied or removed from a piece of metal, the dimensions change, but stress is not induced from within because the expansion or contraction is uniform throughout. However, when the application or removal of heat is not uniform, as occurs in welding, stress is induced into the part and some distortion may result, because the hotter parts of the metal expand more than the portions at lower temperatures.

Figure 7.14 illustrates the dimensional changes that occur in a straight bar (a) that is to be heated just on one side. In (b), the arc has been struck and the plate begins to heat under the influence of the arc. Since the heat is not instantaneously conducted to all parts of the bar, the top of the bar is heated at a greater rate than the bottom of the bar and expands at a greater rate. In (c), the heated portion continues to expand until it causes the bar to develop a downward bend. As heat is continually applied to the top of the bar, a small puddle develops. It does not have the strength to cause the bar to bend any further, so the puddle develops a small reinforcement.

In (d), the arc has been removed, and the molten portion begins to cool as the heat is conducted more evenly throughout the bar. As cooling continues in (e) and solidification occurs, the displaced weld in the form of weld

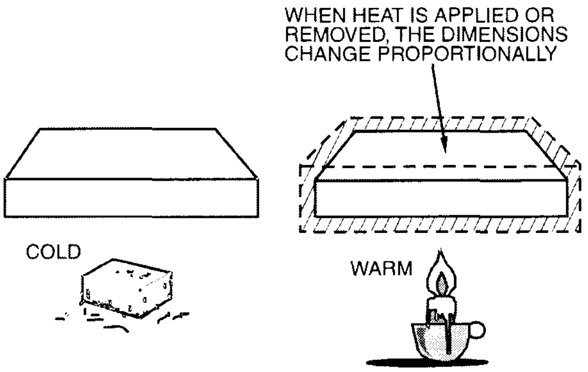


Figure 7.13—Thermal Expansion

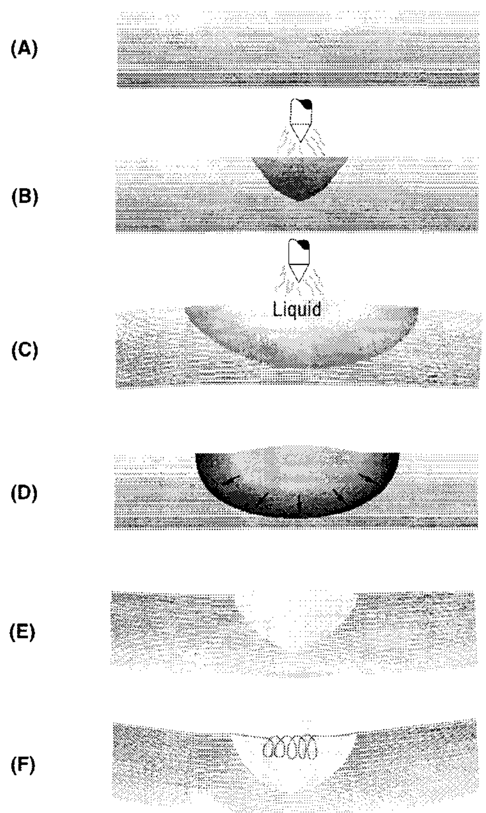


Figure 7.14—Shrinkage in a Weld Caused by Internal Restraint (Also Shown is the Nature of Residual Stress)

reinforcement no longer takes up the same volume as it did before; and as cooling continues, it causes the bar to bend in the opposite direction and results in a concave shape when reaching room temperature. Just from the simple act of nonuniformly melting a portion of the bar, and allowing it to cool, distortion has occurred; the bar now contains a low level of residual stress, represented by the spring shown in (f). If the bar were restrained during the heating and cooling cycle, the residual stress would be much higher. Residual stresses can be great enough to cause cracking on cooling, or cracking in service from fatigue or corrosion stress cracking mechanisms. It is often necessary to remove these residual stresses by a postweld thermal heat treatment referred to as *stress relief.*

There are three methods of removing weld stresses: thermal treatment, peening, and vibratory stress relief. During thermal stress relief, the part is heated uniformly to a temperature below its transformation temperature and held for a prescribed time period. The result of this method is that the uniform heating allows the residual stress to relax because the materials strength is now reduced. Slow uniform cooling to room temperature will then produce a part with much lower residual stress. Table 7.1 shows typical thermal stress relief treatments for several alloys.

Many of the fabrication codes require stress relief and specify the heating rates, holding temperatures, and cooling rates. Stress relief can also be done using peening techniques and vibratory stress relief. Peening is the mechanical distortion of the weld bead through mechanical means, usually when the metal is still quite hot. Peening should not be done on the root pass nor final pass of a weld, but only on the intermediate layers. Peening the root pass when it is hot can result in cracking of the weld, because its size cannot withstand the mechanical distortion, and peening of the final pass can interfere with later visual inspection or other nondestructive testing (see Figure 7.15). The vibratory technique imparts a high-frequency vibrational energy into the part that either prevents the buildup of stresses in the weldment while welding, or removes the stresses after welding.

One technique that may be used to reduce the need for postweld stress relief is referred to as *preheat*. Preheating a part prior to welding slows the cooling rate, and may eliminate the need for postweld stress relief. Preheating reduces the thermal gradients within a weldment and slows the cooling rate, resulting in a more ductile structure with lower residual stress. Preheat is very effective in reducing or eliminating hot cracking of many alloys. Preheat also aids in removing moisture from the part, helps to remove hydrogen, and retards the formation of martensite—a hard, brittle phase that forms on rapid cooling.

Table 7.1
Typical Thermal Stress Relief Heat Treatments for Weldments

	Soaking Temperature	
Material	°C	°F
Carbon Steel	595–680	1100–1250
Carbon—12% Mo steel	595–720	1100–1325
1% Cr—1/2% Mo steel	620–730	1150–1350
2-1/4% Cr—1% Mo steel	705–770	1300–1425
5% Cr—1/2% Mo steel (502)	705–770	1300–1425
7% Cr—1/2% Mo steel	705–760	1300–1400
9% Cr—1% Mo steel	705–760	1300–1400
12% Cr (Type 410) steel	760–815	1400–1500
16% Cr (Type 430) steel	760–815	1400–1500
Low-alloy Cr-Ni-Mo steels	595–680	1100–1250
2% to 5% Ni steels	595–560	1100–1200
9% Ni steels	550–585	1025–1080
Quenched and tempered steels	540–550	1000–1025

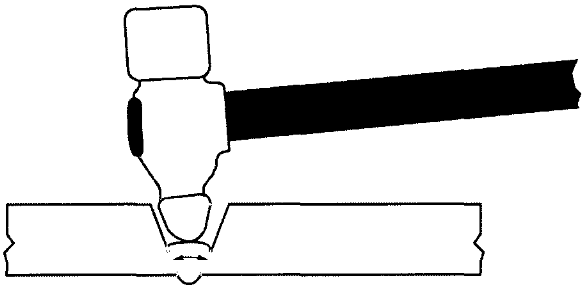


Figure 7.15—Peening the Middle Weld Layer Distributes and Balances Distortion

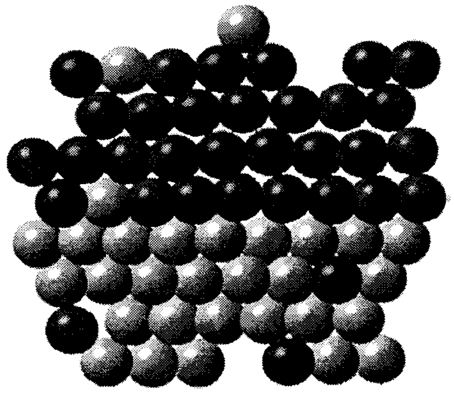


Figure 7.16—An Example of Migrating or Diffusing Atoms

Preheating can be done by several methods, including gas-fired or electric furnaces, electric resistance heating elements, gas torches, or high-energy quartz lamps. Preheating should be done on an area much larger than just the weld zone; if done on too small an area, insufficient heat energy is put into the part and it cools too quickly. The AWS D1.1, *Structural Welding Code—Steel*, requires that the preheat temperature be checked to ensure that all parts on which the weld metal is being deposited are above the minimum specified temperature for a distance equal to the thickness of the part being welded, but not less than 3 in., in all directions, from the area being welded.

Diffusion

Previously it was noted that atoms in the liquid state can move about easily with respect to each other; however, under certain conditions, even atoms in the solid state can change positions. In fact, any atom may "wander" away, step by step, from its home position. These changes of atom position in the solid state are referred to as *diffusion*.

An example of diffusion is shown when smooth, flat bars of lead and gold are clamped tightly together. If they are clamped together at room temperature for several days, the two sheets of metal remain attached when the clamps are removed (see Figure 7.16). This attachment is due to the fact that atoms of lead and gold have each migrated, or diffused, into the other metal, forming a very weak metallurgical bond. This bond is quite weak, and the two metals can be broken apart by a sharp blow at their joint line. If the metals' temperatures are increased, the amount of diffusion increases, and at a temperature above the melting point of both, complete mixing occurs.

Another example of diffusion occurs when hydrogen, a gas, is allowed in the vicinity of molten metal, such as a weld. The most common source of hydrogen is moisture (H_2O), or contamination on the surfaces of the parts to be welded. Many of the contaminants normally found on metals are organic compounds, i.e., oil, grease, etc., and they contain hydrogen in their chemical makeup. The heat of welding will break down the water or organic contaminants into individual atoms, which includes the hydrogen atom (H). The hydrogen atoms are quite small, and can easily diffuse into the base metal structure. As they enter the base metal, the hydrogen atoms often recombine into the hydrogen molecule (H^2), a combination of two atoms of hydrogen, which is much larger than a single atom of hydrogen. The larger molecules often become trapped in the metal at discontinuities such as grain boundaries or inclusions. These hydrogen molecules, because of their larger size, can cause high stresses in the internal structure of the metal and for metals of low ductility, can cause cracking. Hydrogen cracking is often referred to as *underbead* or *delayed* cracking.

The primary cure for hydrogen cracking problems is simply to eliminate the source of hydrogen; the first step is to thoroughly clean all surfaces to be welded. Another approach is to specify the "low-hydrogen" electrodes for use on carbon and low-alloy steels. These low-hydrogen electrodes are specially formulated to keep their hydrogen content quite low, but they do require special handling to avoid moisture pickup after opening the sealed shipping containers. After removal from their containers, low-hydrogen electrodes should be stored in a vented electric oven at a temperature of 250°F. It should be noted that the shielded metal arc electrodes with a cellulosic coating such as EXX10 and EXX11 must not be kept in heated storage. They should be kept dry and stored at room temperature. Heating these electrodes destroys the covering chemistry by removing moisture from the covering, which is required for satisfactory performance. These two classes of electrodes are usually limited to welding plain carbon steels, with low-to-medium carbon content. Preheating the base metals is also effective in eliminating hydrogen pickup, because hydrogen will diffuse out of most metals at temperatures of 200–450°F. The previous methods all aid in reducing the possibility of hydrogen cracking in susceptible metals.

Solid Solubility

Most of us are familiar with the normal solubility of solids into liquids. Adding a spoonful of sugar to a glass of water and stirring will dissolve the sugar. However, most of us are not familiar with one solid dissolving into another solid. In the previous example with the lead and gold, the two metals were diffusing through solid solution into each other. And returning to the example of sugar and water, if additional sugar is added, some of it will not dissolve despite stirring. For that particular amount of liquid and its temperature, a "critical solubility limit" has been reached, and no amount of stirring will dissolve any more sugar. To dissolve more sugar, the liquid volume would either have to be increased, or have its temperature raised. Therefore, for a solid dissolving into a liquid, there is a critical solubility limit depending on liquid volume and temperature. Metals behave similarly, except through diffusion, and they "dissolve" into each other when both are solid.

Like the sugar and water example, however, there are solubility limits of one solid dissolving into another and the critical solubility limit is dependent on temperature. The higher the temperature of a metal, the more dissolving of a second element will occur. Thus, we can get metals combining even when both are solid. Of course, as a metal's temperature is raised, the amount of diffusion and solubility increases.

An example of a solid dissolving into another solid is a method used for increasing the surface hardness of a steel. If the steel is packed into a bed of carbon particles and then heated to a temperature of about 1600–1700°F (well below the melting point of both the carbon and the steel), some of the carbon will diffuse (dissolve) into the surfaces of the steel. The added carbon in the steel's surface makes the surface much harder, and is useful for resisting wear and abrasion. This technique is commonly called *carburizing*. The surface of steels can also be made hard by exposing the steel to an ammonia environment at similar temperatures to carburizing. The ammonia (NH^3) breaks down into its individual components of nitrogen and hydrogen, and the nitrogen atoms enter the surface. This technique is called *nitriding*. Both of these surface hardening techniques demonstrate the diffusion and solid solubility of metals. Knowledge of diffusion and solid solubility will aid the welding inspector in understanding the importance of cleanliness in welding, and the need for proper shielding during all welding operations.

Welding Chemistry

The final aspect of weldability to be discussed is welding chemistry. Welding chemistry deals with the chemical interaction between the base metal elements, the weld metal elements, and the other elements introduced into the area of the weld. The base and weld metals must be compatible; however, other elements in the welding environment must also be considered. For example, the air atmosphere, containing oxygen, nitrogen, and other elements, must be excluded from the weld zone to maintain weld quality. In addition, the elements contained in fluxes must be considered for compatibility and any shielding or purge gasses used.

Metals react with their environment to different degrees, depending on the metal and the environment to which it is exposed. We are familiar with the "rusting" of bare steel in moist air; the steel is reacting with the water and the oxygen through a chemical reaction. Many of the stainless steels can also corrode at very high rates if the environment is severe enough. And, as metals corrode, atomic (nascent) hydrogen atoms (H+) are formed. Earlier discussions about problems with hydrogen emphasize the importance of avoiding corrosion of our welded structures—not only because of the wall thinning aspect, but also because of hydrogen formation and diffusion into the steels.

When molten, metals react with the environment to a much greater degree. Because of this, they must be protected while molten from undesirable elements that may significantly alter their mechanical properties.

Shielding

When welding occurs, the molten weld puddle must be protected from chemical interactions with the unwanted elements (see Figure 7.17). The primary elements causing difficulties are carbon, oxygen, hydrogen, and nitrogen (see Figure 7.18). These unwanted elements are found in moisture, air, improperly adjusted heating flames, and surface contamination. Since the molten metal must be protected, it is accomplished in part through *shielding*, in which a protective "blanket of gas" is formed from electrode coverings, welding fluxes, shielding gasses, or purge gasses.

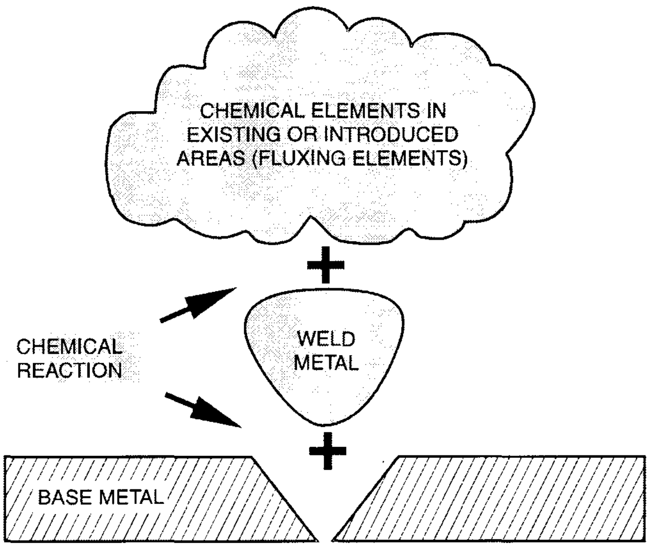


Figure 7.17—Chemical Interactions While Welding

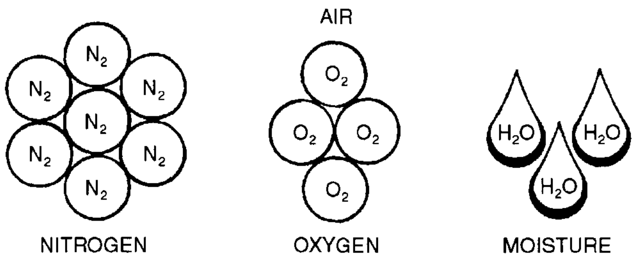


Figure 7.18—Common Elements that can Cause Problems

In shielded metal arc welding, the shielding comes from the vaporization of the electrode covering (see Figure 7.19); in gas tungsten arc welding, the shielding comes from the inert gas passing through the torch; in oxyacetylene welding, the shielding comes from the secondary burn in the outer envelope of a neutral welding flame.

In gas metal arc welding and flux cored arc welding, the shielding gas may be argon, carbon dioxide, CO_2, mixtures of the two, and blends of inert and active gases (see Figure 7.20). Carbon dioxide decomposes on heating into oxygen atoms (O+) and carbon monoxide (CO), the oxygen can be absorbed into the weld metal. To alleviate this possibility, deoxidizers are added to the electrode compositions to combine with any oxygen present and prevent it from degrading the weld metal properties.

Shielding can also take the form of a blanket of flux, which physically excludes the surrounding atmosphere from the weld zone and forms a protective slag when heated. Submerged arc welding uses a flux covering for shielding and slag formation, which protects the weld metal until it cools to room temperature. The protective slag is formed during the heat of welding, and contains deoxidizers added to the flux. *Electroslag* uses a similar granular flux for shielding, as does SAW (see Figure 7.21).

Weld Metal Composition

The elements composing a weld are derived from a variety of sources; the base metal adjacent to the weld that is melted, the weld filler metal, fluxes if used, and the shielding agents that come into contact with the weld

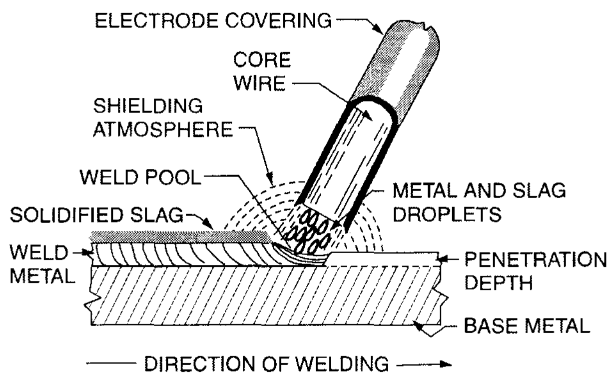


Figure 7.19—Shielded Metal Arc Welding

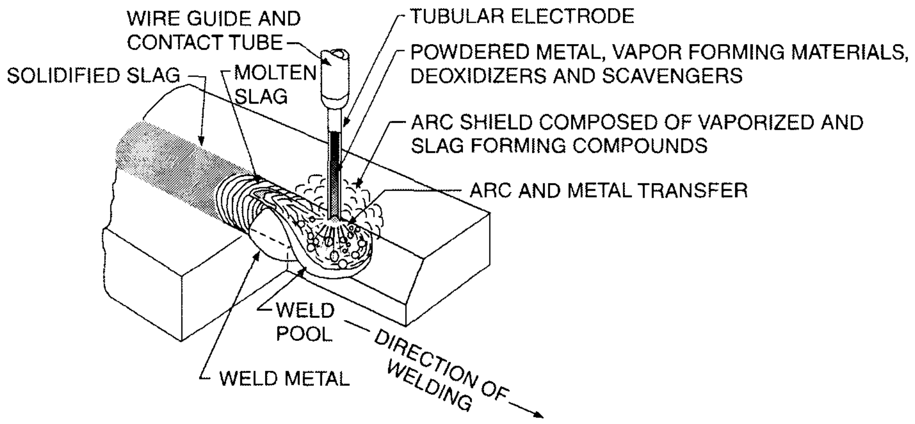


Figure 7.20—Self-Shielded Flux Cored Arc Welding

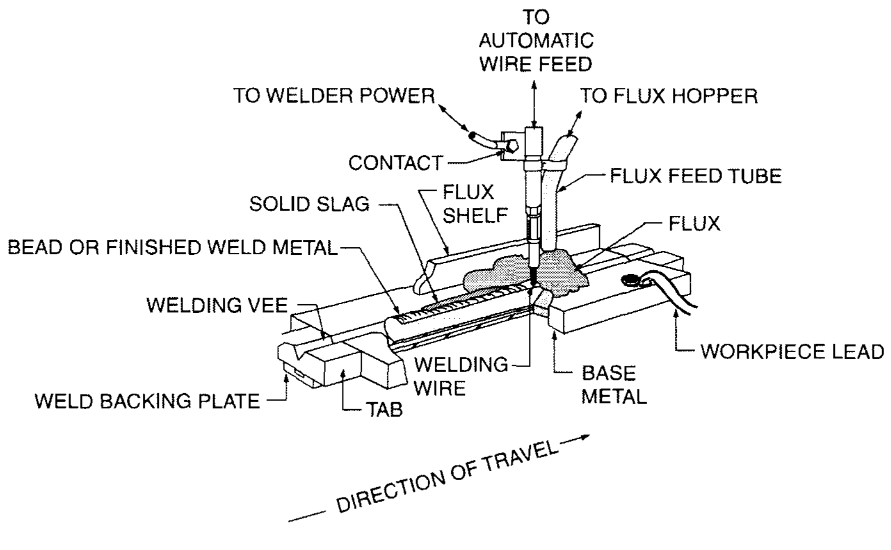


Figure 7.21—Schematic View of Submerged Arc Welding Processes

puddle. Some welds are made without filler metal, and are referred to as *autogenous* welds. Examples are longitudinal seam welds in tubing, and edge and corner welds in sheet metal fabrication. For these welds, the base metal is formed to allow melting and to supply the necessary molten puddle to complete the weld. Some groove welding procedures start with an autogenous root pass, and are completed with filler metals.

The welding inspector must recognize the positive and negative chemical aspects of weld metal composition and their effects on the finished product. For example, if a weld is made without filler metal, the absence of deoxidizers (normally contained in filler metals and fluxing agents) may result in the presence of porosity or even cracking.

Welding Chemistry of Specific Base Metals

The chemistry of the base metals and their corresponding filler metals must be matched for best results. Electrodes have been designed for welding almost every metal. As previously noted, when the carbon content increases, weldability decreases; therefore, plain carbon steel base metals with carbon contents of 0.15% to 0.30% are generally considered easily weldable. As the base metals' carbon content increases above about 0.30%, they become more difficult to weld, and may require changes in the welding procedures such as adding preheat.

Also, as the percentage of other elements added to the base metals increases, weldability usually decreases. Increased chromium, molybdenum, nickel and other elements may require the use of preheat, interpass temperature control, and post weld heat treatments. Preheating the higher carbon base metals, and those with the previously mentioned higher element percents, improves their weldability. This improvement occurs because the weld and HAZ cool more slowly when preheated, the formation of martensite is reduced, hydrogen is removed from the base metal, and the effects of any contamination are minimized.

Carbon Equivalent Calculation

The weldability of carbon steels depends on the base metal's chemistry. A formula has been developed to quantify a metal's weldability, and determine whether preheat is needed. Many such formulas have been developed, but they all take into account the primary alloying elements of the base metal and determine the effect of each, based on a corresponding percent of carbon. The elements usually found in these "carbon equivalent" (CE) formulas include carbon, manganese, chromium, nickel, copper, silicon, and molybdenum. One such formula is listed, and it determines the effect of each element noted regarding martensite formation. Most of the elements promote martensite formation, but to lesser degrees than carbon; their actual percentage is reduced to a carbon equivalent by dividing by some number.

The carbon equivalent formula is as follows:

$$CE = \%C + \frac{(\%Mn + \%Si)}{6} + \frac{(\%Cr + \%Mo)}{5} + \frac{(\%Ni + \%Cu)}{15}$$

When the CE computed by this formula exceeds 0.40, it is recommended that the base metal be preheated in the range of 200–400°F. If the CE exceeds 0.60, the preheat range should be increased to 400–700°F. Additionally, as the CE rises above 0.40, low-hydrogen electrodes are helpful, and postwelding heat treatments may be required. There are many different CE formulas, therefore, to ensure proper usage when selecting CE formulas, the welding inspector must get assistance from the welding engineer.

Welding Chemistry of Stainless Steels

The word "stainless" is a misnomer when applied to the classes of metals referred to as *stainless steels*, because it usually means that they resist corrosion. However, in severe corrosive environments, many of the stainless steels corrode at very high rates. The stainless steels are defined as having at least 12% chromium. There are many types of stainless steels, and when discussing them the welding inspector should use the proper designation for each type.

The four main classes of stainless steels are ferritic, martensitic, austenitic, and precipitation hardening. The first three categories refer to the stable room temperature phase found in each class. The last category, often called "PH" stainless steels, refers to the method of hardening them by an "aging" heat treatment, which is a precipitation hardening mechanism as opposed to a quenching and tempering mechanism. The stable room temperature phase found in stainless steels depends on the chemistry of the steel, and some stainless steels may contain a combination of the different phases. The more common stainless steels are the austenitic grades, which are identified by the "200" and "300" series grades; 304 and 316 stainless steels are austenitic grades. A 416 steel is a martensitic grade, and 430 is a ferritic grade. One of the common PH stainless steels is a 17-4 PH grade.

As might be expected, the weldability of these grades varies significantly. The austenitic grades are very weldable with today's available filler metal compositions. These grades can be subject to hot short cracking, which occurs when the metal is very hot. This problem is solved by controlling the composition of the base and filler metals to promote the formation of a "delta ferrite" phase that helps eliminate the hot short cracking problem. Typically, cracking will be avoided by selecting filler metals with a delta ferrite percent of 4–10%. This percentage is often referred to as the *Ferrite Number* and can be measured with a magnetic gauge. The delta ferrite can be measured using the magnetic gauge since delta ferrite is bcc and magnetic, while the primary phase, austenite, is fcc and non-magnetic.

The ferritic steels are also considered weldable with the proper filler metals. The martensitic grades are the most difficult to weld, and often require special preheating and post weld heat treatment. Procedures to weld these materials have been developed, and they must be followed carefully to avoid cracking problems and maintain the mechanical properties of the base metals. The PH stainless steels are also weldable, but attention must be given to the changes in mechanical properties caused by welding.

One of the common problems to be encountered when welding the austenitic grades is referred to as *carbide precipitation*, or *sensitization*. When heated to welding temperature, a portion of the base metal reaches temperatures in the 800–1600°F range; within this temperature range, the chromium and carbon present in the metal combine to form chromium carbides. The most severe temperature for their formation is about 1250°F, and this temperature is passed through twice on each welding operation cycle—once on heating to weld and again on cooling to room temperature.

These chromium carbides typically are found along the grain boundaries of the structure. The result of their formation is the reduction of the chromium content within the grain itself (adjacent to the grain boundary) referred to as *chromium depletion*, which results in a reduction in the chromium content below the desired level. The final result of this chromium depletion of the grain is a reduced corrosion resistance of the grain itself, due to its reduced chromium content. In certain corrosion environments, the edges of the grains corrode at a high rate, referred to as *intergranular attack* (see Figure 7.22).

Sensitization of austenitic stainless steels during welding can be attacked by several methods. The first method involves reheat treating of the completed structure by heating to 1950°F and quenching rapidly in water. This reheating breaks up the chromium carbides, permitting the carbon to be redissolved into the structure. However, this heat treatment can cause severe distortion of welded structures (see Figure 7.23).

A second method is the addition of stabilizers to the base and filler metals. The two most common stabilizers are titanium or columbium (niobium), added to the 300 series alloys in amounts equal to 8 or 10 times the carbon content. These alloying stabilizers preferentially combine with the carbon and reduce the amount of carbon available for chromium carbide formation, while maintaining the alloys' chromium content and corrosion resistance. The addition of titanium results in the austenitic stainless alloy 321; the addition of columbium results in the 347 grade (see Figure 7.24).

The third method is the reduction of carbon content in the base and filler metals. Initially, these low-carbon aus-

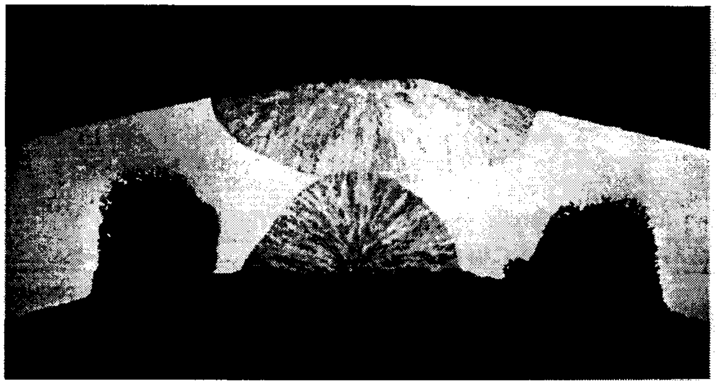


Figure 7.22—Corrosion by Intergranular Attack (IGA) Caused by Sensitization of the HAZ

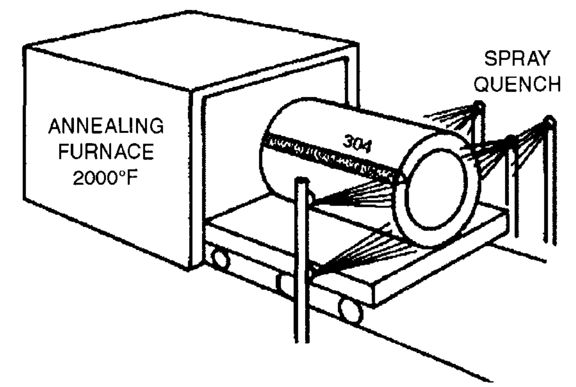


Figure 7.23—For Stabilization Heat Treatment Use 1500°F, No Quench Needed.

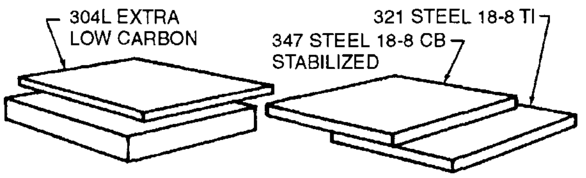


Figure 7.24—Prevention of Corrosion in Welded Stainless Steel

tenitic stainless steels were referred to as *extra low carbon* (ELC). They are currently referred to by the letter "L" designating the carbon content as less than 0.03%. (The standard grades contain up to 0.08% carbon.) By reducing the carbon content in the alloy, less carbon is available to combine with the chromium and sensitization is reduced during welding. Because of their lower carbon content, these low-carbon grades have slightly reduced mechanical properties, which must be considered when selecting these alloys, especially for high temperature use.

Welding Chemistry of Aluminum Alloys

Aluminum alloys have a very tenacious oxide film on their surfaces, which forms very rapidly when the bare aluminum is exposed to air and gives protection in corrosive environments. However, these same oxides on the surface interfere with the joining processes. To braze or solder these alloys, fluxes are used to break down the oxide film so that the parts can be joined. When welding, alternating current is used, which results in breaking down of the oxides by the current reversal of AC welding. Re-formation of the oxide film is avoided by shielding with helium or argon gas. The AC welding method is sometimes referred to as a *surface cleansing technique*.

The metallurgy of aluminum and its alloys is very complex, particularly because of the large number of alloy types and heat treatments. The proper filler metals for most every grade and heat treat condition can be found in AWS A5.10, *Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods*.

Welding Chemistry of Copper Alloys

Unlike steel, pure copper and many of its alloys cannot by hardened by a quench and temper heat treatment. These alloys are usually hardened and strengthened by the amount of "cold work" introduced when forming the alloys into the various shapes. The fact that welding softens the cold-worked material, must be considered before welding on work-hardened copper alloys. There is a series of copper alloys that are strengthened by *aging*, a treatment similar to the precipitation hardening used on the PH stainless steels. When welding on these alloys, a postweld heat treatment is usually specified to restore the original mechanical properties. One of the major problems when welding copper and its alloys is due to their relative low melting point and very high thermal conductivity. Considerable heat must be applied to the metal to overcome its loss through conductivity, and the relatively low melting point often results in the metal melting earlier than expected and flowing out of the weld joint. With proper technique and practice, the welding of most copper alloys is possible.

Welding Chemistry of the Reactive Metals

There are three metals grouped into the class of *reactive metals*: titanium, zirconium and tantalum. These metals are so named because they are extremely reactive with other elements, especially when heated to the temperature required to weld. When they react with even a trace of other elements such as oxygen, hydrogen, and nitrogen, these metals become very embrittled and hard. Extra precaution is required in shielding and purging, and it is often required that tantalum and zirconium be welded in a purging chamber. For welding titanium, a full shielding technique or a trailing shield may be sufficient (see Figure 7.25).

Because of the great affinity these alloys have for trace contaminants, it has been stated that the "art of welding" is really the art of proper cleaning and purging. When attention is given to cleaning and purging, high quality welds can be made.

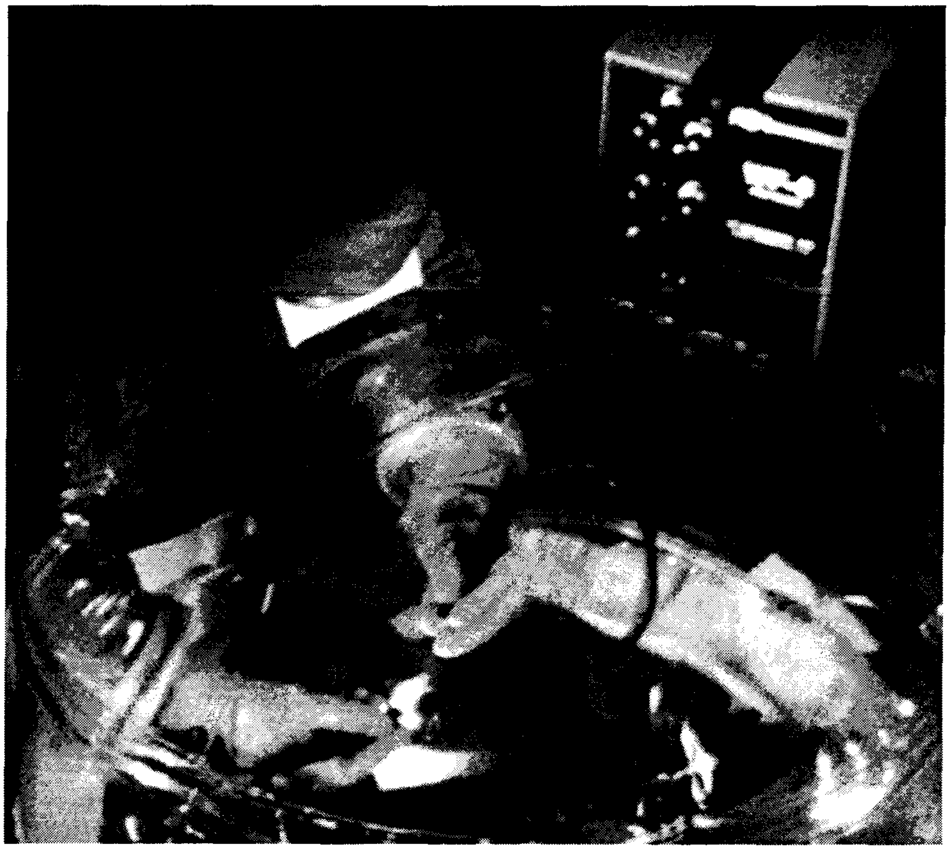


Figure 7.25—Welding in a Controlled Atmosphere

Summary

While the welding inspector is not responsible for selecting the base metals and filler metals, the inspection responsibility will involve many decisions that are based on metallurgical principles. This information has been discussed to provide the inspector with a basic understanding of many of the principles involved. The inspector will also benefit from the knowledge of metallurgical considerations that are applied to the fabrication of structures, which explains the behavior of metals during welding.

Review—Chapter 7—Weldability, Welding Chemistry, and Welding Metallurgy

Q7-1 As a metal is heated:
- a. energy is added to the structure
- b. the atoms move farther apart
- c. the atoms vibrate more vigorously
- d. the metal expands
- e. all of the above

Q7-2 The state of matter which exhibits the least amount of energy is:
- a. solid
- b. liquid
- c. gas
- d. quasi-liquid
- e. none of the above

Q7-3 A problem occurring in weldments caused by the nonuniform heating produced by the welding operation is:
- a. porosity
- b. incomplete fusion
- c. distortion
- d. slag inclusions
- e. none of the above

Q7-4 All but which of the following will result in the elimination or reduction of residual stresses?
- a. vibratory stress relief
- b. external restraint
- c. thermal stress relief
- d. peening
- e. postweld heat treatment

Q7-5 Rapid cooling of a steel from the austenitic range results in a hard, brittle structure known as:
- a. pearlite
- b. carbide
- c. cementite
- d. bainite
- e. martensite

Q7-6 Very slow cooling of steel may result in the production of a soft, ductile microstructure that has a lamellar appearance when viewed under high magnification. This structure is referred to as:
- a. martensite
- b. pearlite
- c. bainite
- d. ferrite
- e. cementite

Q7-7 When rapid cooling produces a martensitic structure, what nonaustenitizing heat treatment may be applied to improve the ductility of the steel?
- a. quenching
- b. tempering
- c. annealing
- d. normalizing
- e. none of the above

Q7-8 The use of preheat will tend to:

a. result in a wider heat-affected zone
b. produce a lower heat-affected zone hardness
c. slow down the cooling rate
d. reduce the tendency of producing martensite in the heat-affected zone
e. all of the above

Q7-9 Which of the following changes will warrant the addition of or increase in the required preheat?

a. decreased carbon equivalent
b. increased carbon equivalent
c. increased base metal thickness
d. both a and c above
e. both b and c above

Q7-10 What heat treatment is characterized by holding the part at the austenitizing temperature for some time and then slow cooling in the furnace?

a. normalizing
b. quenching
c. annealing
d. tempering
e. stress relief

Q7-11 What heat treatment is characterized by holding the part at the austenitizing temperature for some time and then slow cooling in still air?

a. normalizing
b. quenching
c. annealing
d. tempering
e. stress relief

Q7-12 Increasing the heat input:

a. decreases the cooling rate and increases the likelihood of cracking problems
b. decreases the cooling rate and decreases the likelihood of cracking problems
c. increases the cooling rate and increases the likelihood of cracking problems
d. increases the cooling rate and decreases the likelihood of cracking problems
e. none of the above

Q7-13 Increasing preheat:

a. decreases the cooling rate and increases the likelihood of cracking problems
b. decreases the cooling rate and decreases the likelihood of cracking problems
c. increases the cooling rate and increases the likelihood of cracking problems
d. increases the cooling rate and decreases the likelihood of cracking problems
e. none of the above

Q7-14 Increasing the carbon content:

a. decreases the likelihood of cracking problems
b. increases the likelihood of cracking problems
c. has nothing to do with the likelihood of cracking problems
d. all of the above
e. none of the above

Q7-15 Which of the following generally follows quenching?

a. annealing
b. normalizing
c. quenching
d. tempering
e. stress relief

Q7-16 Which of the following can be accomplished using either thermal or mechanical techniques?

a. annealing
b. normalizing
c. quenching
d. tempering
e. stress relief

Q7-17 Which of the following results in the softest structure for steel?

a. annealing
b. normalizing
c. quenching
d. tempering
e. stress relief

Q7-18 For a steel having the following composition: 0.11 carbon, 0.65 manganese, 0.13 chromium, 0.19 nickel, 0.005 copper, and 0.07 molybdenum, what is its carbon equivalent using the following formula?

$$CE = \%C + \frac{(\%Mn)}{6} + \frac{(\%Ni)}{15} + \frac{(\%Cr)}{5} + \frac{(\%Cu)}{14} + \frac{(\%Mo)}{4}$$

a. 0.15
b. 0.23
c. 0.28
d. 0.31
e. 0.42

Q7-19 For a steel having the following composition: 0.16 carbon, 0.85 manganese, 0.25 chromium, 0.09 nickel, 0.055 copper, and 0.41 molybdenum, what is its carbon equivalent using the following formula?

$$CE = \%C + \frac{(\%Mn)}{6} + \frac{(\%Ni)}{15} + \frac{(\%Cr)}{5} + \frac{(\%Cu)}{13} + \frac{(\%Mo)}{4}$$

a. 0.23
b. 0.31
c. 0.34
d. 0.41
e. 0.46

Questions **Q7-20** through **Q7-23** refer to the Heat Input formula below:

$$\text{Heat Input (J/in.)} = \frac{\text{Amperage} \times \text{Voltage} \times 60}{\text{Travel Speed (in./min.)}}$$

Q7-20 The FCAW process is being utilized to weld a 1 in. thick structural steel member to a building column. The welding is being done with a 3/32 in. diameter self-shielded electrode with a 150° minimum preheat and interpass temperature. The welding parameters are adjusted to 30 volts, 250 amperes and 12 in./min. What is the heat input?

a. 375 J/in.
b. 37 500 J/in.
c. 375 kJ/m
d. both a and b above
e. both b and c above

Q7-21 GMAW (short circuiting) welds are produced at 18 volts, 100 amperes and 22 in./min. What is the heat input?

a. 238 J/in.
b. 7333 J/in.
c. 4909 J/in.
d. 30 J/in.
e. none of the above

Q7-22 The GMAW process is mechanized for welding 1/8 in. thick stainless steel sheets against a copper backing bar. The process is operated at 300 amperes, 28 volts and 15 in./min. What is the resulting heat input?

a. 650 kJ/in.
b. 650 000 J/in.
c. 165 000 J/in.
d. 16,500 J/in.
e. none of the above

Q7-23 The GTAW process is being used for welding 1/16 in. thick titanium using DCEN at 110 amperes, 15 volts and 6 in./min. What is the heat input?

a. 21 000 J/in.
b. 21 kJ/in.
c. 16,500 J/in.
d. both a and b above
e. both b and c above

CHAPTER 8

Destructive Testing

Contents

Chapter 8—Destructive Testing

Introduction

In Chapter 7, many of the important properties of metals were discussed in detail. Once it is recognized that these properties may be important to the suitability of a metal or a weld, it then becomes important to determine the actual values for those properties. That is, the designer would now like to assign a number to each of these important properties so that the designer could effectively design a structure using materials with the desired characteristics.

As discussed in Chapter 6, numerous tests exist that are used to determine the various mechanical and chemical properties of metals. While some of these tests provide values for more than one property, most are designed to determine the value of a specific characteristic of the metal. Therefore, it may he necessary to perform several different tests to determine all the desired information (see Figure 8.1).

It is important to understand each of these tests, the results they provide, and how to determine if the results are in compliance with specification requirements. It may also be helpful for the welding inspector to understand some of the methods used in testing, even though the inspector may not be directly involved with the actual testing.

As a group, these tests are referred to as destructive, because generally the test piece is rendered useless for service once the test has been performed. Typically the technician will destroy, or fall, the material to learn how it behaves in resisting failure. Some of these tests are also referred to as destructive tests, even though they do not ruin the part to the extent it cannot he used (e.g., hardness testing). However, that depends on the shape, size, and required surface condition of the part and its end use.

Throughout this discussion, little mention will be made about whether a specific destructive test is being used to determine a base metal or weld metal property. For the most part, this does not represent a significant change in the manner in which the test is performed. There will be occasion when testing is performed specifically to test the base or weld metal, but the mechanics of the testing operation will vary little, if at all.

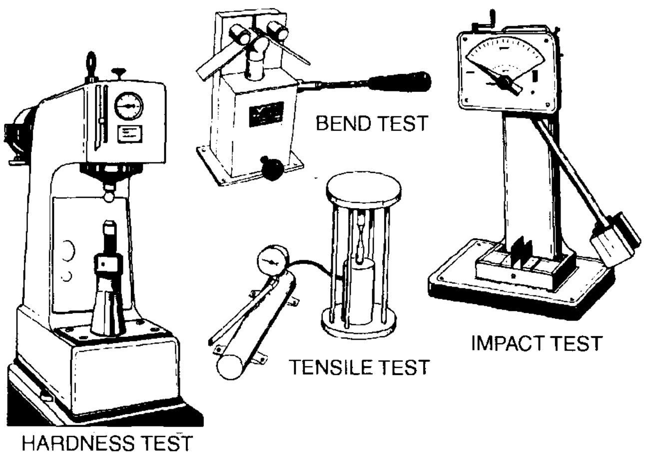


Figure 8.1—Inspectors Must Be Able to Interpret Data from a Variety of Tests

As these various methods are discussed, it is important to relate the actual test method with the appropriate material property(ies). In that way, it will be easier to understand and relate the values determined from the test with the properties that they describe.

The results of destructive testing are often indicated on *Mill Test Reports*. An inspector may be required to compare the Mill Test Report values with the applicable material specification to determine conformance. Consequently, the following discussion should enable the inspector to understand the information appearing on a typical Mill Test Report.

Tensile Testing

The first destructive test method to be discussed will be the *tensile test*. This one test provides us with a great amount of information about a metal. Some properties that can be determined as a result of tensile testing include:

- Ultimate Tensile Strength
- Yield Strength
- Ductility
- Percent Elongation
- Percent Reduction of Area

Some of these values can be determined through a direct reading of a gauge, while others can be quantified only after analysis of the stress-strain diagram that is produced during the test. The values for ductility can be found by making comparative measurements of the tensile specimen before and after testing. The percentage of that difference indicates the amount of ductility present.

> When a tensile test is performed, one of the most important aspects of that test involves the preparation of the tensile specimen. If this part of the test operation is conducted carelessly, the validity of the test results will be severely reduced. Small imperfections in the surface finish, for example, can result in significant reductions in the apparent strength and ductility of the tensile specimen.

At times, the sole purpose of the tensile test will be to determine whether the weld zone performs as well as the base metal. All that is necessary for such an evaluation is removal of a specimen (sometimes referred to as a *strap*) transverse to the longitudinal axis of the weld. The weld is roughly centered in the specimen. The two sides should be cut parallel using a saw or cutting flame, but no further surface treatment (such as removing any existing weld reinforcement) is needed.

This approach is used for procedure and welder qualification testing, in accordance with API 1104, *Standard for Welding Pipelines and Related Facilities*, which describes a successful tensile test as one that has a specimen that fails either:

(1) In the base metal, or

(2) In the weld metal (as long as it fails at some strength level above the specified base metal strength).

In most cases that require a tensile test, however, there is a need to determine the actual values for strength and other properties exhibited by that metal, not just determining whether the weld is as strong as the base metal. When the determination of these values is necessary, the specimen must he prepared in a configuration that provides a reduced section near the center of the length of the specimen.

This reduced section is intended to localize the failure. Otherwise, the failure might tend to occur preferentially near the tensile test machine grips, making the measurements for percent elongation extremely difficult. Also, this reduced section results in increased uniformity of the stresses throughout the cross section of the specimen.

To obtain valid results, the reduced section must exhibit the following three features:

(1) The entire length of the reduced section must be of a uniform cross section.

(2) The cross section should be of a configuration that can be easily measured so that a cross-sectional area can be calculated.

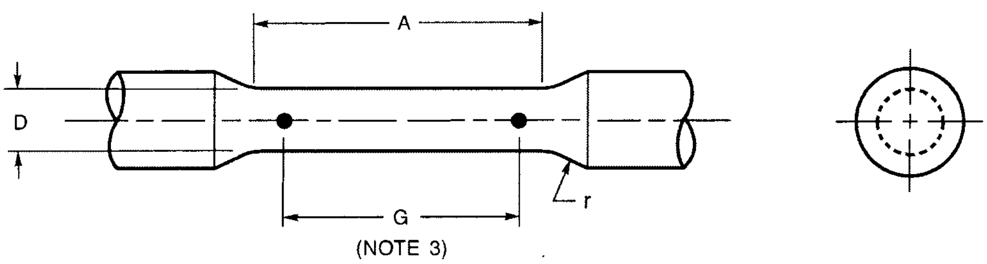
(3) The surfaces of the reduced section should be free of surface irregularities, especially if they are aligned perpendicular to the longitudinal axis of the specimen and the applied stress.

For these reasons, and considering the actual mechanics of preparing a specimen, the two most common cross-sectional configurations for tensile specimens are circular and rectangular. Both are readily prepared and measured (see Figures 8.2 and 8.3).

If required to perform a tensile test, the welding inspector may have to calculate the actual cross-sectional area of the reduced section of the tensile specimen. Examples 1 and 2 show the calculations for both common cross sections as follows:

Example 1: Area of a Circular Cross Section

Diameter (d) = 0.505 in.
Radius (r) = d/2 = 0.2525 in.
Area (A) = πr^2 or $\pi d^2 \div 4$
$A = 3.1416 (0.2525)^2$
$A = 0.2$
or
$A = 3.1416 (0.5052 \div 4)$
$A = 0.2 \text{ in.}^2$

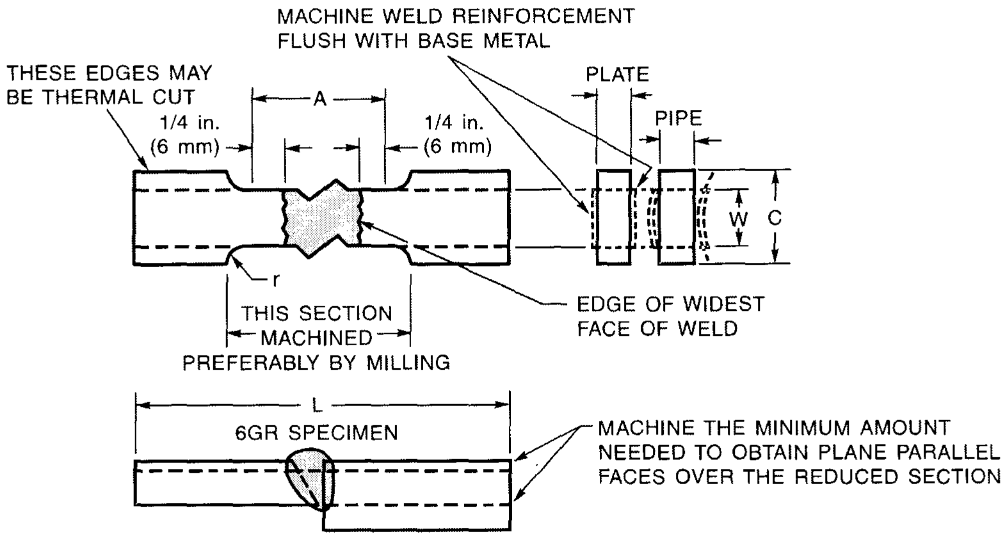


Dimensions in inches			
	Standard Specimen	Small-Size Specimens Proportional to Standard	
Nominal Diameter	0.500 in. Round	0.350 in. Round	0.250 in. Round
G—Gage length	2.000 ± 0.005	1.400 ± 0.005	1.000 ± 0.005
D—Diameter (Note 1)	0.500 ± 0.010	0.350 ± 0.007	0.250 ± 0.005
r—Radius of fillet, min	3/8	1/4	3/16
A—Length of reduced section (Note 2), min	2-1/4	1-3/4	1-1/4

Dimensions (metric version per ASTM E 8M)			
	Standard Specimen	Small-Size Specimens Proportional to Standard	
Nominal Diameter	12.5 mm Round	9 mm Round	6 mm Round
G—Gage length	62.5 ± 0.1	45.0 ± 0.1	30.0 ± 0.1
D—Diameter (Note 1), mm	12.5 ± 0.2	9.0 ± 0.1	6.0 ± 0.1
r—Radius of fillet, mm, min	10	8	6
A—Length of reduced section, mm (Note 2), min	75	54	36

Notes:
1. The reduced section may have a gradual taper from the ends toward the center, with the ends not more than one percent larger in diameter than the center (controlling dimension).
2. If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference marks for the measurement of elongation should be spaced at the indicated gage length.
3. The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. If the ends are to be held in wedge grips, it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.

Figure 8.2—Round Tensile Specimens



Dimensions in inches (mm)

	Test Plate (Note 1)			Test Pipe	
	$Tp \leq 1$ in. (25 mm)	1 in. (25 mm) $< Tp <$ 1-1/2 in. (38 mm)	$Tp \geq$ 1-1/2 in. (38 mm)	2 in. (50 mm) & 3 in. (75 mm) Diameter	6 in. (150 mm) & 8 in. (200 mm) Diameter or Larger Job Size Pipe
A—Length of reduced section	Widest face of weld + 1/2 in. (12 mm), 2-1/4 in. (60 mm) min			Widest face of weld + 1/2 in. (12 mm), 2-1/4 in. (60 mm) min	
L—Overall length, min (Note 2)	As required by testing equipment			As required by testing equipment	
W—Width of reduced section (Notes 3, 4)	3/4 in. (20 mm) min	3/4 in. (20 mm) min	3/4 in.(20 mm) min	1/2 ± 0.01 (12 ± 0.025)	3/4 in. (20 mm) min
C—Width of grip section (Notes 4, 5)	W + 1/2 in. (12 mm) min	W + 1/2 in. (12 mm) min	W + 1/2 in. (12 mm) min	W + 1/2 in. (12 mm) min	W + 1/2 in. (12 mm) min
t—Specimen thickness (Notes 6, 7)	Tp	Tp	Tp/n (Note 7)	Maximum possible with plane parallel faces within length A	
r—Radius of fillet, min	1/2 in. (12 mm)	1/2 in. (12 mm)	1/2 in. (12 mm)	1 in. (25 mm)	1 in. (25 mm)

Notes:
1. Tp = Nominal Thickness of the Plate.
2. It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.
3. The ends of the reduced section shall not differ in width by more than 0.004 in. (0.102 mm). Also, there may be a gradual decrease in width from the ends to the center, but the width of either end shall not be more than 0.015 in. (.381 mm) larger than the width at the center.
4. Narrower widths (W and C) may be used when necessary. In such cases, the width of the reduced section should be as large as the width of the material being tested permits. If the width of the material is less than W, the sides may be parallel throughout the length of the specimen.
5. For standard plate-type specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 1/4 in. (6 mm).
6. The dimension t is the thickness of the specimen as provided for in the applicable material specifications. The minimum nominal thickness of 1-1/2 in. (38 mm) wide specimens shall be 3/16 in. (5 mm) except as permitted by the product specification.
7. For plates over 1-1/2 in. (38 mm) thick, specimens may be cut into approximately equal strips. Each strip shall be at least 3/4 in. (20 mm) thick. The test results of each strip shall meet the minimum requirements.
8. Due to limited capacity of some tensile testing machines, the specimen dimensions for Annex M steels may be as agreed upon by the Engineer and the Fabricator.

Figure 8.3—Transverse Rectangular Tension Test Specimen (Plate)

Example 2: Area of Rectangular Cross Section

Width (w) = 1.5 in.
Thickness (t) = 0.5 in.
Area (A) = w × t
Area (A) = 1.5 × 0.5
Area (A) = 0.75 in.^{2}

Calculating the cross-sectional area before testing is critical, because that value will be used to determine the strength of the metal. The strength will be calculated by dividing the applied load by the original cross-sectional area. Example 3 shows the calculation for a standard circular cross section specimen as follows:

Example 3: Calculation of Tensile Strength

Load = 12 500 lb
Area = 0.2 in.^{2} (see Example 1)
Tensile Strength = Load/Area
Tensile Strength = 12 500/0.2
Tensile Strength = 62 500 psi (lb/in.^{2})

Example 3 shows a typical tensile strength calculation for a standard circular specimen. This standard specimen yields an area of 0.2 in, which is convenient because dividing some number by 0.2 is the same as multiplying that number by 5. Therefore, if this standard tensile specimen is used, the calculation for tensile strength can be performed as shown in Example 4.

Example 4: Alternate Tensile Strength Calculation

Load = 12 500 pounds
Area = 0.2 in.^{2}
Tensile Strength = 12 500 × 5
Tensile Strength = 62 500 psi (lb/in.^{2})

As can be seen, the result of this calculation is identical to that of Example 3. The use of a standard size tensile specimen was very popular years ago, before the arrival of modern calculators. At that time, it appeared easier to machine a tensile specimen to exact size, than to determine the strength arithmetically by dividing the load by some complicated number. However, today we can easily calculate the exact tensile strength—no matter what the actual area happens to be.

Another operation that must be performed before testing is marking a gauge length on the reduced section. This gauge length is normally marked using a pair of center punch marks spaced at some prescribed distance apart. The most common gauge lengths are 1 in. and 2 in. After testing, the new measurement is compared to the original distance between the marks to determine the amount of elongation, or stretch, exhibited by that specimen when stressed.

Once properly measured and marked, the specimen is placed securely in the appropriate grips of both the stationary and moving heads of the tensile machine.

Once in place, the tensile load is then applied at some steady rate. Differences in this rate of loading can result in testing inconsistencies. Before this load application, a device known as an *extensometer* is connected to the specimen at the gauge length marks. During the application of the load, the extensometer will measure the amount of elongation that results from a certain load. Load and elongation data are fed into a strip chart recorder, which results in a plot of the variation in the elongation as a function of the applied load. This result is referred to as a *load vs. deflection curve*. However, tensile test results are normally expressed in terms of stress and strain.

Stress is equivalent to strength, because it is the applied load at any time divided by the cross-sectional area. The strain is the amount of stretch apparent in a given length. Stress is expressed in terms of psi (lb/in.^{2}), while strain is expressed as in./in.

When these values are plotted from the test data, the result is referred to as a *stress-strain diagram*. There are several important features of the stress-strain diagram that should be discussed. The test begins with the stress and strain both equal to zero. As the load is applied, the amount of strain increases linearly with stress and shows what is referred to as *elastic behavior*, where the stress and strain are proportional. For any given material, the slope of this line is some known value. This slope is referred to as the *modulus of elasticity*.

For steel, the modulus of elasticity (when obtained in compression or tension it is *Young's modulus*) is approximately equal to 30 000 000 psi, as compared to 10 500 000 psi for aluminum. This number indicates the stiffness of the metal; that is, the higher the modulus of elasticity, the stiffer the metal.

Eventually, the strain will increase faster than the stress, meaning that the metal is stretching more for a given amount of applied stress. This change marks the end of elastic behavior and the onset of plastic or permanent deformation. The point on the curve showing the extent of the linear behavior is referred to as the *elastic*, or *proportional limit*. If the load were removed at any time up to this point, the specimen would return to its original length.

Many metals tend to exhibit a drastic departure from the initial elastic behavior. With these metals, the stress and strain are no longer proportional; in fact, the stress may drop or remain steady while the strain increases. This phenomenon is characteristic of yielding in ductile steel. The stress increases to some maximum limit and then drops to some lower limit.

These limits are referred to as the *upper and lower yield points*. The upper yield point is that stress at which there is a noticeable increase in strain, or plastic flow, without an increase in stress. The stress then drops and remains relatively constant at the lower yield point, while the strain continues to increase during what is referred to as the *yield point elongation* (see Figure 8.4).

In a metal that exhibits this behavior, the yield strength is described as "the stress corresponding to the upper yield point or some point midway between the upper and lower yield points." During the tensile test, the yield point can be seen as a drop in the gauge or recording device. The yield strength can therefore be determined by simply observing and noting this load reduction. When this method is utilized, it is referred to as the *"drop-of-beam" technique*.

During this yielding phenomenon, the plastic flow of the metal increases at such a rate that stresses are being relieved faster than they are formed. When this plastic flow occurs at room temperature, it is referred to as *cold working*. Because this action causes the metal to become stronger and harder, it is referred to as *work hardened*. The yielding will therefore continue until the metal becomes work hardened, to the extent that it now requires additional stress to produce any further elongation. Corresponding to this, the curve begins to climb in a nonlinear fashion.

The stress and strain continue to increase at varying rates, until some maximum stress is reached. This point is referred to as the *maximum stress*, or *ultimate tensile strength*.

When the offset method is used, a line is drawn parallel to the modulus of elasticity at some prescribed amount of strain. The amount of strain is usually described in terms of some percentage. The most common offset is 0.02%, of the strain; however, other amounts may also be specified. The stress corresponding to the intersection of this offset line with the stress-strain curve is, therefore, the yield stress. To identify how it was determined, the yield stress should be reported as a 0.02% offset yield stress (see Figure 8.5).

For less ductile metals, there may not be a pronounced change in behavior between elastic and plastic deformation. Therefore, the offset technique is used to determine the yield strength.

Following the actual testing, a determination of the metal's ductility is now necessary. This is done in one of two ways, both of which involve making measurements before and after testing. The two ways to express ductility are in terms of percent elongation and percent reduction of area.

To determine the percent elongation, gauge marks are placed on the specimen before pulling. After the specimen has failed, the two pieces are placed together and the new distance between the gauge marks is measured.

This information, plus the original gauge length, makes it possible to calculate the percent elongation as shown in Example 5.

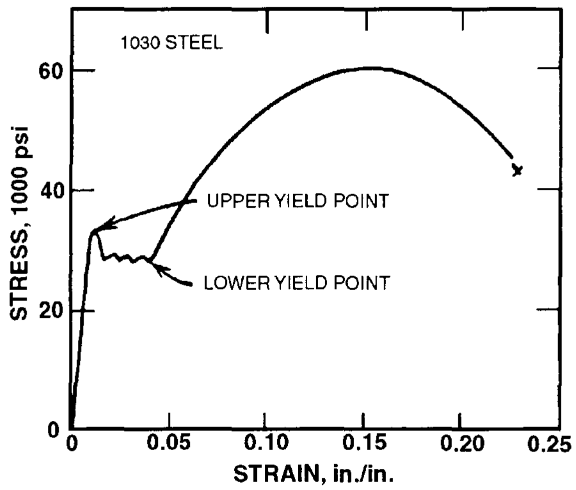


Figure 8.4—Abrupt Yielding of Yield Point in Mild Steel

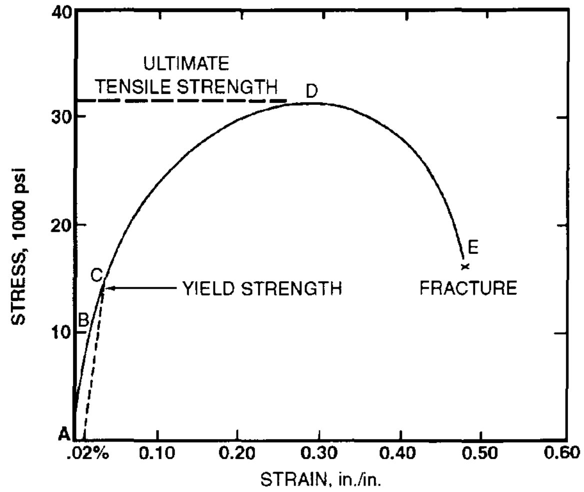


Figure 8.5—Engineering Stress-Strain Diagram for Polycrystalline Copper

Example 5: Determination of Percent Elongation

Original Length = 2.0 in.

Final Length = 2.6 in.

%Elongation = (Final Length – Original Length)/Original Length × 100

%Elongation = (2.6 – 2.0)/2.0 × 100

%Elongation = 0.6/2.0 × 100

%Elongation = 0.3 × 100

%Elongation = 30%

The metal's ductility can also be expressed in terms of how much it "necks down" during the tensile test, referred to as *percent reduction of area*, where the original and final areas of the tensile specimen are measured and compared. Example 6 shows how this calculation is performed.

Example 6: Determination of Percent Reduction of Area

Original Area = 0.2 in.^{2}

Final Area = 0.1 in.^{2}

%Reduction of Area = (Original Area – Final Area)/Original Area × 100

%Reduction of Area = (0.2 – 0.1)/0.2 × 100

%Reduction of Area = 0.1/0.2 × 100

%Reduction of Area = 0.5 × 100

%Reduction of Area = 50%

While both percent elongation and percent reduction of area represent expressions for the amount of ductility exhibited by a tensile specimen, their values will seldom, if ever, be equal. Typically, the value for percent reduction of area may be as much as twice the value for percent elongation.

Hardness Testing

Strength is described as "the ability of a material to transmit some load." Strength can be determined directly by performing a tensile test, or it can be approximated by conducting a hardness test on the material, which is permissible because the hardness and strength of many metals are directly related. Hardness testing is most often employed to provide a measurement of the metal's hardness, which is described as "the ability of a metal to resist penetration."

For the most part, hardness tests are performed using some type of penetrator that is forced against the surface of the test object. Depending upon the type of hardness test being used, either the diameter or depth of the resulting indentation is measured.

Hardness is one of the most measurable features of a metal, which is primarily due to the vast variety of methods that can be used to determine a metal's hardness. The three most common types of hardness tests are: Brinell, Rockwell, and microhardness. In general, the three groups differ from one another in the size of indentation that is produced, with the Brinell being largest and microhardness the smallest (see Figure 8.6).

The Brinell test is commonly used for determining the hardness of metal stock (see Table 8.1). It is well suited for this purpose, because the indentation covers a relatively large area, which eliminates problems associated with localized hard or soft spots in the metal. The characteristically higher loads used for Brinell tests also help to reduce errors produced by surface irregularities.

Before Brinell testing, it is necessary to prepare the surface so that test errors will be minimized. Preparation includes grinding or sanding the surface to remove scale, rust, paint, etc., to achieve a relatively flat test area. The surface should also be of sufficient smoothness so that the size of the indentation can be accurately measured. To perform a Brinell test, a penetrator is forced into the surface of the test object at some prescribed load. Once this load is removed, the diameter of the indentation is then measured using a graduated magnifier. On the basis of the size and type of the indenter, the applied load, and the resulting diameter of the impression, a Brinell Hardness Number (BHN) can be determined. Since this is a mathematical relationship, a BHN can be determined for a variety of indenter types and loads. As previously mentioned, strength and hardness are directly related. For steels, the approximate tensile strength can be determined by multiplying the BHN times 500.

The most commonly applied Brinell test uses a 10-mm hardened steel ball and a 3000 kg load. However, some test conditions, such as specimen hardness and thickness, require variations in the type of ball and the amount of the applied load. Other types of balls that can be used include the 5-mm hardened steel ball and the 10-mm tungsten carbide ball. For soft metals, loads as low as 500 kg may be used. Other loads between 500 and 3000 kg can also be used with equivalent results.

Normally, the BHN can be determined simply by measuring the diameter of the impression and reading the value from a table that has results already calculated (see Figure 8.7).

For additional information regarding Brinell testing, please refer to ASTM E 10, *Standard Test Method for Brinell Hardness of Metallic Materials*.

Quite often, there is a need for testing objects too large to be placed in a stationary Brinell test machine. In such cases, portable test machines can be employed. Although the portable machines come in a variety of types and configurations, the basic test principles are similar to field testing procedures.

COMMERCIALLY USED HARDNESS TESTS

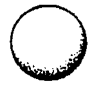
TEST	INDENTER	SHAPE OF INDENTATION
Brinell	10-mm sphere of steel or tungsten carbide	
Vickers	Diamond pyramid	
Knoop microhardness	Diamond pyramid	
Rockwell		
A, C, D	Diamond cone	
B, F, G	1/16 in. diameter steel sphere	
E	1/8 in. diameter steel sphere	

Figure 8.6—Shapes and Types of Indenters Used with Various Hardness Tests

The next hardness test to be discussed will be the Rockwell hardness test (see Table 8.2). This is a group of tests encompassing numerous variations of the same basic principle. Like the Brinell test, the basic Rockwell test can be modified by using different indenters and test loads. As mentioned, the Rockwell tests result in smaller indentations than would be expected for Brinell testing, which allows for the localized testing of relatively small areas of a metal.

Like the Brinell test, Rockwell testing uses different indenters for different hardness ranges. The indenters used are the diamond Brale tool, 1/16 in., 1/8 in., 1/4 in., and 1/2 in. diameter hardened steel balls.

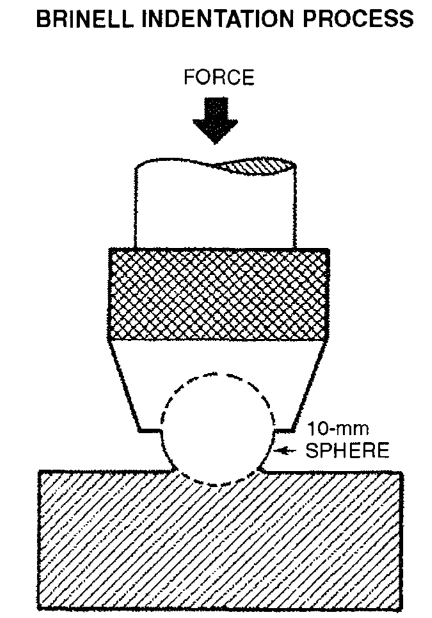
Using one or the other of these indenters, various loads can also be used. These loads are much lower than those used for Brinell testing, ranging from 60 to 150 kg.

Just as with the Brinell test, the test surface must be properly prepared before applying a Rockwell test. Once prepared, the proper scale should be selected based on the approximate range of hardness expected. The "B" and "C" scales are by far the most commonly used scales for steel, with the "B" scale chosen for softer alloys and the "C" scale used for the harder types. When in doubt as to which scale to choose for some unknown alloy, the "A" scale can be employed, because it includes a range of hardness covering both the "B" and "C" scales. Once the proper scale has been selected, the test object is placed on the anvil. The anvil can be of various shapes depending upon the configuration of the test piece. The object must be adequately and fully supported; otherwise, test errors will result. The Rockwell method relies on the accurate depth of penetration measurement of the indenter, therefore, if the test object is not properly supported, this measurement could be inaccurate. A variation in this depth measurement of only 0.00008 in. will result in a change of one Rockwell number. After the specimen has

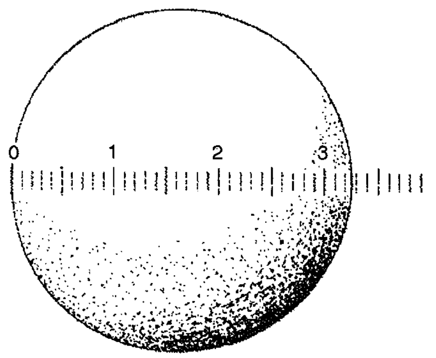
Table 8.1
Brinell Hardness Numbers

Sphere Impression Diameter* (mm)	Brinell Hardness Number (Load, kgf) 500	1000	1500	2000	2500	3000	Sphere Impression Diameter* (mm)	Brinell Hardness Number (Load, kgf) 500	1000	1500	2000	2500	3000
2.00	158	316	473	632	788	945	4.25	33.6	67.2	101	134	167	201
2.05	150	300	450	600	750	899	4.30	32.8	65.6	98.3	131	164	197
2.10	143	286	428	572	714	856	4.35	32.0	64.0	95.9	128	160	192
2.15	136	272	408	544	681	817	4.40	31.2	62.4	93.6	125	156	187
2.20	130	260	390	520	650	780	4.45	30.5	61.0	91.4	122	153	183
2.25	124	248	372	496	621	745	4.50	29.8	59.6	89.3	119	149	179
2.30	119	238	356	476	593	712	4.55	29.1	58.2	87.2	116	145	174
2.35	114	228	341	456	568	682	4.60	28.4	56.8	85.2	114	142	170
2.40	109	218	327	436	545	653	4.65	27.8	55.6	83.3	111	139	167
2.45	104	208	313	416	522	627	4.70	27.1	54.2	81.4	108	136	163
2.50	100	200	301	400	500	601	4.75	26.5	53.0	79.6	106	133	159
2.55	96.3	193	289	385	482	578	4.80	25.9	51.8	77.8	104	130	156
2.60	92.6	185	278	370	462	555	4.85	25.4	50.8	76.1	102	127	152
2.65	89.0	178	267	356	445	534	4.90	24.8	49.6	74.4	99.2	124	149
2.70	85.7	171	257	343	429	514	4.95	24.3	48.6	72.8	97.2	122	146
2.75	82.6	165	248	330	413	495	5.00	23.8	47.6	71.3	95.2	119	143
2.80	79.6	159	239	318	398	477	5.05	23.3	46.6	69.8	93.2	117	140
2.85	76.8	154	230	307	384	461	5.10	22.8	45.6	68.3	91.2	114	137
2.90	74.1	148	222	296	371	444	5.15	22.3	44.6	66.9	89.2	112	134
2.95	71.5	143	215	286	358	429	5.20	21.8	43.6	65.5	87.2	109	131
3.00	69.1	138	207	276	346	415	5.25	21.4	42.8	64.1	85.6	107	128
3.05	66.8	134	200	267	334	401	5.30	20.9	41.8	62.8	83.6	105	126
3.10	64.6	129	194	258	324	388	5.35	20.5	41.0	61.5	82.0	103	123
3.15	62.5	125	188	250	313	375	5.40	20.1	40.2	60.3	80.4	101	121
3.20	60.5	121	182	242	303	363	5.45	19.7	39.4	59.1	78.8	98.5	118
3.25	58.6	117	176	234	293	352	5.50	19.3	38.6	57.9	77.2	96.5	116
3.38	56.8	114	170	227	284	341	5.55	18.9	37.8	56.8	75.6	95.0	114
3.35	55.1	110	165	220	276	331	5.60	18.6	37.2	55.7	74.4	92.5	111
3.40	53.4	107	160	214	267	321	5.65	18.2	36.4	54.6	72.8	90.8	109
3.45	51.8	104	156	207	259	311	5.70	17.8	35.6	53.5	71.2	89.2	107
3.50	50.3	101	151	201	252	302	5.75	17.5	35.0	52.5	70.0	87.5	105
3.55	48.9	97.8	147	196	244	293	5.80	17.2	34.4	51.5	68.8	85.8	103
3.60	47.5	95.0	142	190	238	285	5.85	16.8	33.6	50.5	67.2	84.2	101
3.65	46.1	92.2	138	184	231	277	5.90	16.5	33.0	49.6	66.0	82.5	99.2
3.70	44.9	89.8	135	180	225	269	5.95	16.2	32.4	48.7	64.8	81.2	97.3
3.75	43.6	87.2	131	174	218	262	6.00	15.9	31.8	47.7	63.6	79.5	95.5
3.80	42.4	84.8	127	170	212	255	6.05	15.6	31.2	46.8	62.4	78.0	93.7
3.85	41.3	82.6	124	165	207	248	6.10	15.3	30.6	46.0	61.2	76.7	92.0
3.90	40.2	80.4	121	161	201	241	6.15	15.1	30.2	45.2	60.4	75.3	90.3
3.95	39.1	78.2	117	156	196	235	6.20	14.8	29.6	44.3	59.2	73.8	88.7
4.00	38.1	76.2	114	152	191	229	6.25	14.5	29.0	43.5	58.0	72.6	87.1
4.05	37.1	74.2	111	148	186	223	6.30	14.2	28.4	42.7	56.8	71.3	85.5
4.10	36.2	72.4	109	145	181	217	6.35	14.0	28.0	42.0	56.0	70.0	84.0
4.15	35.3	70.6	106	141	177	212	6.40	13.7	27.4	41.2	54.8	68.8	82.5
4.20	34.4	68.8	103	138	172	207	6.45	13.5	27.0	40.5	54.0	67.5	81.0

*Ball diameter = 10 mm.



(A) SCHEMATIC OF THE PRINCIPLE OF THE BRINELL INDENTATION PROCESS



(B) BRINELL INDENTATION WITH MEASURING SCALE IN MILLIMETERS

Figure 8.7—Indenter Measurements

been prepared and placed in the Rockwell machine, the load is applied and the results are read directly from the dial on the machine. For further information regarding the Rockwell tests, refer to ASTM E 18, *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials* (see Figure 8.8).

As with Brinell testing, there are also portable devices that can be used to determine the Rockwell hardness of a metal. Although their operation may vary slightly from that of the stationary models, the results will be equivalent.

The next group of hardness tests to be discussed are referred to as *microhardness tests*, because their impressions are so small that high magnification is required to facilitate their measurement. Microhardness testing is very beneficial in the investigation of metal microstructures, because these hardness tests can be performed on single grains of a metal to determine the hardness in that microscopic region. Therefore, the metallurgist is primarily interested in this type of hardness testing.

There are two major types of microhardness tests: Vickers and Knoop. Both use diamond indenters, however, their configurations are slightly different. The square-based Vickers indenter provides an indentation in which the two diagonals are approximately equal. The Knoop indenter, however, makes an indentation having a long and a short dimension.

As with the other test methods, the tester has a selection of test loads as well as indenter types. The term microhardness implies that the applied loads will range from 1 to 1000 g. However, the majority of microhardness tests use loads in the range of 100 to 500 g.

To perform either Vickers or Knoop microhardness testing, the preparation of the surface is of utmost importance. Because the surface area is quite minute, even the smallest irregularity can cause inaccuracies. Normally, preparation of the surface for microhardness testing is identical to that for other metallographic investigations. The importance of this surface finish increases as the applied test load is reduced.

Once prepared, the specimen is securely clamped in a test fixture or holder so that the indentations can be accurately placed. Many microhardness machines employ some type of moving stage that facilitates accurate movement of the specimen without the need for its removal and adjustment. Such a device is convenient when taking a number of readings across some region of the metal. An example of this type of application is the determination of the hardness variation across the weld heat-affected zone. The result is referred to as a *microhardness traverse* (see Figure 8.9).

Hardness testing provides a great deal of useful information about a metal. However, as discussed in the preceding section, the hardness method to be used for a given application must be specified, or the desired results may not be obtained.

Toughness Testing

Toughness is the property that describes a metal's ability to absorb energy. It is important to know how a material absorbs energy when a load is applied very rapidly as in an impact, especially when there is a notch present on the surface. Both the rapid loading and the presence of a notch will cause the metal's behavior to change drastically, compared to how it might behave

Table 8.2
Rockwell Standard Hardness

Scale Symbol	Indenter	Major Load (kgf)	Typical Applications
A	Diamond (two scales—carbide and steel)	60	Cemented carbides, thin steel, and shallow case-hardened steel
B	1/16-in. (1.588-mm) ball	100	Copper alloys, soft steels, aluminum alloys, malleable iron
C	Diamond	150	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case-hardened steel, and other materials harder than HRB 100
D	Diamond	100	Thin steel and medium case-hardened steel and pearlitic malleable iron
E	1/8-in. (3.175-mm) ball	100	Cast iron, aluminum and magnesium alloys, bearing metals
F	1/16-in. (1.588-mm) ball	60	Annealed copper alloys, thin soft sheet metals
G	1/16-in. (1.588-mm) ball	150	Phosphor bronze, beryllium copper, malleable irons. Upper limit HRG 92 to avoid possible flattening of ball
H	1/8-in. (3.175-mm) ball	60	Aluminum, zinc, lead
K	1/8-in. (3.175-mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
L	1/4-in. (6.350-mm) ball	60	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
M	1/4-in. (6.350-mm) ball	100	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
P	1/4-in. (6.350-mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
R	1/2-in. (12.70-mm) ball	60	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
S	1/2-in. (12.70-mm) ball	100	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
V	1/2-in. (12.70-mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.

Although a diamond indenter is illustrated, the same principle applies for steel ball indenters and other loads.

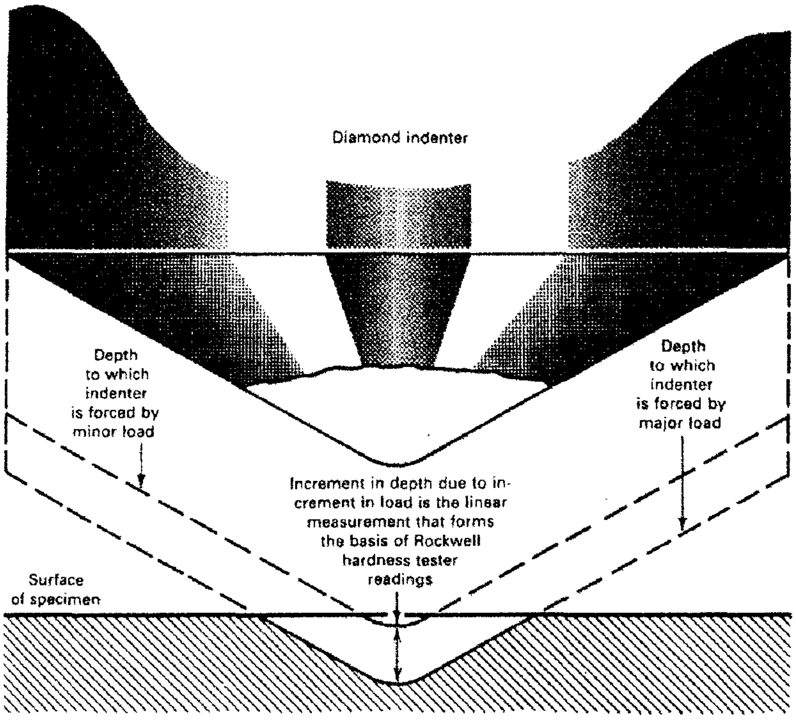
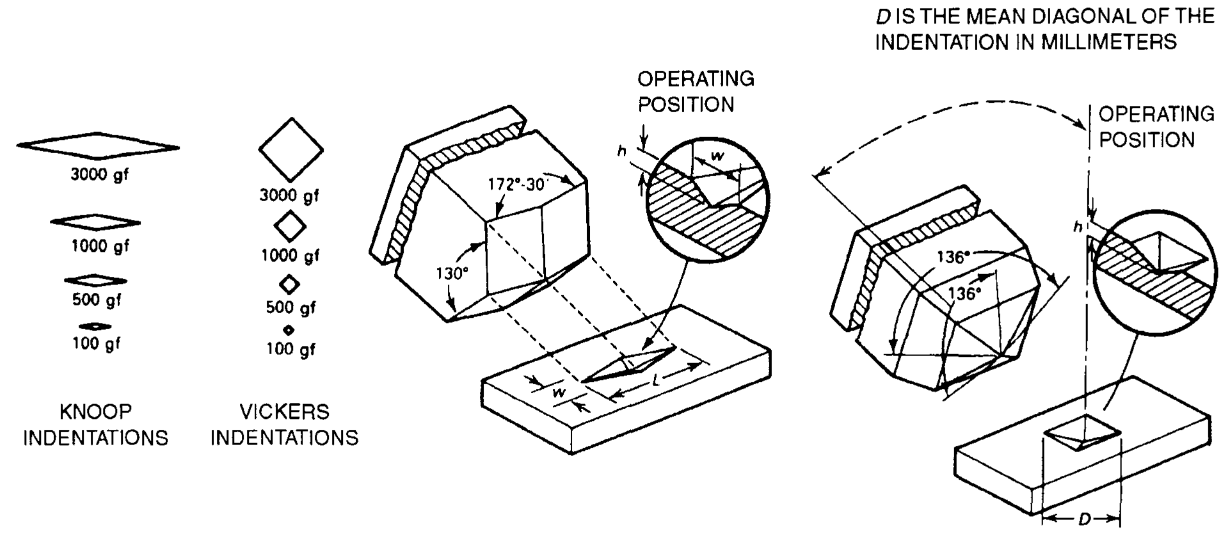


Figure 8.8—Principle of the Rockwell Test



(A) INDENTATIONS MADE BY KNOOP AND VICKERS INDENTERS IN THE SAME WORK METAL AT THE SAME LOAD

(B) PYRAMIDAL KNOOP INDENTER AND RESULTING INDENTATION IN THE WORKPIECE

(C) DIAMOND PYRAMID INDENTER USED FOR THE VICKERS TEST AND RESULTING INDENTATION IN THE WORKPIECE

Figure 8.9—Knoop and Vickers Microhardness Testing

under loading conditions similar to those present in a tensile test.

Therefore, when the load is applied rapidly, the property to be determined is referred to as *notch toughness*, or *impact strength*. The various tests used to determine the notch toughness of a metal will usually use a specimen containing some type of machined notch and the load will be applied in a very rapid manner. Another important factor in impact testing is test temperature. Because the temperature of the specimen has a drastic effect on the test results, impact testing must be performed at some prescribed temperature.

Since the advent of interest in the notch toughness of metals, numerous different tests have been developed to measure this property. When discussing the energy absorption capabilities of a metal, it must be understood that the metal absorbs energy in steps. First, there is a certain amount of energy required to initiate a crack. Then, some additional energy is required to cause that crack to grow, or propagate.

Some of the notch toughness tests can measure the energy of propagation separately from the energy of initiation. Other methods simply provide us with a measure of the combined energy of initiation and propagation. The engineer should specify the test method that will provide the desired information.

Although numerous types of notch toughness tests exist, the most commonly used in this country is the Charpy V-Notch test. The standard specimen used for this test is a bar that measures 55 mm long and 10 mm by 10 mm square. One of the long sides of the specimen has a carefully machined V-shaped notch 2 mm deep. The base of this notch is radiused to precisely 0.25 mm. The machining of this radius is extremely critical, because tiny inconsistencies will result in drastic variations in test results (see Figure 8.10).

Once the specimen has been carefully machined, it is then cooled to the prescribed test temperature, if it is a temperature below room temperature. This can be accomplished using either a liquid or gaseous medium. After the specimen is stabilized at the required temperature, it is then removed from the low-temperature bath and quickly placed in the anvil of the testing machine.

The Charpy testing machine consists of a pendulum with a striker head, an anvil, a release level, and a pointer and scale. Since the goal is to measure the amount of energy that is absorbed during the fracturing of a specimen, a given amount of energy is supplied by raising the pendulum to a specified height. Upon release, the pendulum will fall and continue through its stroke until it reaches a maximum height on the opposite side of its travel (see Figure 8.11).

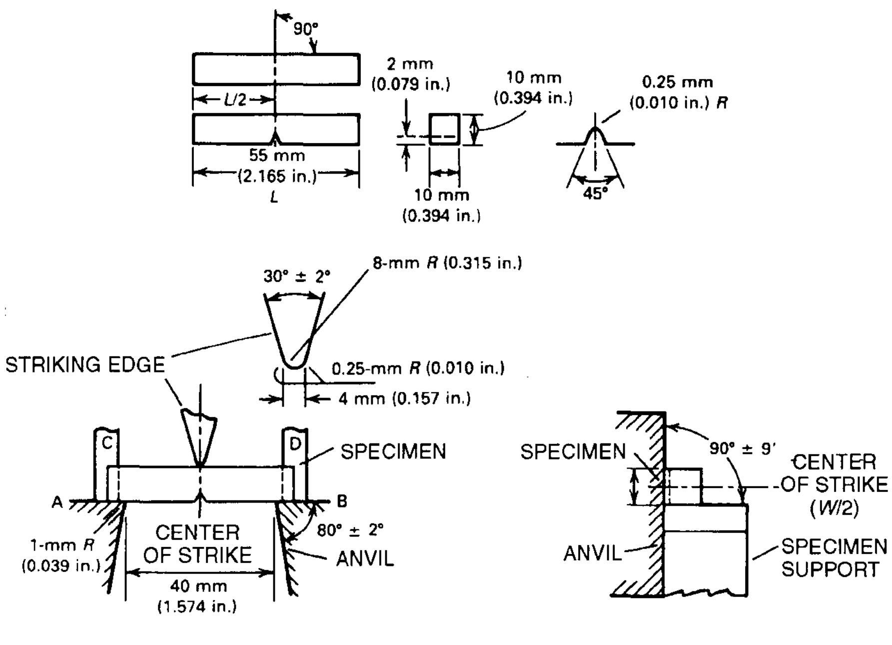


Figure 8.10—ASTM Standard Dimensions for the Type A Charpy V-Notch Specimen and the Striker-Anvil Arrangements

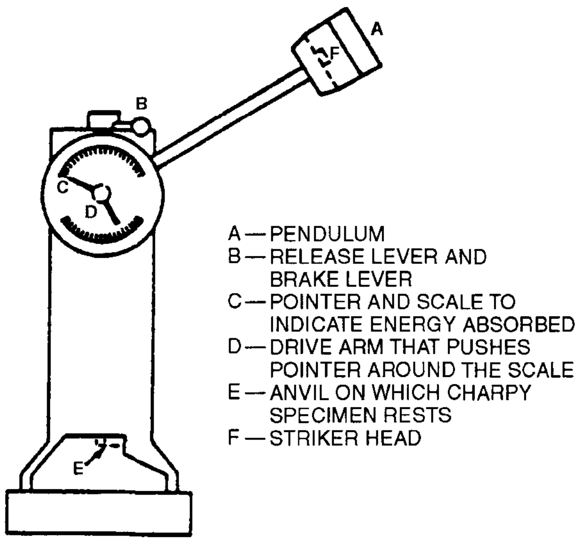


Figure 8.11—Schematic of Typical Charpy Testing Machine

If it meets no resistance, the pendulum will rise to a height that is designated as zero energy absorption. When it contacts the Charpy specimen, there is a certain amount of energy required to initiate and propagate a fracture. This causes the pendulum to rise to a level below that for zero energy absorption. The maximum height of this swing is indicated by the pointer on the scale. Since this scale is calibrated, the amount of energy required to break the specimen can be read directly from the scale.

This value, referred to as *breaking energy,* is the primary information gained from the Charpy impact test. This energy is expressed in terms of foot-pounds of energy. While most Charpy results are expressed in terms of foot-pounds of energy absorption, there are other means of describing the notch toughness of a metal that are determined by measuring various features of the failed Charpy specimen. These values are *lateral expansion* and *percent shear.* Lateral expansion, which is measured in terms of mils, or thousandths of an inch, is the amount of lateral deformation produced during the fracturing of the specimen. Percent shear is the amount of the fracture surface that failed in a ductile, or shearing fashion. No matter which method of measurement is employed, the results are taken from a series of tests. Values change with temperature, therefore, once a number of specimens has been tested at various temperatures, it is possible to determine how the values change with metal temperature. If these values are plotted versus temperature, the result will be a curve having upper and lower horizontal shelves. For each category, there is a temperature at which the values drop abruptly. These temperatures are referred to as *transition temperatures,* because the behavior of the metal changes from ductile to brittle at that temperature. The designer then knows that the metal should behave satisfactorily above that temperature (see Figure 8.12).

In addition to the Charpy test, other tests that can be used to measure a metal's notch toughness include drop-weight nil-ductility, explosion bulge, dynamic tear, and crack tip opening displacement (CTOD). These tests employ different methods for applying the load to the specimen.

Soundness Testing

These groups of tests are designed to aid in the determination of the metal's soundness, or freedom from imperfections. Soundness tests are routinely used for the qualification of welding procedures and welders. After a test plate has been welded, specimens are removed and then subjected to a soundness test to determine if the weld contained any imperfections or defects.

> There are three general types of soundness tests: bend, nick-break, and fillet weld break. Because bend testing can be performed in a number of different ways, it is probably the most common test used to judge the adequacy of a welder's qualification test coupon.

There are several different types of bend tests, depending on the orientation of the weld with respect to the bending action. There are three types of transverse weld bend specimens: face, root and side bends. With these three types, the weld is aligned across the longitudinal axis of the specimen and its name refers to the side of the weld that is placed in tension during the test. That is, the face of the weld is stretched in a face bend, the root of the weld is stretched in a root bend, and the side of a cross section of the weld is stretched in a side bend (see Figure 8.13).

Bend tests are normally performed using some type of test bend jig, or fixture. There are three basic types: guided bend, roller-equipped guided bend, and wrap-around guided bend. The standard guided bend test fixture consists of a plunger (also referred to as *mandrel* or *ram*) and a matching die that forms the previously straight bend specimen into a U shape (see Figure 8.14).

To perform a bend test, the specimen is placed across the shoulders of the die with the side to be placed in tension facing down toward the inside of the die. The

SEMIKILLED STEEL, 0.18%C, 0.54% MN, 0.07% SI

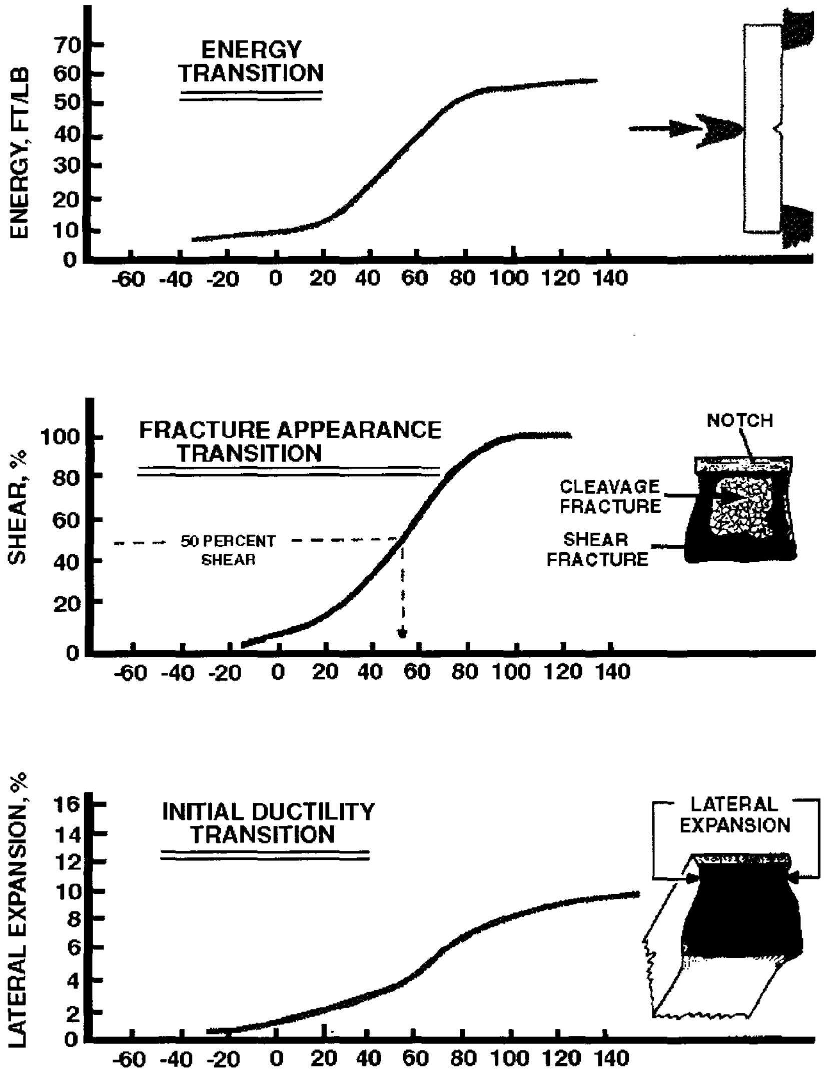
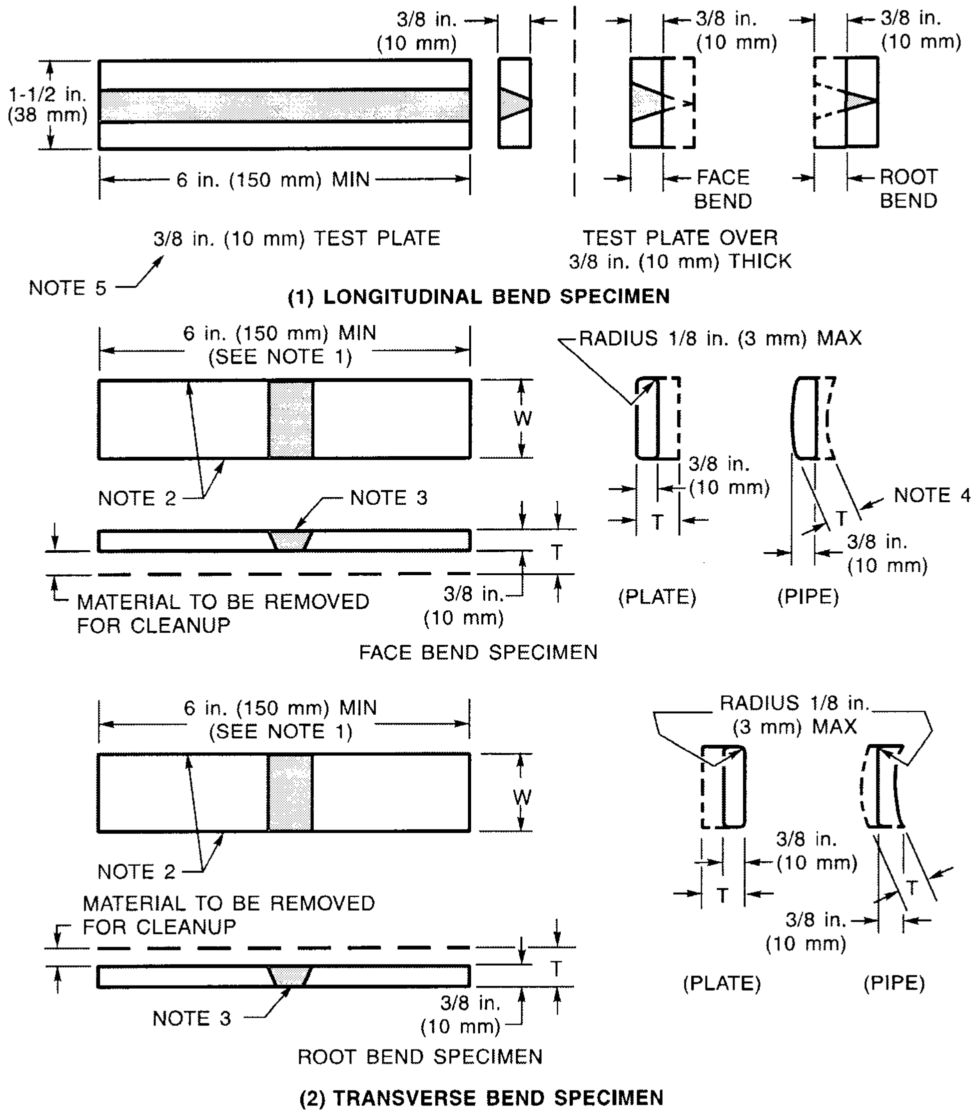


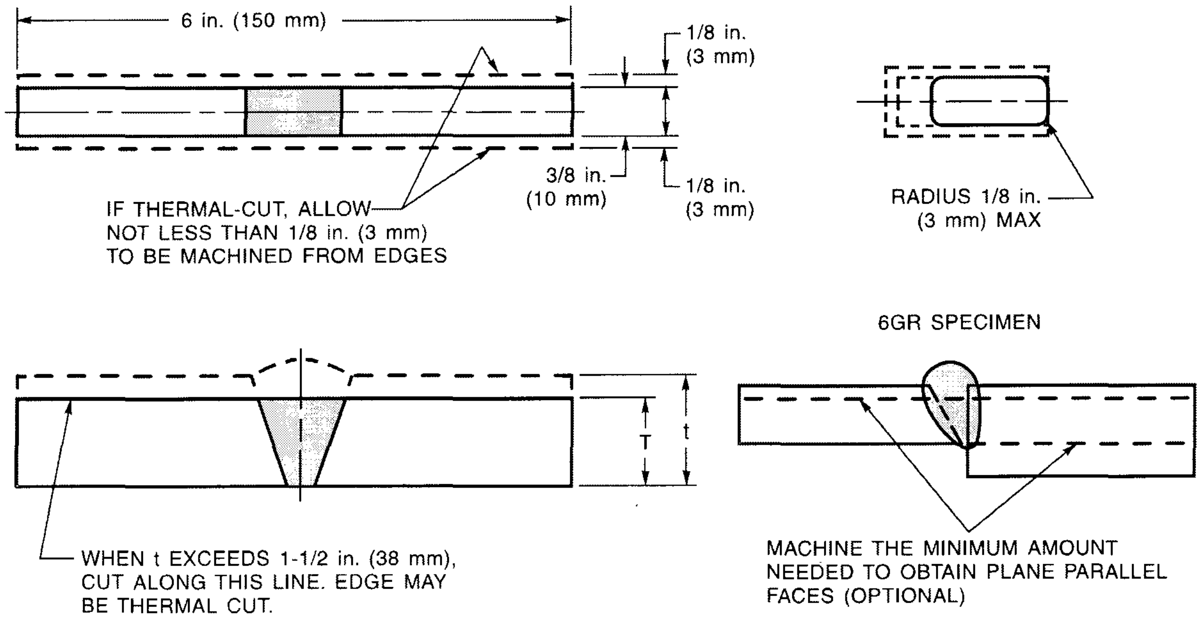
Figure 8.12—Relation Between Energy Transition and Fracture Appearance Transition in Charpy V-Notch Impact Specimens with Changes in Temperature



Dimensions	
Test Weldment	Test Specimen Width, W in. (mm)
Plate	1-1/2 (40)
Test pipe or tube ≤ 4 in. (100 mm) in diameter	1 (25)
Test pipe or tube > 4 in. (100 mm) in diameter	1-1/2 (40)

Notes:
1. A longer specimen length may be necessary when using a wraparound type bending fixture or when testing steel with a yield strength of 90 ksi (620 MPa) or more.
2. These edges may be thermal-cut and may or may not be machined.
3. The weld reinforcement and backing, if any, shall be removed flush with the surface of the specimen (see 5.24.4.1 and 5.24.4.2). If a recessed backing is used, this surface may be machined to a depth not exceeding the depth of the recess to remove the backing; in such a case, the thickness of the finished specimen shall be that specified above. Cut surfaces shall be smooth and parallel.
4. T = plate or pipe thickness.
5. When the thickness of the test plate is less than 3/8 in. (10 mm), use the nominal thickness for face and root bends.

Figure 8.13A—Face and Root Bend Specimens



t, in. (See Note 3)	T, in.
3/8 to 1-1/2	t
> 1-1/2	See Note 2

t, mm	T, mm
10 to 38	t
> 38	See Note 2

Notes:
1. A longer specimen length may be necessary when using a wraparound-type bending fixture or when testing steel with a yield strength of 90 ksi (620 MPa) or more.
2. For plates over 1-1/2 in. (38 mm) thick, cut the specimen into approximately equal strips with T between 3/4 in. (20 mm) and 1-1/2 in. (38 mm) and test each strip.
3. t = plate or pipe thickness.

Figure 8.13B—Side Bend Specimens

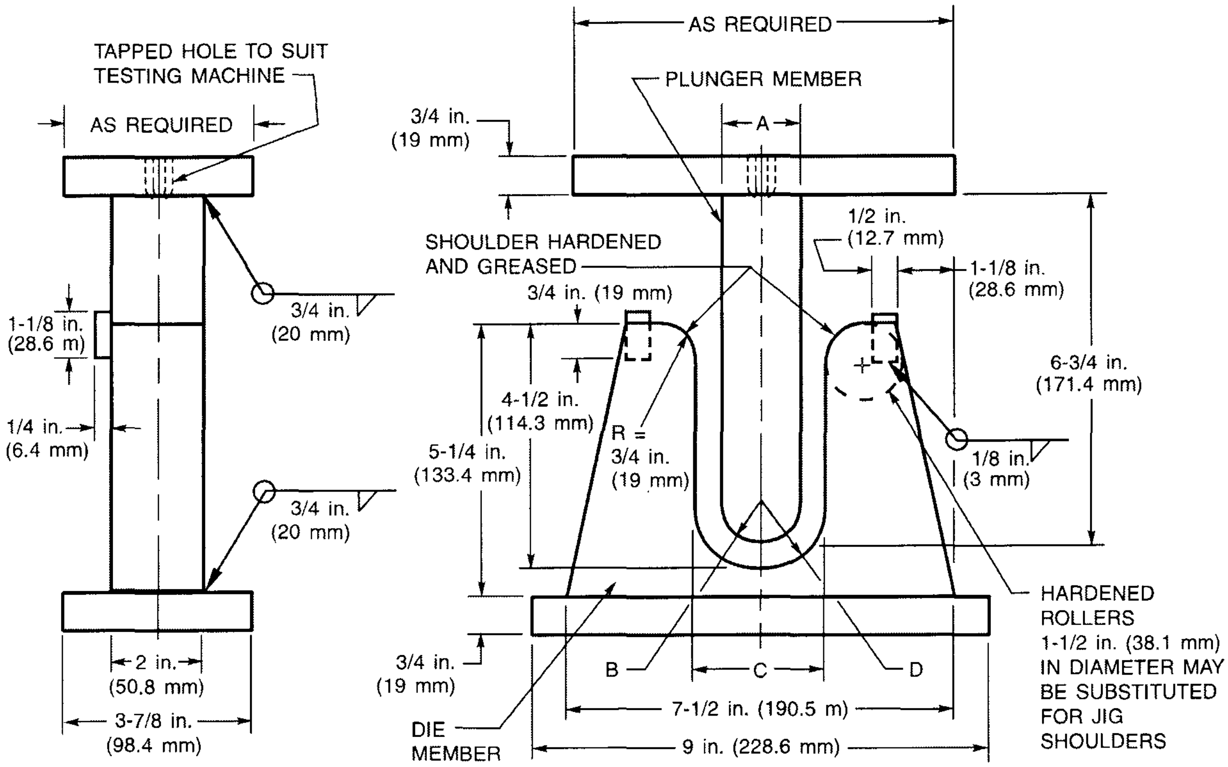
plunger is then situated over the surface area and forced toward the die causing the specimen to be bent 180° and become U shaped. The specimen is then removed and evaluated.

The second type of guided bend test fixture is similar to the standard guided bend fixture, except it is equipped with rollers instead of hardened shoulders on the die portion. This reduces the friction against the specimen, allowing for lower loads to achieve the bending.

The last common type of guided bend test fixture is referred to as the *wraparound jig*, because the specimen is bent by being wrapped around a stationary pin. This type is useful for bending specimens that have different strengths of base and weld metal. If there is a great imbalance, there will be a tendency to bend preferentially in the weaker metal, resulting in a kink or a bend away from the area of intersection.

Not all bend specimens use the same bending diameters. The diameter around which a steel bend test is bent is a function of the type of material and its yield strength. The higher the yield strength of the metal the greater the radius required to bend the specimen. Bending diameters for aluminum also vary greatly. Check the code or specification to ensure that the correct diameter is used.

With any of the bend tests, the specimens must be carefully prepared to prevent test inaccuracies. Any grinding or sanding marks on the tension surface should run parallel to the direction of bending to prevent stress raisers that could cause the specimen to fail prematurely. The corners of the specimen should also be radiused to



Specified or Actual Base Metal Yield Strength	A in. (mm)	B in. (mm)	C in. (mm)	D in. (mm)
50 ksi (345 MPa) & under	1-1/2 (38.1)	3/4 (19.0)	2-3/8 (60.3)	1-3/16 (30.2)
over 50 ksi (345 MPa) to 90 ksi (620 MPa)	2 (50.8)	1 (25.4)	2-7/8 (73.0)	1-7/16 (36.6)
90 ksi (620 MPa) & over	2-1/2 (63.5)	1-1/4 (31.8)	3-3/8 (85.7)	1-11/16 (42.9)

Note: Plunger and interior die surfaces shall be machine-finished.

Figure 8.14A—Guided Bend Test Jig

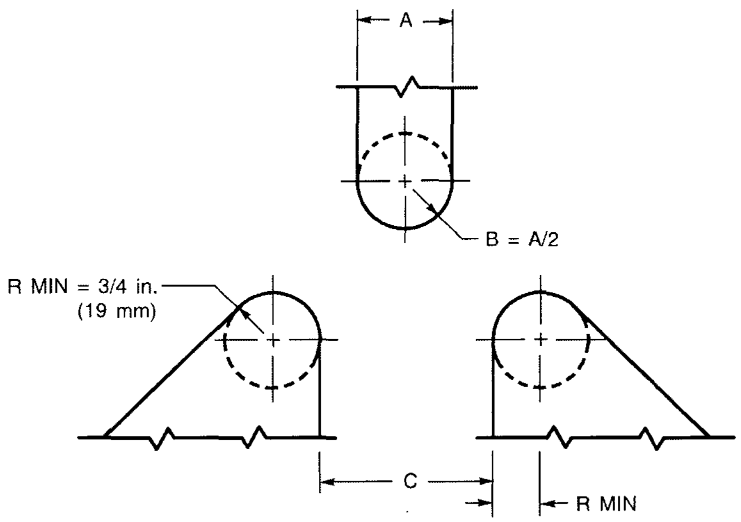
relieve that stress concentration. For specimens removed from pipe coupons, the side of the bend specimen against the ram may need to be ground flat to eliminate the bend in the direction transverse to the bending direction.

The acceptability of bend test specimens is normally based on the size and/or number of defects that appear on the tension surface. The governing code or specification will dictate the exact acceptance/rejection criteria.

The next type of soundness test to be discussed is the nick-break test. This test is used almost exclusively by the pipeline industry as described in API 1104. This method judges soundness by fracturing the specimen through the weld so that the fracture surface can be analyzed for the presence of discontinuities. The fracture is localized in the weld zone with saw cuts along two or three surfaces.

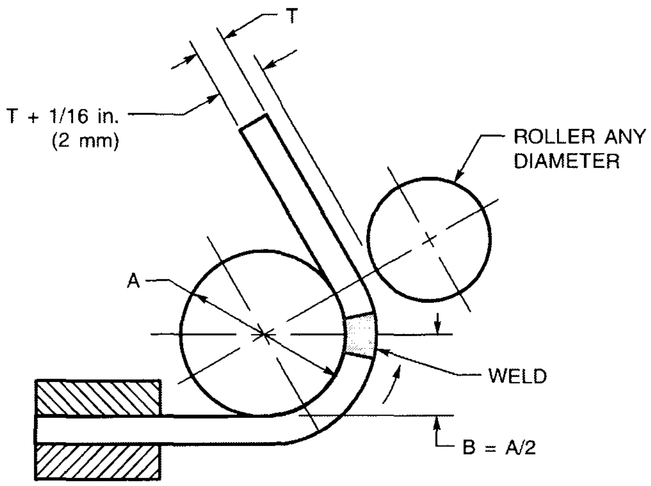
Once the specimen has been saw cut, it is then broken by pulling in a tensile machine, striking the center with a hammer while supporting the ends, or striking one end with a hammer while the other end is held in a vise. It is neither the method of breaking nor the effort required to fail the specimen that is significant. The sole purpose of this test is to fail the specimen through the weld zone so it can be determined if any imperfections are present. The fracture surface is then examined for evidence of any areas of slag inclusions, porosity or incomplete fusion. If present, the imperfections are measured and accepted or rejected, based on the code limitations (see Figure 8.15).

The last soundness test to be discussed here is the *fillet weld break test.* Like the other two types, this soundness test is used primarily in the qualification of welders.



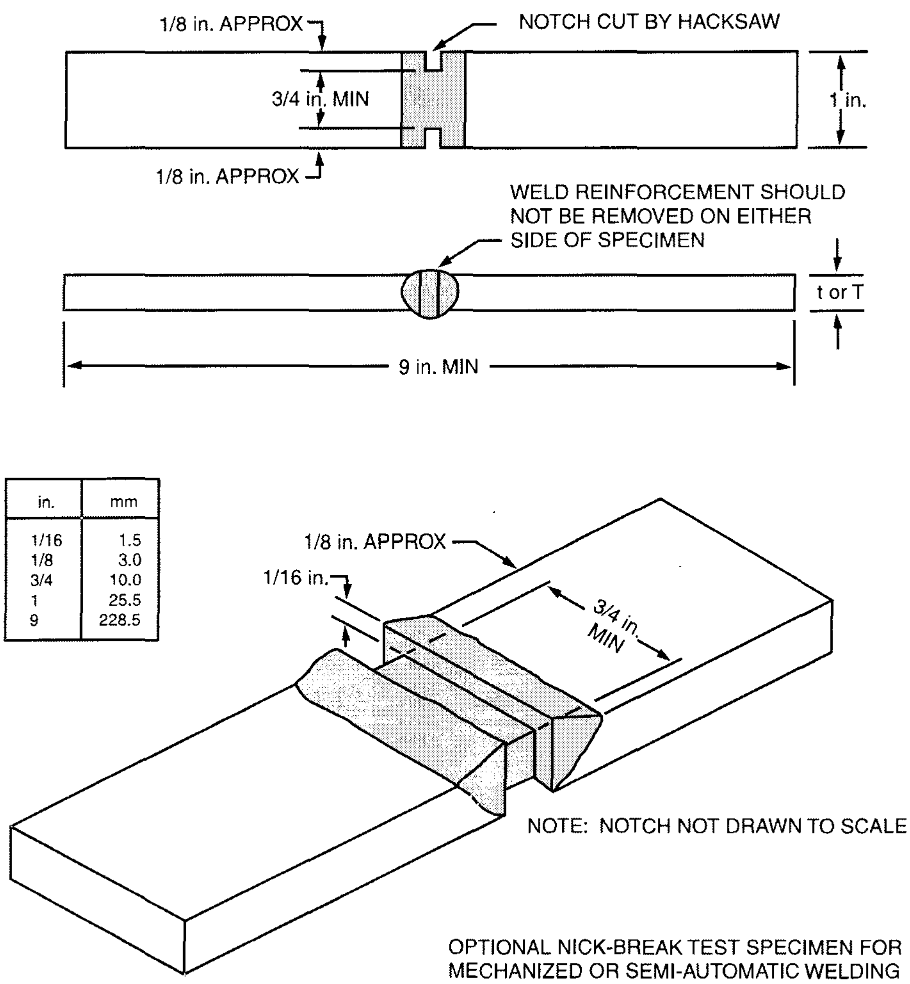
Specified or Actual Base Metal Yield Strength, ksi (MPa)	A in.	B in.	C in.	A mm	B mm	C mm
50 (345) & under	1-1/2	3/4	2-3/8	38.1	19.0	60.3
over 50 (345) to 90 (620)	2	1	2-7/8	50.8	25.4	73.0
90 (620) & over	2-1/2	1-1/4	3-3/8	63.5	31.8	85.7

Figure 8.14B—Alternative Roller-Equipped Guided Bend Test Jig for Bottom Ejection of Test Specimen



Specified or Actual Base Metal Yield Strength, ksi (MPa)	A in.	B in.	A mm	B mm
50 (345) & under	1-1/2	3/4	38.1	19.0
over 50 (345) to 90 (620)	2	1	50.8	25.4
90 (620) & over	2-1/2	1-1/4	63.5	31.8

Figure 8.14C—Alternative Wraparound Guided Bend Test Bend Jig



in.	mm
1/16	1.5
1/8	3.0
3/4	10.0
1	25.5
9	228.5

Figure 8.15—Nick-Break Test Specimen

This is the only test required for the qualification of tackers in accordance with AWS D1.1, *Structural Welding Code—Steel.*

To perform this test, a welder places a fillet weld on one side of a T-joint. Once complete, the specimen is placed in a press and bent to produce a fracture at or near the weld. Again, the significance of this test is not how much load is required for failure, rather the condition of the fracture surface, with respect to the presence of discontinuities.

With this test, the inspector is looking for a weld that has a satisfactory surface appearance. The fractured surface is examined to ensure that the weld has evidence of fusion to the root and that there are no areas of incomplete fusion to the base metal or porosity larger than 3/32 in. in their greatest dimension (see Figure 8.16).

These soundness tests are used routinely in many different industries. Their application and evaluation appear to be quite straightforward. However, the welding inspector should be aware that the evaluation of these tests may not be as simple as the various codes and specifications imply. For this reason, it is important that the inspector actually spend some time performing these tests to become familiar with their performance and interpretation.

Destructive Tests for Chemical Properties

The tests that have been previously discussed are used to determine the mechanical properties of a metal. However, there is also interest in the various chemical properties of a metal. In fact, the chemical makeup of a metal determines to a great degree the mechanical properties of that metal. Therefore, it is often necessary to determine the

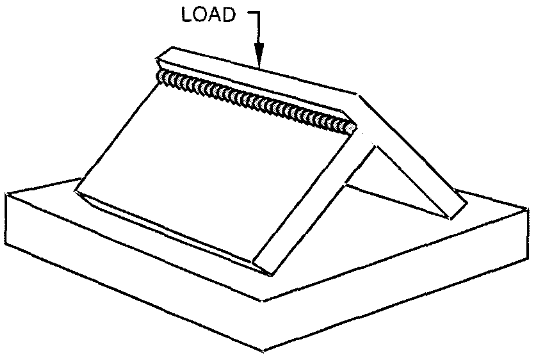


Figure 8.16—Method of Testing Fillet Weld Break Specimen

chemical composition of a metal. The three most common test methods are spectrographic, combustion, and wet chemical analysis.

The welding inspector will rarely be required to perform chemical analysis. However, it may be necessary to review the results of an analysis to determine if a metal complies with a particular specification. For more information regarding chemical analysis of metals, refer to the ASTM specifications that cover this subject. The particular methods used for steel are listed in ASTM A 751, *Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products*.

Another group of tests that can generally be classified as chemical tests are corrosion tests, which are specific tests designed to determine the corrosion resistance of a metal or combination of metals. Because losses from corrosion of metals cost industry tens of billions of dollars annually, designers are very concerned about how a metal will behave in a particular corrosive environment. The tests used to determine the degrees of corrosion resistance are designed to simulate the actual conditions that the metal will encounter during its service. Some of the considerations that must be addressed when setting up a corrosion test are chemical composition, corrosive environment, temperature, presence of moisture, presence of oxygen, presence of other metals, and amount of stress. If any of these features are ignored, the corrosion test may yield invalid results.

Metallographic Testing

Another way in which the characteristics of a metal can be determined is through the use of various metallographic tests. These tests basically consist of removing a section of a metal or a weld and polishing it to some degree. Once prepared, the specimen can then be evaluated with the unaided eye or with the use of magnification.

Metallographic testing can be classified as either macroscopic or microscopic. The tests differ in the amount of magnification that is utilized. Macro tests are generally performed using magnifications of 10X or lower. Micro tests, on the other hand, use magnifications greater than 10X.

A number of features can be observed on a typical macro specimen. The cross section of a weld can be examined to determine depth of fusion, depth of penetration, effective throat, weld soundness, degree of fusion, presence of weld discontinuities, weld configuration, number of weld passes, etc. A picture of a macro specimen is referred to as a *photomacrograph* (see Figure 8.17).

Micro tests can determine features such as microstructural constituents, presence of inclusions, presence of microscopic defects, nature of cracking, etc. Similarly, pictures of micro specimens are referred to as *photomicrographs.*

Metallographic tests can be very useful in such matters as failure analysis, weld procedure and welder qualification, and process control testing.

The two types of specimens also differ in the amount of preparation required. Some macro specimens need only be rough ground, whereas micro specimens require fine grinding and even polishing to produce a mirror finish.

Because so much information can be gained about the properties of a metal by making simple macro and micro

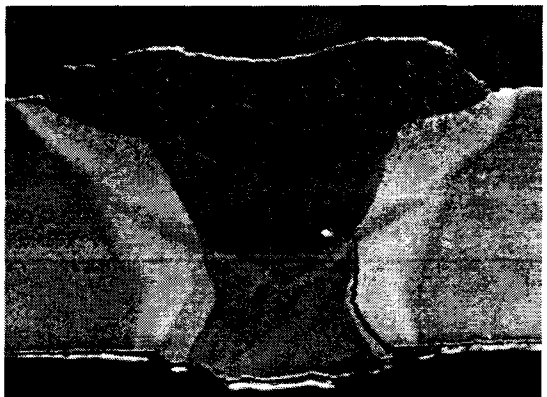


Figure 8.17—Typical Weld Photomacrograph (Crack Adjacent to the Weld)

evaluations, metallographic testing is an important tool for both the welding inspector and the engineer.

Metric Conversions

In recent years, there has been an effort to convert our U.S. customary system of measurement to an international system referred to as the *International System of Units* (in French, "Le Systeme Internationale d'Unites") or SI (see Table 8.3). The welding inspector may have occasion to inspect parts and interpret specifications containing SI units. In addition, the inspector may be asked to convert the SI units into U.S. customary units, for example, when converting temperature from Fahrenheit to Celsius (see Table 8.4). As a minimum, some of these conversions will be required on the AWS CWI examination. The following discussion is meant to provide a basis for the welding inspector to understand how these conversions are performed.

Before examining the conversion process, it is important to understand some of the notations that will be used to express different numeric values. One of the techniques used to express numbers that may be very large or very small is referred to as *scientific notation*. This method reduces some number to an expression that includes a number multiplied by some power of ten. For example, the number 234 567 would be expressed as 2.34567×10^5 in scientific notation.

Note that the same digits are used, however, the decimal place has been moved. The decimal place is always moved so that there is only one number appearing to its left. The number of spaces that the decimal place was moved becomes the power of ten in the scientific notation expression. If the decimal point was moved in the opposite direction, as would be the case for a number less than one, then the power of ten becomes a negative number. The following examples show how scientific notation is used.

Scientific Notation Examples

$234 = 2.34 \times 10^2$
$0.0234 = 2.34 \times 10^{-2}$
$5.678 \times 10^3 = 5678$
$5.67 \times 10^{-4} = 0.000567$

From this exercise, it is evident that movements of the decimal point one space is equivalent to multiplying or dividing by ten, depending on the direction in which the decimal is moved.

Another type of notation that the welding inspector should know is the various prefixes that are used to indicate powers of ten. These are simply abbreviations to reduce the number of digits required. As an example, "kilo" means 1000, so a kilometer is 1000 meters. Similarly, "milli" means one-thousandth, therefore, a millimeter is one-thousandth of a meter or there are 1000 millimeters in one meter. The following are examples of the use of these prefixes.

Examples of Prefixes for Powers of Ten

456 000 000 Pa = 456 MPa
56 km = 56 000 m
234 000 mm = 234 m
456 g = 0.456 kg

With this background, it is now possible to begin a discussion of how to actually perform numeric conversions from U.S. to SI and SI to U.S. The initial point to understand is that the welding inspector is not intended to memorize all of the conversion factors. Every factor that is needed for the AWS CWI examination will be provided. The CWI candidate must be capable of manipulating the numbers to arrive at some solution.

A listing of the more common conversion factors is provided here to illustrate how these conversion factors will be noted on the CWI examination. Tables 8.5 and 8.6 are arranged in four columns that will be used in the same order as they are listed: "Property," "To Convert From," "To," and "Multiply By."

Table 8.3
SI Prefixes

Prefix	Symbol	Exponential Expression	Multiplication Factor
exa	E	10^{18}	1 000 000 000 000 000 000
peta	P	10^{15}	1 000 000 000 000 000
tera	T	10^{12}	1 000 000 000 000
giga	G	10^{9}	1 000 000 000
mega	M	10^{6}	1 000 000
kilo	k	10^{3}	1 000
hecto*	h	10^{2}	100
deka*	da	10^{1}	10
deci*	d	10^{0}	1
centi*	c	10^{-1}	0.1
milli	m	10^{-2}	0.01
micro	µ	10^{-3}	0.001
nano	n	10^{-6}	0.000 001
pico	p	10^{-9}	0.000 000 001
femto	f	10^{-12}	0.000 000 000 001
atto	a	10^{-15}	0.000 000 000 000 001
		10^{-18}	0.000 000 000 000 000 001

*Nonpreferred. Prefixes should be selected in steps of 10^3 so that the resultant number before the prefix is between 0.1 and 1000 (see 6.1). These prefixes should not be used for units of linear measurement, but may be used for higher order units. For example, the linear measurement, decimeter, is nonpreferred, but square decimeter is acceptable.

Table 8.4
Commonly Used Metric Conversions
(Fahrenheit–Celsius Temperature Conversion)

1°F = 5/9°C exactly
°C = 5/9 (°F – 32)
°F = (9/5°C) + 32

Find the number to be converted in the center (boldface) column.
If converting Fahrenheit degrees, read the Celsius equivalent in the column headed "°C."
If converting Celsius degrees, read the Fahrenheit equivalent in the column headed "°F."

°C		°F	°C		°F	°C		°F	°C		°F
-273	**-459**		-79	**-110**	-166	9	**48**	118	88	**190**	374
-268	**-450**		-73	**-100**	-148	10	**50**	122	93	**200**	392
-262	**-440**		-68	**-90**	-130	11	**52**	126	99	**210**	410
-257	**-430**		-62	**-80**	-112	12	**54**	129	104	**220**	428
-251	**-420**		-57	**-70**	-94	13	**56**	133	110	**230**	446
-246	**-410**		-51	**-60**	-76	14	**58**	136	116	**240**	464
-240	**-400**		-46	**-50**	-58	16	**60**	140	121	**250**	482
-234	**-390**		-40	**-40**	-40	17	**62**	144	127	**260**	500
-229	**-380**		-34	**-30**	-22	18	**64**	147	132	**270**	518
-223	**-370**		-29	**-20**	-4	19	**66**	151	138	**280**	536
-218	**-360**		-23	**-10**	14	20	**68**	154	143	**290**	554
-212	**-350**		-18	**0**	32	21	**70**	158	149	**300**	572
-207	**-340**		-17	**2**	36	22	**72**	162	154	**310**	590
-201	**-330**		-16	**4**	39	23	**74**	165	160	**320**	608
-196	**-320**		-14	**6**	43	24	**76**	169	166	**330**	626
-190	**-310**		-13	**8**	46	26	**78**	172	171	**340**	644
-184	**-300**		-12	**10**	50	27	**80**	176	177	**350**	662
-179	**-290**		-11	**12**	54	28	**82**	180	182	**360**	680
-173	**-280**		-10	**14**	57	29	**84**	183	188	**370**	698
-168	**-270**	-454	-9	**16**	61	30	**86**	187	193	**380**	716
-162	**-260**	-436	-8	**18**	64	31	**88**	190	199	**390**	734
-157	**-250**	-418	-7	**20**	68	32	**90**	194	204	**400**	752
-151	**-240**	-400	-6	**22**	72	33	**92**	198	210	**410**	770
-146	**-230**	-382	-4	**24**	75	34	**94**	201	216	**420**	788
-140	**-220**	-364	-3	**26**	79	36	**96**	205	221	**430**	806
-134	**-210**	-346	-2	**28**	82	37	**98**	208	227	**440**	824
-129	**-200**	-328	-1	**30**	86	38	**100**	212	232	**450**	842
-123	**-190**	-310	0	**32**	90	43	**110**	230	238	**460**	860
-118	**-180**	-292	1	**34**	93	49	**120**	248	243	**470**	878
-112	**-170**	-274	2	**36**	97	54	**130**	266	249	**480**	896
-107	**-160**	-256	3	**38**	100	60	**140**	284	254	**490**	914
-101	**-150**	-238	4	**40**	104	66	**150**	302	260	**500**	932
-96	**-140**	-220	6	**42**	108	71	**160**	320	266	**510**	950
-90	**-130**	-202	7	**44**	111	77	**170**	338	271	**520**	968
-84	**-120**	-184	8	**46**	115	82	**180**	356	277	**530**	986
282	**540**	1004	560	**1040**	1904	838	**1540**	2804	1116	**2040**	3704
288	**550**	1022	566	**1050**	1922	843	**1550**	2822	1121	**2050**	3722
293	**560**	1040	571	**1060**	1940	849	**1560**	2840	1127	**2060**	3740
299	**570**	1058	577	**1070**	1958	854	**1570**	2858	1132	**2070**	3758
304	**580**	1076	582	**1080**	1976	860	**1580**	2876	1138	**2080**	3776
310	**590**	1094	588	**1090**	1994	866	**1590**	2894	1143	**2090**	3794
316	**600**	1112	593	**1100**	2012	871	**1600**	2912	1149	**2100**	3812
321	**610**	1130	599	**1110**	2030	877	**1610**	2930	1154	**2110**	3830
327	**620**	1148	604	**1120**	2048	882	**1620**	2948	1160	**2120**	3848
332	**630**	1166	610	**1130**	2066	888	**1630**	2966	1166	**2130**	3866

(continued)

Table 8.4 (Continued)

°C		°F	°C		°F	°C		°F	°C		°F
338	**640**	1184	616	**1140**	2084	893	**1640**	2984	1171	**2140**	3884
343	**650**	1202	621	**1150**	2102	899	**1650**	3002	1177	**2150**	3902
349	**660**	1220	627	**1160**	2120	904	**1660**	3020	1182	**2160**	3920
354	**670**	1238	632	**1170**	2138	910	**1670**	3038	1188	**2170**	3938
360	**680**	1256	638	**1180**	2156	916	**1680**	3056	1193	**2180**	3956
366	**690**	1274	643	**1190**	2174	921	**1690**	3074	1199	**2190**	3974
371	**700**	1292	649	**1200**	2192	927	**1700**	3092	1204	**2200**	3992
377	**710**	1310	654	**1210**	2210	932	**1710**	3110	1210	**2210**	4010
382	**720**	1328	660	**1220**	2228	938	**1720**	3128	1216	**2220**	4028
388	**730**	1346	666	**1230**	2246	943	**1730**	3146	1221	**2230**	4046
393	**740**	1364	671	**1240**	2264	949	**1740**	3164	1227	**2240**	4064
399	**750**	1382	677	**1250**	2282	954	**1750**	3182	1232	**2250**	4082
404	**760**	1400	682	**1260**	2300	960	**1760**	3200	1238	**2260**	4100
410	**770**	1418	688	**1270**	2318	966	**1770**	3218	1243	**2270**	4118
416	**780**	1436	693	**1280**	2336	971	**1780**	3236	1249	**2280**	4136
421	**790**	1454	699	**1290**	2354	977	**1790**	3254	1254	**2290**	4154
427	**800**	1472	704	**1300**	2372	982	**1800**	3272	1260	**2300**	4172
432	**810**	1490	710	**1310**	2390	988	**1810**	3290	1266	**2310**	4190
438	**820**	1508	716	**1320**	2408	993	**1820**	3308	1271	**2320**	4208
443	**830**	1526	721	**1330**	2426	999	**1830**	3326	1277	**2330**	4226
449	**840**	1544	727	**1340**	2444	1004	**1840**	3344	1282	**2340**	4244
454	**850**	1562	732	**1350**	2462	1010	**1850**	3362	1288	**2350**	4262
460	**860**	1580	738	**1360**	2480	1016	**1860**	3380	1293	**2360**	4280
466	**870**	1598	743	**1370**	2498	1021	**1870**	3398	1299	**2370**	4298
471	**880**	1616	749	**1380**	2516	1027	**1880**	3416	1304	**2380**	4316
477	**890**	1634	754	**1390**	2534	1032	**1890**	3434	1310	**2390**	4334
482	**900**	1652	760	**1400**	2552	1038	**1900**	3452	1316	**2400**	4352
488	**910**	1670	766	**1410**	2570	1043	**1910**	3470	1321	**2410**	4370
493	**920**	1688	771	**1420**	2588	1049	**1920**	3488	1327	**2420**	4388
499	**930**	1706	777	**1430**	2606	1054	**1930**	3506	1332	**2430**	4406
504	**940**	1724	782	**1440**	2624	1060	**1940**	3524	1338	**2440**	4424
510	**950**	1742	788	**1450**	2642	1066	**1950**	3542	1343	**2450**	4442
516	**960**	1760	793	**1460**	2660	1071	**1960**	3560	1349	**2460**	4460
521	**970**	1778	799	**1470**	2678	1077	**1970**	3578	1354	**2470**	4478
527	**980**	1796	804	**1480**	2696	1082	**1980**	3596	1360	**2480**	4496
532	**990**	1814	810	**1490**	2714	1088	**1990**	3614	1366	**2490**	4514
538	**1000**	1832	816	**1500**	2732	1093	**2000**	3632	1371	**2500**	4532
543	**1010**	1850	821	**1510**	2750	1099	**2010**	3650	1377	**2510**	4550
549	**1020**	1868	827	**1520**	2768	1104	**2020**	3668	1382	**2520**	4568
554	**1030**	1886	832	**1530**	2786	1110	**2030**	3686	1388	**2530**	4586
1393	**2540**	4604	1460	**2660**	4820	1527	**2780**	5036	1593	**2900**	5252
1399	**2550**	4622	1466	**2670**	4838	1532	**2790**	5054	1599	**2910**	5270
1404	**2560**	4640	1471	**2680**	4856	1538	**2800**	5072	1604	**2920**	5288
1410	**2570**	4658	1477	**2690**	4874	1543	**2810**	5090	1610	**2930**	5306
1416	**2580**	4676	1482	**2700**	4892	1549	**2820**	5108	1616	**2940**	5324
1421	**2590**	4694	1488	**2710**	4910	1554	**2830**	5126	1621	**2950**	5342
1427	**2600**	4712	1493	**2720**	4928	1560	**2840**	5144	1627	**2960**	5360
1432	**2610**	4730	1499	**2730**	4946	1566	**2850**	5162	1632	**2970**	5378
1438	**2620**	4748	1504	**2740**	4964	1571	**2860**	5180	1638	**2980**	5396
1443	**2630**	4766	1510	**2750**	4982	1577	**2870**	5198	1643	**2990**	5414
1449	**2640**	4784	1516	**2760**	5000	1582	**2880**	5216	1649	**3000**	5432
1454	**2650**	4802	1521	**2770**	5018	1588	**2890**	5234			

Table 8.5
General Conversions

Property	To Convert From	To	Multiply By
acceleration (angular)	revolution per minute squared	rad/s^2	$1.745\,329 \times 10^{-3}$
acceleration (linear)	$in./min.^2$	m/s^2	$7.055\,556 \times 10^{-6}$
	$ft/min.^2$	m/s^2	$8.466\,667 \times 10^{-5}$
	$in./min.^2$	mm/s^2	$7.055\,556 \times 10^{-3}$
	ft/s^2	m/s^2	$3.048\,000 \times 10^{-1}$
angle, plane	degree	rad	$1.745\,329 \times 10^{-2}$
	minute	rad	$2.908\,882 \times 10^{-4}$
	second	rad	$4.848\,137 \times 10^{-6}$
area	$in.^2$	m^2	$6.451\,600 \times 10^{-4}$
	ft^2	m^2	$9.290\,304 \times 10^{-2}$
	yd^2	m^2	$8.361\,274 \times 10^{-1}$
	$in.^2$	mm^2	$6.451\,600 \times 10^{2}$
	ft^2	mm^2	$9.290\,304 \times 10^{4}$
	acre (U.S. Survey)	m^2	$4.046\,873 \times 10^{3}$
density	pound mass $in.^3$	kg/m^3	$2.767\,990 \times 10^{4}$
	pound mass per ft^3	kg/m^3	$1.601\,846 \times 10$
energy, work, heat, and impact energy	foot pound-force	J	1.355 818
	foot poundal	J	$4.214\,011 \times 10^{-2}$
	Btu*	J	$1.055\,056 \times 10^{3}$
	calorie*	J	4.186 800
	watt hour	J	$3.600\,000 \times 10^{3}$
force	kilogram-force	N	9.806 650
	pound-force	N	4.448 222
impact strength	(see energy)		
length	in.	m	$2.540\,000 \times 10^{-2}$
	ft	m	$3.048\,000 \times 10^{-1}$
	yd	m	$9.144\,000 \times 10^{-1}$
	mile (statute)	m	$1.609\,344 \times 10^{3}$
mass	pound mass (avdp)	kg	$4.535\,924 \times 10^{-1}$
	metric ton	kg	$1.000\,000 \times 10^{3}$
	ton (short, 2000 lbm)	kg	$9.071\,847 \times 10^{2}$
	slug	kg	$1.459\,390 \times 10$
power	horsepower (550 ft. lbf/s)	W	$7.456\,999 \times 10^{2}$
	horsepower (electric)	W	$7.460\,000 \times 10^{2}$
	Btu/h*	W	$2.930\,711 \times 10^{-1}$
	calorie per minute*	W	$6.976\,333 \times 10^{-2}$
	foot pound-force per minute	W	$2.259\,697 \times 10^{-2}$
pressure	psi	kPa	6.894 757
	bar	kPa	$1.000\,000 \times 10^{2}$
	atmosphere	kPa	$1.013\,250 \times 10^{2}$
	$kip/in.^2$	kPa	$6.894\,757 \times 10^{3}$
temperature	degree Celsius, t_C	K	$t_K = t_C + 273.15$
	degree Fahrenheit, t_F	K	$t_K = (t_F + 459.67)/1.8$
	degree Rankine, T_R	K	$t_K = t_R/1.8$
	degree Fahrenheit, t_F	°C	$t_C = (t_F - 32)/1.8$
	kelvin, T_K	°C	$t_C = t_K - 273.15$
tensile strength (stress)	ksi	MPa	6.894 757
torque	pound-force inch	N·m	$1.129\,848 \times 10^{-1}$
	pound-force foot	N·m	1.355 818

*Thermochemical

Table 8.5 (Continued)

Property	To Convert From	To	Multiply By
velocity (angular)	revolution per minute	rad/s	$1.047\ 198 \times 10^{-1}$
	degree per minute	rad/s	$2.908\ 882 \times 10^{-4}$
	revolution per minute	degree/min.	$3.600\ 000 \times 10^{2}$
velocity (linear)	in./min.	m/s	$4.233\ 333 \times 10^{-4}$
	ft/min.	m/s	$5.080\ 000 \times 10^{-3}$
	in./min.	mm/s	$4.233\ 333 \times 10^{-1}$
	ft/min.	mm/s	5.080 000
	mile/hour	km/h	1.609 344
volume	in.^{3}	m^3	$1.638\ 706 \times 10^{-5}$
	ft^3	m^3	$2.831\ 685 \times 10^{-2}$
	yd^3	m^3	$7.645\ 549 \times 10^{-1}$
	in.^{3}	mm^3	$1.638\ 706 \times 10^{4}$
	ft^3	mm^3	$2.831\ 685 \times 10^{7}$
	in.^{3}	L	$1.683\ 706 \times 10^{-2}$
	ft^3	L	$2.831\ 685 \times 10$
	gallon (US)	L	3.785 412

*Thermochemical

For any conversion exercise, the first step is to decide what particular property is described by the units that are to be converted. Once the proper category has been chosen from the "Property" column, look at the second column ("To Convert From") and locate the line that contains the unit that is given in the exercise. This is the unit that will be converted. Moving straight across to the right, look for the unit that matches the unit to which the conversion will be made. When the line that contains both the known and desired units is located, the value found in the last column ("Multiply By") is the appropriate conversion factor. At this point, simply multiply the number of the known units by this conversion factor. The result is the number of desired units. Examples that show how to use this table to perform typical conversions are as follows.

Conversion Example 1:

An oxygen gauge shows a pressure of 550 kPa. That is how many psi?

(1) Property = pressure (gas and liquid)
(2) Known unit= 550 kPa
(3) Desired unit= psi
(4) Conversion factor = 1.450×10^{-1}

Solution:

550 kPa × .1450 = ? psi
550 kPa = 79.75 psi

Conversion Example 2:

A tensile specimen was pulled and displayed an ultimate tensile strength of 655 MPa. This corresponds to how many psi?

(1) Property = tensile strength
(2) Known unit = 655 MPa
(3) Desired unit = psi
(4) Conversion factor = 1.450×10^{2}

Solution:

655 MPa × 145.0 = ? psi
655 MPa = 94 975 psi

Conversion Example 3:

What is the diameter in millimeters of a 5/32 in. electrode?

(1) Property = linear measurements
(2) Known unit = 5/32 in. (0.156 in.)
(3) Desired unit = mm
(4) Conversion factor = 2.540×10

Solution:

0.156 in. × 25.4 = ? mm
0.156 in. = 3.96 mm

Conversion Example 4:

Welding parameters were adjusted to produce a weld metal deposition rate of 7.3 kg/h. What is that deposition rate in terms of lb/h?

(1) Property = deposition rate
(2) Known unit = 7.3 kg/h
(3) Desired unit = lb/h
(4) Conversion factor = 2.2

Solution:

7.3 kg/h × 2.2 = ? lb/h
7.3 kg/h = 16.06 lb/h

Table 8.6
Conversions for Common Welding Terms

Property*	To Convert From	To	Multiply By
area dimensions (mm^2)	in.^{2}	mm^2	$6.451\ 600 \times 10^2$
	mm^2	in.^{2}	$1.550\ 003 \times 10^{-3}$
current density (A/mm^2)	A/in.^{2}	A/mm^2	$1.550\ 003 \times 10^{-3}$
	A/mm^2	A/in.^{2}	$6.451\ 600 \times 10^2$
deposition rate (kg/h)	lb/h	kg/h	$4.535\ 924 \times 10^{-1}$
	kg/h	lb/h	2.204 623
electrical resistivity (Ω·m)	Ω·cm	Ω·m	$1.000\ 000 \times 10^{-2}$
	Ω·m	Ω·cm	$1.000\ 000 \times 10^2$
electrical force (N)	pound-force	N	4.448 222
	kilogram-force	N	9.806 650
	N	lbf	$2.248\ 089 \times 10^{-1}$
flow rate (L/min.)	ft^3/h	L/min.	$4.719\ 474 \times 10^{-1}$
	gallon per hour	L/min.	$6.309\ 020 \times 10^{-2}$
	gallon per minute	L/min.	3.785 412
fracture toughness ($MN{\cdot}m^{-3/2}$)	ksi·in.$^{1/2}$	$MN{\cdot}m^{-3/2}$	1.098 843
	$MN{\cdot}m^{-3/2}$	ksi·in.$^{1/2}$	$9.100\ 477 \times 10^{-1}$
heat input (J/m)	J/in.	J/m	$3.937\ 008 \times 10$
	J/m	J/in.	$2.540\ 000 \times 10^{-2}$
impact energy absorption	foot pound-force	J	1.355 818
linear measurements (mm)	in.	mm	$2.540\ 000 \times 10$
	ft	mm	$3.048\ 000 \times 10^2$
	mm	in.	$3.937\ 008 \times 10^{-2}$
	mm	ft	$3.280\ 840 \times 10^{-3}$
power density (W/m^2)	W/in.^{2}	W/m^2	$1.550\ 003 \times 10^3$
	W/m^2	W/in.^{2}	$6.451\ 600 \times 10^{-4}$
pressure (gas and liquid) (kPa)	psi	kPa	6.894 757
	lbf/ft^2	kPa	$4.788\ 026 \times 10^{-2}$
	N/mm^2	kPa	$1.000\ 000 \times 10^3$
	kPa	psi	$1.450\ 377 \times 10^{-1}$
	kPa	lbf/ft^2	$2.088\ 543 \times 10$
	kPa	N/mm^2	$1.000\ 000 \times 10^{-3}$
pressure (vacuum) (Pa)	torr (mm Hg at 0°C)	Pa	$1.333\ 224\ 10^2$
	micron (μm Hg at 0°C)	Pa	$1.333\ 224 \times 10^{-1}$
	Pa	torr	$7.500\ 617 \times 10^{-3}$
	Pa	micron	7.500 617
	bar	psi	$1.450\ 377 \times 10^1$
tensile strength (MPa)	psi	MPa	$6.894\ 757 \times 10^{-3}$
	lbf/ft^2	MPa	$4.788\ 026 \times 10^{-5}$
	N/mm^2	MPa	1.000 000
	MPa	psi	$1.450\ 377 \times 10^2$
	MPa	lbf/ft^2	$2.088\ 543 \times 10^4$
	MPa	N/mm^2	1.000 000
thermal conductivity (W/(m·K))	cal/(cm·s·°C)	W/(m·K)	$4.184\ 000 \times 10^2$
travel speed, wire feed speed (mm/s)	in./min.	mm/s	$4.233\ 333 \times 10^{-1}$
	mm/s	in./min.	2.362 205

*Preferred units are given in parentheses.

Review—Chapter 8—Destructive Testing

Q8-1 Which property cannot be determined from a tensile test?
- a. ultimate tensile strength
- b. percent elongation
- c. percent reduction of area
- d. impact strength
- e. yield strength

Q8-2 The property that describes the ability of a metal to resist some applied load is:
- a. strength
- b. toughness
- c. hardness
- d. ductility
- e. none of the above

Q8-3 The point at which a metal's behavior changes from elastic to plastic (onset of permanent deformation) is referred to as:
- a. yield strength
- b. ultimate tensile strength
- c. modulus of elasticity
- d. Young's modulus
- e. none of the above

Q8-4 Which of the following is an expression for a metal's ductility?
- a. percent elongation
- b. percent reduction of area
- c. proportional limit
- d. both a and b above
- e. both b and c above

Q8-5 What is the percent elongation of a specimen whose original gauge length was 2 in. and final gauge length was 2.5 in.?
- a. 30%
- b. 25%
- c. 50%
- d. 40%
- e. none of the above

Q8-6 The property of metals that describes their resistance to indentation is called:
- a. strength
- b. toughness
- c. hardness
- d. ductility
- e. none of the above

Q8-7 The type of testing that is used routinely for the qualification of welding procedures and welders is:
- a. tensile strength
- b. hardness
- c. soundness
- d. impact strength
- e. all of the above

Q8-8 Of the following, which properties can be determined as a result of tensile testing?
- a. ultimate tensile strength
- b. ductility
- c. percent elongation
- d. yield strength
- e. all of the above

Q8-9 The family of hardness tests that uses both a minor and major load is called:
- a. Brinell
- b. Vickers
- c. Rockwell
- d. Knoop
- e. none of the above

Q8-10 Which of the following tests are referred to as microhardness tests?
- a. Rockwell
- b. Vickers
- c. Knoop
- d. both a and b above
- e. both b and c above

Q8-11 What type of test uses a weighted pendulum that strikes a notched test specimen?
- a. Brinell test
- b. fatigue test
- c. tensile test
- d. crack opening displacement (COD)
- e. Charpy impact test

Q8-12 Of the following, which is one of the most measurable features of a metal?
- a. fatigue
- b. hardness
- c. soundness
- d. tension
- e. none of the above

Q8-13 Which of the following is not considered a soundness test?
- a. tensile
- b. face bend
- c. fillet break
- d. root bend
- e. nick-break

Q8-14 The type of testing used to evaluate the type of microstructure present in a metal is called:
- a. tensile
- b. hardness
- c. toughness
- d. metallographic
- e. none of the above

Q8-15 A 50 lb can of welding electrodes weighs approximately how many kg?
- a. 227 kg
- b. 2.3 kg
- c. 22.7 kg
- d. 23 000 kg
- e. none of the above

Q8-16 Which two metal properties are directly related for many steels?
- a. impact strength and fatigue strength
- b. tensile strength and ductility
- c. tensile strength and hardness
- d. toughness and fatigue strength
- e. none of the above

Q8-17 What is the wire feed speed that is measured at 175 in./min.?
a. .125 m/s
b. 74 mm/s
c. 7.4 mm/s
d. both a and b above
e. both b and c above

Q8-18 The property of metals that describes their ability to carry some type of load is:
a. strength
b. toughness
c. hardness
d. ductility
e. none of the above

Q8-19 For less ductile metals, which method is used to determine the yield strength?
a. drop of beam
b. offset technique
c. stress-strain curve
d. abrupt yielding
e. none of the above

Q8-20 The ability of a metal to absorb energy is called:
a. strength
b. ductility
c. hardness
d. toughness
e. none of the above

Q8-21 A weld joint is measured and found to be 345 mm long. How long is that joint in terms of inches?
a. 135.8 in.
b. 13.58 in.
c. 8760 in.
d. 876 in.
e. none of the above

Q8-22 Which of the following tests is used to verify the soundness of a weld?
a. nick break
b. fillet break
c. bend test
d. radiographic test
e. all of the above

Q8-23 With the SAW process we achieve a deposition rate of 19.7 kg/h. How many lb/h is this?
a. 434 lb/h
b. 43.34 lb/h
c. 87.5 lb/h
d. 8.9 lb/h
e. none of the above

Q8-24 Ultimate tensile strength can be determined using which of the following tests?
a. tensile
b. bend
c. Charpy
d. nick break
e. nil-ductility drop-weight

Q8-25 Calculation of percent elongation is determined after measuring the change in:
a. percent reduction of area
b. depth of indentation
c. diameter of indentation
d. cross-sectional area
e. length between gauge marks

Q8-26 With the GMAW process we use a wire feed speed of 170 mm/s. How many in./min. is this?
a. 40.16 in./min.
b. 53.7 in./min.
c. 401.6 in./min.
d. 537 in./min.
e. none of the above

Q8-27 With the GTAW process, flow rates are measured at 22 L/min. How many ft^3/h is this?
a. 10.4 ft^3/h
b. 1.39 ft^3/h
c. 46.6 ft^3/h
d. 83.2 ft^3/h
e. none of the above

Q8-28 Calculation of tensile strength is accomplished by dividing the tensile load by:
a. cross-sectional area
b. percent elongation
c. percent reduction of area
d. gauge length
e. none of the above

Q8-29 The metal property describing its freedom from imperfections is:
a. tensile strength
b. soundness
c. impact strength
d. toughness
e. ductility

Q8-30 If a metal exhibits a great deal of elongation prior to falling when a tensile load is applied is said to have high:
a. tensile strength
b. hardness
c. impact strength
d. toughness
e. ductility

Q8-31 A specimen approximately 2 in. long with a V-notch machined in the center of one of its sides is used for which of the following tests?
a. tensile
b. nil-ductility drop-weight
c. Charpy
d. bend
e. tuck break

Q8-32 Which of the following properties can be determined from a tensile test?
a. ultimate tensile strength, yield strength, ductility
b. yield strength, ductility, toughness
c. ductility only
d. toughness only
e. all of the above

CHAPTER 9

Welding Procedure and Welder Qualification

Contents

Chapter 9—Welding Procedure and Welder Qualification

Introduction

A welding procedure details the steps by which the welding of a specific joint or weldment is to be accomplished. It gives the prescribed values or ranges of values for all the controllable variables in the process and specifies all materials to be used. A welding procedure determines the mechanical properties of a welded joint.

Almost every welding job needs a welding procedure. Commonly, the contract or the specifications require that a written procedure be prepared. The requirements often are those of a general specification or standard, which the fabricator may be following as a quality control standard.

When the governing specifications or standards comprise a code that has been adopted by a governing agency such as a city, state, or province, then the welding procedure becomes a legal entity under that code.

The purpose of this section is as follows:

- To define the welding procedure specification, including its types, content, documentation, and application.
- To explain the qualification of the welding procedure specification.
- To define circumstances when certain parts of the specification may require requalification.
- To define the welding inspector's responsibilities during the qualification process and later during the fabrication inspection process.

Welding Procedure Specification

The purpose of a welding procedure specification is to define and document the details that are to be carried out in welding specific materials or parts.

Many companies prepare a quality assurance manual that establishes the responsibilities for preparation, review, and approval of the welding procedures to be used, although the procedures themselves will not ordinarily be included in the quality assurance manual.

Contents

The written welding procedure specification should be arranged in accordance with the contract or purchase requirements. The information should be sufficiently detailed to ensure that the welding will meet all requirements of the applicable code, standard or specification.

The topics that follow in this section are the most common and generally the most essential in welding procedure specifications. Every item will not apply to every process or application, and some items that are familiar to you may not be listed at all. The list is given to guide the welding inspector in reviewing welding procedure specifications or in determining whether or not production welding is being performed in accordance with welding procedure specifications. It must be emphasized that the welding inspector is not responsible for producing the welding procedure specification. The following can serve as a checklist for the welding inspector when reviewing a welding procedure specification produced by a welding engineer or other responsible individual.

> The generation of a welding procedure is the specific responsibility of the manufacturer or contractor and not the welding inspector. According to AWS QC1, the CWI "verifies that the welding procedures are as specified and qualified and that the welding is performed in accordance with the applicable procedure."

(1) **Scope.** *Have the types of welding, the materials, and the governing specifications been clearly stated?*

(2) **Base Metals and Applicable Specifications.** *Are suitable base metals specified?* They should be identified by their chemical composition and applicable specifications. The procedure should indicate what condition the base metal should be in before welding (that is, normalized, annealed, quenched and tempered, solution treated, etc.). There may also be a requirement that the fabricator know the identity of all material. Full plates or sections

can be identified by the mill numbers; small portions cut from full plates or sections should be marked with the same numbers. The rolling direction of the plate should also be identified.

(3) **Welding Process.** *What welding process is to be used?*

(4) **Type, Classification, and Composition of Filler Metals.** The welding process should be clearly named, and the composition, identifying type, or classification designation of the filler metal should always be spelled out to ensure proper use. In addition, the sizes of filler metals or electrodes that can be used when welding different thicknesses of material in different positions must be designated. Some types of filler metals are even identified on each individual pass or layer. Identification of filler metals may be lost when original containers are discarded. Electrode marking, moreover, does not guarantee that the electrode is in satisfactory condition. For example, low-hydrogen electrodes that have been exposed to the atmosphere must be baked in an oven to restore their low moisture content. Such baking requirements should be included in the welding procedure, following the manufacturer's specification.

(5) **Type of Current and Current Ranges.** *What type of current is to be used?* Some electrodes work well on either ac or dc. If dc is needed, the proper polarity should be specified (DCEP or DCEN). In addition, current ranges for different electrode sizes, different procedure positions, and various thicknesses of materials should be listed.

(6) **Welder Qualification Requirements.** The procedure specification may designate the requirements for welder or welding operator qualification. Applicable welder qualification specifications or paragraphs of the governing specifications may be referenced in the welding procedure specification. The latter portion of this Chapter is devoted to the topic of welder qualification.

(7) **Joint Designs and Tolerances.** Permissible joint design details and the designated welding sequence should be identified. Use of cross-sectional sketches that show the thickness of material, details of the joint, or references to standard drawings or specifications are suitable ways of expressing this information. Tolerances for all dimensions must be listed (see Figure 9.1).

(8) **Joint Preparation and Cleaning of Surfaces to be Welded.** *What methods may be used to prepare the joints? How are the surfaces to be cleaned?* Joint preparation methods such as oxyfuel cutting, air carbon arc cutting, and plasma arc cutting (with or without after-cleaning) should be specified. Any required machining or grinding, and any special cleaning such as vapor, ultrasonic, dip, or lint-free cloth cleaning must be specified. There may also be mention of whether weld anti-spatter compounds may be used. Be sure that methods or

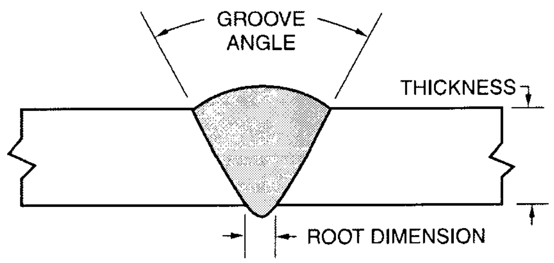


Figure 9.1—Joint Design and Tolerances

practices specified for production work are also specified for qualifying the welding procedure (see Figure 9.2).

(9) **Tack Welding.** *What tack welding practices are to be followed?* The applicable code should be referenced to determine whether tack welders must be qualified.

(10) **Joint Welding Details.** Details of electrode sizes for the different portions of each welding position, the arrangement of weld passes for filling the joints, the thickness of each pass, pass width or electrode weave limitations, amperage ranges and whatever other details are important for each particular joint must be specified.

(11) **Positions of Welding.** *In which positions may welding be done?* (see Figures 9.3 and 9.4).

(12) **Preheat and Interpass Temperatures.** *What are the temperature limits for any preheat or interpass temperature?*

(13) **Peening:** Peening is a mechanical treatment utilized to reduce the effects of welding heat cycles that could produce excessive residual stresses, distortion and even cracking. Indiscriminate use of peening should not be permitted; however, it is sometimes applied to highly restrained or thick welds to avoid warpage or cracking of

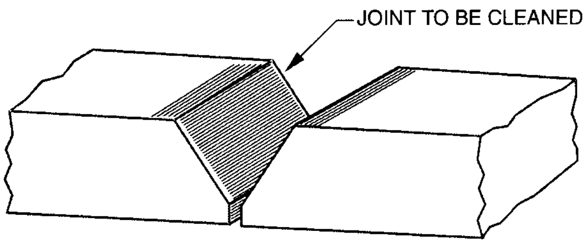
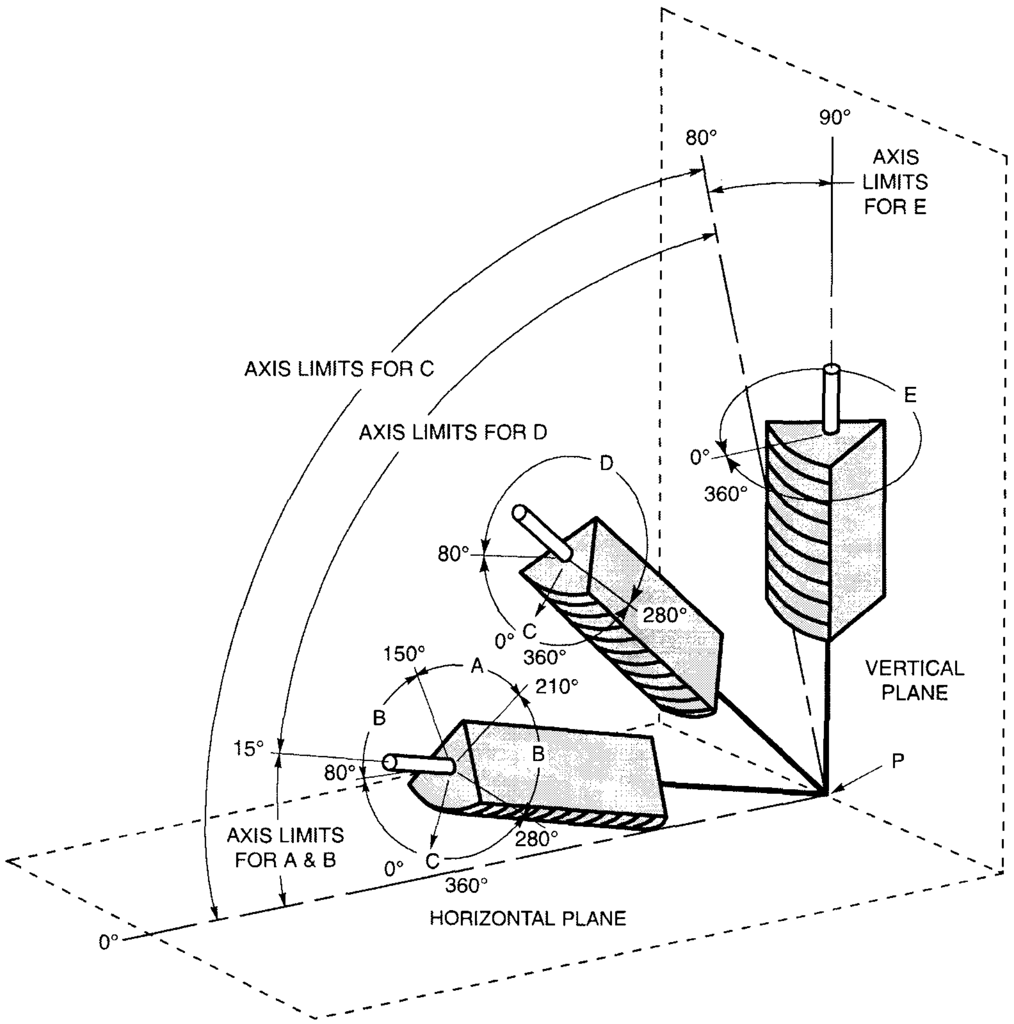


Figure 9.2—Joint Preparation and Cleaning of Surfaces for Welding

Tabulation of Positions of Groove Welds

Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150° 210° to 280°
Overhead	C	0° to 80°	0° to 80° 280° to 360°
Vertical	D E	15° to 80° 80° to 90°	80° to 280° 0° to 360°



Notes:
1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

Figure 9.3—Positions of Groove Welds

Tabulation of Positions of Fillet Welds			
Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	125° to 150° 210° to 235°
Overhead	C	0° to 80°	0° to 125° 235° to 360°
Vertical	D E	15° to 80° 80° to 90°	125° to 235° 0° to 360°

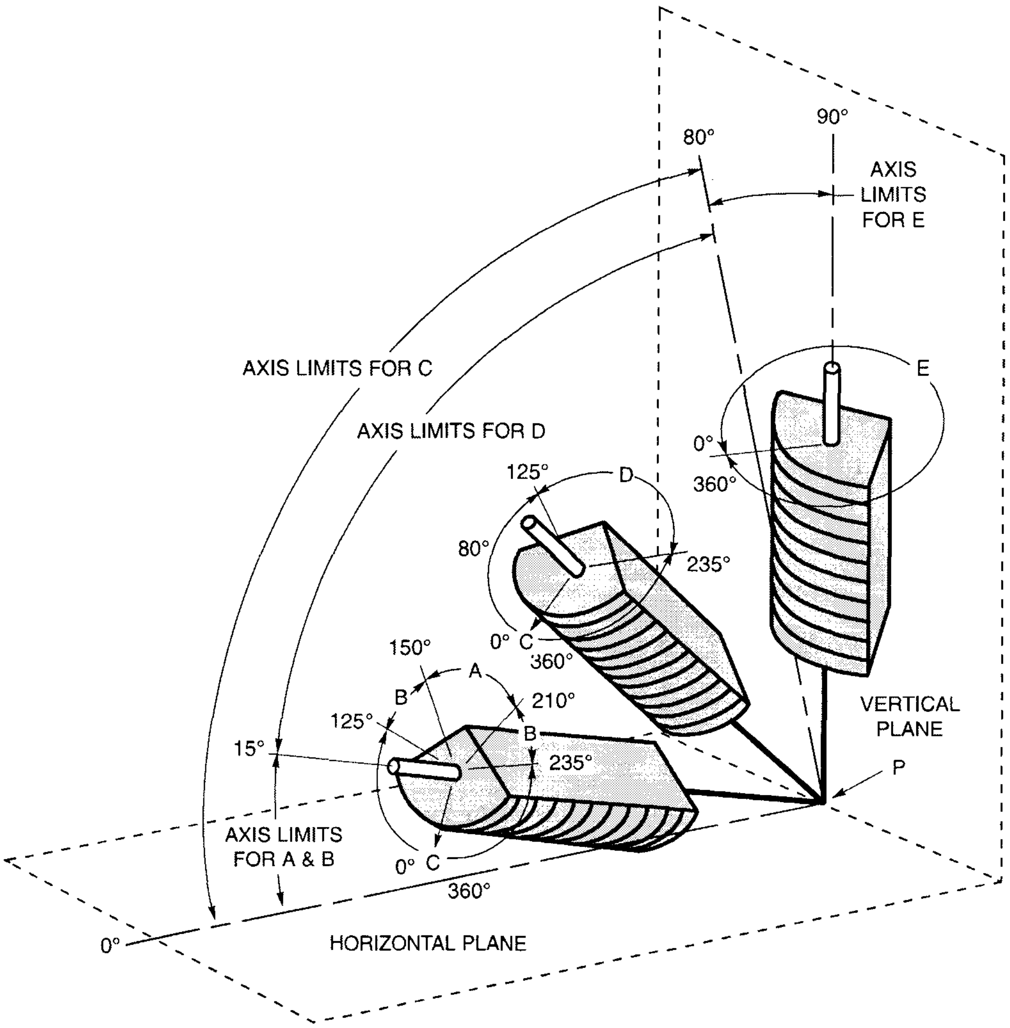


Figure 9.4—Positions of Fillet Welds

the weld or base metal. If peening is to be used, details of its application must be specified in the welding procedure specification (see Figure 9.5).

(14) **Heat Input.** With heat-treated alloy steels and austenitic stainless steel alloys, the energy input during welding must not heat the work adjacent to the weld above certain temperatures. To control this, there must be specification of the preheat and interpass temperatures, arc voltage, current, and travel speed within well defined ranges, as determined during the procedure qualifications. This will allow for maintenance of the desirable properties in the heat-affected zone of the base metal.

(15) **Root Preparation Prior to Welding Second Side.** In joints welded from both sides, there should be a description of the root of the first weld and how it may be prepared for back welding. The procedure specification should state whether chipping, grinding, air carbon arc cutting, oxyacetylene gouging, etc., is to be used.

(16) **Removal of Weld Sections for Repair.** *What methods are to be used for removing welds or sections of welds for repair?* The methods may be the same as those used for preparing the root of the first pass for welding from the second side.

(17) **Repair Welding.** Details of any repair welding methods and procedures that may differ from the standard methods to be used to create a welded joint should be identified.

(18) **Examination.** *What type and extent of examination is each weld joint to receive?* The examination may include radiography, magnetic particle, ultrasonic, penetrant, or other types of testing. Although visual examination of every weld is routinely required, it should be spelled out in the procedure.

(19) **Postheat Treatment.** *What heat treatment or stress relief will be required after welding?* It should be the same treatment that is applied to all procedure qualification test welds. A full description of the heat treatment should be specified or a suitable heat treating note, drawing, or document should be referenced. Check to see that postheat treatment of heat-treated alloy steels will not exceed the final tempering temperature that was given to the base metal. If a full reheat treatment is intended, it may be desirable to weld the metal in the annealed condition.

(20) **Marking.** Some codes require that welders make identification marks on or near each weld, or maintain a record of welds. The identification marking should be made with low-stress steel die stamps, rather than sharp-edged stamps (see Figure 9.6).

(21) **Records.** There should be details of what welding records will be required, and the specific requirements for these records.

(22) **Welding Procedure Specification Sample.** Samples of a general welding procedure and several joint welding procedure specifications are illustrated in Annex B. These samples are for illustration only and are not the specific details to follow for any particular application. The data given for electrode size, welding current and voltage, preheat and interpass temperature, location and sequence of weld passes, etc., have been filled in solely for illustration, not for actual use.

Welding Procedure Qualification

The purpose of procedure qualification testing is to demonstrate that the materials and methods prescribed in a procedure specification will produce weld joint mechanical properties that meet the application and specification requirements.

There are four steps in the qualification of a welding procedure: (1) preparation and welding of suitable samples; (2) testing of representative specimens; (3) evaluation

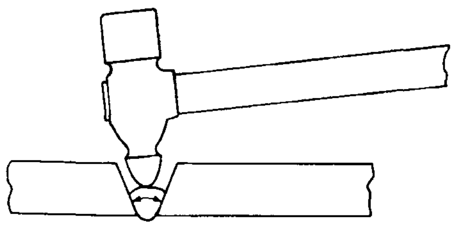


Figure 9.5—Peening the Middle Layer of a Weld Distributes and Balances Stresses

Figure 9.6—Marking a Completed Weldment

of overall preparation, welding, testing, and end results; and (4) approval (if the results are favorable). Details of these steps are as follows:

(1) **Preparation of Procedure Qualification Sample Joints.** Test assemblies usually have a representative joint in their middle. The size, type, and thickness are related to the type and thickness of material to be welded in production and the number, type, and size of specimens to be removed for testing. The materials and welding details to be used are governed by the particular welding procedure specifications that are to be qualified.

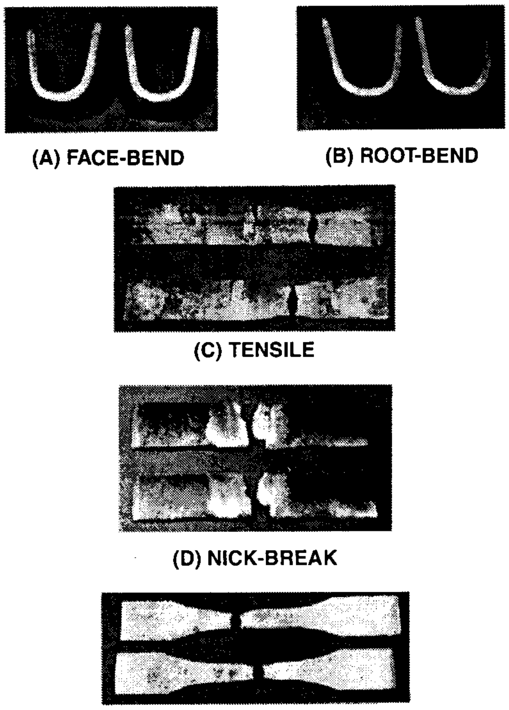
(2) **Testing of Procedure Qualification Welds.** Specified tests and examinations are made on the sample joints. The type and number of specimens to be removed for destructive tests will depend upon the requirements of the particular application or specification. Such tests may include: tensile, bend, nick-break, Charpy, fillet-break, etc. Often nondestructive examinations will also be applied. The welding inspector should be certain that the records show how the procedure qualification welds were made and tested (see Figure 9.7).

(3) **Evaluation of Test Results.** The test results for a procedure qualification sample weld, with the records of joint preparation, welding, and testing, should be made available for review. These results will be analyzed by the responsible parties to determine whether the test details and results meet the requirements of the applicable specification.

(4) **Approval of Qualification Tests and Procedure Specifications.** As a rule, the inspection agency or customer must approve the procedure qualification tests, the test results, and the procedure specifications before any production welding is done.

Qualification is accomplished when the required tests have been completed and approval has been obtained. However, authentic documentary evidence must be available to show that the joints were qualified as satisfactory. The welding inspector should witness the welding and testing of all specimens, if possible.

At any time during the use of a qualified procedure, the welding inspector may request requalification of that procedure, if production use shows that the procedure is not producing consistently reliable results.



(A) FACE-BEND (B) ROOT-BEND

(C) TENSILE

(D) NICK-BREAK

(E) REDUCED TENSILE

Figure 9.7—Sample Specimens for Destructive Testing

Code Qualification Requirements

(1) **AWS D1.1, *Structural Welding Code—Steel.*** AWS D1.1 covers the welding of various structures, including buildings, bridges, and tubular structures. This document features a unique welding procedure concept referred to as *prequalified weld joints*. As long as the welding is performed in accordance with the design, workmanship, and technique requirements set forth in the code, no actual procedure qualification testing is required.Use of procedures operating outside these prescribed limitations will require actual qualification testing.

Sample forms approved by the AWS Structural Welding Committee for recording procedure qualifications are reproduced in the Annexes.

(2) **ASME *Boiler and Pressure Vessel Code*—Section IX.** This document covers the welding of pressure vessels. Any welding performed in accordance with this code must be done using welding procedures that have been qualified using the guidelines set forth in ASME Section IX of that code, entitled "Welding and Brazing Qualifications." This code section also applies to qualification for welding pressure piping in accordance with ASME B31, *Code for Pressure Piping*.

Unlike the AWS D1.1, ASME Section IX always requires procedure qualification testing. It covers both the welding and brazing of virtually all types of construction alloys using a wide variety of processes.

Documentation for a welding procedure qualified in accordance with ASME Section IX consists of both a

When a welding inspector is working with more than one code, it is important to consult the code frequently to verify that code's requirements. It is all too easy to "remember" a code requirement that comes from a different code and is not applicable to your immediate situation. Consult the code book often.

Welding Procedure Specification (QW-482) and a Procedure Qualification Record (QW-483). Copies of these two forms appear in Annex B.

(3) **API 1104, *Standard for Welding Pipelines and Related Facilities*.** The welding of cross-country pipelines and other types of petroleum equipment is controlled by the requirements set forth in API 1104. This standard describes how each welding procedure will be qualified. It is unique in that it also describes the inspection and quality requirements for the production welding. Like ASME Section IX, each change in a qualified procedure requires actual qualification testing.

If a fabricator has qualified a welding procedure but desires at some later date to make a change in that procedure, it may be necessary to conduct additional qualifying tests. Requalification is necessary when any one of the essential variables listed in the governing standard or code is changed beyond the limits that have been established.

For example, one such variable is the heat treatment that follows welding. Heat treatment has a profound effect on most welds. Its omission (when called for) or its addition to a welding procedure (when not called for) would be a change in an important essential variable, requiring requalification of the procedure.

Essential, supplementary essential, and nonessential variables are covered in detail in Chapter 4.

Welding Inspector Responsibilities

(1) **Welding Procedure Qualification.** Before any production welding is started under a contract, it is the welding inspector's duty to verify that welding procedures have been established and that they are capable of producing welded joints of the type and quality required. To be certain of this, the welding inspector should witness the welding and testing of the qualification weld specimens. Authentic documentary evidence that the joints were satisfactory must be available. As mentioned earlier, the welding inspector should try to witness the tests to increase his familiarity with the details of the procedure.

(2) **Welding Inspection.** It should be kept in mind that the passing of a qualification test does not ensure proper application of the procedure. Adequate inspection is necessary to verify how the qualified procedure is being applied. When performing an inspection, the welding inspector will find it advantageous to prepare a checklist for each procedure specification.

Once the welding procedures have been reviewed and found to be acceptable, the task now becomes one of assuring that the production welding is being performed in accordance with those procedures. Qualified welding procedures are useless if not followed. The welding inspector should also note changes in any welding procedure that are in excess of the limits prescribed for the essential variables, see that the procedure specification is changed accordingly, and determine whether requalification of the procedure is required. If requalification is required, the welding inspector should verify that the modified procedure is not applied to production work until requalification testing has been completed and the change has been proven satisfactory.

Make certain that weldments needing repair are corrected using qualified welding procedures. The welding and quality requirements for the repair are the same as those for the original welding.

Welder and Brazer Qualification

Performance qualification tests determine the ability of welders, welding operators, and brazers to produce acceptably sound welds and brazes with the processes, materials, and techniques defined in the qualified welding or brazing procedures. Qualification of these personnel is the legal responsibility of the employer of that individual.

The manufacturer, contractor, fabricator, erector, and owner are responsible for the quality of their work. They should establish quality assurance programs that utilize in-house and outside experienced and qualified personnel to ensure that they meet or exceed the minimum specified requirements.

Qualification requirements for these personnel are usually defined in the governing standard or the contract specification. The welding inspector's responsibility is to verify that every welder, welding operator or brazer who works under the standard or specification has been properly qualified for the work to be done.

Qualification Testing

Performance qualification tests improve the probability of obtaining satisfactory welds in finished products. Although test welds demonstrate that a welder, welding operator, or brazer is capable of producing acceptably sound joints, the tests do not indicate whether such personnel will normally produce acceptable welds under every production condition. For that reason, complete reliance should not be placed on qualification testing of welders, welding operators, and brazers. Production welds and brazes should be inspected both during and after the actual welding.

Tests prescribed by most codes, specifications, and governing rules are similar, for the most part. The most common types of tests will be described for the following applications: plate and structural member welding, pipe welding, sheet metal welding, and brazing.

In addition, various test methods used to examine the qualification test welds or braze joints will be discussed. Another factor that has a great impact on the ability of a welder or brazer to produce a satisfactory weld or braze is the position in which the test is performed, which depends on the position, or positions, in which production welding or brazing is done.

(1) **Plate and Structural Member Welding.** Qualification requirements for welders of plate and structural parts usually have the welder or welding operator make one or more test welds on plate or pipe in accordance with the requirements of the qualified welding procedure (see Figures 9.8–9.13). Each qualification weld is tested in a specific manner, often both destructively and nondestructively. The requirements prescribe the thicknesses of material and the test positions that qualify for production work.

Other details cover groove welds with or without backing and the direction of welding when welding in the vertical position.

(2) **Pipe Welding.** Qualification requirements for welding pipe differ from those for welding plate and structural members, mainly in the type of test assemblies and test positions. Another major difference with pipe welding is the fact that often there is no practical access to the root surface, requiring the use of some backing ring, consumable insert, or the production of a one-side weld with an open root (no backing). This procedure also requires more skill than is needed for the welding of plate or structural joints with backing.

To simulate the difficulties of production welding, the pipe weld qualification tests utilize pipe coupons that are welded in the position, or positions, for which the welder wishes to be qualified. There may also be space restrictions placed on the welder during the test that measures the individual's ability to produce a satisfactory weld in locations where joint access is limited (see Figures 9.14–9.16).

(3) **Sheet Metal Welding.** The welding of sheet metal requires special skills, because the thin members tend to melt rapidly, and can result in burning holes rather than joining parts together. Consequently, the qualification tests examine the ability of the welder to produce sound welds in these thin sheet metal thicknesses. Note that all codes place limits on the minimum thicknesses that a welder can weld in production. Often, the minimum thickness qualified is that thickness used during qualification (see Table 9.1).

(4) **Brazing.** Like welders, brazers also require some type of qualification testing. The test usually consists of the production of some type of joint arrangement that is positioned in a manner similar to that expected in production. The evaluation of the test results is normally accomplished by cross sectioning the brazed joint and measuring the amount of bonding results.

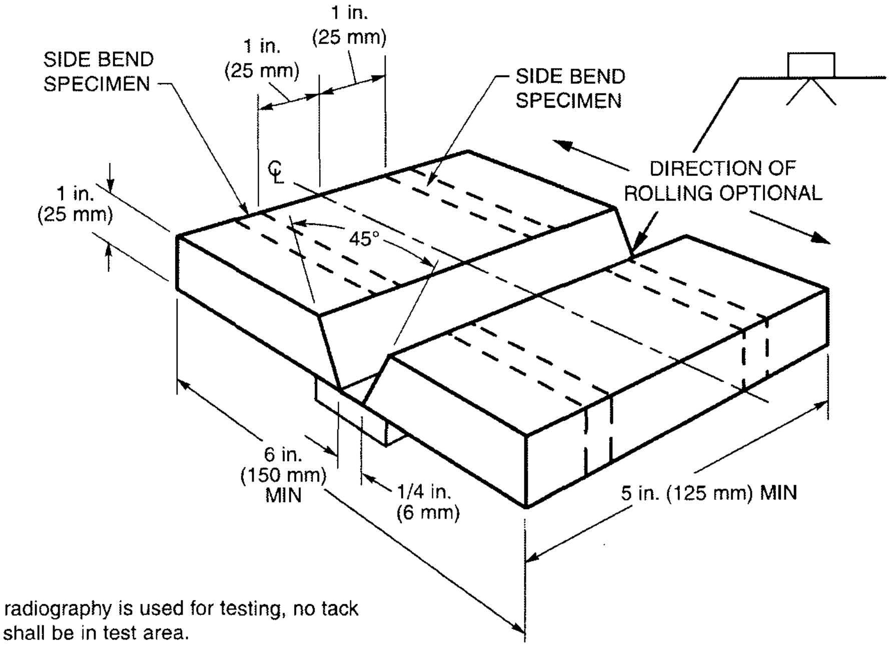
(5) **Positions of Welding and Brazing.** Welder and brazer qualification tests usually must be made in the most difficult positions to be encountered in production (for example, vertical, horizontal, and overhead), if the production work involves other than flat position welding and brazing. Qualification in a more difficult position usually qualifies for welding or brazing in less difficult positions; e.g., qualification in the vertical, horizontal, or overhead positions usually qualifies for welding or brazing in the flat position. Also, qualification tests on groove welds will normally qualify that welder for the production of fillet welds in the same position. The code in force will dictate the exact limits on production welding and brazing positions, depending on the qualification test position(s) (see Figures 9.17 and 9.18).

(6) **Testing of Qualification Welds and Brazes.** All codes and specifications have definite rules for testing qualification welds and brazes. Most frequently, for welds, mechanical bend tests are made on specimens cut from specific locations in the welds. Some codes permit welder qualification testing using radiography instead of mechanical bend testing. This radiographic examination may be permitted, either alone or in conjunction with mechanical or other tests. Other types of nondestructive test methods, such as penetrant testing, may also be applied to measure the apparent soundness of the qualification weldment. All codes require that the test welds be sound and thoroughly fused to the base metal.

Examination of braze qualification coupons is normally accomplished by cutting through the joint and measuring the degree of bonding between the members being joined.

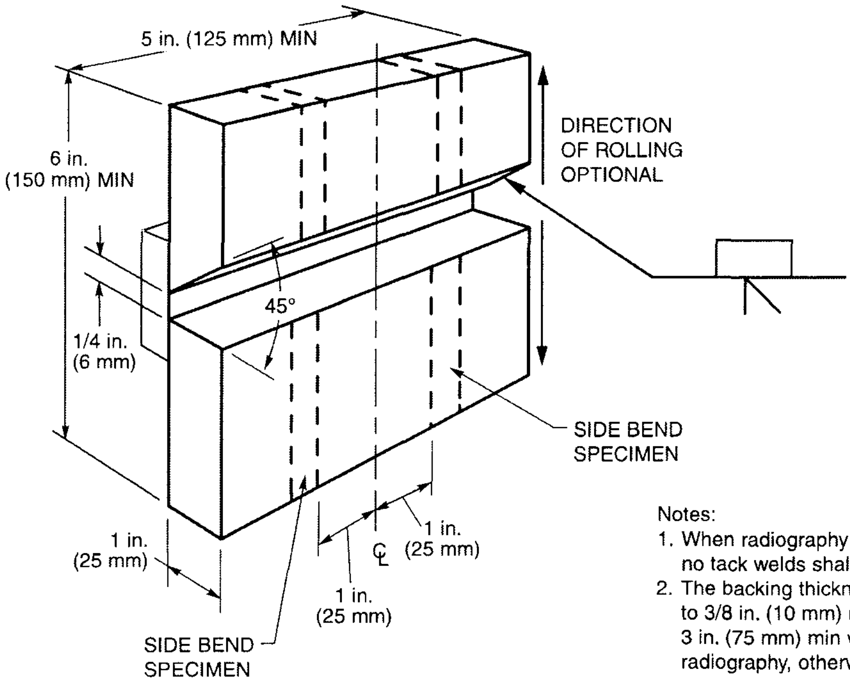
Other properties required of procedure qualification welds, such as tensile strength and fracture toughness of the weld metal, usually are not specified in welder qualification.

Welders or brazers whose test welds or brazes meet the prescribed requirements are qualified to apply the process and to weld or braze with filler metals and procedures similar to those used in testing. The prescribed limits of similarity of the substitute filler metals and procedures must be stated.



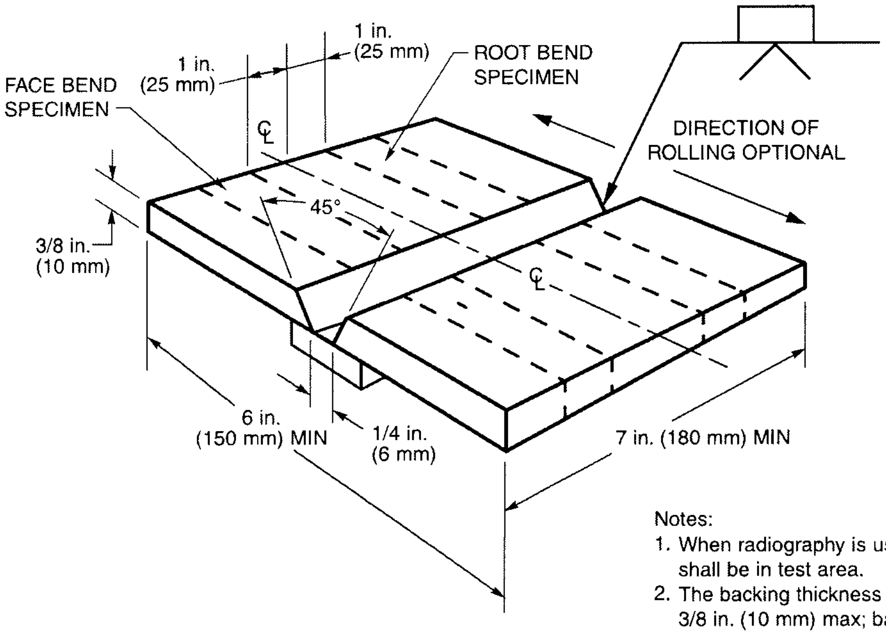
Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in. (6 mm) min to 3/8 in. (10 mm) max; backing width shall be 3 in. (75 mm) min when not removed for radiography, otherwise 1 in. (25 mm) min.

Figure 9.8—Test Plate for Unlimited Thickness—Welder Qualification



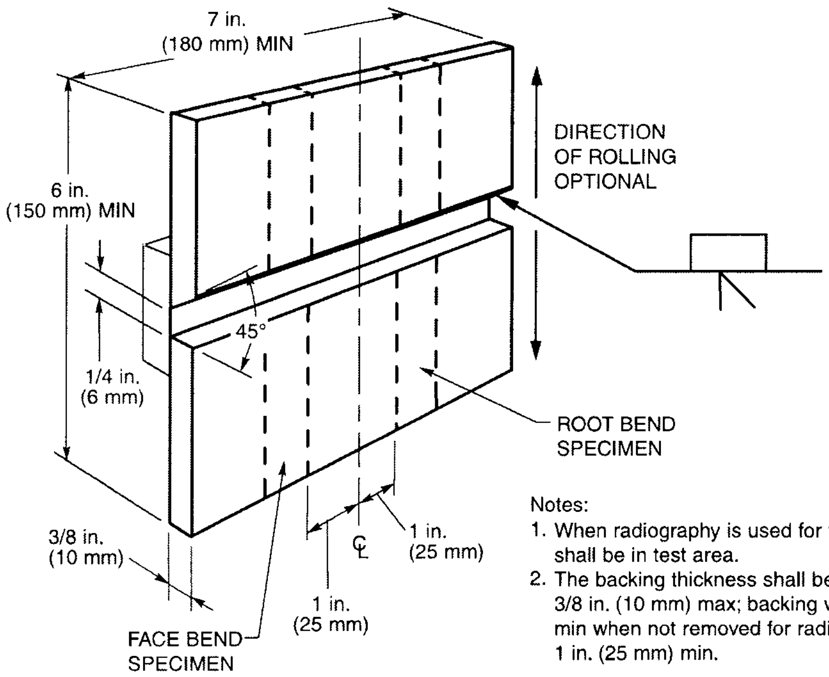
Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in. (6 mm) min to 3/8 in. (10 mm) max; backing width shall be 3 in. (75 mm) min when not removed for radiography, otherwise 1 in. (25 mm) min.

Figure 9.9—Optional Test Plate for Unlimited Thickness—Horizontal Position—Welder Qualification



Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in. (6 mm) min to 3/8 in. (10 mm) max; backing width shall be 3 in. (75 mm) min when not removed for radiography, otherwise 1 in. (25 mm) min.

Figure 9.10—Test Plate for Limited Thickness—All Positions—Welder Qualification



Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in. (6 mm) min to 3/8 in. (10 mm) max; backing width shall be 3 in. (75 mm) min when not removed for radiography, otherwise 1 in. (25 mm) min.

Figure 9.11—Optional Test Plate for Limited Thickness—Horizontal Position—Welder Qualification

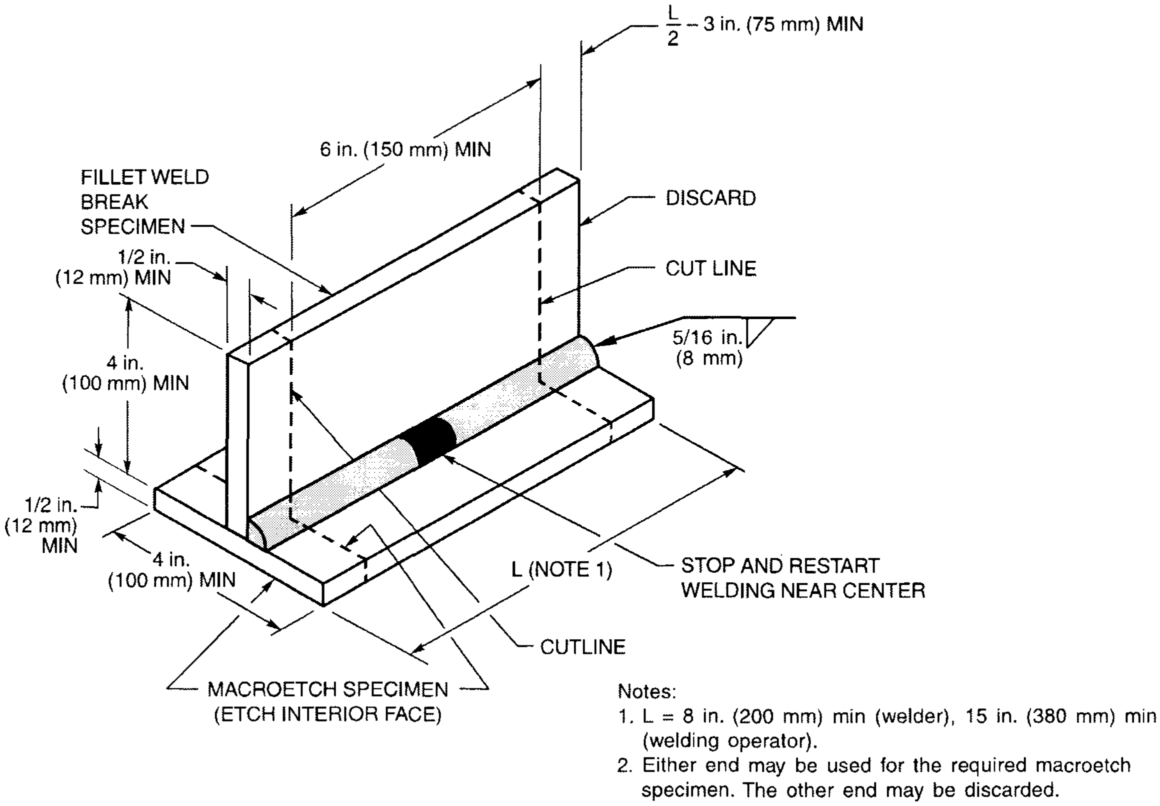


Figure 9.12—Fillet Weld Break and Macroetch Test Plate—Welder Qualification—Option 1

Retests

When do welders or welding operators require retesting? Some of the circumstances are as follows:

- Failure of the initial test welds.
- A significant change in the welding procedure.
- An absence from welding, i.e., a welder has not been engaged in a particular welding process for an extended period (usually three to six months).
- A reason exists to question a welder's or welding operator's ability.

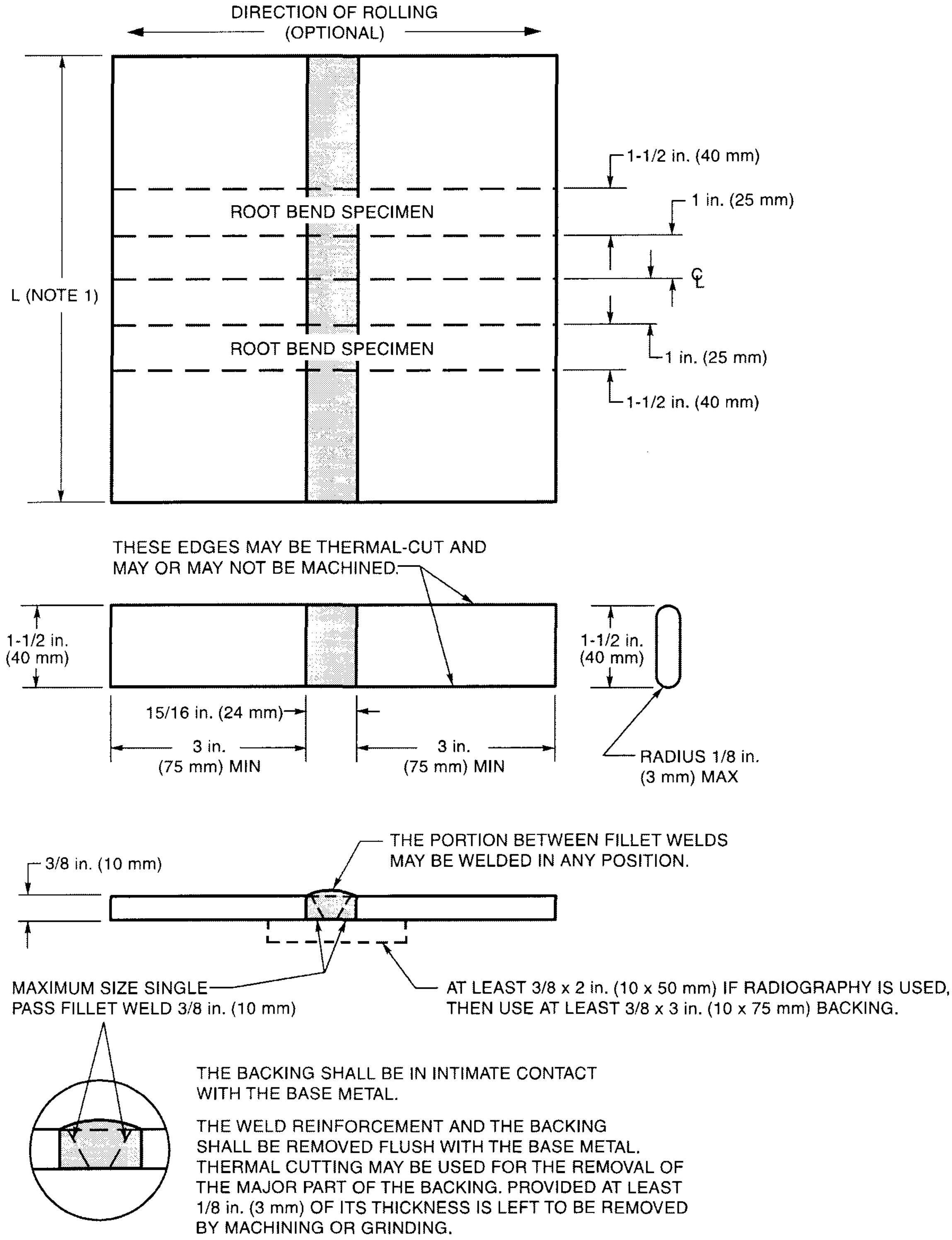
Refer to the applicable code or specification for the specifics of such retests.

Code Requirements

(1) **AWS D1.1, *Structural Welding Code—Steel.*** The AWS D1.1 requires that all welders, welding operators, and tackers to be employed under this code shall have been qualified by tests as specified in Section 4. The tests are often administered by the welding inspector. If the welder, welding operator, or tacker has previously demonstrated his qualification under other acceptable supervision, the welding inspector may ascertain that fact and then consider the applicant qualified for the present job.

(2) **ASME *Boiler and Pressure Vessel Code—Section IX.*** This document specifies that only welders, welding operators and brazers who are qualified in accordance with ASME Section IX shall be used. The ASME Section IX qualification tests for welders and welding operators call for the same kinds of bend specimens as used for procedure qualification.

Any welder, welding operator, or brazer who makes a procedure qualification test that passes satisfactorily is automatically qualified for that process, within the limitations prescribed in ASME Section IX. Welders and welding operators making repair welds shall be qualified in accordance with ASME Section IX as well. Qualification



NOTE 1: L = 7 in. (125 mm) MIN (WELDER), L = 15 in. (380 mm) MIN (WELDING OPERATOR).

Figure 9.13—Fillet Weld Root Bend Test Plate—Welder Qualification—Option 2

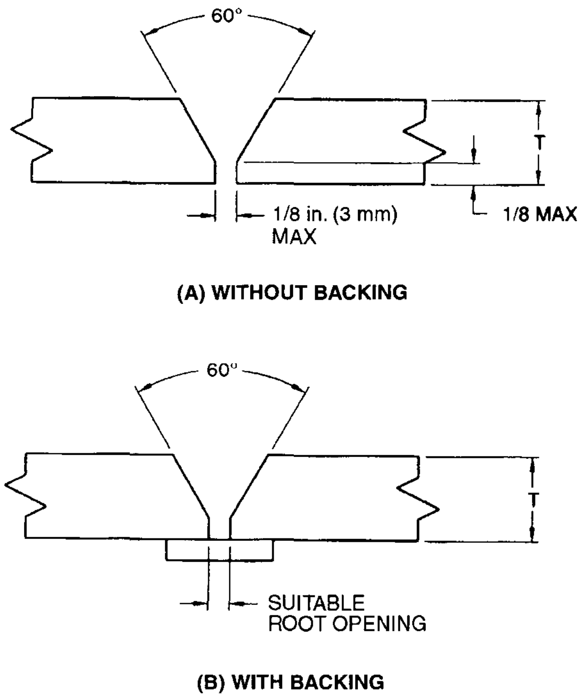


Figure 9.14—Typical Tubular Butt Joint Welder Qualification

remains indefinitely as long as the welder remains with the employer and has used the process within a six-month period.

(3) **API Standard 1104,** ***Standard for Welding of Pipelines and Related Facilities.*** The API Standard 1104 relies on visual examination and destructive tests (optionally, on radiographic examination) to qualify welders. Since this standard deals with the requirements for welding pipelines and related equipment, all qualification tests are performed on pipe. No limitations are placed on the persons doing the testing, except the radiographer. The company, represented in practice by the inspector, is required to keep records of qualified welders and welding operators.

Destructive Test Qualification

Destructive tests and examinations are made in-house or outside by personnel who are qualified through training, education or the manufacturer's certification standards. Many fabricators do not have properly trained or qualified people nor the proper testing equipment, therefore, they call on a contract laboratory to run the tests. On the other hand, fabricators with the necessary equipment may arbitrarily declare that certain of their technicians, inspectors, or engineers are qualified, and the tests are then run in-house.

Destructive tests may be made without qualification of personnel. It is the welding inspector's responsibility to verify that the tests are conducted according to the governing code, specification or other reference documents. For example, the AWS D1.1 requires the all-weld-metal tension test (subsection 5.11.4) to be performed in accordance with ASTM A 370, *Mechanical Testing of Steel Products*.

Summary

The welding inspector will likely be involved to some degree in the qualification of welding procedures and welders. The inspector may be responsible for administering the tests, or simply reviewing the documentation to determine if the qualifications are applicable and accurate.

The most important aspect of the welding inspector's job with regard to qualification is the evaluation of production welding to determine whether the procedures and welders who use them are producing welds of acceptable quality.

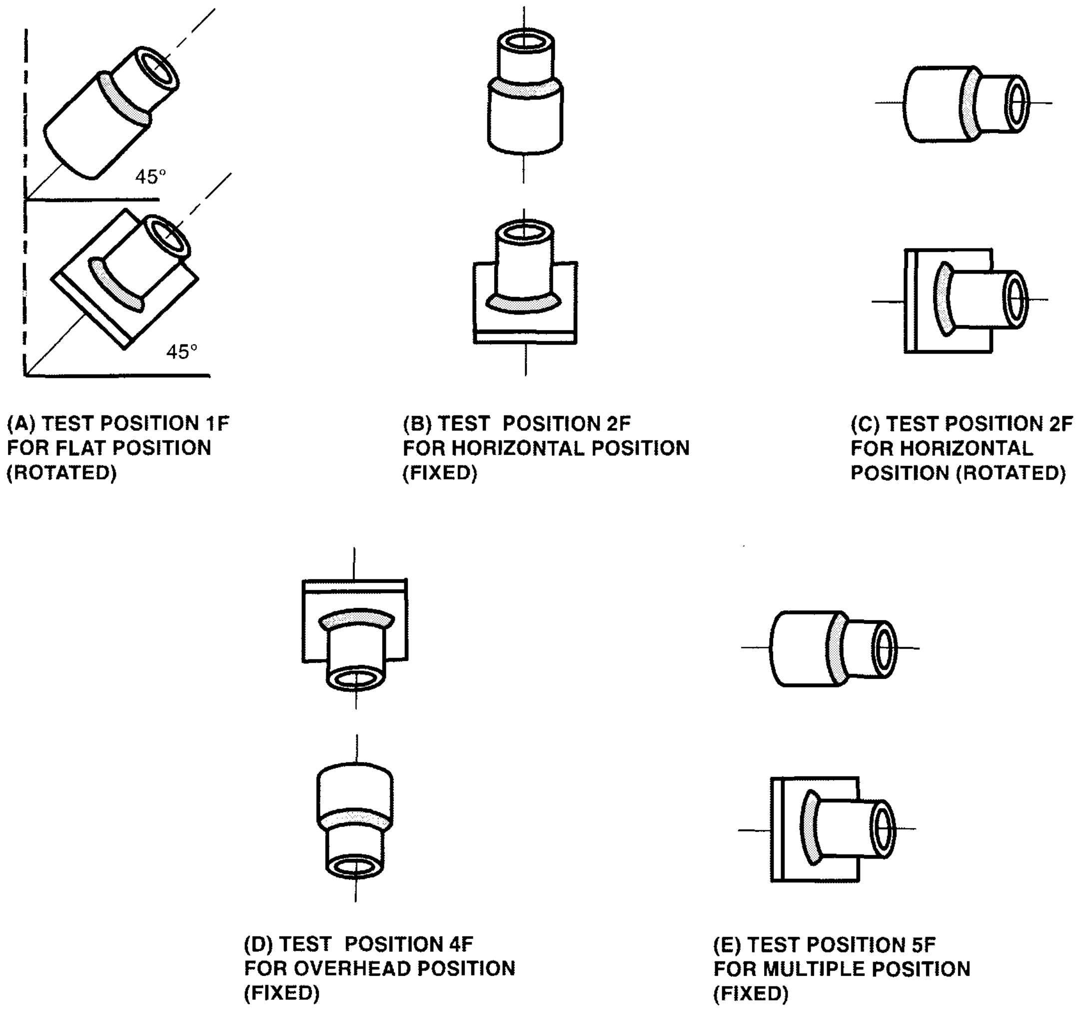


Figure 9.15—Positions of Test Pipes or Tubing for Fillet Welds

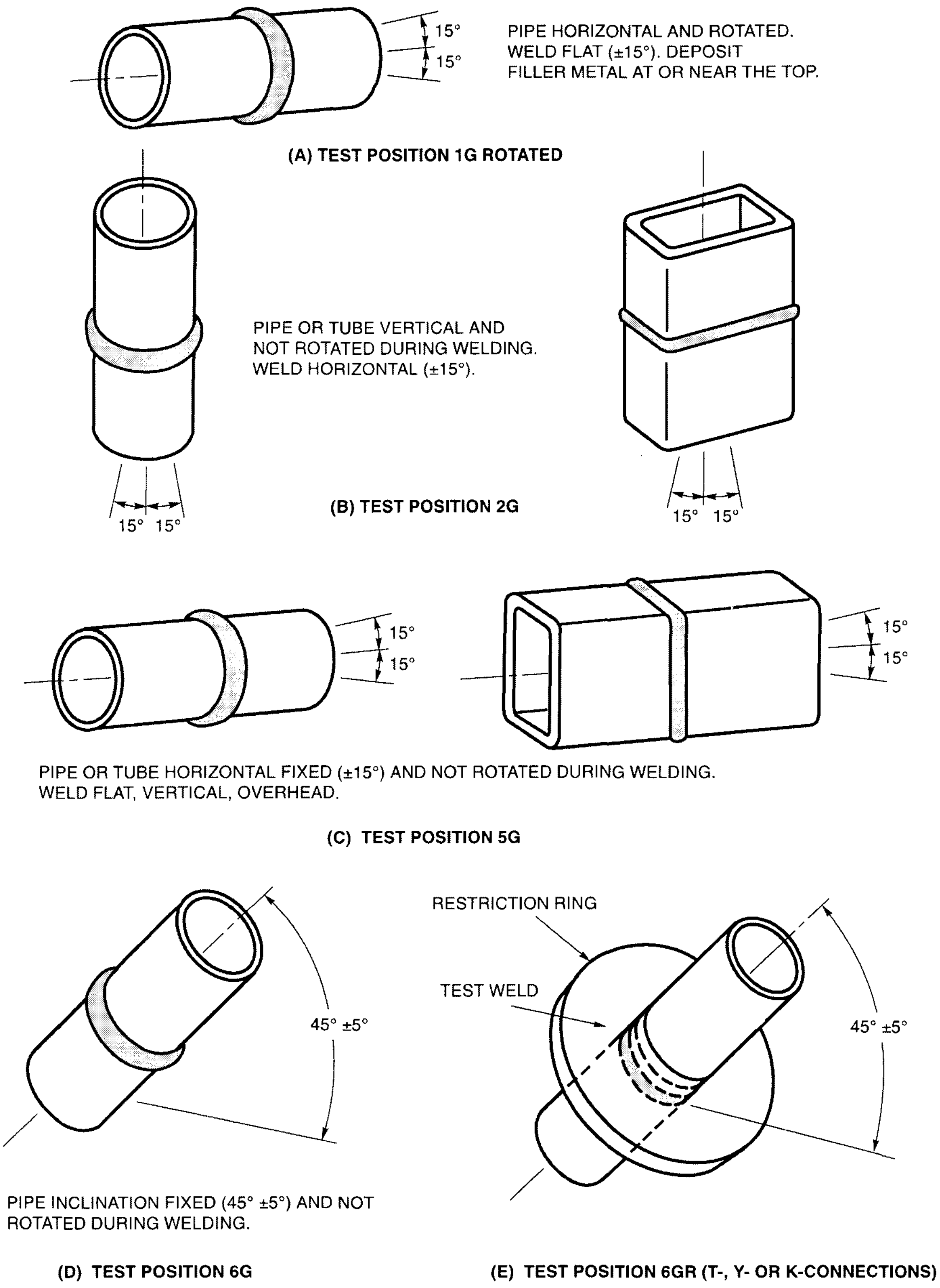
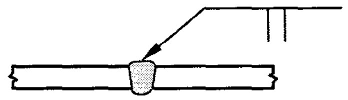
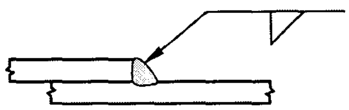
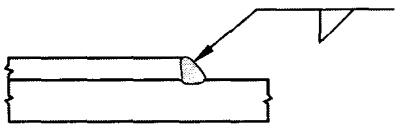
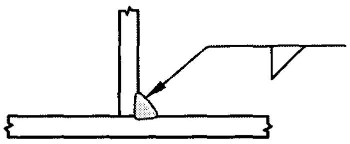
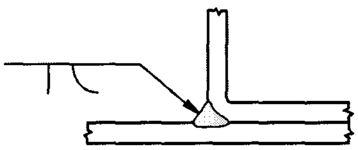
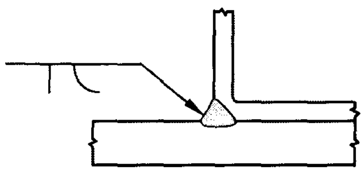


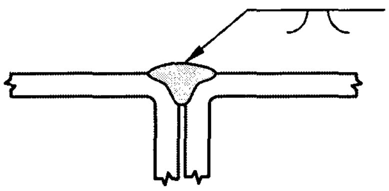
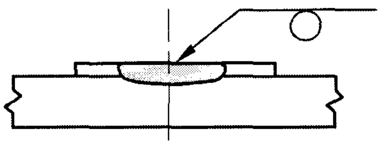
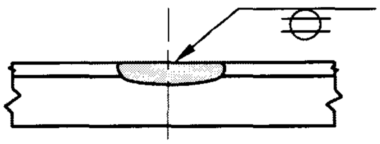
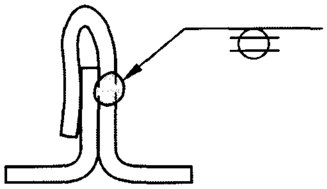
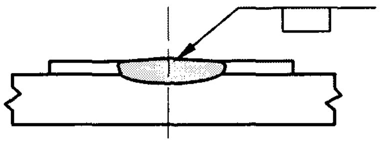
Figure 9.16—Positions of Test Pipe or Tubing for Groove Welds

Table 9.1
Welder Performance Qualification Tests[1]

Test Assemblies Shown in Figure:	Type of Welded Joint Tested	Type of Test	Position: Tested	Position: Qualified	Qualified: Welded Joint	Qualified: Thickness
9.1 	Square-groove weld in butt joint—sheet to sheet	Bend	F H V OH	F F, H F, H, V F, H, OH	Square-groove weld in butt joint—sheet to sheet	Thickness tested
9.2A 	Fillet weld in lap joint—sheet to sheet	Bend	F H V OH	F F, H F, H, V F, H, OH	Fillet weld in lap joint—sheet to sheet, and sheet to supporting structural member	Thickness tested and thicker
9.2A 	Fillet weld in lap joint—sheet to supporting structural member	Bend	F H V OH	F F, H F, H, V F, H, OH	Fillet weld in lap joint—sheet to supporting structural member	Thickness tested and thicker
9.2A 	Fillet weld in T-joint—sheet to sheet	Bend	F H V OH	F F, H F, H, V F, H, OH	Fillet weld in T- or lap joint—sheet to sheet and sheet to supporting structural member	Thickness tested and thicker
9.3A 	Flare-bevel-groove weld—sheet to sheet	Bend	F H V OH	F F, H F, H, V F, H, OH	Flare-bevel-groove weld—sheet to sheet and sheet to supporting structural member, and flare-V-groove weld—sheet to sheet	Thickness tested and thicker
9.3B 	Flare-bevel-groove weld—sheet to supporting structural member	Bend	F H V OH	F F, H F, H, V F, H, OH	Flare-bevel-groove weld—sheet to supporting structural member	Thickness tested and thicker

Note 1: Two tests shall be required for each assembly.

Table 9.1 (Continued)

Test Assemblies Shown in Figure:	Type of Welded Joint Tested	Type of Test	Position		Qualified	
			Tested	Qualified	Welded Joint	Thickness
9.3C 	Flare-V-groove weld—sheet to sheet	Bend	F H V OH	F F, H F, H, V F, H, OH	Flare-V-groove weld—sheet to sheet and flare-bevel-groove weld—sheet to sheet and sheet to supporting structural member	Thickness tested and thicker
9.4 	Arc spot weld—sheet to supporting structural member	Torsion	F	F	Arc spot and arc seam weld—sheet to supporting structural member	Thickness tested
9.5A 	Arc seam weld—sheet to supporting structural member	Bend	F	F	Arc seam weld—sheet to supporting structural member	Thickness tested
9.5B 	Arc seam weld—sheet to sheet	Bend	H	H	Arc seam weld—sheet to sheet	Thickness tested
9.6 	Arc plug weld—sheet to supporting structural member	Torsion	F H V OH	F F, H F, H, V F, H, OH	Arc plug weld—sheet to sheet and sheet to supporting structural member	Thickness tested

Note 1: Two tests shall be required for each assembly.

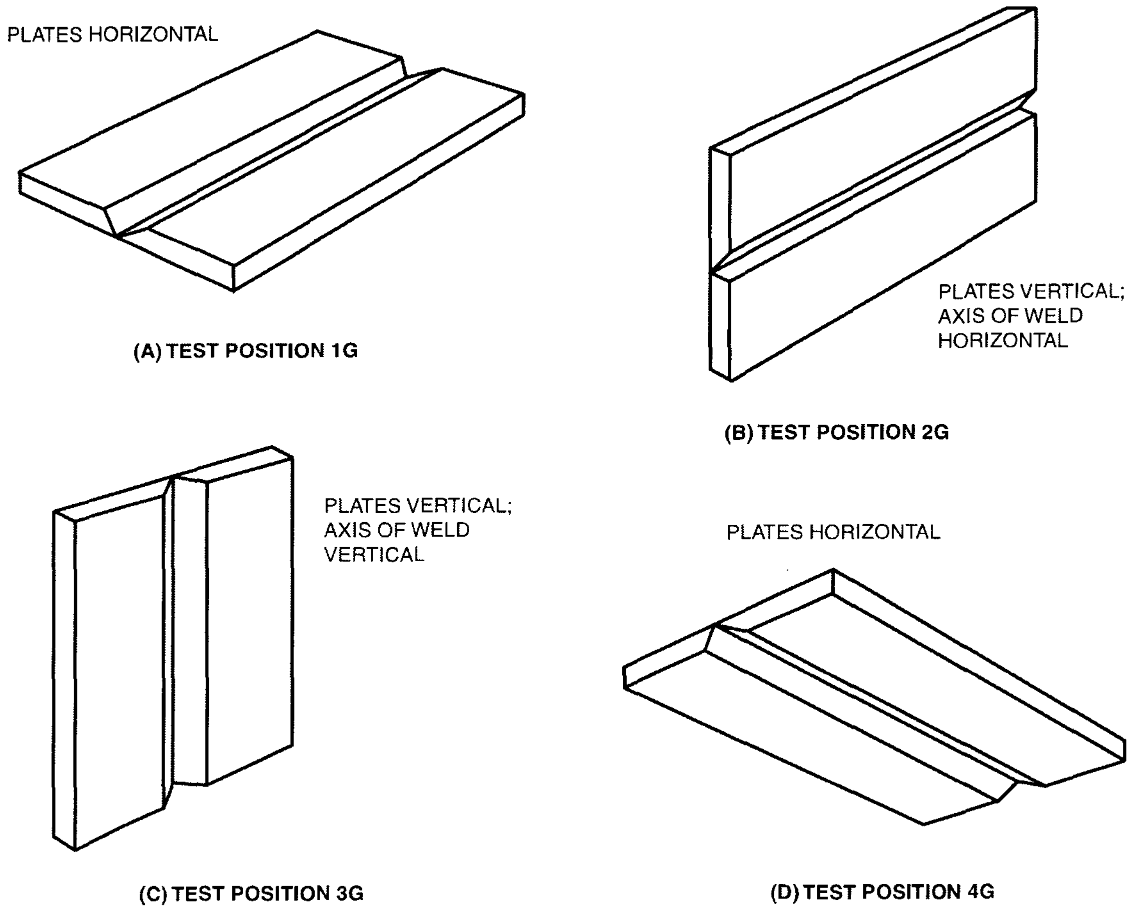


Figure 9.17—Positions of Test Plates for Groove Welds

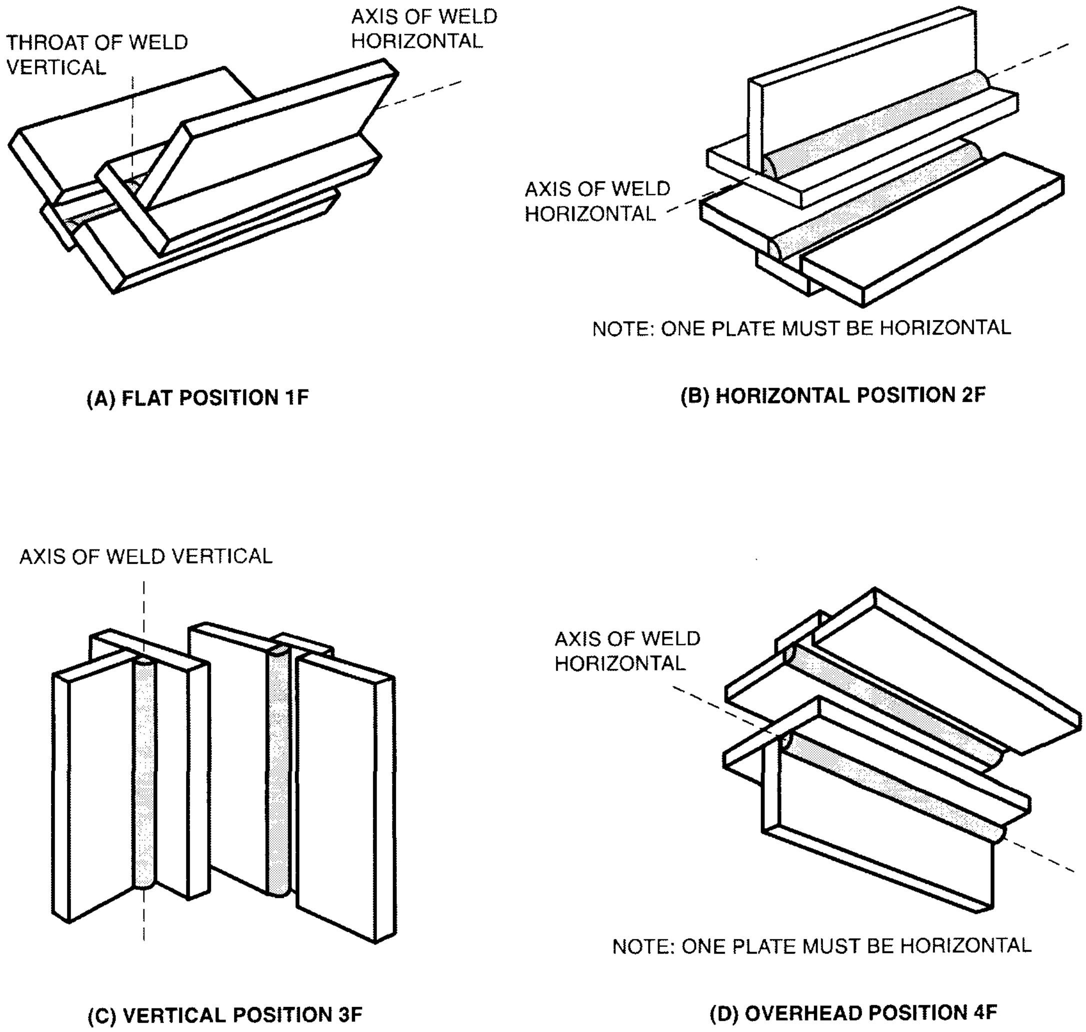


Figure 9.18—Positions of Test Pipes for Fillet Welds

Review—Chapter 9—Welding Procedure and Welder Qualification

Q9-1 Who is normally responsible for the qualification of welding procedures and welders?
- a. welder
- b. architect
- c. welder's employer
- d. independent test lab
- e. code body

Q9-2 Which of the following destructive testing methods may be used for procedure qualification testing?
- a. tensile
- b. nick-break
- c. Charpy
- d. bend
- e. all of the above

Q9-3 What is the pipe welding position in which the pipe remains fixed with its axis horizontal, and the welder must weld around the joint?
- a. 1G
- b. 2G
- c. 5G
- d. 6G
- e. 6GR

Q9-4 What is the pipe welding position in which the axis of the pipe lies fixed at a 45° angle?
- a. 1G
- b. 2G
- c. 5G
- d. 6G
- e. none of the above

Q9-5 What is the necessary pipe position test for welders who are trying to qualify to weld T-, Y-, and K-connections?
- a. 1G
- b. 2G
- c. 5G
- d. 6G
- e. 6GR

Q9-6 With regard to procedure and welder qualification, what is the most important responsibility of the welding inspector?
- a. watching the welding qualification test
- b. identifying samples
- c. cutting test specimens
- d. testing specimens
- e. monitoring production welding

Q9-7 For most codes, if a welder continues to use a particular procedure, how long does his qualification remain in effect?
- a. indefinitely
- b. 6 months
- c. 1 year
- d. 3 years
- e. until he produces a rejectable weld

Q9-8 What document describes the requirements of welder qualification in accordance with ASME?

a. ASME Section III
b. ASME Section II, Part A
c. ASME Section IX
d. ASME Section XI
e. ASME Section V

Q9-9 Qualification to weld cross-country pipelines is normally done in accordance with:

a. ASME Section III
b. AWS D1.1
c. AWS D14.3
d. API 1104
e. API 650

CHAPTER 10

Welding, Brazing, and Cutting Processes

Contents

Chapter 10—Welding, Brazing, and Cutting Processes

Introduction

This chapter covers the relevance of welding, brazing, and cutting processes with regard to inspection (see Figure 10.1). The information in the previous chapters will be summarized for each of the welding, brazing, and cutting processes named in AWS QC1, *Standard for AWS Certification of Welding Inspectors*. Each of the processes will be treated as follows:

- Weldability
- Welding metallurgy
- Welding chemistry
- Discontinuities
- Inspection processes

Limiting factors associated with each process will also be covered.

Limiting Factors

In addition to the considerations covered in previous chapters, each welding process has certain limiting factors that make a particular process a better choice for some applications than others. Although it may have been the obvious choice, a process is usually selected based upon a balance between cost and quality factors.

When a process is specified by the engineer, the welding inspector and welder must be aware of the limiting factors for the job, because they both must be able to anticipate and overcome any factors that could cause discontinuities or other more serious problems. In addition to weldability, the factors that influence the selection of a welding process are:

- Dimensions of the material being welded, especially its thickness, shape, and form
- Position in which welding must be done
- Requirements for the weld root
- Back side accessibility
- Joint preparation
- Availability of welding equipment, power sources, and fixtures

Dimensions of Material

The dimensions of a metal can limit the use of some processes and encourage use of others. For heavy sections, the engineer may select flux cored arc, submerged arc, or electroslag welding. However, sheet metal is often brazed, soldered, oxyacetylene welded, resistance welded, gas tungsten arc welded, or gas metal arc welded.

Welding Position

When the position of the joints cannot be located for flat position welding, limits on the application of arc and gas welding processes are imposed by the force of gravity. The small weld pool that must be used has little penetration, and the inspector may find slag inclusions and incomplete fusion as a result.

Root Requirements

The root of the weld joint must be fused by one technique or another, unless partial penetration welds have been specified by the design. Processes with deep penetration such as submerged arc, flux cored arc, and spray transfer gas metal arc welding are chosen by the engineer in preference to shielded metal arc welding, if that will simplify the joint preparation.

Root penetration in a tight butt joint that is welded by submerged arc welding in one pass from each side cannot be visually inspected. A joint that is backgouged to sound metal can be inspected with more confidence that the new root pass will fuse properly. The inspector relies on radiography and ultrasonic examination for volumetric inspection of such welds.

Back Side Accessibility

The accessibility of the back side of a joint strongly influences the choice of process. If inadequate aid is provided,

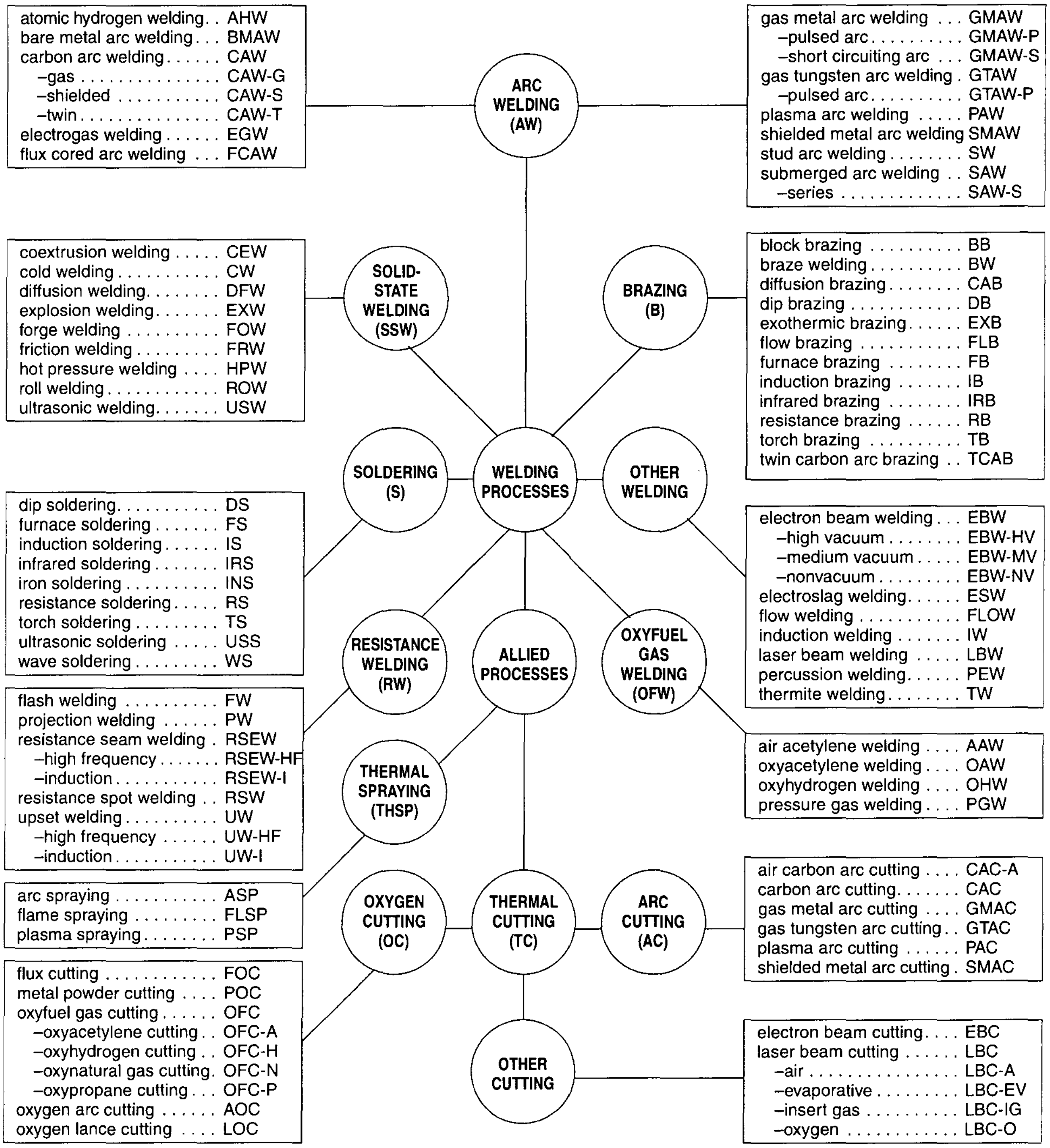


Figure 10.1—Master Chart of Welding and Allied Processes

the welder will need expert skill in making a root pass from one side of the joint. Made carelessly, such a weld commonly displays incomplete fusion, incomplete joint penetration, excessive melt-through, or other discontinuities.

Inaccessible roots are often welded using backing rings, consumable inserts, or automatic welding equipment. The inspector should expect to see a good fit of the parts prior to welding from one side of the joint. A familiar example is the pipeline weld, which is traditionally deposited with E6010 type shielded metal arc electrodes. Radiographic inspection detects discontinuities in the root of many such welds.

Joint Preparation

The suitability of available joint preparation also influences the process choice. For example, the square-groove butt joint of an electroslag weld is unsuited for manual welding, while a double-V-groove preparation may be manually welded with no difficulty.

To accommodate the nozzle of the gun, the groove angle of V-groove welds in heavy plate must be opened wider for gas metal arc welding than for covered electrodes. In any of these cases, unsuitable joint preparation can cause difficulty for the welder and can possibly result in imperfections which the inspector must catch.

Availability of Welding Equipment

The availability and portability of welding equipment are considerations that limit the choice of welding or cutting processes—particularly in the field. In remote areas, the process to be used is dictated by the availability of fixtures, power sources and consumables.

> Although a wide selection of filler metals is now available for welding a variety of metals, some filler metals still require special handling. For example, once removed from their original containers, low-hydrogen electrodes must be stored in vented electric ovens. Submerged arc fluxes, which are considered low hydrogen, also require storage in electric ovens. Solid and flux cored electrodes should be covered with a plastic bag when not in use, to protect them from airborne contaminants.

Examples of situations where the availability of welding equipment limits the choice of process are:

- Attempting gas tungsten arc welding without high-frequency-starting requires a higher level of skill than is normally available.
- Using copper starting tabs or striking the arc within the joint.
- Without using a foot-controlled rheostat, arc decay is more of a problem.
- Using gas metal arc welding in the pulsed arc mode requires a special power supply.
- Welding thin sheets that are subject to warping requires hold-down fixtures and chill bars, unless welding speeds are high.

Welding Processes

Welding is a process that results in the joining of metals through their melting together by application of heat, with or without the application of pressure, and with or without the addition of filler metal. The following welding processes are those that the welding inspector must know for the AWS CWI examination:

- Shielded Metal Arc Welding (SMAW)
- Gas Metal Arc Welding (GMAW)
- Flux Cored Arc Welding (FCAW)
- Gas Tungsten Arc Welding (GTAW)
- Plasma Arc Welding (PAW)
- Submerged Arc Welding (SAW)
- Electroslag Welding (ESW)
- Oxyacetylene Welding (OAW)
- Stud Welding (SW)

Shielded Metal Arc Welding (SMAW)

Shielded metal arc welding uses the heat of an electric arc between a covered metal electrode and the work. Shielding comes from the decomposition of the electrode flux coating. Filler metal is supplied by the electrode core wire and covering (see Figures 10.2 and 10.3).

This process is manually applied. The basic equipment is a power source, electrode cable, work cable, an electrode holder, a work clamp, and the electrode.

> All welding processes use one of three types of current. The correct way of expressing the current is alternating current, (ac) direct current electrode positive (dcep), or direct current electrode negative (dcen).

The electrode numbering for SMAW electrodes is shown in Figure 10.4. "E" stands for electrode. The first two digits (three in a five-digit number) are the tensile strength of the weld deposit times 1000. The third digit is the position in which the electrode can be used. "1" is all position, "2" is flat and horizontal only, and "4" is a vertical down low-hydrogen electrode. The last digit is the composition of the flux coating (see Table 10.1).

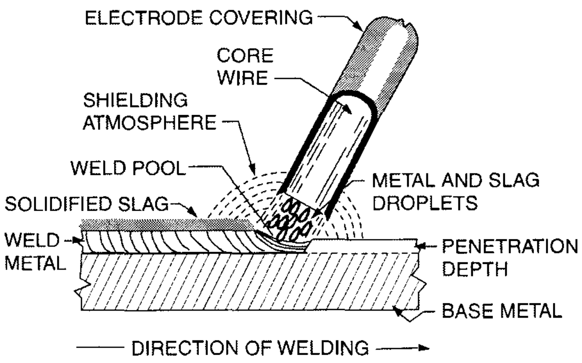


Figure 10.2—Shielded Metal Arc Welding

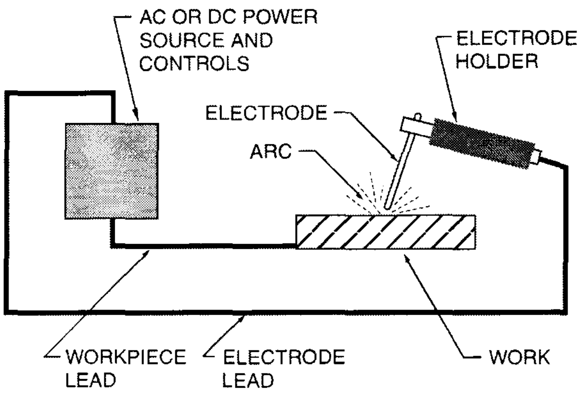


Figure 10.3—Typical Welding Circuit for Shielded Metal Arc Weld

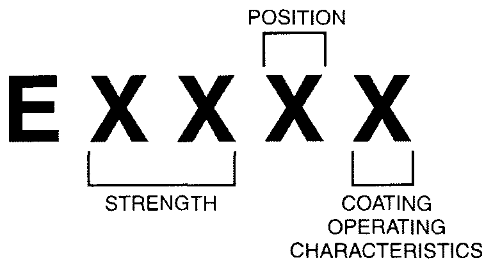


Figure 10.4—SMAW Electrode Identification System

Electrodes for SMAW operate variously on ac (alternating current), dcep (reverse polarity), or dcen (straight polarity).

A shielded metal arc weld is strengthened by adding alloying elements to the electrode covering. Unfortunately, some ingredients and the binder in the covering can attract and hold moisture (a source of hydrogen), which can cause cracking in certain metals. A group of electrodes specifically formulated to result in weld deposits having very low levels of hydrogen are referred to as *low hydrogen*. Electrodes that are classified as low hydrogen have identification numbers ending with 5, 6, or 8.

The electrode coating provides the following:

(1) Arc stabilization from ionizing elements (which dictate the usability of the electrode on ac, dcep, or dcen).

(2) Gas shielding for the weld puddle when some of the coating breaks down.

(3) Slagging agents contained in the coating that remove impurities from the work surface and weld puddle.

(4) Deoxidizers contained in the coating that reduce the tendency for porosity in the weld.

(5) An insulating blanket formed by the slag that protects the cooling weld metal from the atmosphere.

(6) Alloying elements contained in the coating that strengthen the weld metal.

(7) Increased weld metal deposition, when iron powder is incorporated in the coating.

Advantages

SMAW equipment is relatively simple and inexpensive. Gasoline and diesel powered equipment make the process portable. Newer solid-state power sources are so small and lightweight that they can be carried to the job. The availability of numerous electrodes makes the process quite versatile.

Disadvantages

The process is relatively slow, because the welder has to stop periodically to change electrodes. A layer of solidified slag must be removed. Low-hydrogen electrodes require special storage.

> For safety, inspectors must wear adequate eye protection. The arc should never be viewed without a number 10, 11, or 12 lens. Safety glasses with side shields should always be used in all welding and cutting operations.

Discontinuities

Almost any discontinuity can be produced by the SMAW process, if not applied properly. Porosity normally results when moisture or contamination is present

Table 10.1
Significance of Last Digit of SMAW Identification

Classification		Current	Arc	Penetration	Covering and Slag	Iron Powder
F3	EXX10	dcep	Digging	Deep	Cellulose–sodium	0–10%
F3	EXXX1	ac and dcep	Digging	Deep	Cellulose–potassium	0
F2	EXXX2	ac and dcen	Medium	Medium	Rutile–sodium	0–10%
F2	EXXX3	ac and dc	Light	Light	Rutile–potassium	0–10%
F2	EXXX4	ac and dc	Light	Light	Rutile–iron powder	25–40%
F4	EXXX5	dcep	Medium	Medium	Low hydrogen–sodium	0
F4	EXXX6	ac or dcep	Medium	Medium	Low hydrogen–potassium	0
F4	EXXX7	ac or dcep	Medium	Medium	Low hydrogen–iron powder	25–40%
F1	EXX20	ac or dc	Medium	Medium	Iron oxide–sodium	0
F1	EXX24	ac or dc	Light	Light	Rutile–iron powder	50%
F1	EXX27	ac or dc	Medium	Medium	Iron oxide–iron powder	50%
F1	EXX28	ac or dcep	Medium	Medium	Low hydrogen–iron powder	50%

Note: Iron powder percentage based on weight of covering.

in the weld region, i.e., in the electrode coating, on the surface of the material, or from the surrounding atmosphere. Porosity can also be caused by faulty technique. Cluster porosity often occurs due to long arcing at the initiation and termination of the arc.

Porosity can also result from the presence of a phenomenon called *arc blow.* (Although it can occur with any arc welding process, arc blow will be discussed here because it is a common problem for the manual welder.)

To understand arc blow, one must first understand that a magnetic field is developed whenever an electric current is passed through a conductor (see Figure 10.5). Because this magnetic field is developed in a direction perpendicular to the direction of the electric current, it can be visualized as a series of concentric circles around the conductor. This magnetic field is strongest when it is contained entirely within a magnetic material and resists having to travel through the air outside the magnetic material. Consequently, when a magnetic material such as steel is welded, the field can become distorted when the arc approaches the edge of the plate, the end of a weld or some abrupt change in the contour of the part being welded (see Figure 10.6).

To reduce the effect of arc blow:

(1) Change from dc to ac.

(2) Hold as short an arc as possible.

(3) Reduce welding current.

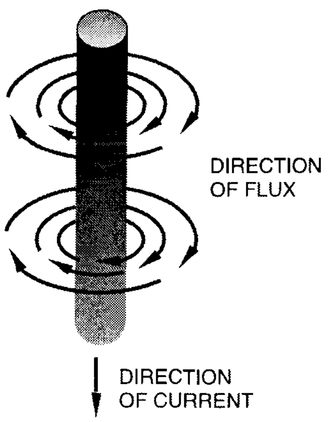


Figure 10.5—Magnetic Field Around Electric Conductor

(4) Angle the electrode in the direction opposite the arc blow.

(5) Use heavy tack welds at either end of a joint, with intermittent tack welds along the length of the joint.

(6) Weld toward a heavy tack or toward a completed weld.

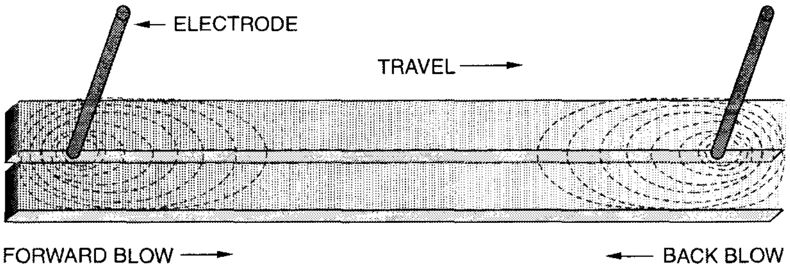


Figure 10.6—Distorted Magnetic Fields and Ends of Welds

(7) Use a backstep technique.

(8) Weld away from the ground to reduce back blow; weld toward the ground to reduce forward blow.

(9) Attach the work cable to both ends of the joint to be welded.

(10) Wrap work cable around the workpiece and pass work current through it in such a direction that the magnetic field setup will tend to neutralize the magnetic field causing the arc blow.

(11) Extend the end of the joint by attaching runoff plates.

In addition to porosity, arc blow can also cause spatter, undercut, improper weld contour, and decreased penetration. Slag inclusions are most often the result of improper welding technique, insufficient interpass cleaning, or faulty manipulation of the electrode. In addition, if the designer provides insufficient access for welding within the joint, slag inclusions can result.

Since SMAW is primarily accomplished manually, numerous discontinuities can result from improper manipulation of the electrode, such as incomplete fusion, incomplete joint penetration, undercut, overlap, incorrect weld size, and improper weld profile.

Gas Metal Arc Welding (GMAW)

GMAW uses the heat of an electric arc between a continuous bare wire filler metal electrode and the work. Shielding is obtained entirely from externally supplied inert gas such as argon or helium, an active gas such as CO_2 or O_2, or some combination thereof (see Figure 10.7).

GMAW can be a semiautomatic, machine, automatic, or automated process. In the semiautomatic mode, the welder controls both the inclination and distance of the welding gun from the work, and also the travel speed and manipulation of the arc. Arc length and electrode feed are controlled automatically by the power source and wire feeder controller (see Figure 10.8). The gas metal arc process deposits the weld metal in the joint by one of the following modes: spray transfer, globular, short circuiting transfer, or PAW (see Figure 10.9).

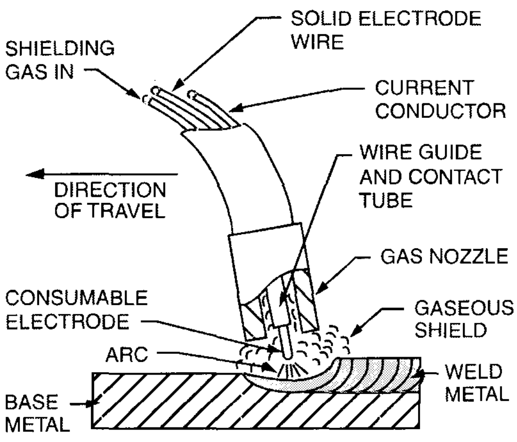


Figure 10.7—Gas Metal Arc Welding Process

Spray transfer occurs when the transition current and voltage exceed a level that depends upon the type and size of the wire. Current and voltage are high and the gas is inert or inert with small additions on active gases. For each electrode size and type, there is a transition current above which the metal "pinches off" in fine droplets many times per second. The current propels the droplets axially down the center of the arc, away from the electrode, and straight into the pool. Spray transfer mode best defines the arc and the pool for the welder. Spray transfer mode requires high current relative to the diameter of the electrode. Due to its high heat capacity, this mode of transfer is best suited for flat and horizontal position welding.

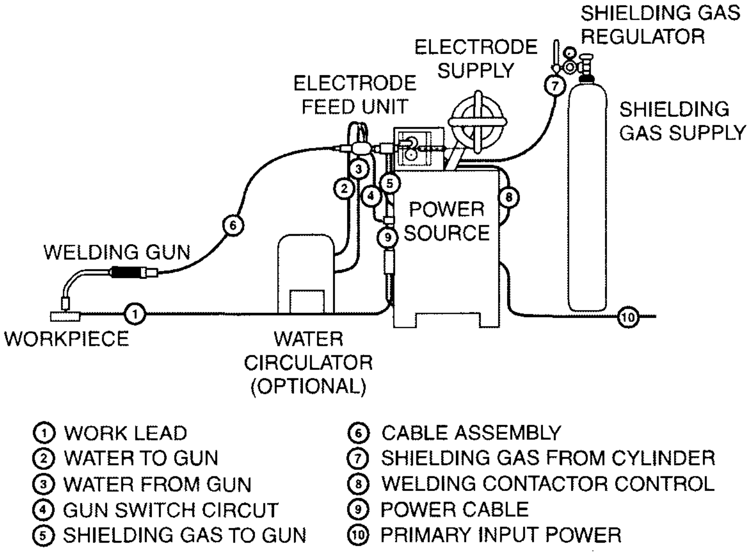


Figure 10.8—Diagram of Gas Metal Arc Welding Equipment

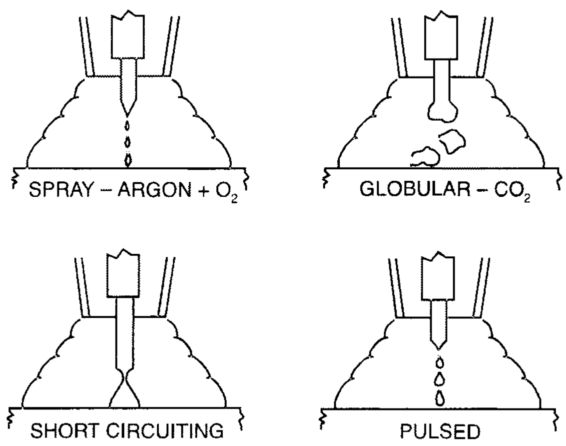


Figure 10.9—The Four Types of Metal Transfer

Globular transfer occurs at low currents compared to spray transfer—low, that is, in relation to the size of the electrode. Low-current density at the electrode tip produces large, irregular drops of metal that transfer to the pool without much direction. The result is increased amounts of spatter, as compared to spray transfer.

In short circuiting transfer, the wire contacts the workpiece and the arc is extinguished. Current continues to flow and the resistance causes the wire to separate and the arc to reignite, which causes the weld to be deposited drop by drop up to 200 drops per second.

The short circuiting mode is a relatively cold process, and its misapplication can result in incomplete fusion. It readily bridges gaps. Sheet metal can be welded without excessive melt-through and welds may be made in all positions.

Pulsed arc welding maintains a low voltage and current arc as the background condition. This condition causes an arc to maintained, but does not cause metal transfer. The power supply can be adjusted to provide a pulse of high current and voltage, which takes the welding conditions above the transition level and detaches a drop from the electrode and propels it across the arc. The number of pulses per second can usually be adjusted; transfer occurs during each pulse. Pulsing the power lowers the average heat input from the current, and out-of-position welding then becomes possible using larger wire sizes. The power supply must have pulsing capabilities.

Figure 10.10 shows the numbering system for GMAW electrodes. "E" denotes an electrode; "R" denotes a rod (round) electrode. The next two digits (three in a 5-digit number) stand for the tensile strength of the weld deposit, times 1000. "S" denotes a solid electrode. The last digit is the chemical classification.

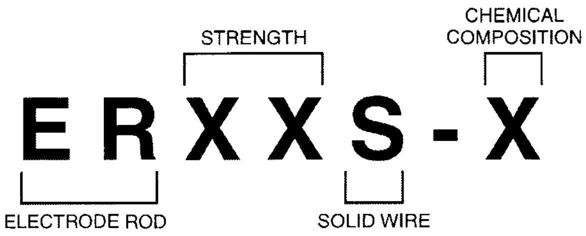


Figure 10.10—GMAW Electrode Identification System

> Shielding gases protect gas metal arc welds from the atmosphere. Fluxes are not used in this process. All deoxidizers and alloying elements are incorporated into the electrode wire.

Advantages

GMAW can be effectively used to join or overlay many types of ferrous and nonferrous metals. The use of a gas shielding instead of a flux which can become contaminated, can reduce the possibility of hydrogen being introduced into the weld zone; therefore, GMAW can be used successfully in situations where the presence of hydrogen could cause problems. Due to the lack of a slag coating that must be removed after welding, GMAW is well suited for automatic and robotic welding or high production. Since there is little or no cleaning required following welding, overall operator productivity is greatly improved. This efficiency is further increased because the continuous spool of wire does not require changing as often as the individual electrodes used in SMAW. GMAW is a clean process, because there is no flux present. When no slag is present, the welder can more easily observe the action of the arc and the weld puddle to improve control.

Disadvantages

Since GMAW uses shielding gas alone to protect the puddle from the atmosphere excessive contamination of the base metal may cause porosity. Drafts or wind may disperse shielding gases, which makes GMAW unsuitable for field welding. The equipment used is more complex than that used for SMAW, increasing the possibility of mechanical problems that can lead to quality problems. The use of short-circuiting transfer can lead to lack of fusion discontinuities.

Discontinuities

GMAW can result in any of the common weld discontinuities, except slag inclusions. Porosity, which is caused by gas trapped in the weld, is often caused by improper gas shielding. The shielding gas must displace the surrounding atmosphere, which contains oxygen and nitrogen. Welding without adequate shielding permits atmospheric oxygen and nitrogen to dissolve in the molten metal. Use of higher shielding gas flow rates will also lead to the production of porosity, due to the vortex action produced that tends to draw atmospheric gases into the arc region.

Incomplete fusion is possible, especially in welds made with short-circuiting transfer. The presence of undercut and underfill reflect poor technique by the welder. Overlap is more prevalent in globular transfer and with the short circuiting arc.

Flux Cored Arc Welding (FCAW)

FCAW uses the heat of an arc between a continuous filler metal electrode and the work, which is similar to GMAW, except that in FCAW the electrode is tubular and contains a granular flux instead of the solid wire used in GMAW (see Figures 10.11 and 10.12). Shielding is obtained, in whole or in part, from a flux contained within the tubular electrode. Self-shielded electrodes require no external gas protection, while other flux cored electrodes use additional external gas shielding (commonly carbon dioxide or argon/carbon dioxide mixes) supplied through the welding gun.

The FCAW electrode contains flux, deoxidizers, and alloying elements within the tubular wire. If external shielding is provided, the choice of shielding gas is usually carbon dioxide, or a mix of carbon dioxide and argon. Thus, 75% argon–25% carbon dioxide can be used to improve the operating characteristics of the arc and provide excellent mechanical properties of the finished weld.

> Self-shielded cored electrodes depend entirely on elements in the flux to provide the shielding for the weld puddle. To achieve this, self-shielded cored wires depend on an electrical stickout to produce the gas. The stickout causes resistance heating of the wire, which breaks down the gas-producing elements in the wire that produces the protective gas. Electrical stickout is an important variable when using self-shielded cored wires.

The numbering system for FCAW is shown in Figure 10.13. "E" denotes electrode. The next digit is the tensile strength of the weld deposit times 10 000. The next digit

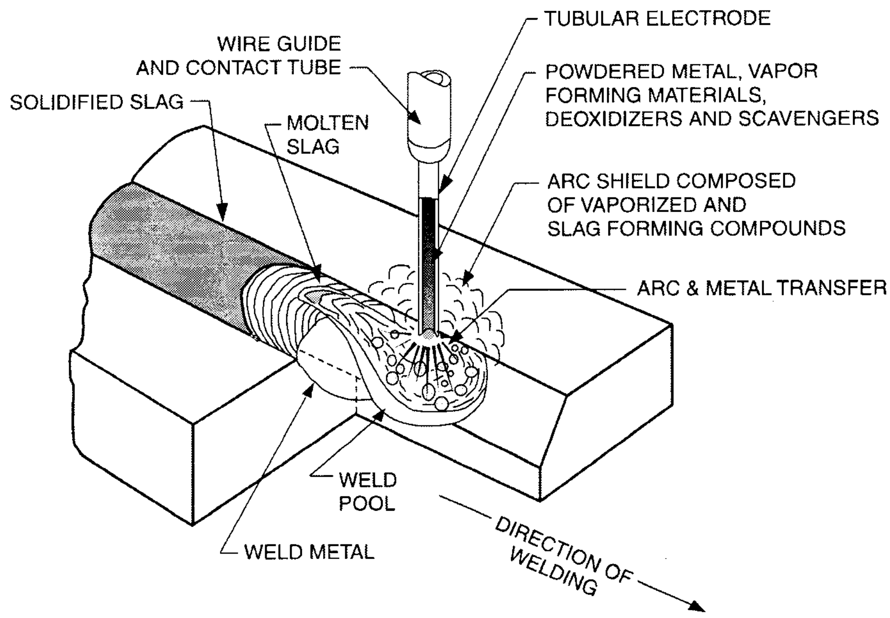


Figure 10.11—Self-Shielded Flux Cored Arc Welding

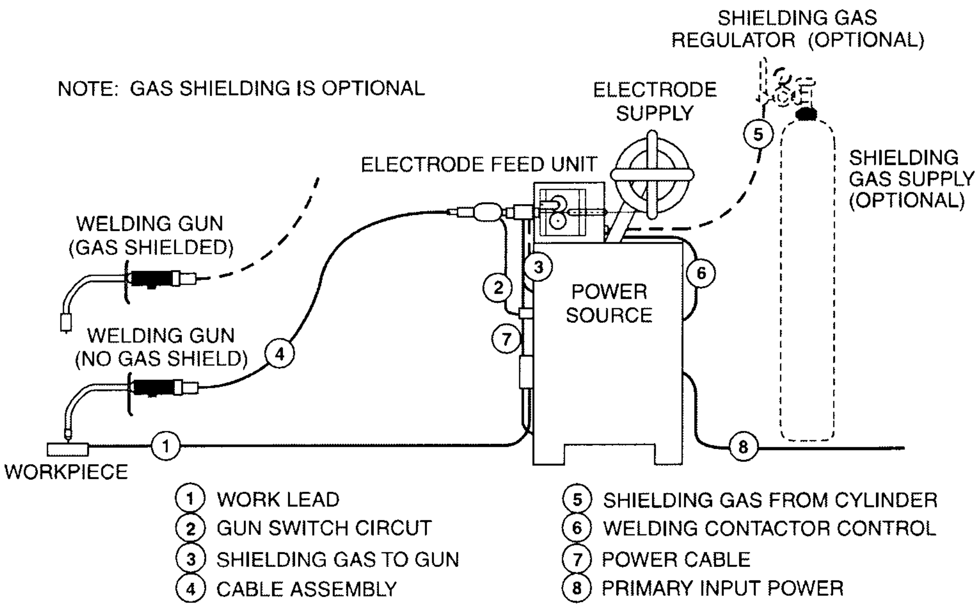


Figure 10.12—Diagram of Flux Cored Arc Welding Equipment

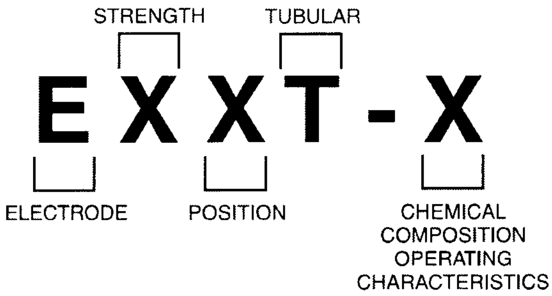


Figure 10.13—FCAW Electrode Identification System

is the position the electrode can be used in. A "1" can be used in all positions. A "0" can be used flat and horizontal only. "T" denotes a tubular wire, and the last digit is the chemical classification.

Advantages

Due to increased deposition rates and a high tolerance for contamination, FCAW has replaced SMAW and GMAW in many applications. FCAW can be used in both shop and field applications, and provides high productivity in the terms of the amount of weld metal that can be deposited in a given period of time, particularly for the hand-held process. This process is characterized by an aggressive, deeply penetrating arc that tends to reduce the possibility of fusion-type discontinuities. FCAW can be used in all positions.

Disadvantages

Because a flux is present during welding, a layer of solidified slag must be removed. The flux also generates a significant amount of smoke, which reduces the welder's visibility and makes the weld puddle more difficult to observe.

Discontinuities

The most prevalent discontinuities are porosity and slag entrapment. Inadequate shielding, or a disruption in the shielding atmosphere causes porosity, while improper travel speed or incorrect manipulation of the welding gun often results in slag entrapment.

Gas Tungsten Arc Welding (GTAW)

GTAW uses an electric arc between a nonconsumable electrode and the work. Shielding is obtained from an inert gas or inert gas mixture. Filler metal can be added as needed. The torch is usually water cooled, but can be air cooled for low-current applications (see Figures 10.14 and 10.15).

This type of welding can be accomplished by manual, mechanized, or automatic methods. When filler metal is added, the process calls for a two-handed technique, as in oxyacetylene welding. Cold-wire and hot-wire feeds are automated versions of that technique.

Slow heating and low temperatures combined with the slow cooling rates that are characteristic of GTAW result in improved weld metal and heat-affected zone (HAZ) mechanical properties. The tungsten electrode provides

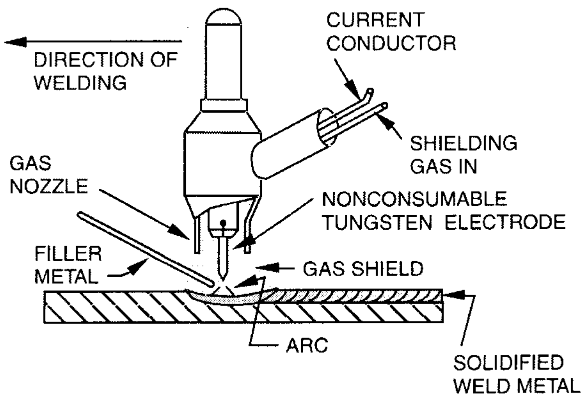


Figure 10.14—Gas Tungsten Arc Welding Operation

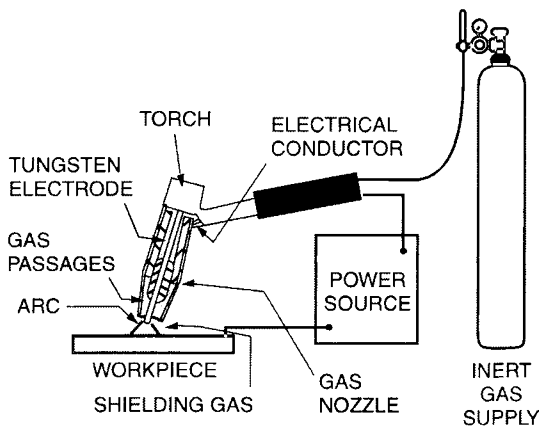


Figure 10.15—Gas Tungsten Arc Welding Equipment

the means of initiating the arc. The melting is essentially slow and that most of the gases evolved can escape from the weld pool before it freezes.

With the exception of aluminum, which is normally welded using ac, most of the GTAW is done using dcen. Aluminum forms an oxide immediately upon being cleaned. Oxide cleaning occurs when using dcep or ac, however, dcep is impractical due to the electrode's poor current-carrying capacity, but ac provides cleaning every half cycle. Arc reignition is normally accomplished by a superimposed high-frequency current (see Table 10.2). Although the electrode is called nonconsumable, it does become contaminated by contact with the weld puddle or the filler metal, and becomes consumed as it is cleaned.

Several classifications of tungsten electrodes are available, however, EWTh-2 is recommended for use with dcen and when welding with ac, EW-P is recommended (see Table 10.3). It is recommended that tungsten for welding dcen be a hollow ground taper with a small, blunt end. When welding with ac, the recommendation is to "ball" the tungsten; however, the characteristics of some of the newer power supplies suggest different end shapes. Consult the manufacturer for recommendations.

For mechanized applications, filler wire may be added manually or by the use of a wire feeder. The classification for filler wire for GTAW operations is the same as that for the GMAW process.

Advantages

The GTAW process is capable of welding virtually all metals, even extremely thin materials. The principal advantage of GTAW is that high-quality welds with excellent visual appearance can be produced. Also because no flux is used, the process is quite clean and there is no slag to remove after welding.

Disadvantages

The skill level necessary to produce high-quality welds is acquired only after much experience in manipulating the electrode and feeding the filler wire. Because the process has a low tolerance for contamination, the base and filler metals must be extremely clean prior to welding. GTAW is among the slowest of the available welding processes.

Discontinuities

All of the common types of discontinuities are possible with GTAW, except slag inclusions. A problem unique to

Table 10.2
Effect of Welding Current Type on Penetration for GTAW

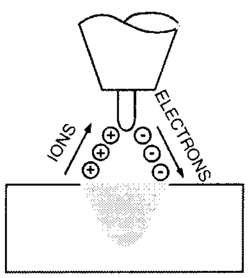
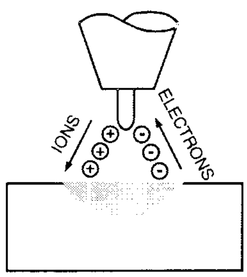
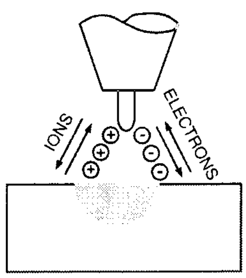
Current Type	dc	dc	ac (balanced)
Electrode Polarity	Negative	Positive	
Electron and Ion Flow Penetration Characteristics			
Oxide Cleaning Action	No	Yes	Yes—Once every half cycle
Heat Balance in the Arc (Approx.)	70% at work end 30% at electrode end	30% at work end 70% at electrode end	50% at work end 50% at electrode end
Penetration	Deep; narrow	Shallow; wide	Medium
Electrode Capacity	Excellent (e.g., 3.18 mm [1/8 in.] – 400 A	Poor (e.g., 6.35 mm [1/4 in.] – 120 A	Good (e.g., 3.18 mm [1/8 in.] – 225 A

Table 10.3
AWS Tungsten Electrode Classifications

AWS Classification	Alloy	Color
EWP	Pure Tungsten	Green
EWTh-1	0.8–1.2% Thoria	Yellow
EWTh-2	1.7–2.2% Thoria	Red
EWTh-3	0.35–0.55% Thoria	Blue
EWZr	0.15–0.40% Zirconia	Brown
EWCe-2	1.8%–2.2% Ceria	Orange

GTAW welding is tungsten inclusions. This discontinuity occurs when some of the tungsten becomes imbedded in the weld. Tungsten inclusions may result from accidental touching of the tungsten electrode to the weld pool. The hot tip may have a molten spot to which the arc is attached. The molten drop is readily transferred to the pool, thus producing a tungsten inclusion in the weld. Use of excessive welding currents for a given electrode diameter can also contribute to the deterioration of the electrode and result in tungsten inclusions. The use of a "scratch-start" technique in the absence of high-frequency current can also result in the production of this discontinuity. Whether such inclusions are rejectable depends on the governing specifications.

Plasma Arc Welding (PAW)

PAW is a process which utilizes a constricted arc between the electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc). In many respects, this process is quite similar to GTAW; however, the constricted arc provides a much more localized heat source (see Figures 10.16 and 10.17).

Shielding for this process is obtained from the hot, ionized gas issuing from the torch, which may be supplemented by an auxiliary source of shielding gas. This shielding gas may be inert gas or a mixture of gases. There is no pressure utilized and filler metal may or may not be required.

Like the gas tungsten arc process, PAW uses a tungsten electrode, but the electrode is recessed into the torch. The constricted arc produces a more localized heat source that results in the ability to weld materials at higher travel speeds than those obtainable with GTAW. This tends to reduce the heat input, resulting in faster HAZ cooling rates. However, the HAZ hardness in some materials may increase to the degree that cracking might result. Like GTAW, filler metal addition may not be necessary if the edges of the base metals are melted and fused together (see Figure 10.18).

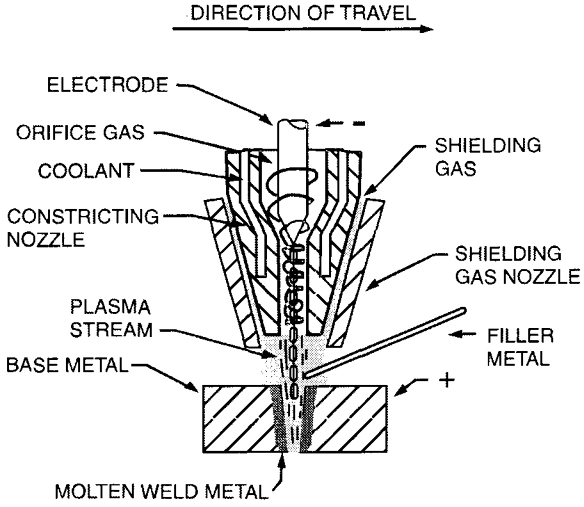


Figure 10.16—Plasma Arc Welding (Keyhole Mode)

Since the tungsten electrode is not intended to be consumed, it contributes neither deoxidation nor fluxing to the molten metal. Filler metals to be used should contain deoxidizers to reduce the tendency for the production of porosity. Base and filler metal cleanliness is also important for this process, as with GTAW.

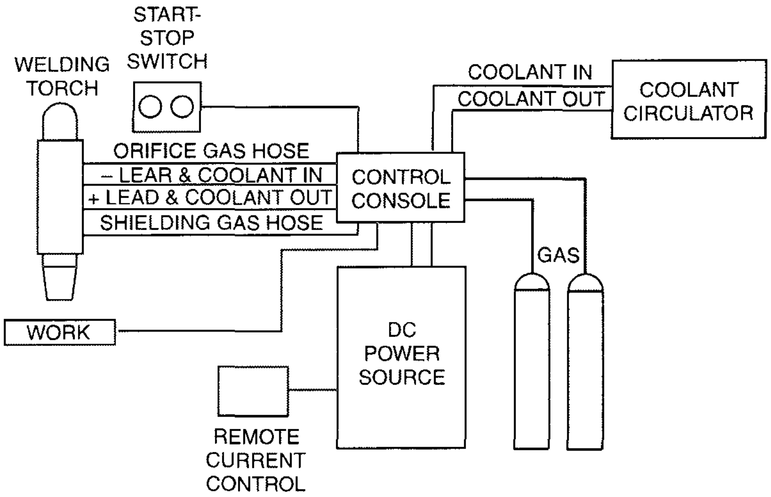


Figure 10.17—Typical Equipment for Plasma Arc Welding

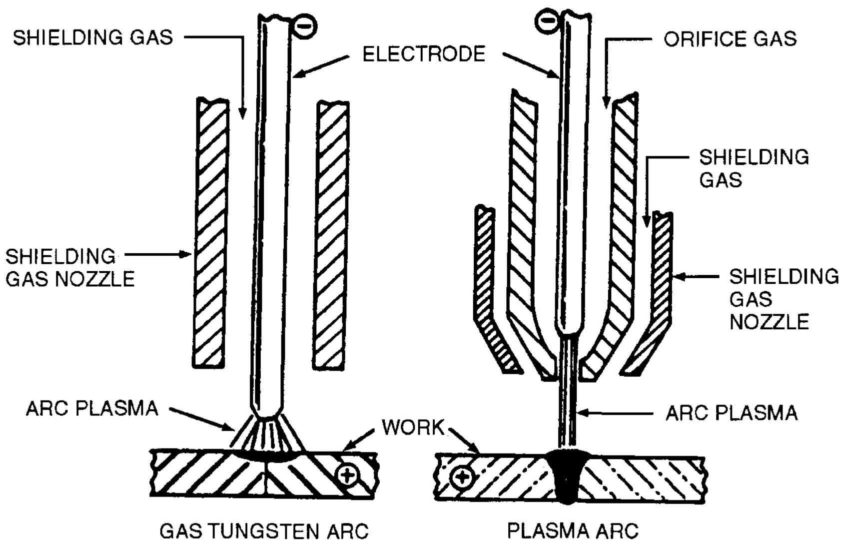


Figure 10.18—Comparison of GTAW and PAW Torches

Advantages

PAW provides a very localized heat source. The constricted arc is less sensitive to changes in arc length, plus the distance from the torch to the work is longer than that for gas tungsten arc welding. Both of these factors tend to make the PAW process easier to control manually.

One variation of PAW used for producing complete joint penetration groove welds is referred to as the *keyhole* technique (see Figure 10.19). With this method, welding is performed on a square-groove butt joint with zero root opening. The concentrated heat of the arc penetrates through the material thickness to form a small keyhole. As welding progresses, the keyhole moves along the joint melting the edges of the base metal which then flow together and solidify after the welding arc passes. This creates a high quality weld, with no elaborate joint edge geometry and faster welding travel speeds compared to GTAW.

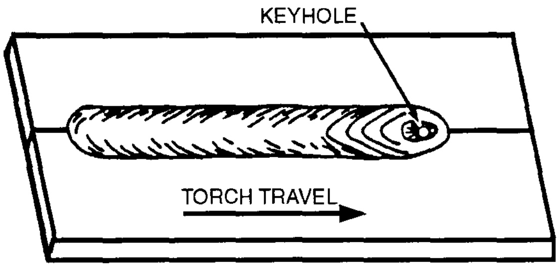


Figure 10.19—Keyhole Technique for Plasma Arc Welding

The faster welding speeds obtainable with this method tend to reduce the amount of distortion present after welding.

Disadvantages

PAW is limited to materials 1 in. thick or less. The use of PAW may require greater operator skill due to more complex equipment.

Discontinuities

All of the discontinuities discussed for GTAW are also applicable for PAW.

There is a reduced tendency for tungsten inclusions with PAW, due to the fact that the tungsten is recessed in the torch. Use of excessive welding currents can cause overheating of the copper constricting nozzle, resulting in copper inclusions in the weld. Because the arc is constricted, mistracking of the joint is possible, which may result in incomplete fusion—especially when the keyhole technique is being used. Another discontinuity unique to PAW with the keyhole technique is commonly referred to as *tunneling*, which is a pore oriented through the weld throat at the termination of a keyhole weld. Tunneling occurs when the welder fails to properly fill the keyhole at the weld termination.

Submerged Arc Welding (SAW)

SAW uses the heat of an electric arc or arcs between the electrode or electrodes and the work, all shielded by a blanket of granular flux.

Welding under a granular flux is a semiautomatic, mechanized or automatic process in which electrode feed and arc length are controlled by the wire feeder and power supply. In automatic welding, a travel mechanism moves either the torch or the work, and a flux recovery system recirculates the unfused granular flux back to the flux hopper for reuse (see Figures 10.20 and 10.21).

The arc is hidden in submerged arc welding, which frees the welder or operator from his helmet but hides the path he must follow. For machine or automatic welding, the path is prealigned or a seam-tracking apparatus controls the orientation of the torch relative to the joint centerline. In semiautomatic submerged arc welding, the gun is actually moved along the joint in contact with the faces of the work (usually a T-joint or groove weld) to control the location of the weld. This process can produce deep penetration by the arc. Straight butt joints can be welded in metal 1 in. thick in one pass from each side with complete joint penetration, if the joint is accurately followed and the current density is high.

The high heat input of this process produces rapid heating and cooling. Sound welds are deposited rapidly and economically, with excellent metallurgical properties.

The weld composition results from contributions from the melted base metal and the electrode, modified by chemical reactions with the flux, and alloys added through the flux. Since the flux and filler wire are independently dispensed in this process, great flexibility in obtaining weld properties is possible. The inspector must make sure that the proper procedures are followed (see Figure 10.22). Shop dirt, grease or moisture can contaminate the flux, resulting in cracks. Some fluxes require heated storage containers and hoppers to ensure that the flux is dry when used.

Advantages

SAW can be performed on numerous metals. Due to the high rate of weld metal deposition, SAW has shown itself to be quite effective for overlaying or building up of material surfaces. It can typically deposit more metal than any of the more common processes. It has operator appeal—because of the lack of an arc, the operator has no need for a filter lens and other heavy protective clothing. Another benefit is that there is less smoke generated than with the other processes. SAW has very deep penetrating capabilities.

Disadvantages

Cleaning the work surfaces and aligning the machine travel with the joint are particularly important in submerged arc welding. Improper alignment will result in offset beads with incomplete joint penetration. In a highly restrained joint, joint misalignment may also cause cracks. The flux is of a low-hydrogen type that may require storage in heated ovens. Because of its deep

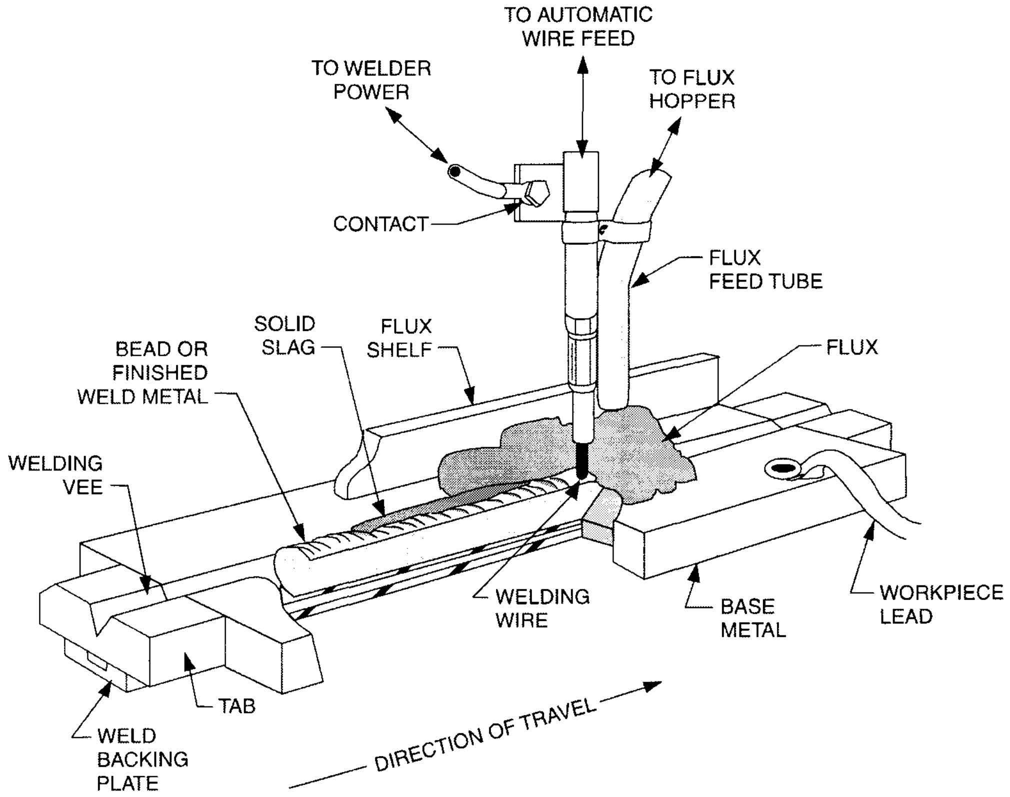


Figure 10.20—Schematic View of Submerged Arc Welding Process

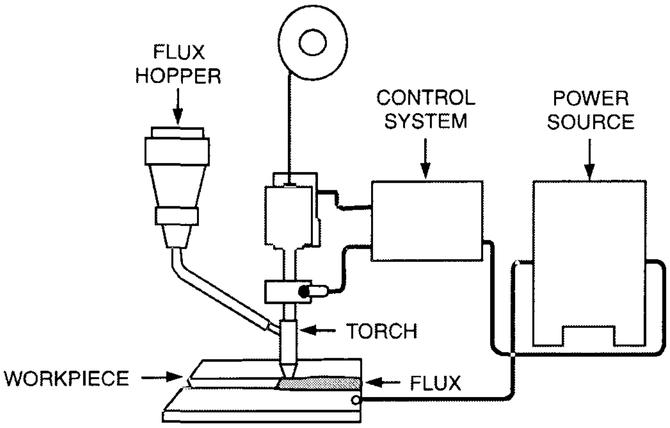
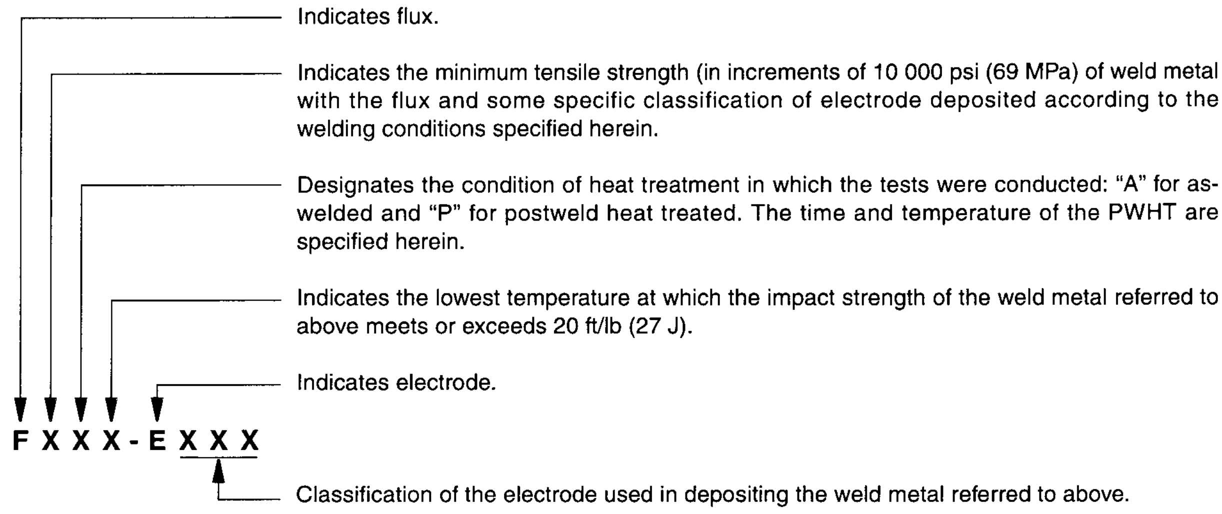


Figure 10.21—Submerged Arc Welding Equipment



EXAMPLE

F7A6-EM12K is a complete designation. It refers to a flux that will produce weld metal which, in the as-welded condition, will have a tensile strength no lower than 70 000 psi and Charpy V-notch impact strength of at least 20 ft/lb at −60°F when deposited with an EM12K electrode under the conditions called for in this specification.

Figure 10.22—SAW Filler Metal Classification System

penetrating arc it may have an extreme width to depth ratio, that can lead to centerline cracking.

Discontinuities

Welds may exhibit all of the common discontinuities. Porosity is sometimes encountered in submerged arc welds, because of wet or dirty flux or a contaminated joint.

Slag inclusions are found in many submerged arc welds. Convex bead profiles in multiple pass welds are frequently the cause. Convex beads leave narrow pockets against prior beads and along the groove faces in which slag will cling, or within which new slag will become trapped under the next bead.

Incomplete fusion may occur in attempting too large a weld in one pass or in welding too fast. Incomplete joint penetration also occurs when the welding arc is carelessly aligned with the joint.

Undercut is common in SAW when high welding currents are used.

Cracks in submerged arc welds may occur when the material is hot or cold, sometimes due to excessive depth-to-width ratios (see Figure 10.23). Crater cracks may be anticipated unless the operator has perfected a crater-filling technique. Runoff tabs are commonly used to put starts and stops outside the weld joint area. Throat cracks in small root pass weld beads between heavy sections are typical in a highly restrained joint.

Electroslag Welding (ESW)

ESW uses an electrically melted metallurgical flux that melts the filler metal and the surfaces of the work. The heat is created by the electrical resistance of the flux. There is no arc, except at the start of the weld before the granular flux melts and becomes conductive. The slag is then kept molten by its resistance to the flow of electric current passing between the electrode and the work.

Electroslag welding is purely a mechanized or automatic process. The melted base metal, electrode, and guide tube (in consumable guide welding) collect at the bottom of the flux pool. Welding is done in the flat position, with welding progressing from the bottom to top of a weld joint positioned vertically. Water-cooled backing shoes in contact with the joint sides contain the molten weld metal and the molten flux. The weld surface is molded by the contour of the shoes. The vertical progression of welding provides directional solidification of the molten pool and ready flotation of all nonmetallic impurities into the floating slag layer. As the molten metal slowly solidifies in upward progression, it joins the plates together. This process has a high deposition rate,

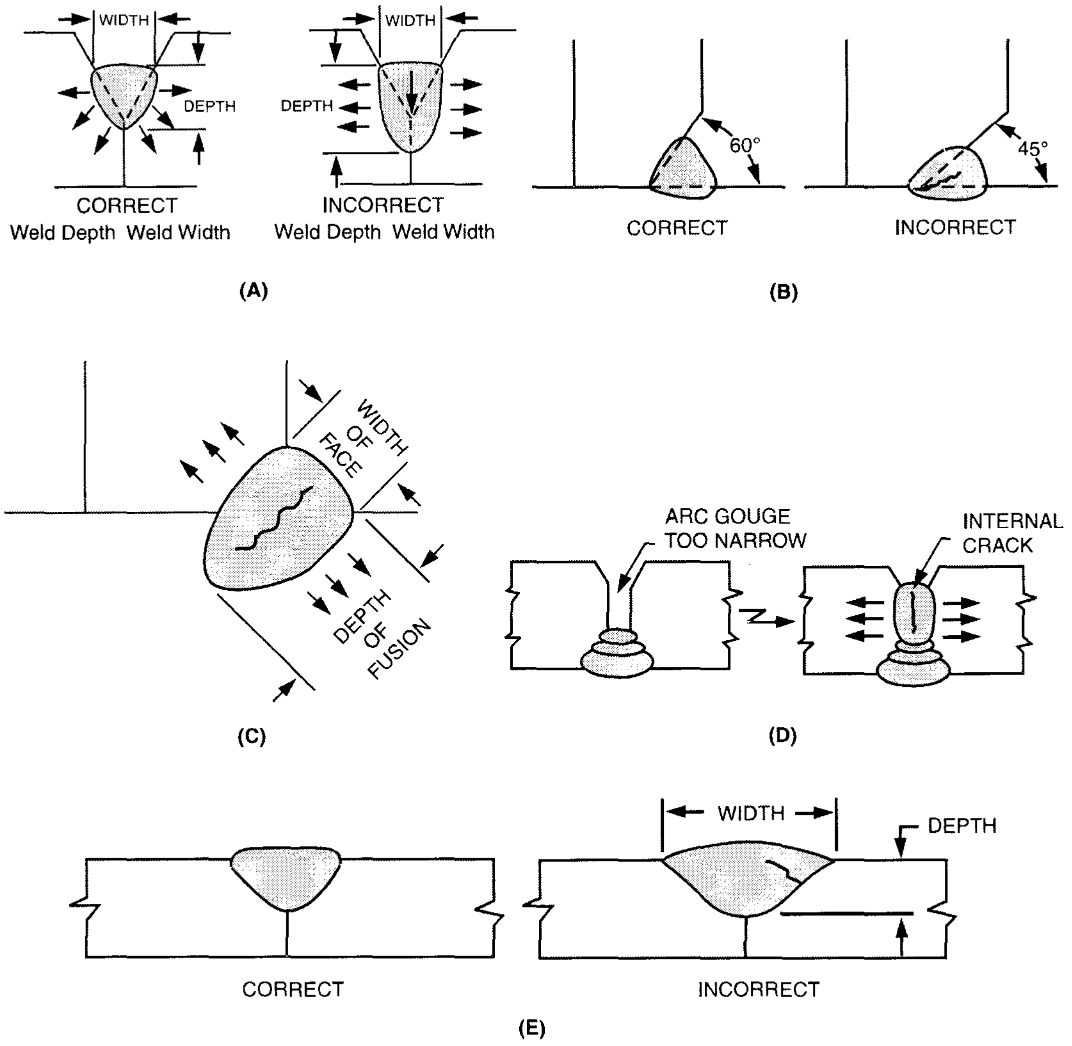


Figure 10.23—Solidification Cracking Because of Weld Profile

therefore, a substantial amount of base metal is melted to form part of the weld in this process (see Figure 10.24).

> Two metallurgical factors are important in electroslag welding: symmetrical stress patterns, which result in no angular distortion, and large weld metal grain sizes resulting from slow cooling. The stresses induced during the slow cooling of the weld is symmetrical with no distortion, which is different from the result when groove welds are welded from one side of a joint using some other welding processes. The large grains associated with electroslag welding tend to reduce the mechanical properties of the weld metal and cracking may result, especially if the weld joint is highly restrained.

The welding composition is controlled by a combination of base metal, electrode, and consumable guide tubes (if used) and the metal is protected from oxidation and refined by the molten slag. The slag used in this process is a metallurgical flux that refines both the fused base metal and the filler metal. As welding progresses, the slag also shields the weld pool along the full cross section of the joint.

Advantages

The major advantage of ESW is its high deposition rate. If single electrode welding is not enough, then multiple electrodes can be used. ESW requires no special joint preparation. Because the entire thickness of the joint

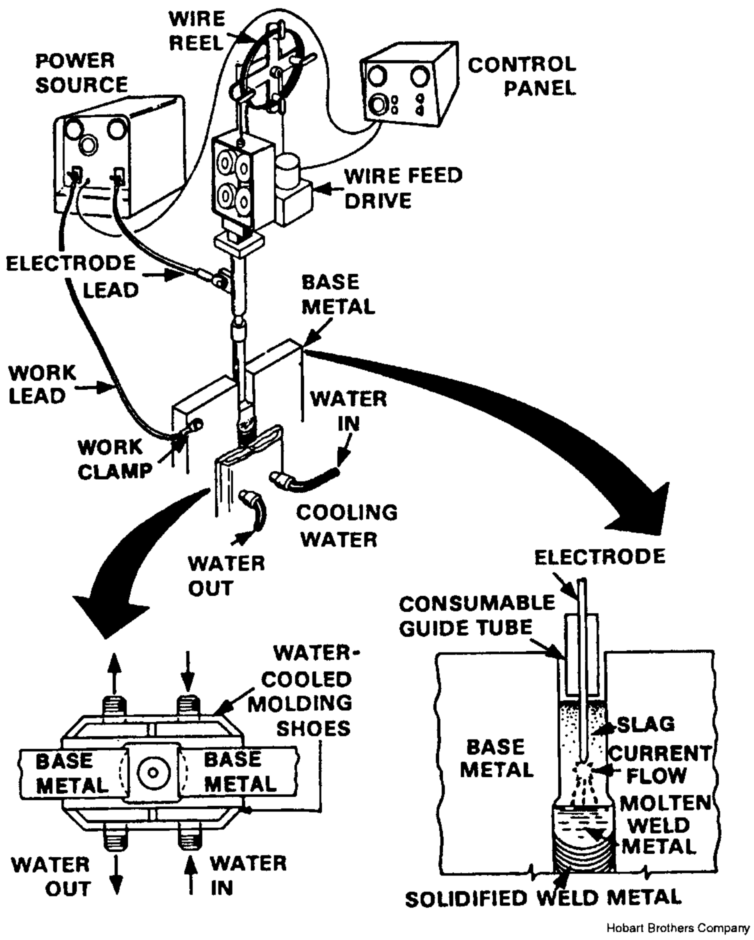


Figure 10.24—Electroslag Welding Equipment

is fused in a single pass, there is no tendency for angular distortion.

Disadvantages

Due to the extensive time required for this setup, only thicker sections can be economically joined using this process. Preweld preparation is simple. Faces of the joint must be aligned, but this is not as critical as with some other processes. The plate edges must be smooth and fairly uniform in thickness for proper positioning of the backing shoes.

Discontinuities

All of the common discontinuities may appear in electroslag welds.

Porosity usually occurs in the gross form of piping porosity, which can be caused by moisture in the flux or by the "sweating" of the water-cooled backing shoes.

Slag inclusions are uncommon but may exist. They normally result from improper operating parameters that may allow solidified slag to become mechanically trapped. An inadequate starting sump (joint extension) will leave poorly melted metal and slag in the weld. Shallow runoff tabs at the top of the joint may fail to allow the joint to be completely filled, resulting in underfill. Incomplete fusion often occurs in welds with poor shape of the pool. Welds in thick plates in which the heat is distributed by oscillating the electrode(s) may have incomplete fusion in the central portion, or near the shoes. The cooling effect of the shoe may prevent melting of the base metal out to the surface. The resulting indication resembles an undercut.

Overlap may occur if the shoes do not ride smoothly and closely on the plates, allowing the pool to grow outward from the surface plane. Cracking, often severe, may occur in electroslag welds made in a deep, narrow pool at high welding speeds, due to the undesirable solidification patterns which result.

Oxyacetylene Welding (OAW)

OAW is a chemical welding process which relies on the chemical reaction between the oxyacetylene flame and the base metal to produce the necessary heat for melting the base and filler metals, if filler metal is used (see Figures 10.25 and 10.26).

The oxyacetylene flame is produced by burning acetylene gas with pure oxygen fed through a torch, completing the combustion with oxygen in the air. Oxyacetylene welding is a manual process. While other fuel gases are effective for cutting operations, only acetylene provides sufficient heat to produce a satisfactory weld in steel. The temperature of the oxyacetylene flame is about 5600°F, which is sufficient to melt the commonly used metals. The flame provides both the heat and the necessary shielding of the molten metal for most applications; however, fluxes are available to improve the cleaning action on some materials. Both the heat and shielding are provided by the chemical reaction of the flame with the base metal. An important variable is the size of the torch tip, which must be large enough to preheat the weldment and maintain a molten pool.

The welder must regulate the torch flame to burn under neutral conditions, with the primary reaction exactly balanced, yielding only carbon monoxide and hydrogen. The flame atmosphere is then neither carburizing nor oxidizing. This flame adjustment must be determined from the appearance of the inner flame cone and the noise of the flame. The hot metal is then protected from the

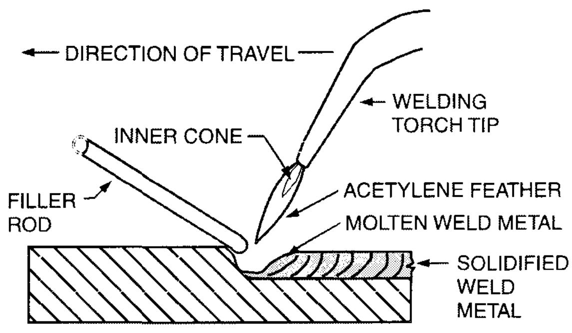


Figure 10.25—Oxyacetylene Welding

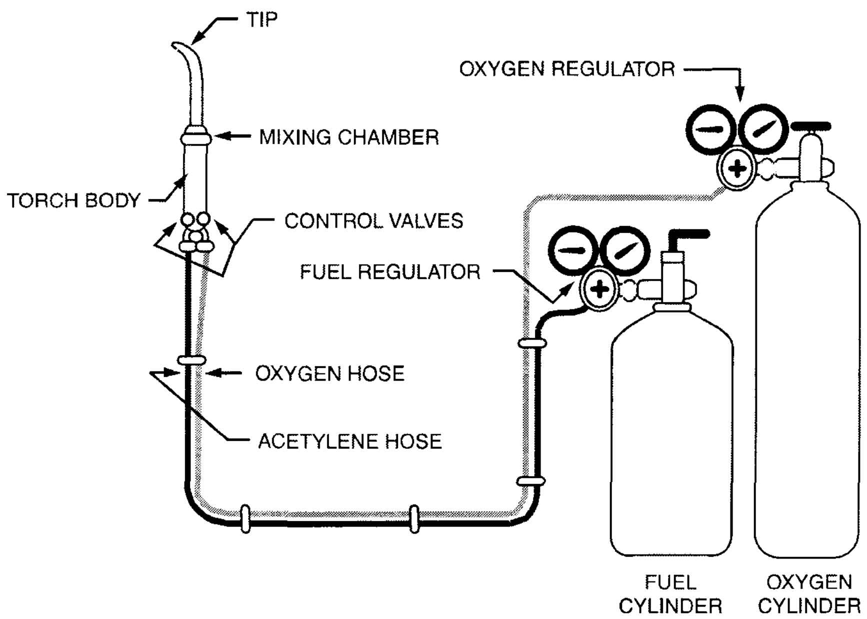


Figure 10.26—Oxyfuel Welding Equipment

atmosphere by the combustion products in the neutral flame, and fluxes, if used.

There are three types of flames, carburizing, oxidizing, and neutral. In a carburizing flame there is an excess fuel gas in the flame, while in an oxidizing flame there is excess oxygen. In a neutral flame there is no excess of either gas, therefore, this is the best flame for welding steel. The use of a carburizing or oxidizing flame nay result in a degradation of the material properties.

Advantages

OAW is relatively inexpensive and can be made very portable. There is no electricity required.

Disadvantages

The flame does not provide a heat source that is as concentrated as an arc. Oxyacetylene welding requires a high level of skill to minimize discontinuities.

In preweld preparation, the joint opening must be sufficiently large for oxyacetylene weld penetration. Also, joints in the vertical and overhead positions require appropriate technique to overcome the effects of gravity. The joint must be cleaned properly to avoid contaminating the weld.

Discontinuities

The most commonly found discontinuities are porosity, incomplete fusion, incomplete joint penetration, undercut, underfill, overlap, and various forms of cracks. Proper welding technique will eliminate most of these problems.

Uniformly scattered porosity generally reveals faulty welding technique, improper filler metal, or contaminated base metal. Incomplete fusion of the base metal edges frequently occurs when the edges are inadvertently oxidized. Incomplete fusion occurs even with the best flame adjustment if improper manipulation is used. Undercut, underfill and overlap are other weld faults attributed directly to the welder.

Cracks are generally hot cracks in oxyacetylene welds. The process does not lead to cold cracking because the slow application of heat provides adequate preheat and makes the weld cool slowly. Throat cracks may result if the weld deposit is too thin to resist weld shrinkage stresses.

Stud Welding (SW)

Stud welding is a two-step process used to join attachments to metal surfaces. It heats a metal stud or similar part and a workpiece by drawing an arc between them, and then rapidly forces the heated surfaces together under pressure until they have united.

The process may be fully automatic or semiautomatic. A stud gun holds the tip of the stud against the workpiece. It then applies heat by creating an electrical arc between the stud and the underlying spot on the work surface. A timer in the control circuit then cuts off the current, and the stud-holding mechanism in the gun plunges the stud into the molten pool to make a weld (see Figures 10.27 and 10.28). Freezing is almost instantaneous, because the weld is chilled by the surrounding base metal. When the weld is complete, the gun is removed and the ceramic ferrule is removed.

Studs may be welded in all positions. Stud welding is widely used in shipbuilding, bridges, automobiles, railroads, boilers, and industrial equipment.

Welding Chemistry

Partial shielding may be provided by a ferrule (a ceramic device) surrounding the stud base or by a shielding gas. A flux may also be present on the stud tip.

Advantages

Since the process is controlled by the electrical control unit and the attached gun, little operator skill is required once the control unit settings have been made. It is an economical and effective method for welding attachments to a surface.

Disadvantages

The welding operator must correctly adjust the stud arc equipment. Defective gun action, improper current levels, and arc blow may result in incomplete fusion or undercut.

Discontinuities

There are only three main discontinuities that may be encountered with this process: (1) incomplete fusion may occur if the stud is not joined to the base metal across its entire cross section, (2) undercut may also occur if excessive welding current is used, and (3) the weld is not considered complete unless there is flash present around the entire circumference of the stud base.

Brazing (B)

Brazing is a group of joining processes that produces coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a

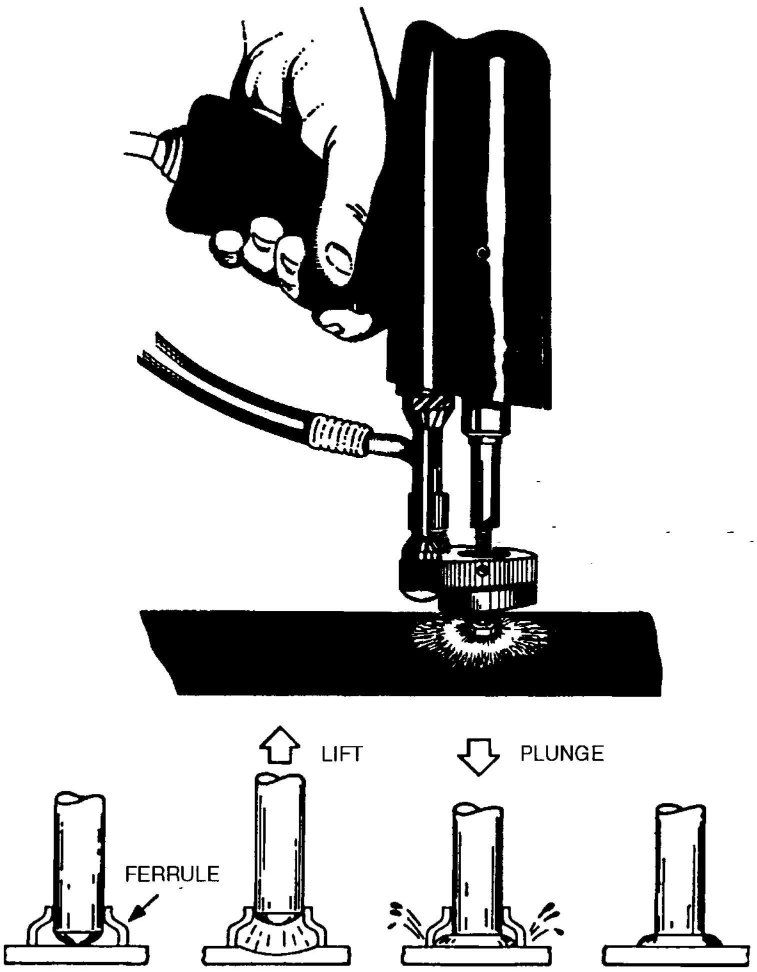


Figure 10.27—Stud Welding

melting point above 840°F and below the melting point of the base metals. The filler metal is distributed between the closely fitted faying surfaces of the joint by capillary action. The major difference between the various brazing methods is the manner in which the heat is applied to the joint.

Current brazing methods include the following:

- Torch brazing (TB)
- Furnace brazing (FB)
- Induction brazing (IB)
- Resistance brazing (RB)
- Dip brazing (DB)
- Infrared brazing (IRB)
- Diffusion brazing (DFB)

Brazing compounds are complex alloys with carefully adjusted melting points and flow characteristics. The work must be cleaned of oxides and films, which explains the reason for fluxes used in most type of brazing except furnace brazing. Furnace brazing cleans the surfaces by using reducing type gases or a vacuum.

Brazing occurs when the filler metal melts at a temperature exceeding 840°F. Filler metals that melt below 840°F are solders. Unlike welding, when brazing or soldering the base metal is not melted.

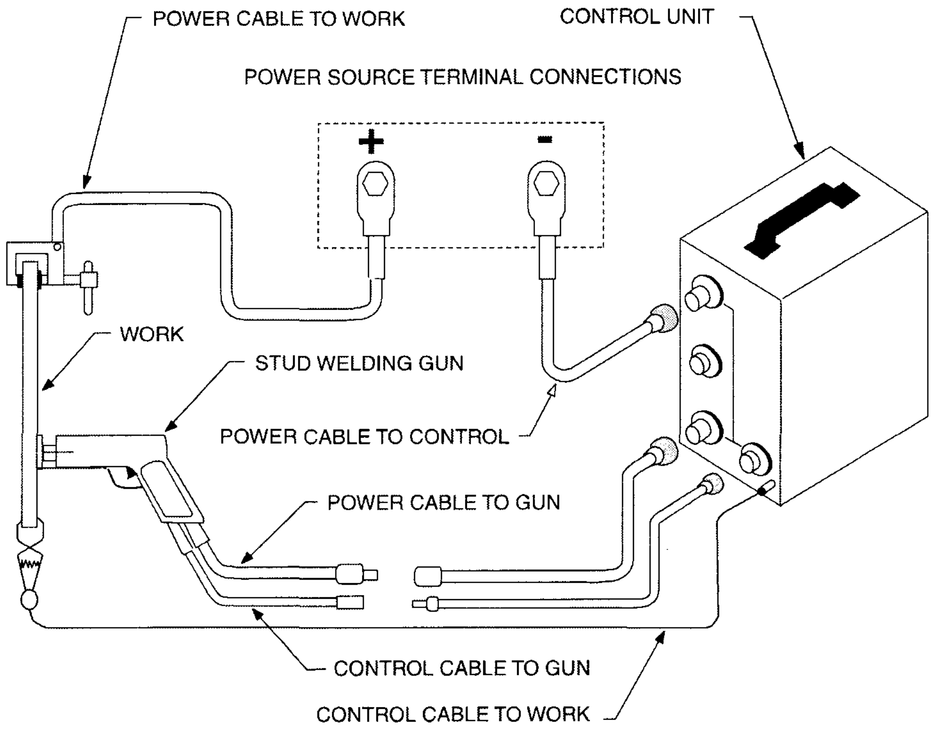


Figure 10.28—Basic Equipment Setup for Arc Stud Welding

Torch Brazing (TB)

TB is accomplished by heating with a gas torch or torches. The fuel gas (acetylene, propane, natural gas, etc.) can be burned with air, compressed air or oxygen. Brazing filler metal can be preplaced in the forms of rings, washers, strips, slugs, powder, etc., or it can be face-fed, that is, fed from hand-held filler metal, usually in the form of wire or rod. Proper cleaning and fluxing before brazing are essential. This process may be performed manually, by machine or automatically (see Figure 10.29).

Manual torch brazing is particularly useful on assemblies involving sections of unequal mass. Machine operations are set up when the rate of production warrants, using one or more torches equipped with single- or multiple-flame tips. The machine may move either the work or the torches, or both.

Torch brazing should be a reliable process. The flux, by its melting, indicates when the work is at a temperature suitable for brazing. The filler metal then flows into the joint by capillary action and should be visible at all exposed edges of the joint.

Furnace Brazing (FB)

FB is preferred when the parts to be brazed can be assembled with the filler metal preplaced near or in the joint. The preplaced brazing filler metal may be in the form of wire, foil, powder, paste, or tape. Most high production brazing is done in a reducing gas atmosphere, such as hydrogen, but much furnace brazing is done in a vacuum, which prevents oxidation. Brazing in a vacuum ensures the clean surfaces needed for good wetting and flow of filler metals without the use of fluxes. However, several base metals and filler metals are harmed by vacuum brazing because the constituents may evaporate.

Induction Brazing (IB)

IB is an automatic process that uses an induction coil to heat the metal. The parts are placed in or near a coil carrying alternating current. They become heated by an electric current induced in the parts to be joined. The brazing filler metal is usually preplaced. Careful design of the joint and the coil setup are necessary to ensure that all surfaces reach brazing temperature at the same time.

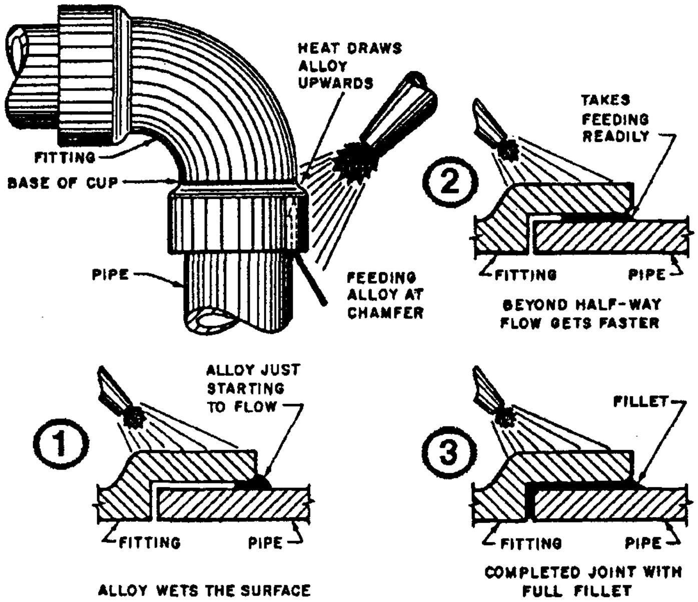


Figure 10.29—Brazing Process

Resistance Brazing (RB)

RB is an automatic or semiautomatic process that uses the electrical resistance in the joint being welded as the heating device. The brazing filler metal is preplaced or added in some convenient form. Fluxing must take into account the conductivity of the flux. Most fluxes are electrical insulators when solid. The parts being brazed are held between two electrodes, and proper pressure and current are applied. The pressure is maintained until the joint solidifies.

Dip Brazing (DB)

DB is performed in a chemical bath or a molten metal bath. In chemical bath dip brazing, the brazing filler metal is preplaced and the assemblies are then immersed in a molten salt. The salt bath furnishes the heat necessary for brazing and usually protects against oxidation; if not, suitable flux should be used. In molten metal dip brazing, the parts are immersed in a bath of molten brazing filler metal. A cover of flux is maintained over the molten bath.

Infrared Brazing (IRB)

IRB uses a high-intensity quartz lamp to provide radiant heat to bring the work to brazing temperature. Assemblies to be brazed are supported so that the energy impinges on the joints to be brazed.

Diffusion Brazing (DFB)

DFB uses a filler metal that diffuses into the base metal to create joint properties approaching those of the base metal. Migration of atoms (in the solid state) away from their home positions in the crystal lattice results in interdiffusion of the filler metal and base metal. This results in partially or completely eliminating any trace of filler metal as a layer in the joint. Such a braze develops increased mechanical properties and a higher remelt temperature. In some joints, a diffusion of atoms is planned that will create a liquid phase, which may be distributed by capillary action as in other brazing methods.

Advantages

Brazing can join dissimilar metals. It is suitable for joining metals that are not readily welded. Because brazing uses lower temperatures, thin metals can be joined without melt-through or distortion.

Disadvantages

Preparation for brazing requires proper cleaning of each joint and jigging to hold correct joint alignment during capillary flow of the brazing filler metal.

Flux residue must be removed to avoid subsequent corrosion of the joint or base metal.

Discontinuities

Typical discontinuities found in brazed joints include voids, erosion, and incomplete joint penetration.

Cutting Processes

The previous discussion has dealt exclusively with those methods used to join metals together. However, in the welding environment, the necessity also exists for metal removal or severing. There are numerous methods available, including both thermal and mechanical types.

Thermal cutting is the standard method of preparing base metal joints for welding, of cutting out defects for weld repair, and of backgouging. The area cut is confined to a narrow, well-defined zone of controlled width referred to as the *kerf* (see Figures 10.30 and 10.31). Metal is removed by combustion (oxidation) in oxyfuel gas cutting, by simple melting in the plasma jet, or by arc melting in a blast of air.

The cutting process may be manual, semiautomatic, or automatic. Standards for quality of cut surfaces vary with the requirements of the structure being welded. If the resulting irregularities are excessive, they can be chipped with a blunt tool or ground back with an abrasive wheel.

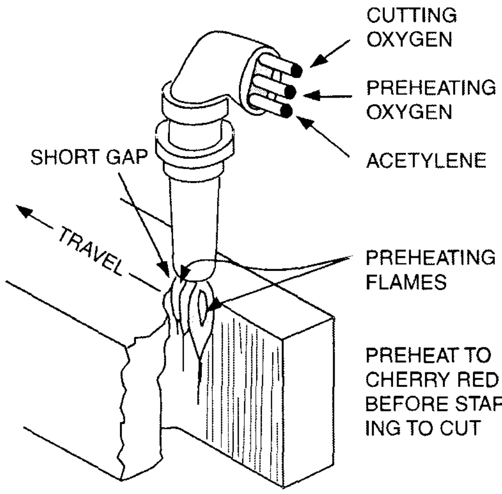


Figure 10.30—Process Diagram Oxygen Cutting

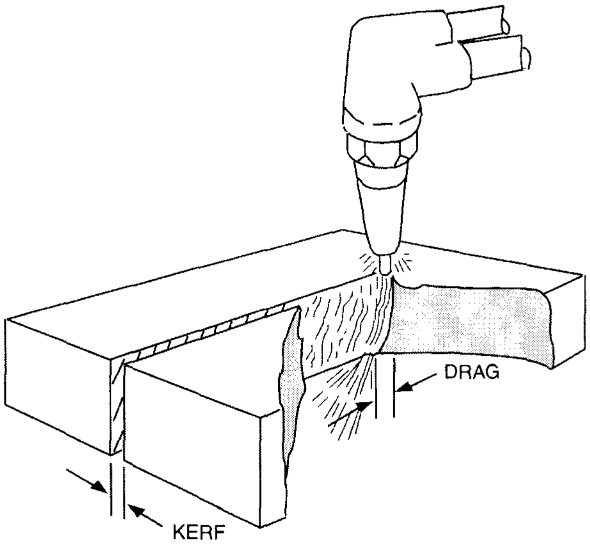


Figure 10.31—Kerf and Drag in Oxyfuel Gas Cutting

For safety, filter lenses are required for observing thermal cutting operations, and safety goggles with side shields are needed for protection from sparks and spatter.

The three primary thermal cutting processes are the following:

- Oxyfuel gas cutting (OFC)
- Air carbon arc cutting (CAC-A)
- Plasma arc cutting (PAC)

Oxyfuel Gas Cutting (OFC)

OFC was at one time exclusively oxyacetylene cutting (OFC-A), but today oxyfuel cutting may be with oxygen and natural gas (OFC-N), propane (OFC-P), hydrogen (OFC-H), a proprietary mixture such as stabilized methylacetylene and propadiene, or metal powder cutting (POC). Metal powder cutting is used for stainless steel, aluminum and copper alloys. Torch modifications to suit each fuel gas are required.

Oxyfuel gas cutting severs ferrous metals by oxidizing the iron in oxygen to form iron oxide. Above the oxidation temperature of about 1700°F, the oxidation of iron (rusting) becomes combustion, which is confined to a narrow zone. The metal to be cut is heated to the oxidation temperature by preheat flames disposed around the oxygen cutting jet.

The quality of the cut surface varies over wide limits. The skill of the cutter or operator affects all operations, because the cutting flame must be manually adjusted, even for automatic cutting.

The major limitation of this method is that it can effectively cut only those materials that oxidize at a temperature below their melting point. Consequently, it is difficult to produce a quality cut in stainless steels using this method.

Air Carbon Arc Cutting (CAC-A)

CAC-A melts the metal with an electric carbon arc and then blows it out with a high velocity air jet, traveling parallel to the electrode and striking the weld pool just behind the arc (see Figures 10.32 and 10.33).

Plasma Arc Cutting (PAC)

PAC uses the greater heat of the plasma arc (18 000°F to 25 000°F) to cut through any metal, ferrous or nonferrous. PAC removes the molten material with a high-velocity jet of hot ionized gas. The process uses a constricted arc between a water-cooled electrode (dcen) and the workpiece. The orifice that constricts the arc is also water-cooled (see Figure 10.34).

The quality of plasma arc cutting is superior to other types of thermal cutting, because of the high temperature of the jet. The kerf is normally slightly unsquare; however, use of water-injected torches will tend to minimize this effect.

Mechanical Cutting

Joints are also prepared for welding by mechanical means such as milling, grinding, shaping, sawing, shearing, and chipping. The major concern after mechanical cutting is the removal of sulfurized cutting oils used to lubricate the cutting tools. Sulfur may cause cracking in welds, and all oils are a source of hydrogen (see Figure 10.35).

Summary

The welding inspector is primarily responsible for judging the quality of welds produced by numerous processes. Knowledge of the various processes will be extremely helpful in deciding what types of welding problems might be anticipated. Actual welding experience is also quite helpful for the welding inspector; however, this is not a requirement for qualification as a CWI.

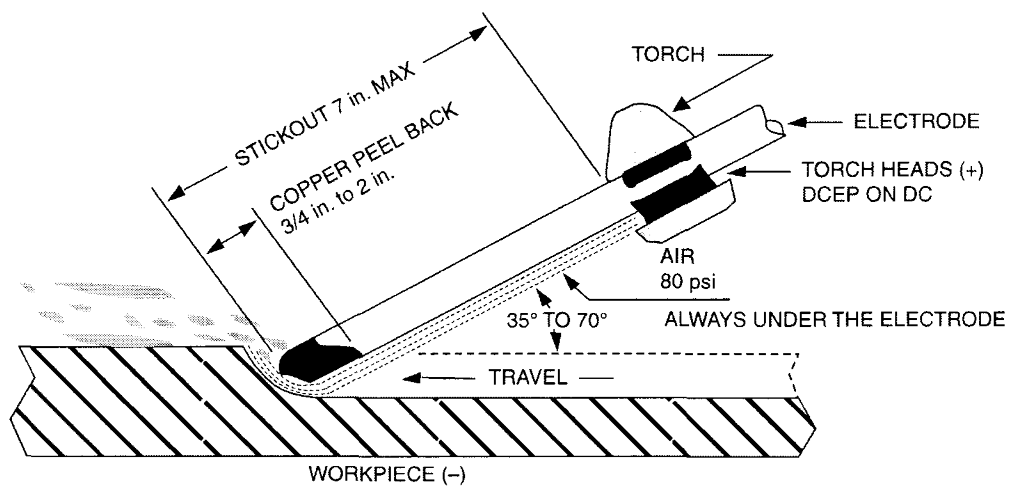


Figure 10.32—Typical Operating Procedures for Air Carbon Arc Gouging

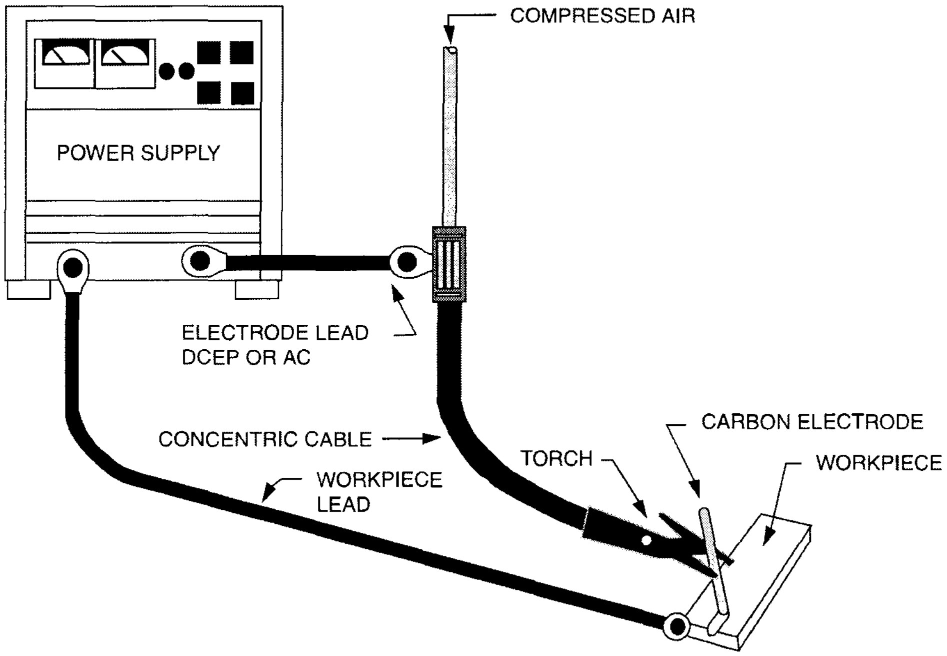


Figure 10.33—Typical Air Carbon Arc Gouging Equipment

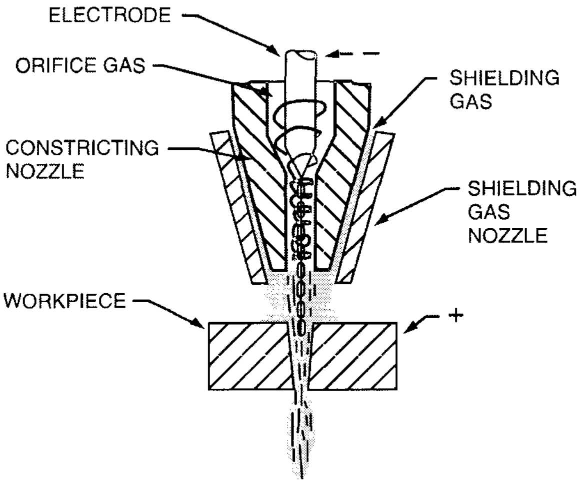


Figure 10.34—Typical Plasma Arc Cutting Torch

Figure 10.35—Mechanical Cutting

Review—Chapter 10—Welding, Brazing, and Cutting Processes

Q10-1 Of the following, which is not a necessary requirement for a welding process?
a. source of energy
b. electricity
c. means of shielding molten metal
d. base material
e. none of the above

Q10-2 Which of the following are functions of the flux coating of a SMAW electrode?
a. insulating
b. alloying
c. deoxidation
d. shielding
e. all of the above

Q10-3 In the AWS system of SMAW electrode designations, the next to the last number refers to:
a. usability
b. electrode coating
c. position
d. strength
e. none of the above

Q10-4 Which of the following is an incorrect statement about a SMAW electrode designated as an E7024?
a. It is a low-hydrogen type.
b. The weld deposit has a minimum tensile strength of 70 000 psi.
c. It is suitable for use in the flat and horizontal fillet positions only.
d. all of the above
e. none of the above

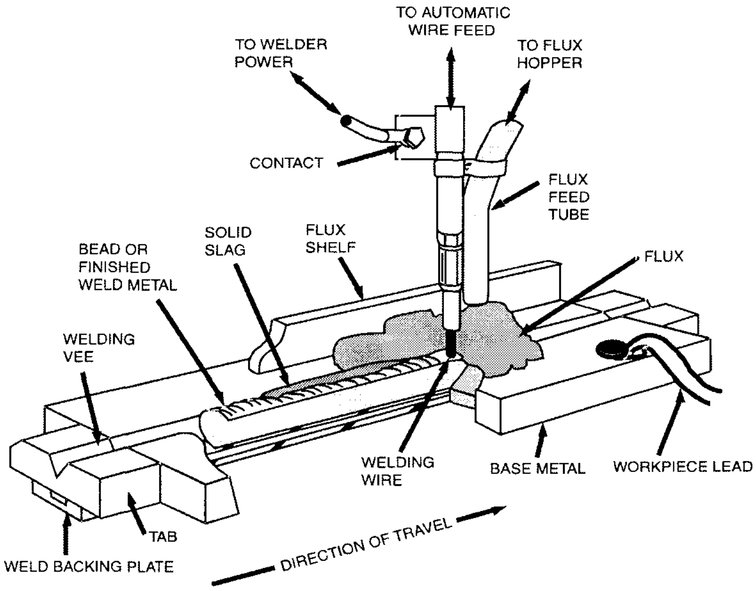
Q10-5 Which of the following is not an essential part of a typical SMAW system?
a. constant current power supply
b. wire feeder
c. covered electrode
d. electrode lead
e. work lead

Q10-6 Shielding of the molten metal in GMAW is accomplished through the use of:
a. granular flux
b. slag
c. fuel gas and oxygen
d. both a and b above
e. inert and reactive gases

Q10-7 Which of the following is not considered a type of metal transfer for GMAW?
a. short circuiting
b. spray
c. globular
d. droplet
e. pulsed arc

Q10-8 Which of the following types of metal transfer in GMAW is considered to be the lowest energy, and therefore prone to incomplete fusion?
a. short circuiting
b. spray
c. globular
d. droplet
e. pulsed arc

Q10-9 What type of welding process is pictured below?



a. SMAW
b. GMAW
c. FCAW
d. SAW
e. ESW

Q10-10 Which of the following is not considered an arc welding process?
a. SMAW
b. GMAW
c. FCAW
d. ESW
e. none of the above

Q10-11 In the electrode designation system for FCAW, the second number refers to:
a. strength
b. position
c. chemical composition
d. usability
e. none of the above

Q10-12 Which of the following is not always an essential element of a FCAW system?
a. constant voltage power supply
b. tubular electrode
c. wire feeder
d. shielding gas
e. work (ground) lead

Q10-13 What aspect of the GTAW and PAW processes is different from the other arc welding processes?
a. nonconsumable electrode
b. power supply
c. shielding
d. all of the above
e. none of the above

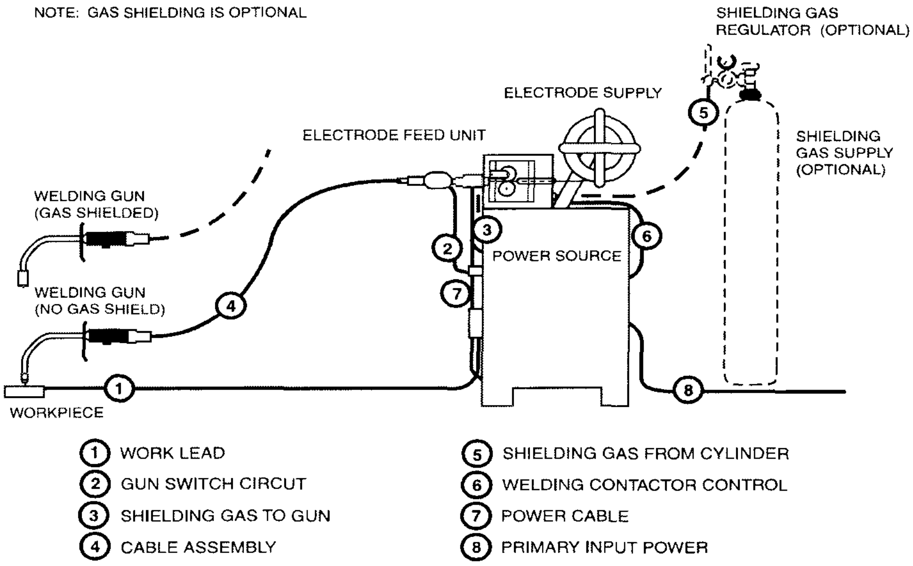
Q10-14 Shielding for the GTAW and PAW processes is accomplished through the use of:
a. granular flux
b. slag
c. inert gas
d. reactive gas
e. none of the above

Q10-15 A green stripe on a tungsten electrode designates:
a. pure tungsten
b. 1% thoriated tungsten
c. 2% thoriated tungsten
d. zirconated tungsten
e. none of the above

Q10-16 When welding aluminum with the GTAW process, what type of welding current is most commonly used?
a. dcep
b. dcen
c. ac
d. both a and b above
e. both b and c above

Q10-17 SAW and ESW are similar in that:
a. both are arc welding processes
b. both use shielding gases
c. both use a granular flux
d. both a and b above
e. both a and c above

Q10-18 The diagram below depicts what welding process?



a. SMAW
b. ESW
c. FCAW
d. SAW
e. PAW

Q10-19 Solidification cracking due to improper width-to-depth ratio of the weld nugget may be a problem with which welding process?
a. OFW
b. SW
c. SAW
d. all of the above
e. none of the above

Q10-20 A welding process done essentially in the flat position with welding progressing from the bottom to top of the weld joint positioned vertically identifies:
a. GMAW
b. SAW
c. ESW
d. both a and b above
e. both b and c above

Q10-21 Which of the following are not common to both GTAW and PAW?
a. nonconsumable tungsten electrode
b. copper constricting nozzle
c. shielding gas nozzle
d. externally-applied filler metal
e. none of the above

Q10-22 What technique is employed with PAW to produce full penetration welds?
a. stringer beads
b. weave beads
c. keyhole
d. backstep
e. none of the above

Q10-23 What welding process produces welds in the flat position, in a single pass, with the progression vertically upward along the joint?
a. SAW
b. ESW
c. FCAW
d. both a and b above
e. both b and c above

Q10-24 Which of the following is not an advantage of the ESW process?
a. high deposition rate
b. ease of setup
c. capable of joining thick sections
d. no tendency for angular distortion
e. none of the above

Q10-25 Which welding process is considered to be a chemical welding process?
a. SMAW
b. ESW
c. SAW
d. OAW
e. none of the above

Q10-26 Which arc welding process provides an efficient means of joining attachments to some planar surface?

a. OAW
b. SW
c. GMAW
d. GTAW
e. SMAW

Q10-27 Brazing differs from welding in that:

a. no filler metal is used.
b. an oxyfuel flame is used.
c. the base metal is not melted.
d. all of the above
e. none of the above

Q10-28 For satisfactory results, a braze joint should have:

a. a large surface area.
b. a small gap between pieces to be joined.
c. a precise bevel.
d. both a and b above
e. both b and c above

Q10-29 Which of the following is not an advantage of brazing?

a. ease of joining thick sections
b. ability to join dissimilar metals
c. ability to join thin sections
d. both a and b above
e. both b and c above

Q10-30 Of the following metals, which cannot be effectively cut using OFC?

a. high-carbon steel
b. low-carbon steel
c. medium-carbon steel
d. stainless steel
e. none of the above

Q10-31 Which of the following gases can be used to perform OFC?

a. MAPP
b. propane
c. acetylene
d. natural
e. all of the above

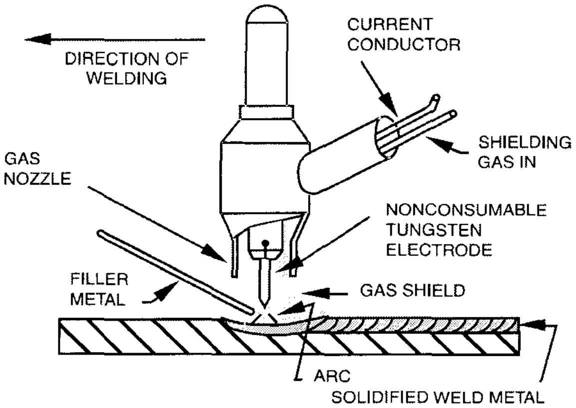
Q10-32 Which of the following cutting processes can be used to cut any metal?

a. OFC
b. CAC-A
c. PAC
d. both a and b above
e. both b and c above

Q10-33 The width of a cut is technically referred to as the:

a. gap
b. dross
c. kerf
d. drag
e. none of the above

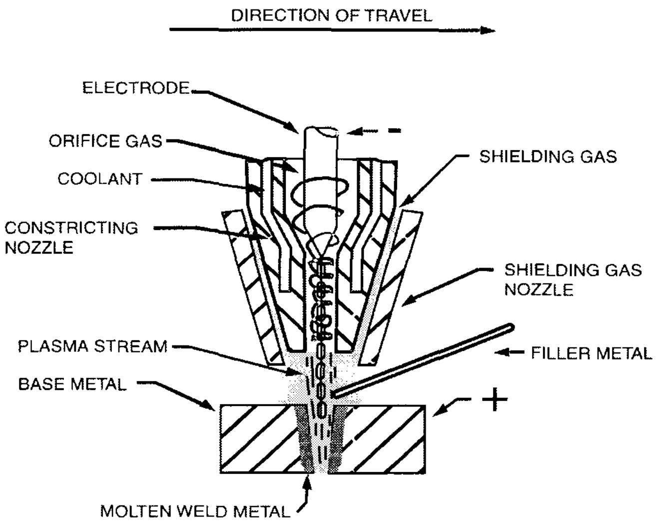
Q10-34 Which process is illustrated below?



a. GMAW
b. PAW
c. GTAW
d. BMAW
e. CAW

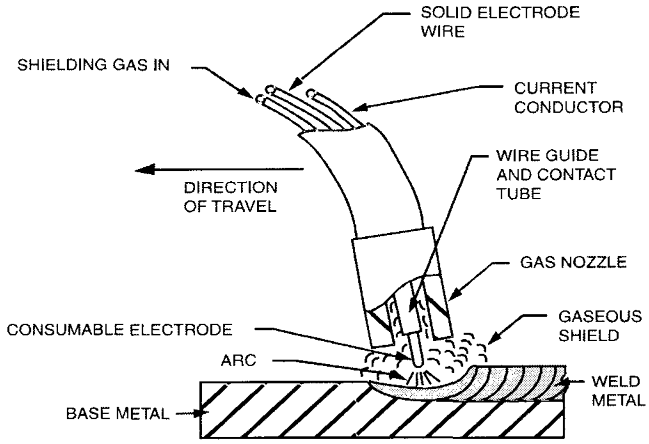
Q10-35 ESW designates which process?
a. electric slag arc welding
b. electroslag arc welding
c. electric slag welding
d. electroslag welding
e. electric stud welding

Q10-36 Which process is illustrated below?



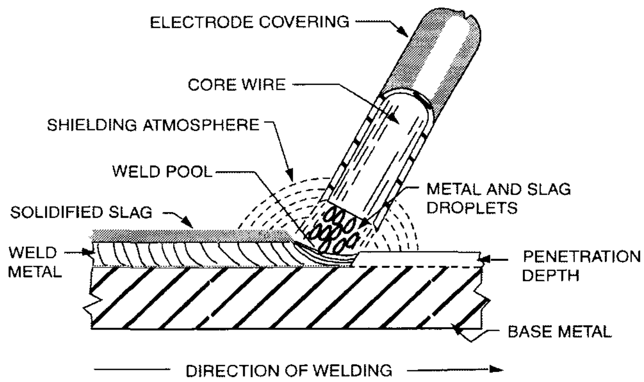
a. GMAW
b. PAW
c. GTAW
d. TIG
e. CAW

Q10-37 Which process is illustrated below?



a. GMAW
b. PAW
c. GTAW
d. TIG
e. CAW

Q10-38 Which process is illustrated below?



a. GMAW
b. SAW
c. GTAW
d. SW
e. SMAW

Q10-39 SMAW designates which process?
a. stick metal arc welding
b. shielded metal arc welding
c. submerged arc welding
d. seam metal arc welding
e. short circuiting metal arc welding

Q10-40 SW designates which process?
a. stud welding
b. stud arc welding
c. submerged welding
d. stick welding
e. submerged arc welding

Q10-41 SAW designates which process?
a. stud welding
b. stud arc welding
c. submerged welding
d. stick welding
e. submerged arc welding

Q10-42 FCAW designates which process?
a. flux cored arc welding
b. flux centered arc welding
c. furnace controlled arc welding
d. friction arc welding
e. flow arc welding

Q10-43 GMAW designates which process?
a. gas machine arc welding
b. gas method arc welding
c. gas material arc welding
d. gas metal arc welding
e. general material arc welding

Q10-44 GTAW designates which process?
a. gas tungsten arc welding
b. general tungsten arc welding
c. globular transfer arc welding
d. gas torch arc welding
e. none of the above

Q10-45 PAW designates which process?
a. plasma arc welding
b. pressure arc welding
c. plate arc welding
d. percussion arc welding
e. none of the above

Q10-46 Which of the following could result in the creation of porosity in the GTAW of 6061-T6 aluminum structural members for an aircraft application?
a. insufficient cleaning of the weld joint
b. contaminated filler metal
c. leak in the shielding gas hose
d. presence of drafts during the welding operation
e. all of the above

Q10-47 An ER70S-6 electrode can be used with which of the processes?
a. GTAW
b. GMAW
c. PAW
d. all of the above
e. none of the above

Q10-48 A granular flux is a characteristic of which of the following?
a. ESW
b. SAW
c. SMAW
d. both a and b
c. both b and c

Q10-49 Which of the classifications listed below produces the strongest weld metal?
a. ER70S-6
b. E70T-5
c. E7018
d. F7A2-EM12K
e. no difference

Q10-50 Which process is classified as a chemical welding method?
a. GTAW
b. GMAW
c. ESW
d. PAW
e. OAW

Q10-51 Which cutting methods use electricity?
a. PAC
b. CAC-A
c. OAC
d. a and b above
e. b and c above

Q10-52 A tubular electrode is a significant characteristic of which process?
a. SAW
b. ESW
c. FCAW
d. SMAW
e. GMAW

Q10-53 Which arc welding process is used very effectively for the welding of various types of attachments to surfaces of plates and structural members?
a. SMAW
b. GMAW
c. FCAW
d. SW
e. ESW

Q10-54 Molding shoes is a term associated with which process?
a. SAW
b. GTAW
c. ESW
d. FCAW
e. GMAW

Q10-55 Short circuiting metal transfer is a mode of operation for:
a. GTAW
b. FCAW
c. SMAW
d. none of the above
e. all of the above

Q10-56 The need for electrode holding ovens for some types of its filler metal is a disadvantage of which process below?

a. SMAW
b. FCAW
c. SAW
d. all of the above
e. a and b

Q10-57 Which process uses a carbon electrode?

a. SMAW
b. GMAW
c. GTAW
d. CAC-A
e. PAC

Q10-58 EWTh-1 is an electrode designation for which of those processes listed below?

a. GTAW
b. PAW
c. GMAW
d. a and b above
e. b and c above

Q10-59 Of the following, which brazing process is preferred when the parts to be brazed can be assembled with the filler metal preplaced near or in the joint?

a. torch
b. induction
c. furnace
d. diffusion
e. none of the above

Q10-60 F7P6-EM12 is a filler metal designation for:

a. SMAW
b. GMAW
c. FCAW
d. SAW
e. PAW

Q10-61 The ability to perform keyhole welding is a primary advantage of:

a. GTAW
b. PAW
c. SMAW
d. FCAW
e. SAW

Q10-62 Which gases can be used for OFW?

a. MAPP
b. acetylene
c. natural gas
d. propane
e. all of the above

Q10-63 Which gases below can be used for TB?

a. acetylene
b. oxygen
c. natural gas
d. propane
e. all of the above

Q10-64 A ferrule is an item used for shielding in which process below?
a. ESW
b. PAW
c. PAC
d. SW
e. FB

Q10-65 When GTAW is used, what type of current results in the greatest amount of penetration?
a. dcen
b. dcep
c. ac
d. hwac
e. no difference

Q10-66 A constricting nozzle is one of the components for which welding process?
a. PAW
b. GTAW
c. SAW
d. GMAW
e. SW

Q10-67 What gases can be used for GMAW?
a. carbon dioxide
b. argon
c. 75% argon–25% carbon dioxide
d. 98% argon–2% oxygen
e. all of the above

Q10-68 The process which can be used either with or without an external shielding gas is:
a. GMAW
b. SMAW
c. FCAW
d. GTAW
e. PAW

Q10-69 Which of the welding processes below is generally considered to provide the highest deposition rate?
a. SAW
b. ESW
c. FCAW
d. SMAW
e. GMAW

Q10-70 When welding carbon steel with the OAW process, the torch should be adjusted to provide:
a. an oxidizing flame
b. a carburizing flame
c. a neutral flame
d. a heating flame
e. none of the above

Q10-71 Of the following, which of the processes make use of water-injected torches to minimize the effect of irregular kerf?
a. PAC
b. CAC-A
c. GTAW
d. a and b above
e. b and c above

Q10-72 The use of a constricting orifice, is the distinguishing feature of which of the following?

a. GTAW
b. GMAW
c. FCAW
d. PAW
e. none of the above

Q10-73 Which of the following processes utilize a flux to provide necessary shielding?

a. SMAW
b. SAW
c. GMAW
d. a and b above
e. all of the above

CHAPTER 11

Weld and Base Metal Discontinuities

Contents

Chapter 11—Weld and Base Metal Discontinuities

Introduction

Discontinuities are imperfections in welds or base metals. Ideally, a sound weld should have no discontinuities; however, welds are not perfect and imperfections exist in varying degrees.

There is a temptation to call discontinuities defects, but as a matter of terminology the terms discontinuity and defect should be carefully distinguished by all inspectors. A defect is rejectable. Some discontinuities are acceptable. A discontinuity becomes a defect when it exceeds acceptable limits imposed by acceptance standards. An imperfection of lesser magnitude than that is still a discontinuity, but it is not a defect.

The welding inspector's primary job is to inspect the fabricator's work to see that it meets the requirements of the contract. To be able to do this, the inspector must be familiar with the acceptance standards that spell out the acceptable limits for discontinuities. If a particular type of discontinuity is permissible in the welds to be inspected, the acceptance standard, code, or specification must specify the criteria used to discriminate between acceptable imperfections and defects.

The criteria used to discriminate between acceptable imperfections and defects are described in the following terms:

- Type of discontinuity
- Size of discontinuity
- Location of discontinuity

All three criteria must be considered to judge whether a discontinuity is severe enough to be considered a defect.

Types of Discontinuities

Discontinuities have been categorized as listed below, and shown in Tables 11.1 and 11.2.

(1) Porosity
(2) Inclusions, both metallic and nonmetallic
(3) Underfill
(4) Incomplete fusion
(5) Incomplete joint penetration
(6) Overlap
(7) Undercut
(8) Lamination and delamination
(9) Seams and laps
(10) Lamellar tearing
(11) Crack
(12) Arc strike
(13) Porosity

Porosity

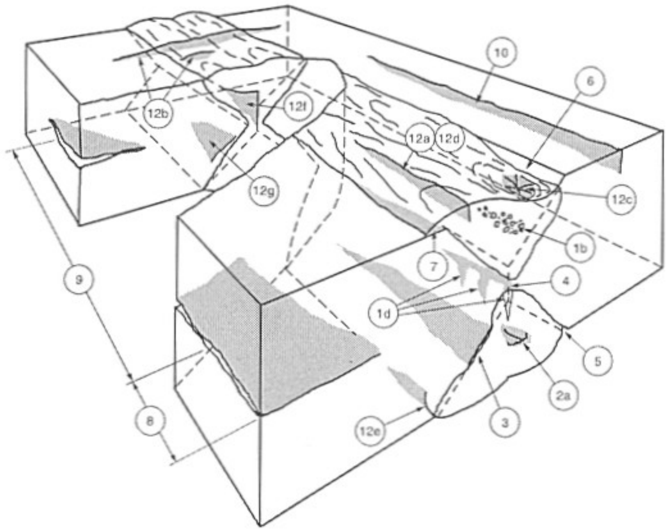
Porosity results when gas is trapped in solidifying metal. Porosity will be discussed only as it relates to welds (although porosity is also commonly seen in castings). The trapped gas comes from either the gas used in the welding process or the gas released from chemical reactions that occurred during the welding process. Faulty or dirty materials may also produce gas. The gas becomes trapped in the form of porous discontinuities in the weld. Proper welding technique avoids gas formation and entrapment.

Porosity usually occurs in the form of rounded discontinuities, but in a severe case the porosity is cylindrical. These large cylindrical pores are referred to as *piping porosity* or "wormholes" (see Figure 11.1). The presence of porosity indicates that the welding process is not being properly controlled or that the base metal and welding fluxes are contaminated with gas producing elements. In general, porosity in small amounts does not significantly intensify stress, therefore, in comparison it is less critical than those discontinuities with sharp ends.

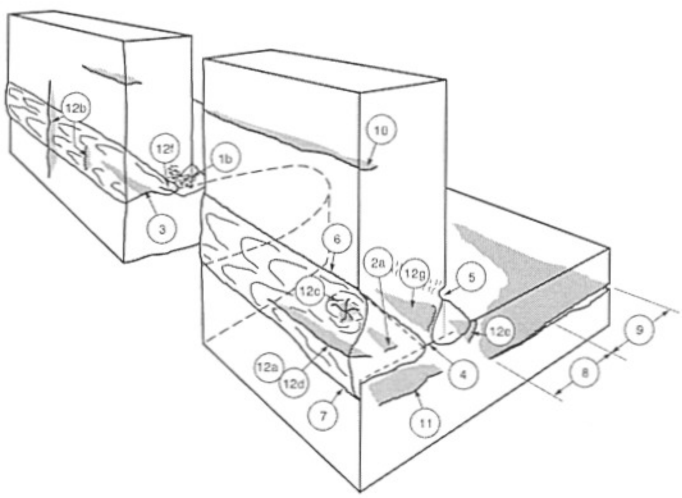
The distribution of porosity can help determine the type of fault that caused the porosity. A cluster of porosity is likely to result from improper initiation or termination of the weld (see Figure 11.2). If the porosity is uniformly scattered, the cause could be either faulty materials or poor technique used throughout the weld (see Figure 11.3).

Table 11.1
Common Types of Discontinuities

Type of Discontinuity
(1) Porosity (a) Uniformly scattered (b) Cluster (c) Piping (d) Aligned (e) Elongated
(2) Inclusion (a) Slag (b) Tungsten
(3) Incomplete fusion
(4) Incomplete joint penetration
(5) Undercut
(6) Underfill
(7) Overlap
(8) Lamination
(9) Delamination
(10) Seam and lap
(11) Lamellar tear
(12) Crack (includes hot cracks and cold cracks described in text) (a) Longitudinal (b) Transverse (c) Crater (d) Throat (e) Toe (f) Root (g) Underbead and HAZ



Double-V-Groove Weld in Butt Joint



Single-Bevel-Groove and Fillet Welds in Corner Joint

Table 11.2
Discontinuities Commonly Encountered with Welding Processes

Welding Process	Type of Discontinuity						
	Porosity	Slag	Incomplete Fusion	Incomplete Joint Penetration	Undercut	Overlap	Cracks
Arc							
SW—Stud welding	X		X		X		X
PAW—Plasma arc welding	X		X	X	X		X
SAW—Submerged arc welding	X	X	X	X	X	X	X
GTAW—Gas arc tungsten welding	X		X	X	X		X
EGW—Electrogas welding	X		X	X	X	X	X
GMAW—Gas metal arc welding	X		X	X	X	X	X
FCAW—Flux cored arc welding	X	X	X	X	X	X	X
SMAW—Shielded metal arc welding	X	X	X	X	X	X	X
CAW—Carbon arc welding	X	X	X	X	X	X	X
Resistance							
RSW—Resistance spot welding	X*		X	X			X
RSEW—Resistance seam welding	X*		X	X			X
PW—Projection welding			X	X			X
FW—Flash welding			X	X			X
UW—Upset welding			X	X			X
Oxyfuel Gas							
OAW—Oxyacetylene welding	X		X	X	X	X	X
OHW—Oxyhydrogen welding	X		X	X			X
PGW—Pressure gas welding	X		X				X
Solid-State**							
CW—Cold welding			X				X
DFW—Diffusion welding			X				X
EXW—Explosion welding			X				
FOW—Forge welding			X				
FRW—Friction welding			X				
USW—Ultrasonic welding			X				
Other							
EBW—Electron beam welding	X		X	X			X
ESW—Electroslag welding	X	X	X	X	X	X	X
IW—Induction welding			X				X
LBW—Laser beam welding	X		X	X			X
PEW—Percussion welding			X				X
TW—Thermite welding	X	X	X				X

*Porosity in resistance welds is more properly called "voids."
**Solid-state is not a fusion process, so incomplete joining is incomplete welding rather than incomplete fusion.

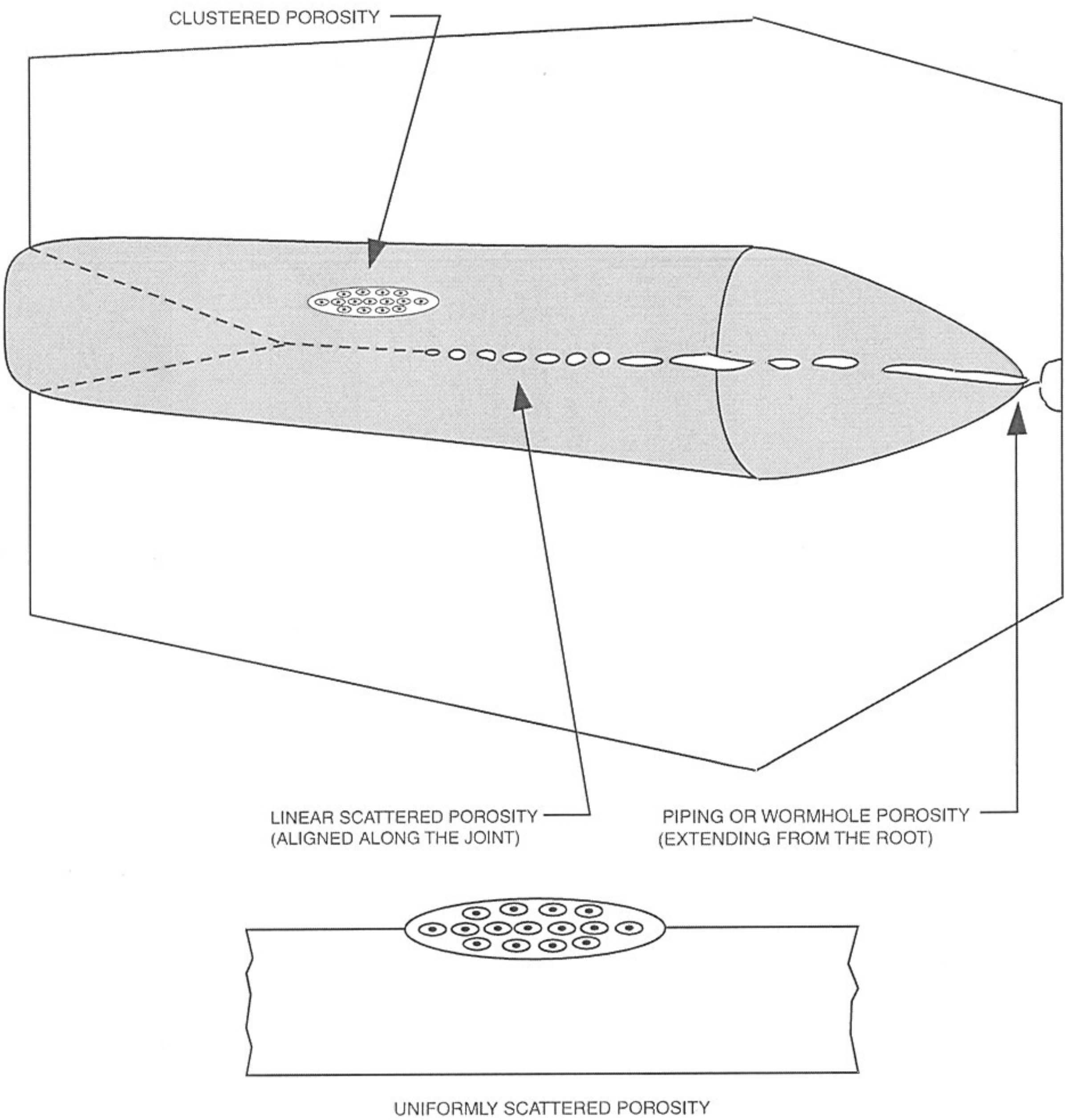
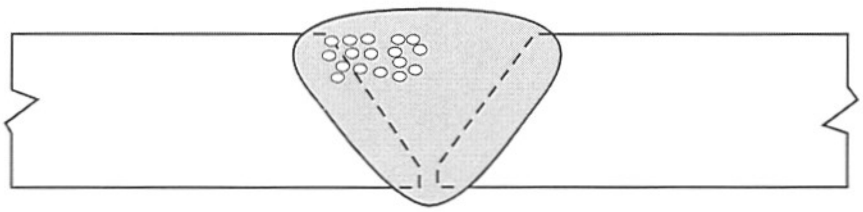
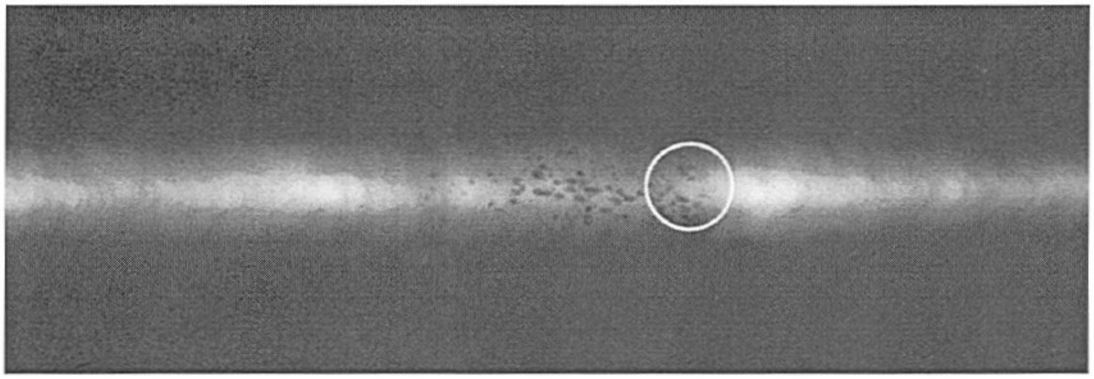


Figure 11.1—Porosity Illustrated



CLUSTER POROSITY



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RADIOGRAPH OF CLUSTER POROSITY

Figure 11.2—Cluster Porosity

> By itself, randomly scattered porosity is not detrimental to the strength of the weld. When the porosity aligns and becomes linear, clusters in a particular area, or develops a "tail," the weld is usually rejectable.

Linear porosity aligned along a joint boundary suggests that contamination triggered a chemical reaction, which produced unwanted gas. Such contamination could have been eliminated by proper joint preparation (see Figure 11.4).

Piping porosity, an elongated gas discontinuity that extends from the weld root toward the surface, is also evidence of the presence of surface contamination (see Figure 11.5).

Inclusions

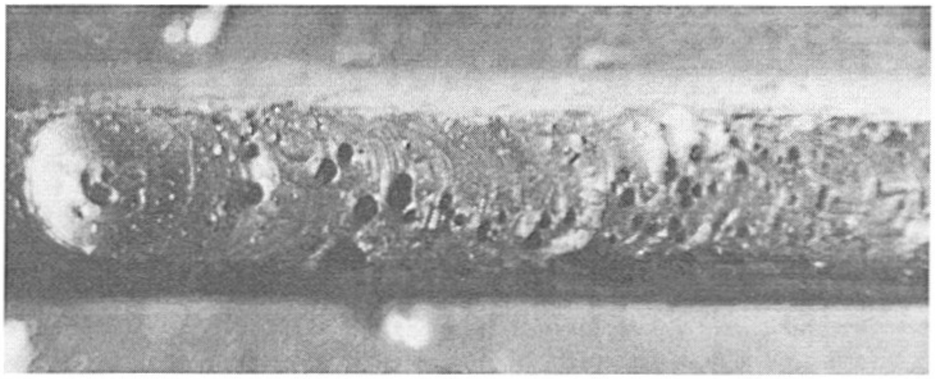
Inclusions result when solid materials are trapped in solidifying metal. Because inclusions interrupt the continuity of the weld, the presence of inclusions will result in some loss of structural integrity (see Figure 11.6).

Nonmetallic (Slag and Oxides) Inclusions

These types of inclusions result from faulty welding or cleaning techniques and/or the failure of the designer to provide proper access for welding within the joint. Molten slag and oxides will flow to the top of the weld, if allowed. Sharp notches in joint boundaries or between passes often cause slag to become trapped under the molten weld metal. Parallel lines of elongated slag inclusions, sometimes called "wagon tracks" because of their radiographic appearance, often result if the welder produces a convex root pass in an open root pipe joint and fails to adequately clean the slag on either side of this weld pass (see Figure 11.7).

Metallic Inclusions

These inclusions are usually tungsten particles trapped in weld metal (see Figure 11.8). They most often occur in gas tungsten arc welding, but may also result if the plasma arc welding process is improperly applied. These tungsten inclusions appear as light areas on radiographs, because tungsten is highly opaque to radiation. This is opposite from most other discontinuities, which show up as dark regions on the radiographic film.



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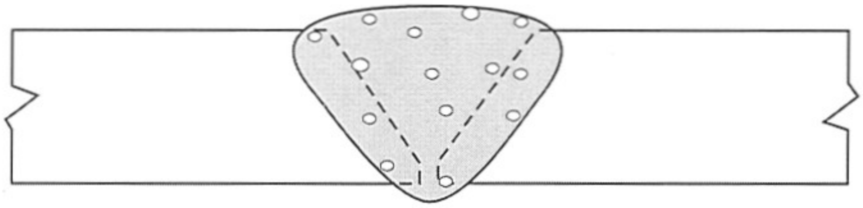
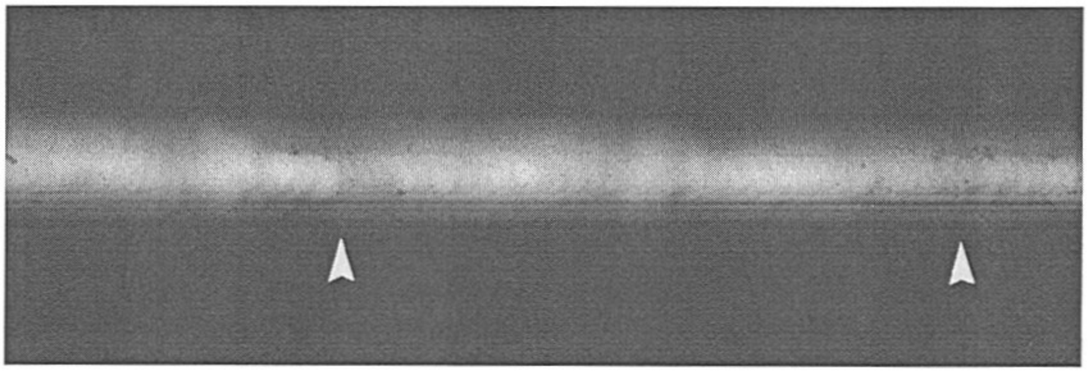
SCATTERED SURFACE POROSITY





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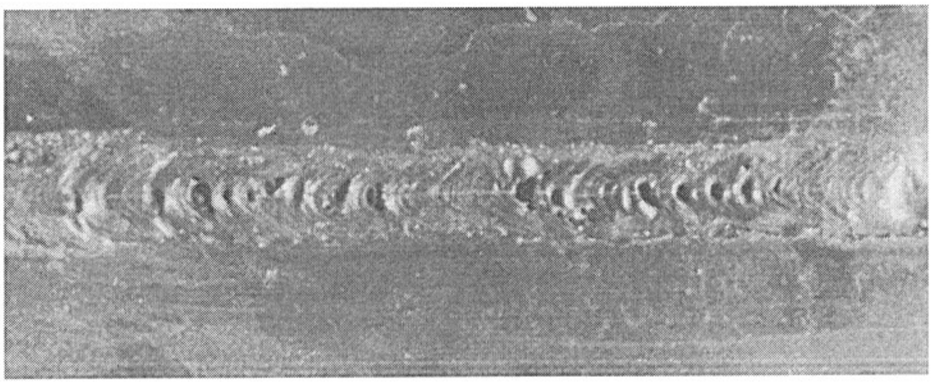
RADIOGRAPH OF SCATTERED POROSITY

Figure 11.3—Scattered Porosity



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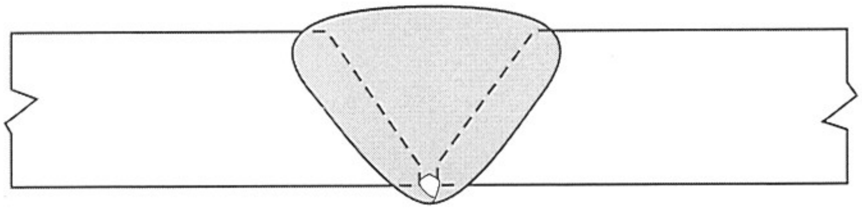
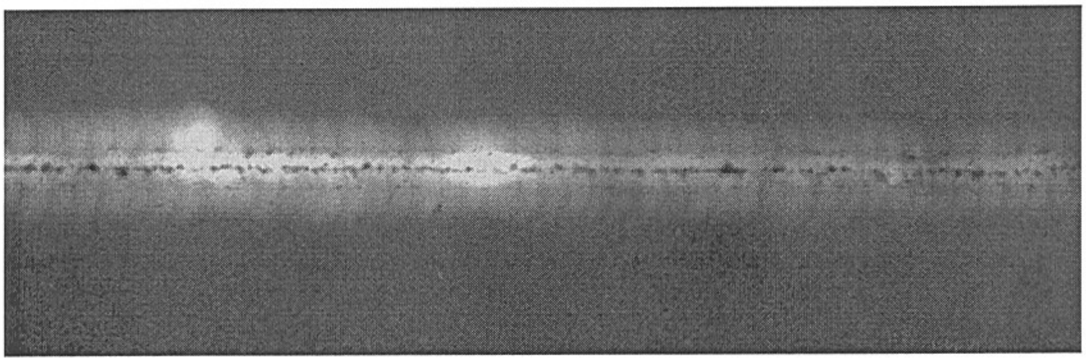
SCATTERED LINEAR POROSITY





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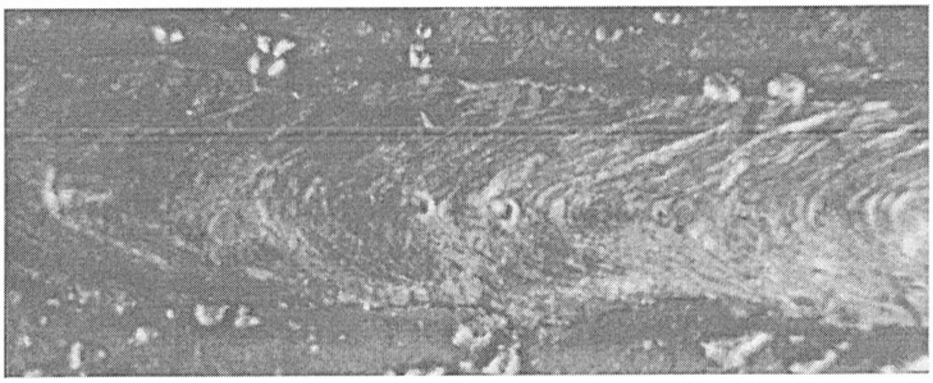
RADIOGRAPH OF LINEAR (ALIGNED) POROSITY

Figure 11.4—Linear Porosity



Guide for the Visual Examination of Welds (AWS B1.11)

Figure 11.5—Surface Appearance of Piping Porosity

Copper inclusions result when copper backing bars or backing shoes are used, as in electroslag welding. Improper application of the plasma arc welding process can result in overheating of the copper constricting nozzle, which can also cause copper inclusions in the weld.

Underfill

Underfill is a depression on the face or root surface of the weld below the surface plane of the adjacent base metal. In other words, if a welder or welding operator fails to completely fill the groove, the result is an undersize weld (see Figure 11.9). On pipe welds, underfill at the weld root may also be referred to as *internal concavity* or *suck-back*.

Incomplete Fusion

Incomplete fusion is the failure of liquid weld metal to fuse into the groove face of the joint or to adjacent weld beads. Incomplete fusion is usually caused by insufficient application of heat to all faces of the joint. However, incomplete fusion can also be caused by the presence of oxides, which inhibit fusion by remaining tightly secured to the base metal (see Figures 11.10–11.12).

Incomplete Joint Penetration

Incomplete joint penetration results when the weld metal fails to extend completely through the joint thickness. The amount of joint penetration required in any joint should be specified on drawings. Whether that amount of joint penetration can be obtained depends upon the accessibility of the heat source and filler rod to the face area. This discontinuity can also result from improper joint designs.

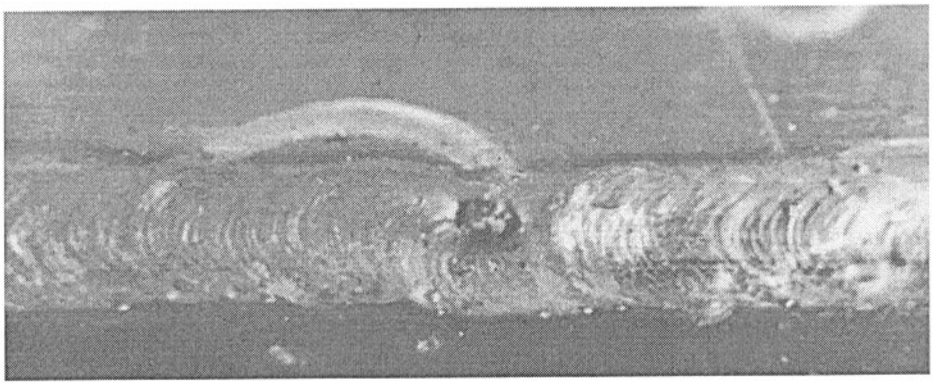
The presence of incomplete joint penetration in a joint requiring complete joint penetration can also be referred to as *inadequate joint penetration*, or joint penetration that is less than specified. Many codes require the use of joint backing for single-groove welds or backgouging of double-groove welds to ensure that complete joint penetration can be attained (see Figure 11.13).

Incomplete joint penetration can be present only at the root of the joint. Incomplete fusion can occur anywhere within the joint, i.e., between weld bead and groove faces, and between weld beads.

Overlap

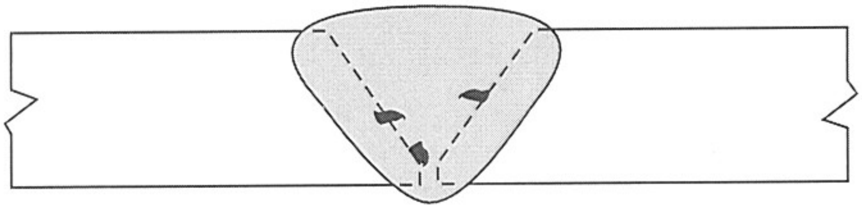
Overlap is the protrusion of weld metal beyond the toe or weld root of the weld joint without fusion. The resulting discontinuity is a severe mechanical notch on the surface. This discontinuity is similar to incomplete fusion—the difference is the location where the fusion failed to take place (see Figure 11.14). Overlap is caused by the inability of the weld metal to fuse with the surface, especially when tightly adhering oxides cover the base metal. Overlap results from lack of control of the welding process in the form of insufficient heat (current too low), inadequate travel speed, improper selection of welding materials (lack of deoxidizers), or improper preparation of the joint (failure to remove mill scale or other surface coatings). Excessive weld metal buildup on a groove weld is referred to as *excess weld reinforcement*.

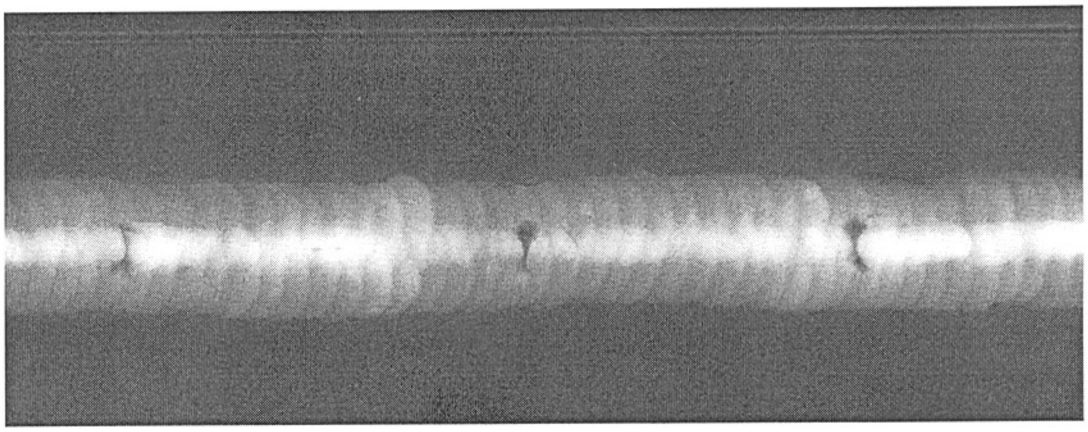
Overlap and undercut create a notch at the toe of the weld. This is a stress riser and depending upon the type of load on the weldment can cause a crack. Undercut is limited by the type of load. Overlap is prohibited in AWS D1.1.



Guide for the Visual Examination of Welds (AWS B1.11)

SURFACE SLAG INCLUSIONS





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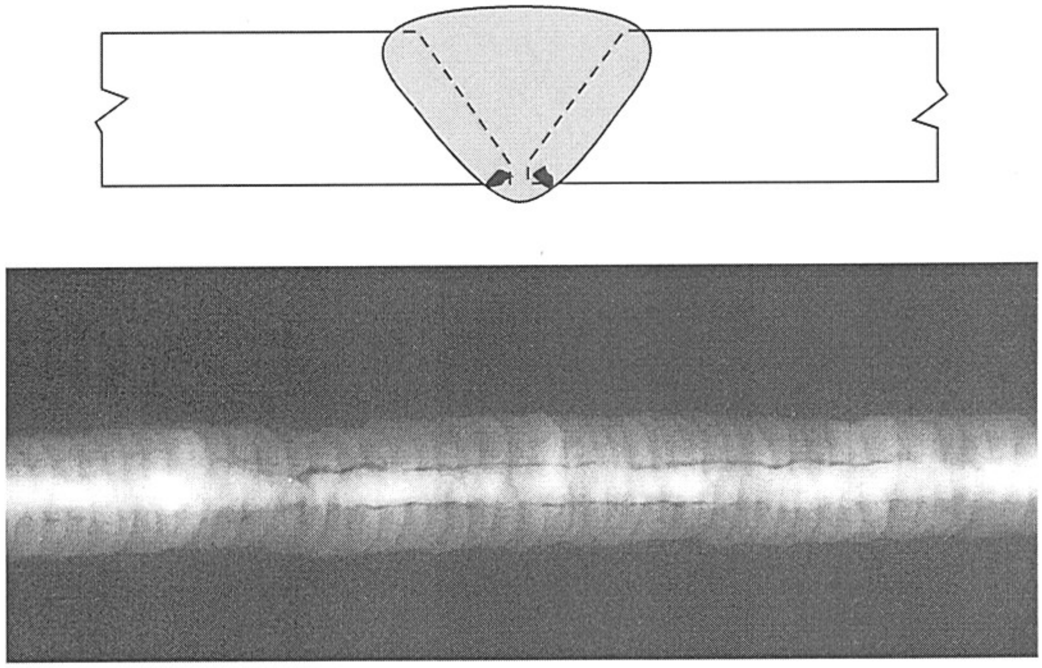
RADIOGRAPH OF INTERPASS SLAG INCLUSIONS

Figure 11.6—Slag Inclusions



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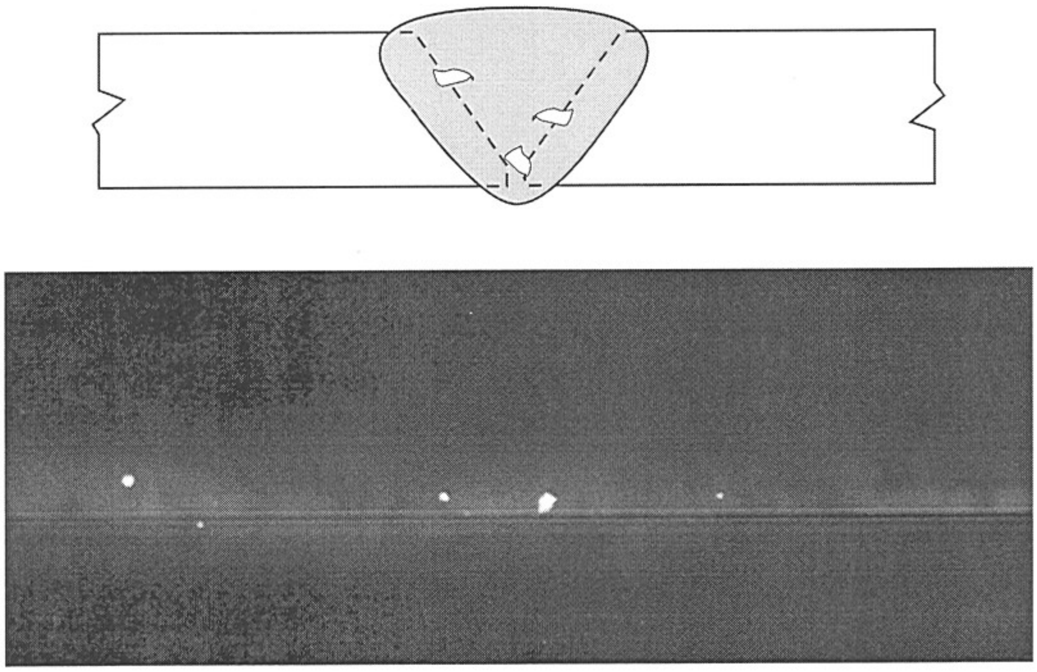
RADIOGRAPH OF ELONGATED SLAG LINES (WAGON TRACKS)

Figure 11.7—Elongated Slag Lines



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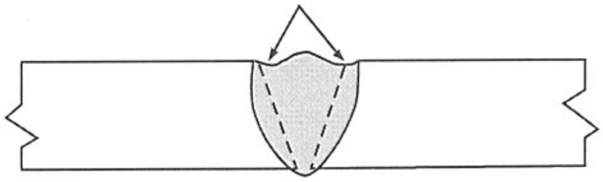
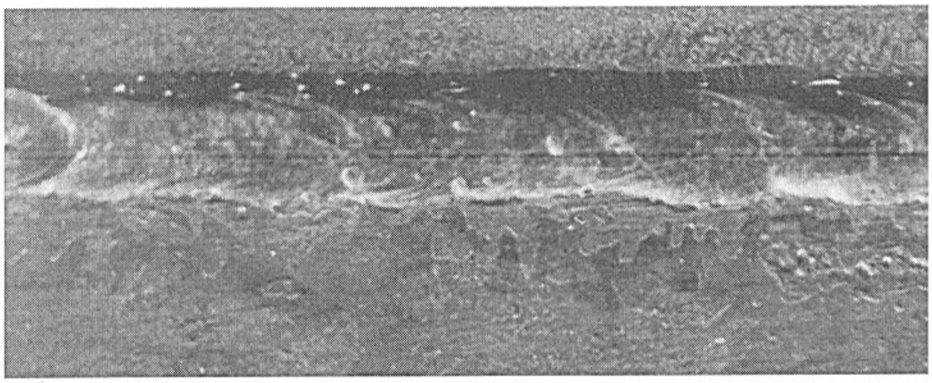
RADIOGRAPH OF TUNGSTEN INCLUSIONS

Figure 11.8—Tungsten Inclusions



UNDERFILL



Guide for the Visual Examination of Welds (AWS B1.11)

UNDERFILL AFTER USING FLUX CORED ARC WELDING IN STEEL

Figure 11.9—Underfill

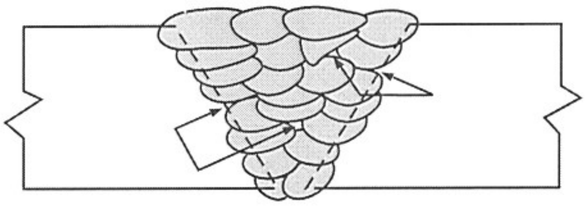
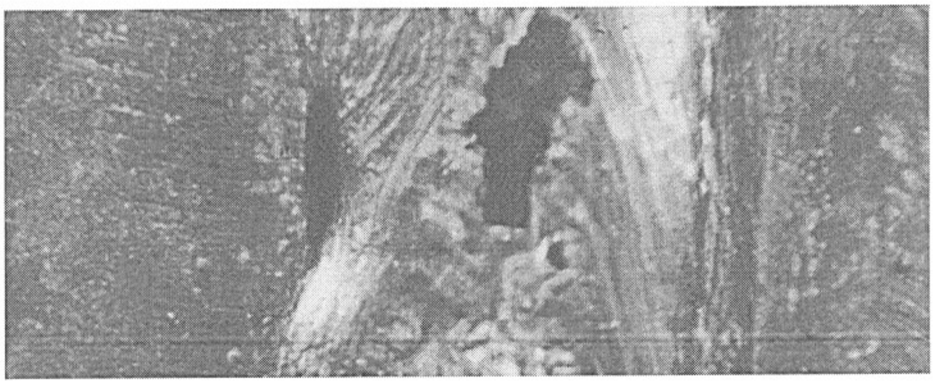
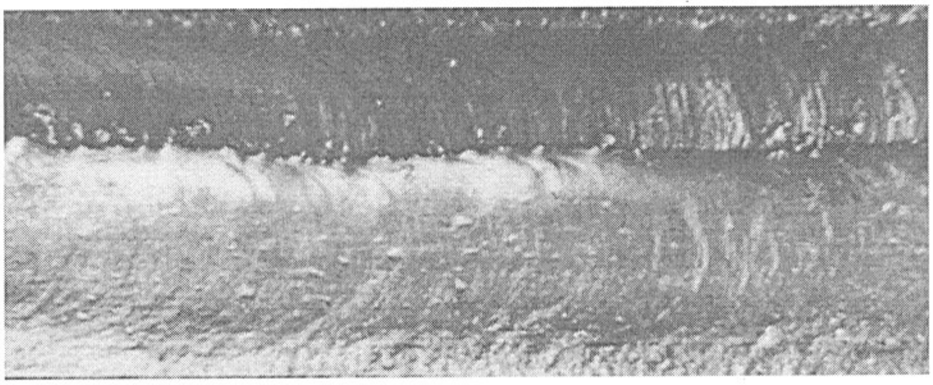


Figure 11.10—Various Locations of Incomplete Fusion



Guide for the Visual Examination of Welds (AWS B1.11)

Figure 11.11—Incomplete Fusion at Weld Face



Guide for the Visual Examination of Welds (AWS B1.11)

Figure 11.12—Incomplete Fusion Between Individual Weld Beads

Undercut

Undercut is a surface discontinuity that results from melting of the base metal at either the weld toe or weld root (see Figures 11.14 and 11.15). It takes the form of a mechanical notch at the these locations. Undercut is caused by the application of excessive heat (excessive weld current) or improper electrode manipulation, which melts away the base metal. Use of excessive travel speeds will also cause undercut.

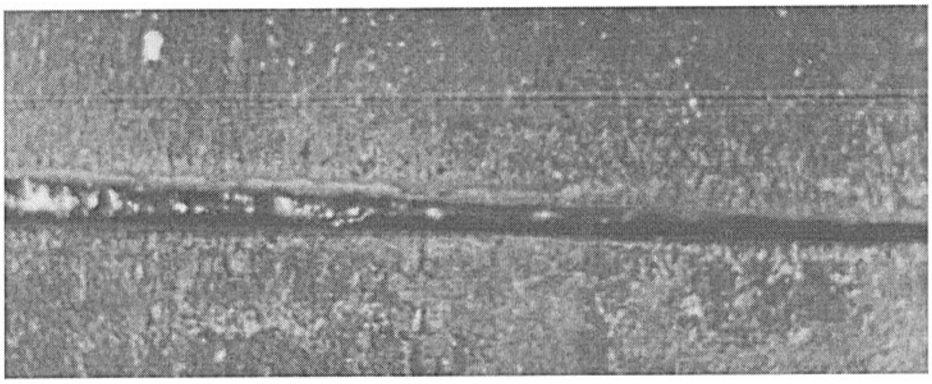
Lamination and Delamination

Laminations are flat, generally elongated, planar base metal discontinuities found near the center of rolled products. Laminations are formed when gas voids in the shrinkage cavity in the ingot are rolled flat, but are not subsequently welded under the pressure of hot rolling. They generally run parallel to the surface of the rolled product and are most commonly found in structural shapes and plates (see Figures 11.16 and 11.17).

Laminations most often appear near the centerline of the material thickness. Because it would open as a sandwich, metal containing laminations cannot reliably carry stress in the through-thickness direction.

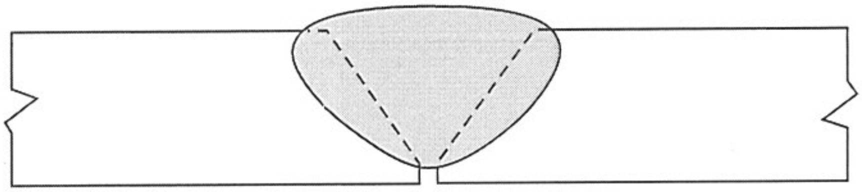
A delamination is the separation of a lamination under stress. The stress may be a result of distortion during flame cutting, residual stress from welding, or applied stress.

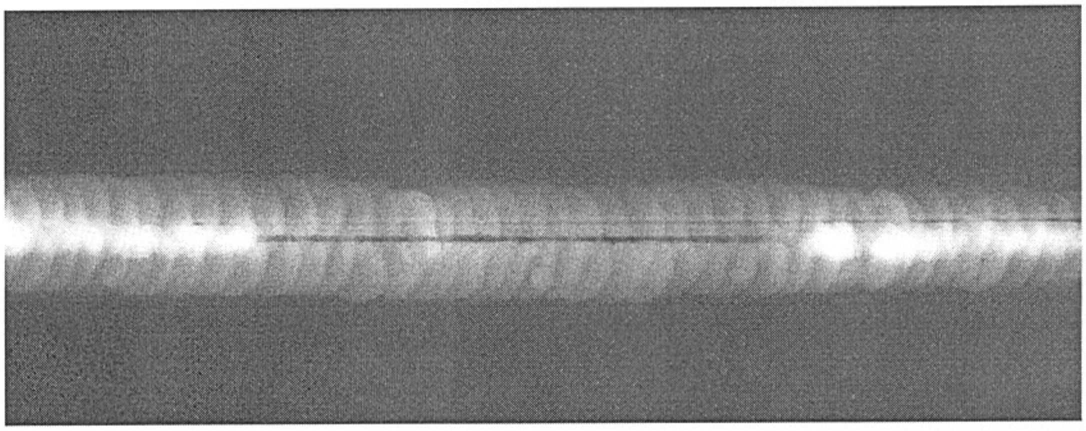
Ultrasonic testing is the only effective means of locating laminations, unless they extend to an exposed edge of the material. Laminations will not be revealed by radiographic testing.



Guide for the Visual Examination of Welds (AWS B1.11)

INCOMPLETE JOINT PENETRATION





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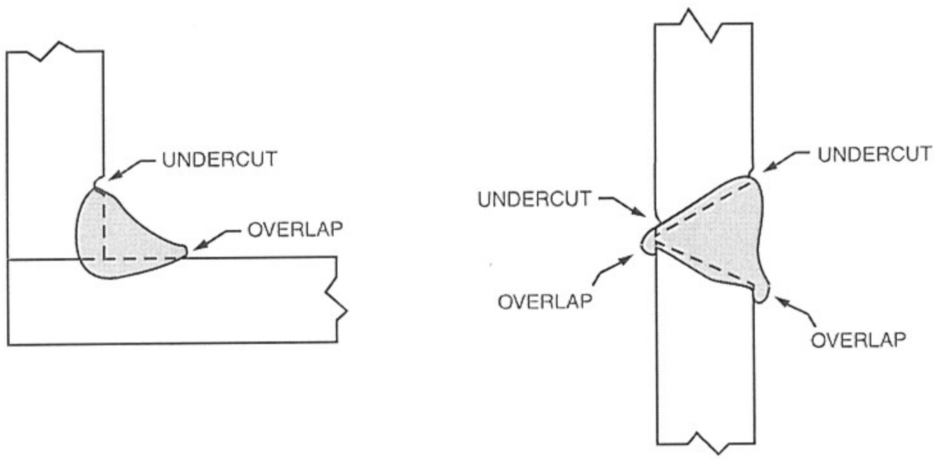
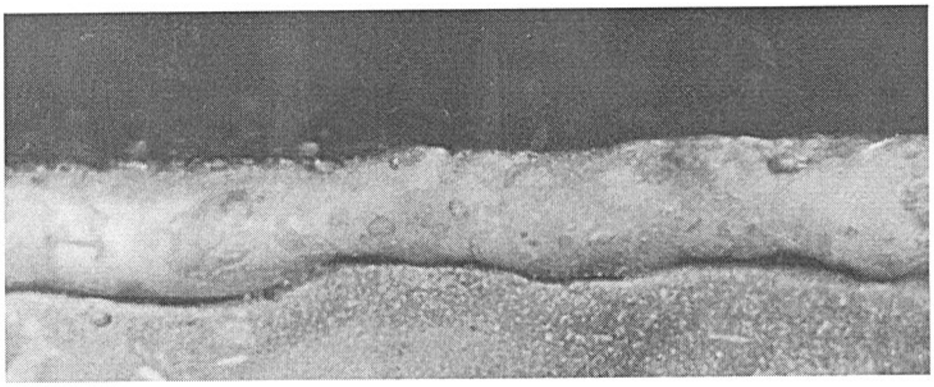
RADIOGRAPH OF INCOMPLETE JOINT PENETRATION

Figure 11.13—Incomplete Joint Penetration



WELD FLAWS



Guide for the Visual Examination of Welds (AWS B1.11)

OVERLAP

Figure 11.14—Undercut and Overlap

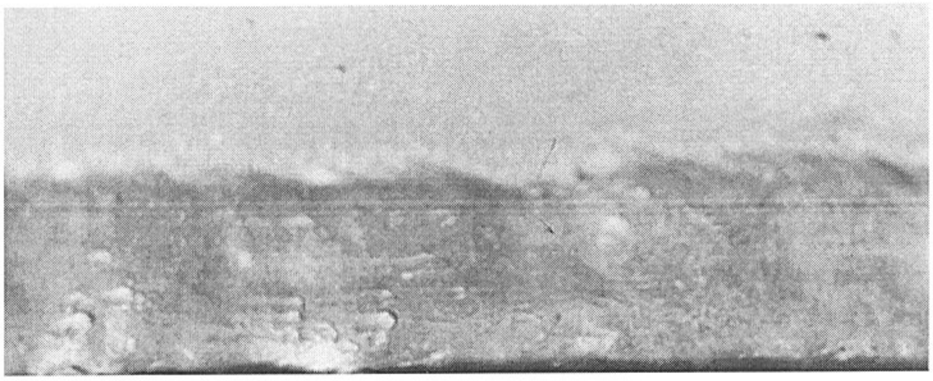
Seams and Laps

Seams and laps are linear base metal discontinuities found in rolled products that result from improper steel-making practices. Seams and laps differ from laminations in that they always appear on the rolled surfaces. When they are parallel to the principal stress, seams and laps are generally not considered to be a critical defect. When perpendicular to the applied or residual stress, they will often propagate as a crack. Welding over seams and laps can cause cracking.

Lamellar Tearing

Lamellar tearing is a fracture separation in heavy weldments, found within or just beneath the heat-affected zone (HAZ) of thick plates that were not adequately refined by the steel mill. From their ingot stage to the final thickness, heavy plates and structural shapes receive limited working, which may not remove all traces of ingotism. Rolling and forging impart good properties in the direction of metal flow (the "X" direction) but the strength and ductility perpendicular to the rolled surface (the through-thickness or "Z" direction) remain poor (see Figure 11.18).

Massive welds that are poorly located (i.e., adjacent to a thick plate) transmit weld shrinkage stresses into the plate in its weakest direction. This creates tears parallel to the surface, which then are linked together by shear fractures, to form steps connected by risers perpendicular to the surface. The phenomenon is called *lamellar tearing*,



Guide for the Visual Examination of Welds (AWS B1.11)

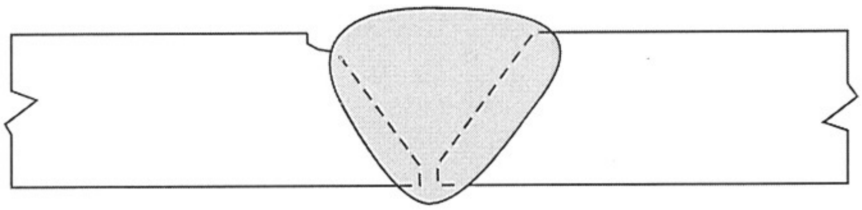


Figure 11.15—Undercut at Weld Toe

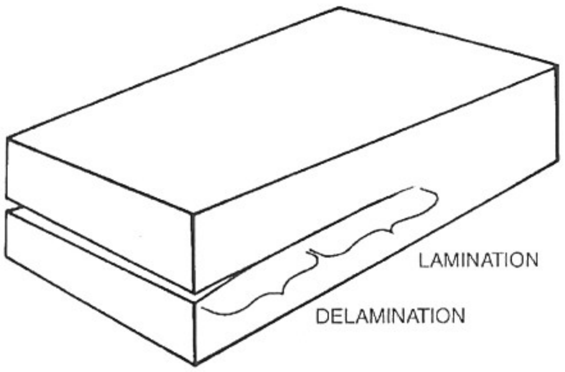


Figure 11.16—Lamination and Delamination

because the plate opens up as though it were made of stacked sheets or lamellae. The engineer should change the joint design to bring the shrinkage stresses more in line with the rolling direction (see Figure 11.19).

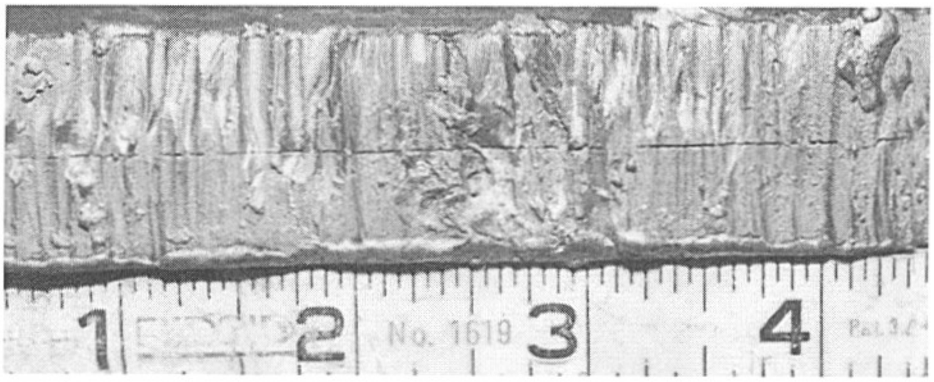
A reduction in the amount of weld required will also reduce the tendency for this type of discontinuity.

Lamellar tears may extend over long distances and are located more deeply than underbead cracks, which differ in shape, cause, and location.

Cracks

Cracks may occur in the weld or base metal, or both, when localized stresses exceed the strength of the material. Cracking is generally associated with discontinuities in welds and base metals, with notches, with high residual stresses, and often with hydrogen embrittlement (see Figure 11.20). Welding-related cracks often appear as though the metal were brittle. There is little evidence at the crack boundaries that the metal deformed before it cracked. Cracks can be classified as either "hot" cracks or "cold" cracks.

Hot cracks develop at high temperatures. They commonly form on preferential solidification of alloys of the metal near the melting point. Hot cracks propagate between the grains when the preferential solidification occurs. Cold cracks develop after solidification is complete and are often service-related. Delayed cracks are commonly caused by the presence of hydrogen in a crack-susceptible microstructure that is subjected to some applied stress. Cold cracks may propagate either through or between grains.



Guide for the Visual Examination of Welds (AWS B1.11)

Figure 11.17—Laminations

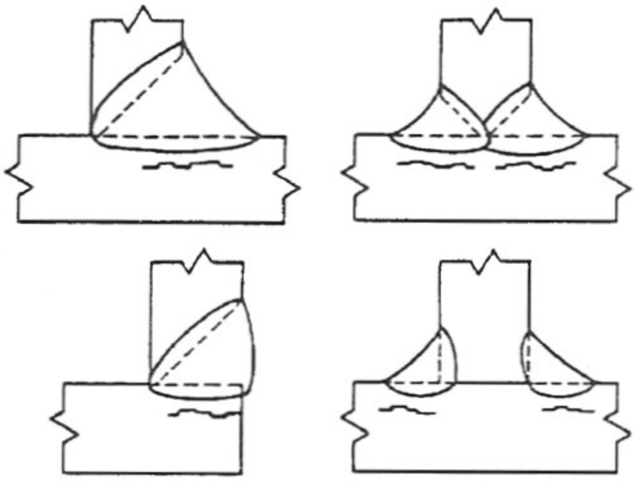


Figure 11.18—Weld Configuration Which May Cause Lamellar Tearing

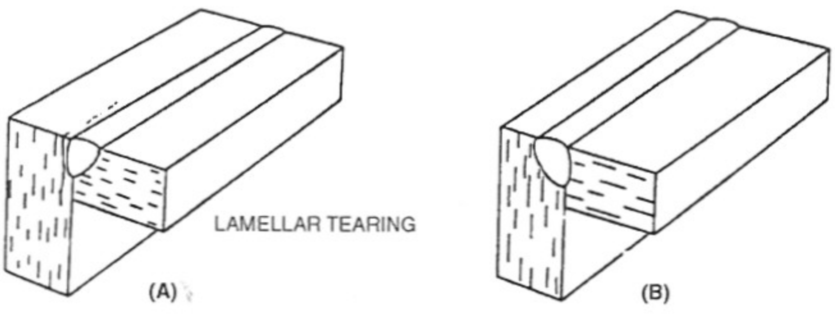


Figure 11.19—Redesigned Corner Joint to Prevent Lamellar Tearing

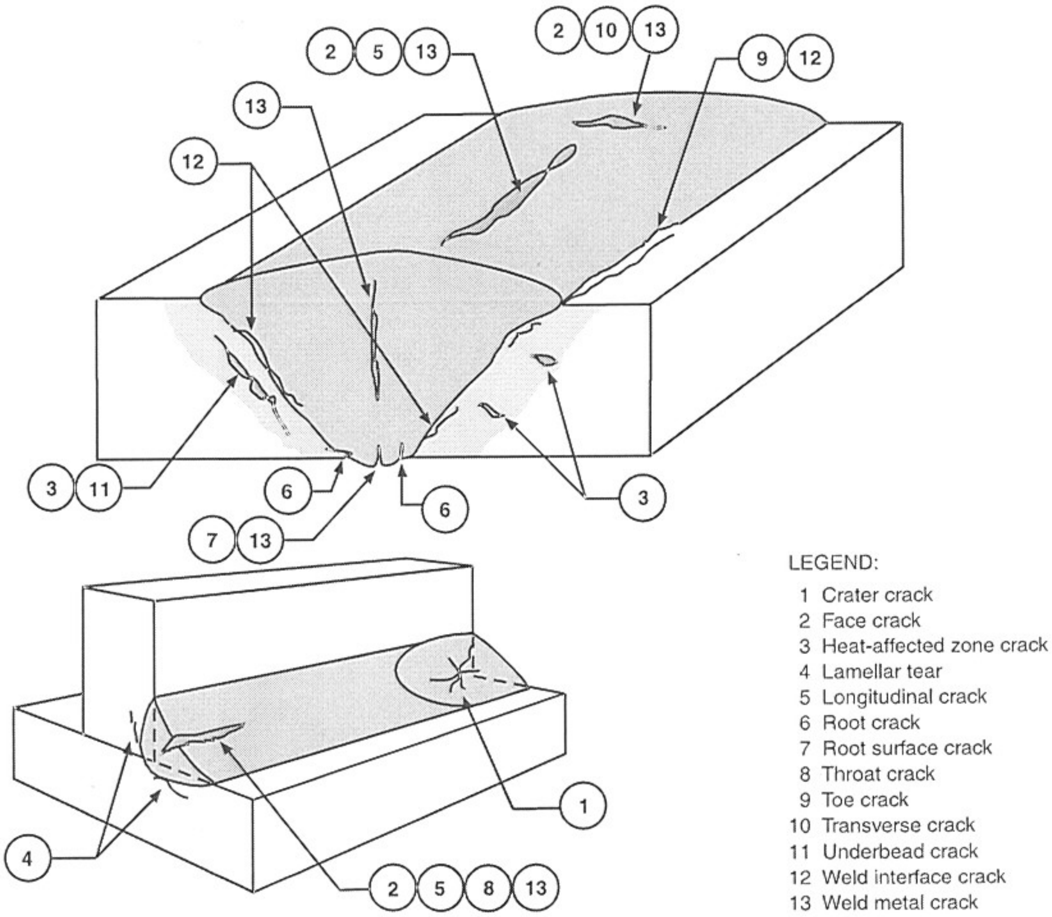


Figure 11.20—Crack Types

Longitudinal cracks are aligned parallel to the weld axis. They are called longitudinal cracks, whether they are centerline cracks in the weld metal or toe cracks in the HAZ of the base metal (see Figure 11.21).

> Cracks are the most severe discontinuity. They have a very sharp end condition and are likely to propagate. Most welding codes disallow cracks.

Transverse cracks are perpendicular to the weld axis. They may remain within the weld metal or extend from the weld metal into the adjacent HAZ and the remainder of the base metal. In some weldments, transverse cracks can form in the HAZ of the base metal and not in the weld.

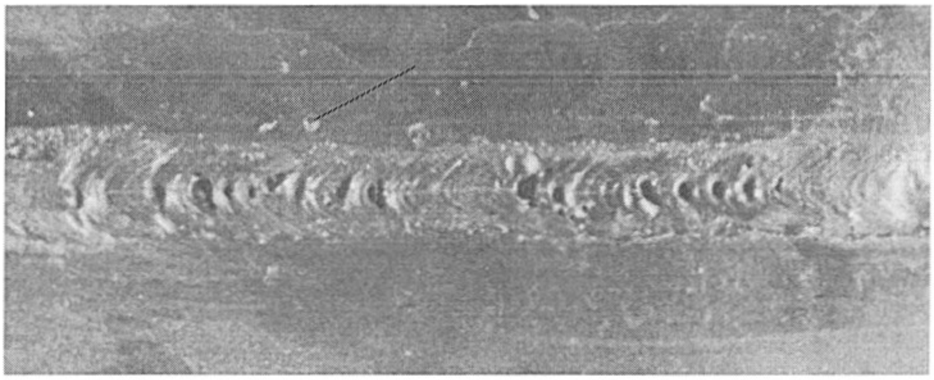
Crater cracks occur in the crater that is formed by improper termination of a weld pass. They are considered hot cracks and are sometimes referred to as *star cracks* because they often radiate in several directions from the center of the crater. However, they also have other shapes. Crater cracks are usually shallow, which allows for their removal with minimal grinding (see Figure 11.22).

A throat crack is a longitudinal crack in the weld face of either a groove or fillet weld (see Figure 11.23).

Toe cracks are generally cold cracks. They begin and grow from the weld toe where residual stresses are high, especially when the weld exhibits excessive reinforcement or convexity (see Figure 11.24). Toe cracks initiate approximately perpendicular to the metal surface, but may tend to curve and follow the weld HAZ.

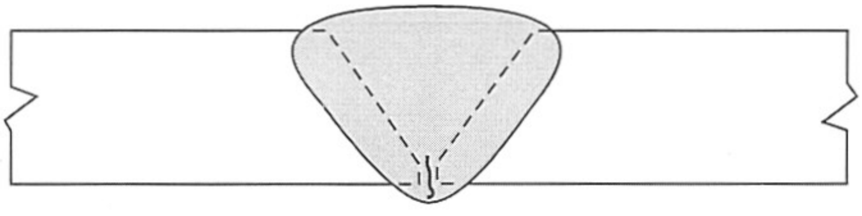
Root cracks are longitudinal cracks in the weld root. They are generally a form of hot cracking.

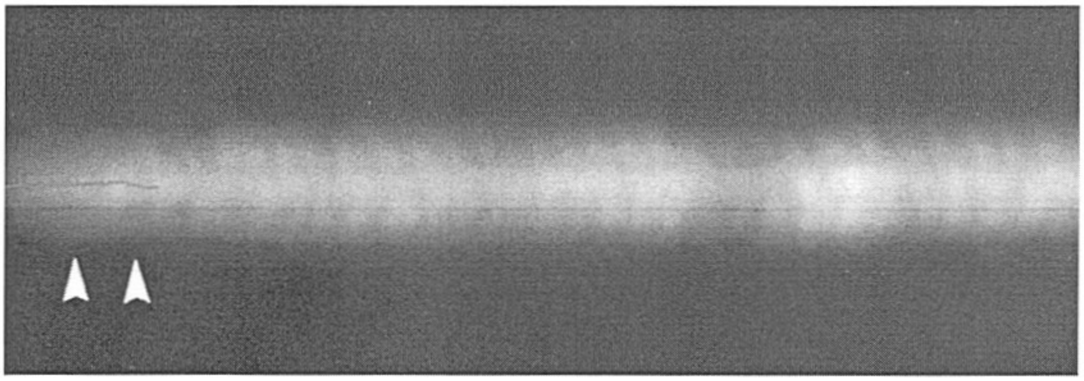
Underbead and HAZ cracks are usually cold cracks that form in the HAZ of the base metal. They are most



Guide for the Visual Examination of Welds (AWS B1.11)

LONGITUDINAL CRACK AND LINEAR POROSITY





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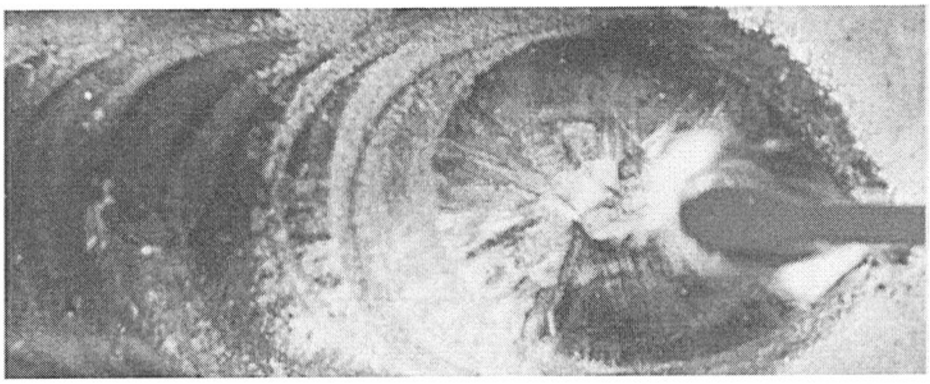
RADIOGRAPH OF LONGITUDINAL CRACK

Figure 11.21—Longitudinal Cracks



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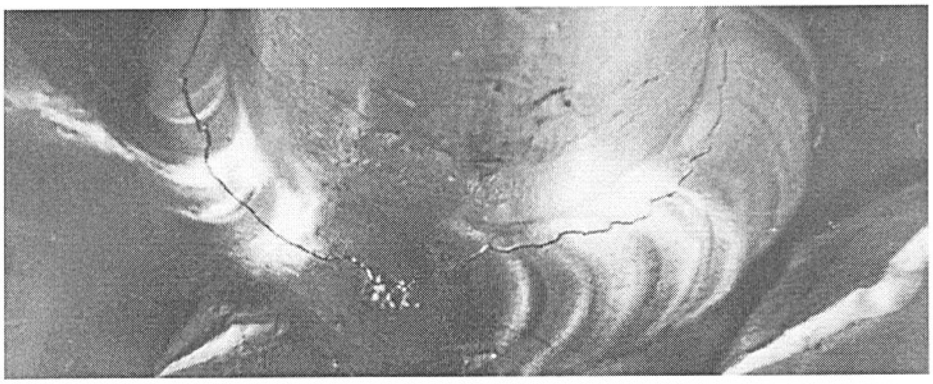
CRATER CRACK



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LONGITUDINAL CRACK PROPAGATING FROM CRATER CRACK

Figure 11.22— Cracks

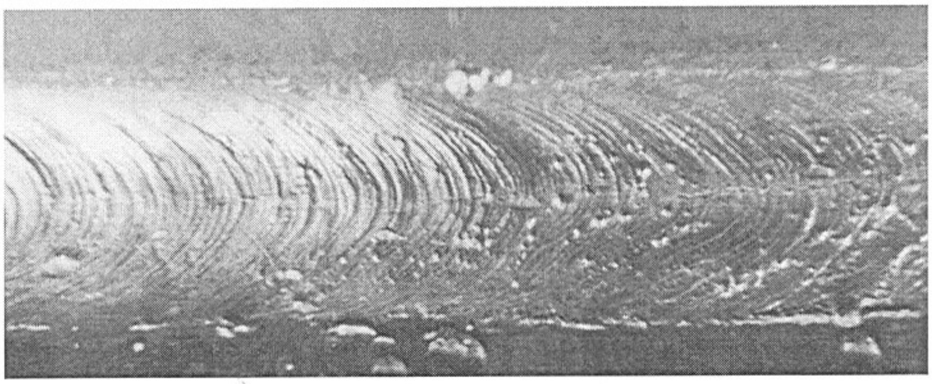

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Figure 11.23—Throat Crack

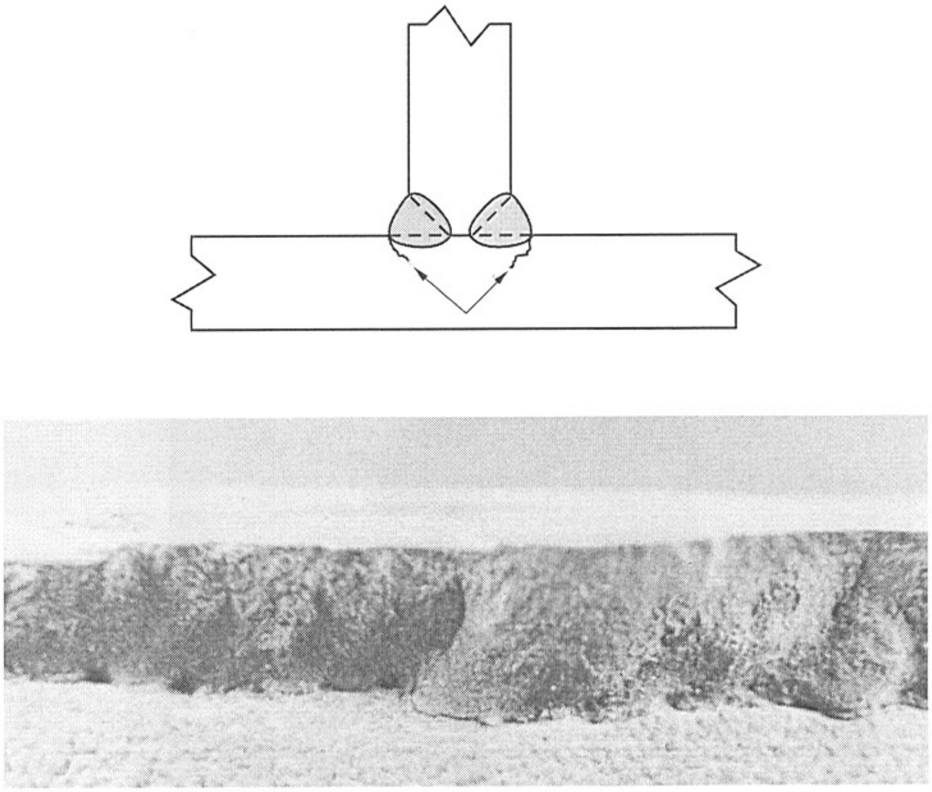

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Figure 11.24—Toe Cracks

often short, but they may join to form a continuous crack, especially when three simultaneous conditions are present: (l) hydrogen, (2) high-strength material (Rockwell "C" hardness of 30 or higher), and (3) high residual stress. Underbead and HAZ cracks can be either longitudinal or transverse (see Figure 11.25).

Fissures are small or moderate size separations along grain boundaries. This discontinuity is easiest to see in electroslag welds because of the large grains commonly present. The separations may be either hot or cold cracks. The term "microfissure" is used if the fissures are so small that magnification must be used to detect the separation. Fissures are termed "macrofissure" if the separation is large enough to be seen with the unaided eye (see Figure 11.26).

Arc Strike

Arc strikes represent unintentional melting or heating outside the intended weld deposit area. They are usually caused by the welding arc, but can be produced beneath an improperly secured work connection during welding. Arc strikes can also result from improper contact of the prods used for magnetic particle testing.

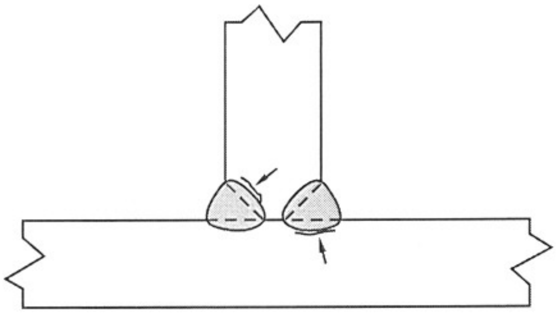


Figure 11.25—Underbead Cracks

The result is a small, remelted area that can be the source of undercutting, hardening, or localized cracking, depending upon the metal composition. For that reason,

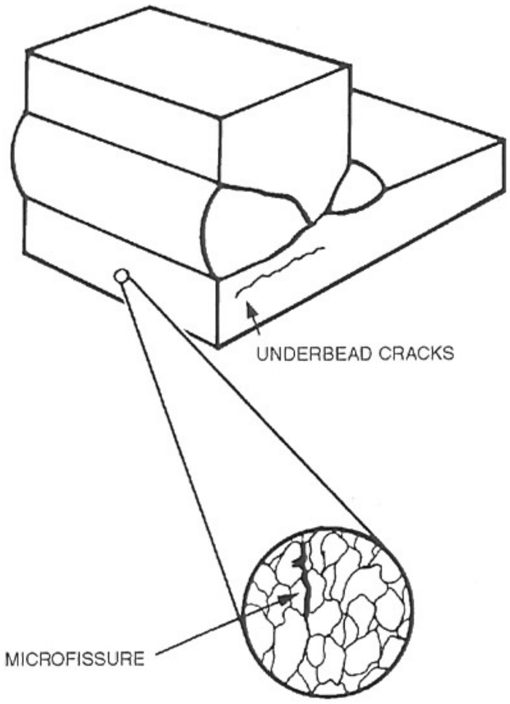


Figure 11.26—Underbead Cracks and Microfissure

arc strikes represent a dangerous condition that can result in catastrophic failure of the weldment.

Size of Discontinuity

The size of the discontinuity must be considered when evaluating the structural integrity of the entire weld. Acceptance standards specify the allowable size of discontinuity in terms of its linear dimensions.

Some discontinuities are acceptable, as long as their size does not exceed specified limits. However, other types such as cracks are normally unacceptable, regardless of length. In general, nonlinear discontinuities are permitted to be larger than linear types.

Location of Discontinuity

The location of a discontinuity may suggest the cause of the problem and its seriousness. The location of porosity can identify where contamination exists. The welding inspector must consider the location and orientation of some discontinuities to determine how much the load-carrying capacity of the structure will be degraded.

For structures that will be subjected to fatigue (or cyclic) types of loads, those discontinuities exposed to the surface are generally considered to be more severe. In fact, small surface discontinuities may be more damaging than subsurface ones, even though the size of those subsurface discontinuities is much greater.

Summary

The welding inspector will be asked to examine welds to determine their acceptability in accordance with various codes and specifications. One of the aspects of this activity will be the visual identification of weld discontinuities. The inspector must be capable of identifying the type of discontinuity, because different types of discontinuities have different levels of permissibility.

In addition to identifying the types of weld discontinuities present, the inspector should also know what conditions might have lead to the creation of those discontinuities. That way, corrective action can be taken to prevent further occurrence.

Review—Chapter 11—Weld and Base Metal Discontinuities

Q11-1 A discontinuity is:
- a. always a defect
- b. always a reject
- c. always acceptable
- d. rejectable if it exceeds code limits
- e. none of the above

Q11-2 Of the following, which is commonly caused by the presence of hydrogen in a crack susceptible microstructure subjected to applied stress?
- a. lamellar tearing
- b. delamination
- c. porosity
- d. delayed cracking
- e. none of the above

Q11-3 Porosity, occurring in the form of large cylindrical pores is called:
- a. clustered porosity
- b. linear scattered porosity
- c. uniformly scattered porosity
- d. elongated porosity
- e. none of the above

Q11-4 Which of the following discontinuities is least likely to be detected visually?
- a. toe crack
- b. undercut
- c. lamellar tear
- d. overlap
- e. none of the above

Q11-5 Underbead cracks can result from which of the following welding practices?
- a. use of wet electrodes
- b. welding on contaminated steels
- c. welding over paint
- d. all of the above
- e. none of the above

Q11-6 The weld discontinuity that results from improper termination of the welding arc is referred to as:
- a. undercut
- b. overlap
- c. crater crack
- d. incomplete fusion
- e. all of the above

Q11-7 All but which of the following processes may result in the presence of slag inclusions in the completed weld?
- a. SMAW
- b. PAW
- c. FCAW
- d. SAW
- e. none of the above

Q11-8 That discontinuity that results from the entrapment of gas within the weld cross section is referred to as:
- a. crack
- b. slag inclusion
- c. incomplete fusion
- d. porosity
- e. none of the above

Q11-9 What base metal discontinuity, located at the weld toe, is caused by the welder traveling too rapidly?

a. underfill
b. undercut
c. incomplete fusion
d. overlap
e. none of the above

Q11-10 What weld discontinuity results when the welder travels too slowly, which causes excess weld metal to pour out of the joint and lay on the base metal surface without fusing?

a. undercut
b. underfill
c. overlap
d. incomplete fusion
e. none of the above

Q11-11 What weld metal discontinuity results when the welder fails to completely fill the weld groove?

a. underfill
b. undercut
c. overlap
d. incomplete fusion
e. none of the above

Q11-12 Excessive weld metal buildup on a groove weld is referred to as:

a. excess convexity
b. excess weld reinforcement
c. overfill
d. all of the above
e. none of the above

Q11-13 The weld discontinuity that results from the initiation of the welding arc outside the weld joint is referred to as:

a. incomplete fusion
b. undercut
c. overlap
d. scratch start
e. arc strike

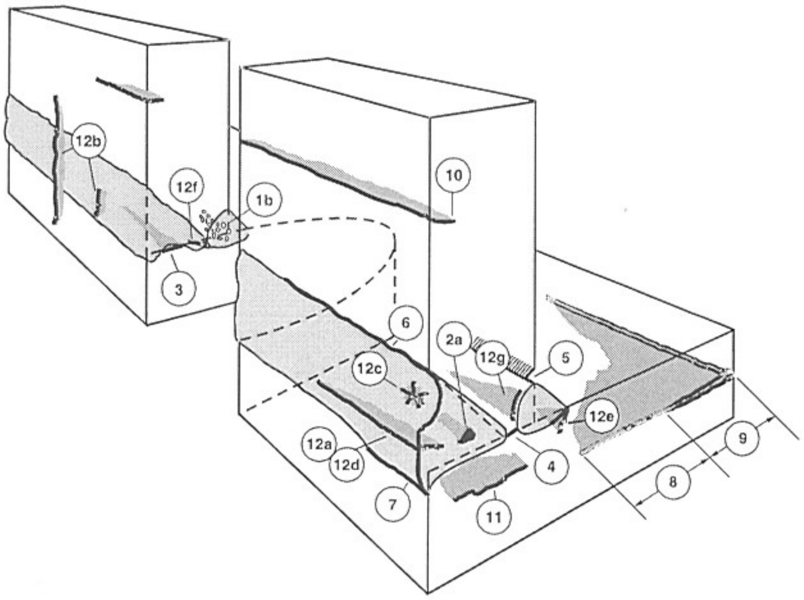
Q11-14 Of the following, which weld discontinuity shows up as a light region on a radiograph?

a. porosity
b. incomplete joint penetration
c. a and b above
d. tungsten inclusion
e. none of the above

Q11-15 What base metal discontinuity results from improper steelmaking practice and is associated with the rolled surface?

a. lamination
b. delamination
c. seam
d. crack
e. none of the above

Questions **Q11-16** through **Q11-20** refer to the figure below:



Q11-16 What discontinuity is shown by #12b?
- a. longitudinal crack
- b. transverse crack
- c. face crack
- d. toe crack
- e. root crack

Q11-17 What discontinuity is shown by #11?
- a. lamination
- b. base metal crack
- c. lamellar tear
- d. seam
- e. lap

Q11-18 What discontinuity is shown by #12g?
- a. toe crack
- b. incomplete fusion
- c. root crack
- d. lamellar tear
- e. underbead crack

Q11-19 What discontinuity is shown by #5?
- a. undercut
- b. underfill
- c. overlap
- d. incomplete fusion
- e. toe crack

Q11-20 What discontinuity is shown by #10?
- a. lamination
- b. seam
- c. delamination
- d. base metal crack
- e. incomplete fusion

CHAPTER 12

Nondestructive Examination (NDE) Processes

Contents

Chapter 12—Nondestructive Examination (NDE) Processes

Introduction

Under some specifications, a knowledgeable welding inspector has the authority to accept welds by visual examination alone. Some of the welds in a weldment or structure, however, cannot be easily certified. The welding inspector can employ one or more of the following methods to collect the necessary evidence for specification compliance.

- Nondestructive examination (NDE) performed by technicians who are qualified in accordance with the guidelines of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A, when required
- Chemical analysis qualified to ASTM standards
- Metallurgical analysis
- Mechanical testing

This chapter will help the welding inspector to:

- Know the principal features to be considered when choosing a nondestructive examination method.
- Understand how this NDE differs in the various applications of welding.
- Understand the fundamental aspects of the different techniques of NDE.
- Relate the proper examination technique to a given weld joint design and welding process.
- Know the responsibilities with regard to sample selection, examination methods, retests, repairs, and evaluation of data.

Selection of Examination Method

There are three principal features to be considered when choosing an examination method:

(1) Limitations of the examination method
(2) Acceptance standards
(3) Economics

Limitations of the Examination Method

The limitations of the examination method are a consideration when determining which method will provide the best results for a particular test. For example, radiography can detect cracks that are aligned parallel to the radiation beam because such cracks are typically perpendicular to the plate surfaces, but radiography usually *cannot* detect laminations in the plate. Ultrasonic examination, however, *can* detect laminations in the plate and, with the proper choice of technique, can usually be relied upon to detect cracks perpendicular to the plate surfaces.

Acceptance Standards

The statement, "the weld shall be radiographically examined," has no meaning unless acceptance standards are stated. The acceptance standards must state each type of discontinuity and whether such a discontinuity is permissible. If a particular type of discontinuity is permissible, then the acceptance standards must specify the maximum size at which the discontinuity is acceptable. Acceptance standards, commonly used as references in purchase specifications, are an integral part of most of the codes and standards listed in Annex A.

Economics (Cost)

Each examination method has a different cost in a particular situation. Two basic cost factors to be considered in the selection of an NDE method are the initial equipment availability and cost, and the cost of performing the tests. Typically the least expensive method, visual examination is limited to the detection of surface discontinuities. In general, NDE methods such as radiographic, ultrasonic, and eddy current are more expensive than visual, magnetic particle, and liquid penetrant methods of examination.

Selection of the proper examination method can be quite complex. In many cases, a single test is inadequate, and it may be necessary to apply two or more tests to ensure complete coverage. For example, the examination of a large carbon steel weldment might include radiography for subsurface evaluation and magnetic particle testing for surface examination. For critical applications or large volumes of testing, the services of a competent laboratory or consultant should be engaged.

Examination Methods and Limitations

Visual Examination

As the welding inspector gains experience, it will be noted that to a large degree the quality of a weld can be determined by its surface appearance. When the welding inspector sees that the preparation of the joint was good and knows that the welder had the requisite ability, the odds favor that the weld will be sound and within specification.

It is important to remember that the evidence needed by the inspector is provided by the governing code, engineering standards, job specifications, or job requirements. The welding inspector can neither accept less nor ask for more than is required by these documents.

> It has been shown that an effective program of visual inspection results in the early discovery of most defects that, if left undetected, would later be found by using a more costly method of NDE.

Visual examination is limited to the detection of surface discontinuities. However, when conscientiously applied before, during, and after welding, visual examination can prevent the vast majority of discontinuities that would be later detected by other examination methods. In fact, preventing discontinuities before a weld is complete is one of the most important features of visual examination (see Figure 12.1).

Visual Examination Practice

Any good visual weld examination program requires the inspector to have a working knowledge of:

- Applicable codes, standards and specifications, including weld acceptance criteria
- Workmanship standards
- Welding processes being used
- Good weld fabrication practices

The welding inspector's responsibilities start before welding begins. In fact, these initial steps are critical enough to set the tone for the final quality of the entire project. If these preliminary duties are carefully carried out, the attainment of quality welding will be more ensured.

Preliminary duties can include:

- Reviewing applicable documentation
- Checking welding procedures
- Checking individual welder qualifications
- Establishing hold points
- Developing an inspection plan
- Developing a plan for recording inspection results and maintaining those records
- Developing a system for identification of rejects
- Checking condition of welding equipment
- Verifying base metal and filler metal identifications

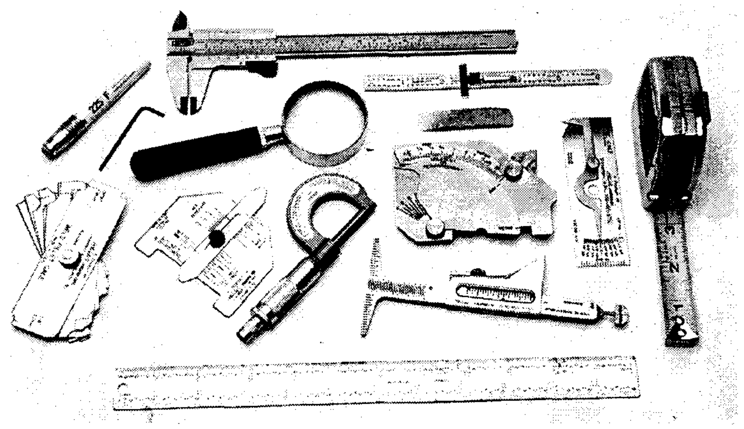


Figure 12.1—Visual Inspection Tools

- Checking quality and condition of base and filler metals
- Checking weld preparations
- Checking joint fit
- Checking adequacy of alignment devices
- Checking weld joint cleanliness
- Checking preheat, when required

Once welding begins, the welding inspector's duties are primarily related to the assurance that the welding is being done in accordance with the welding procedures and any applicable standards. The inspector's goal is to identify problems before they occur (or as soon as possible after they occur) so that they can be corrected in the most economic and effective way.

During the actual welding operation, the inspector should:

- Check welding variables for compliance with welding procedure
- Check quality of individual weld passes
- Check interpass cleaning
- Check interpass temperature
- Check placement and sequencing of individual weld passes
- Check back-gouged surfaces
- Schedule in-process NDE, if required

After the welding has been completed, the role of visual examination is simply the verification that all of the preceding steps have been successfully completed and the resulting weldment is acceptable.

When welding is complete, the inspector should:

- Check finished weld appearance
- Check weld size
- Check weld length
- Check dimensional accuracy of weldment
- Schedule additional NDE, if required
- Monitor postweld heat treatment, if required
- Prepare inspection reports

There are numerous advantages of visual examination, including low cost to apply, little need for expensive equipment, and problems easily identified, and quickly and inexpensively corrected.

Penetrant Testing (PT)

Penetrant testing is a sensitive method used for locating discontinuities, such as cracks and porosity, in nonporous materials. The discontinuities must be clean and open to the surface. This method employs a penetrating liquid that is applied to the surface to be examined, and which enters the discontinuity. The excess penetrant is then cleaned from the surface. Any penetrant that subsequently exudes from openings and causes discoloration of developer powder on the surface indicates the location of a discontinuity (see Figure 12.2).

There are two general classifications of penetrants: visible dye and fluorescent. They differ in that the visible dye can be observed under normal white light, while the fluorescent type requires an ultraviolet (or black) light to produce an indication. There are several methods for effective application of penetrants, such as dipping, brushing, flooding, or spraying. Use of fluorescent penetrants results in a more sensitive test, because the eyes can more readily detect a fluorescent indication. Consequently, for critical applications where minute discontinuities must be detected, the fluorescent penetrant method is desirable.

The penetrant test generally consists of four steps, including precleaning the test surface, application of the penetrant that remains for some prescribed time (referred to as the *dwell time*), removal of excess penetrant from the test surface, and application of the developer. Following the application and drying of the developer, all indications are evaluated in accordance with applicable standards. For a detailed explanation of these steps, please refer to ASTM E 165, *Standard Practice for Liquid Penetrant Inspection*.

Uses

This method is applicable to magnetic materials; however, it is particularly useful on nonmagnetic materials such as aluminum, magnesium, and austenitic stainless steels, which cannot be examined by magnetic particle testing.

Advantages

PT is relatively inexpensive and quick. The process is simple and operators find little difficulty in learning to apply it properly. There are few, if any, false or nonrelevant indications to be observed on smooth surfaces.

Limitations

The main limitation of PT is that discontinuities must be clean and open to the surface to be detected. Some substances used as penetrants can have a deleterious effect on welds and base metals and can affect the service life of the weldment or end use of the product. Penetrants are difficult to remove completely from discontinuities. If a penetrant is corrosive to the material or otherwise incompatible with the use of the product, it should be avoided.

The contour of the surface under examination should not have sharp depressions between beads or weld ripples that may interfere with complete cleaning and excess penetrant removal, and result in false observations

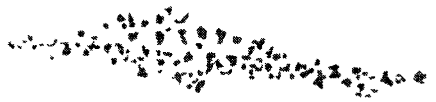
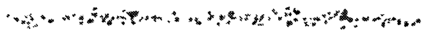
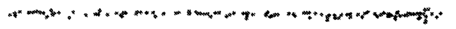
IF YOU SEE:	INDICATION	YOU HAVE:
A CONCENTRATION OF RED SPOTS		PITS AND POROSITY
A CONTINUOUS STREAK WHICH BLEEDS UP RAPIDLY		LARGE CRACK OR OPENING
A BROKEN LINE OF DOTS WHICH TAKES SEVERAL MINUTES TO COME UP		CRACK OR COLD SHUT
A SERIES OF RED DOTS FORMING AN IRREGULAR LINE		FATIGUE CRACK, PARTIAL WELD OR LAP

Figure 12.2—Developer Interpretation

or irrelevant indications. If these conditions do exist, the weld surface should be ground smooth before inspection.

Interpretations

It is important that the technician not reduce the recommended dwell times for penetrant or developer. Large cracks and voids can quickly be found without penetrant testing, however, tightly closed cracks take longer to discover because they absorb the penetrant slowly and respond to the developer equally as slow.

Inadequate removal of the superficial penetrant will give many false indications, such as a general glow under a black light for fluorescent penetrant testing, or a pink coloration of the developer with visible dye penetrant testing. Precleaning the surface without the addition of more penetrant provides a clearer indication, showing only seepage from surface discontinuities. Indications that repeat at the same location through several cleanings undoubtedly reveal open discontinuities.

Care must also be taken to avoid spraying cleaner directly on the test surface between application of the penetrant and developer.

Magnetic Particle Testing (MT)

MT is used for locating surface or near surface discontinuities in ferromagnetic materials. This method involves the establishment of a magnetic field within the material and can be examined with the aid of prods, yokes, or coils (see Figures 12.3 and 12.4).

The pattern of discontinuities is revealed by the buildup of iron powder particles that are applied to the surface, either as a dry powder or suspended in a liquid.

The particles may be dyed for greater visibility or coated with fluorescent dye to be viewed under ultraviolet light with the same improved sensitivity associated with fluorescent penetrant testing. The type of surface and the type of discontinuity suspected should determine the material selected.

Fluorescent magnetic particle and fluorescent penetrant testing are more sensitive because the human eye can more readily perceive a fluorescent indication than a visible indication.

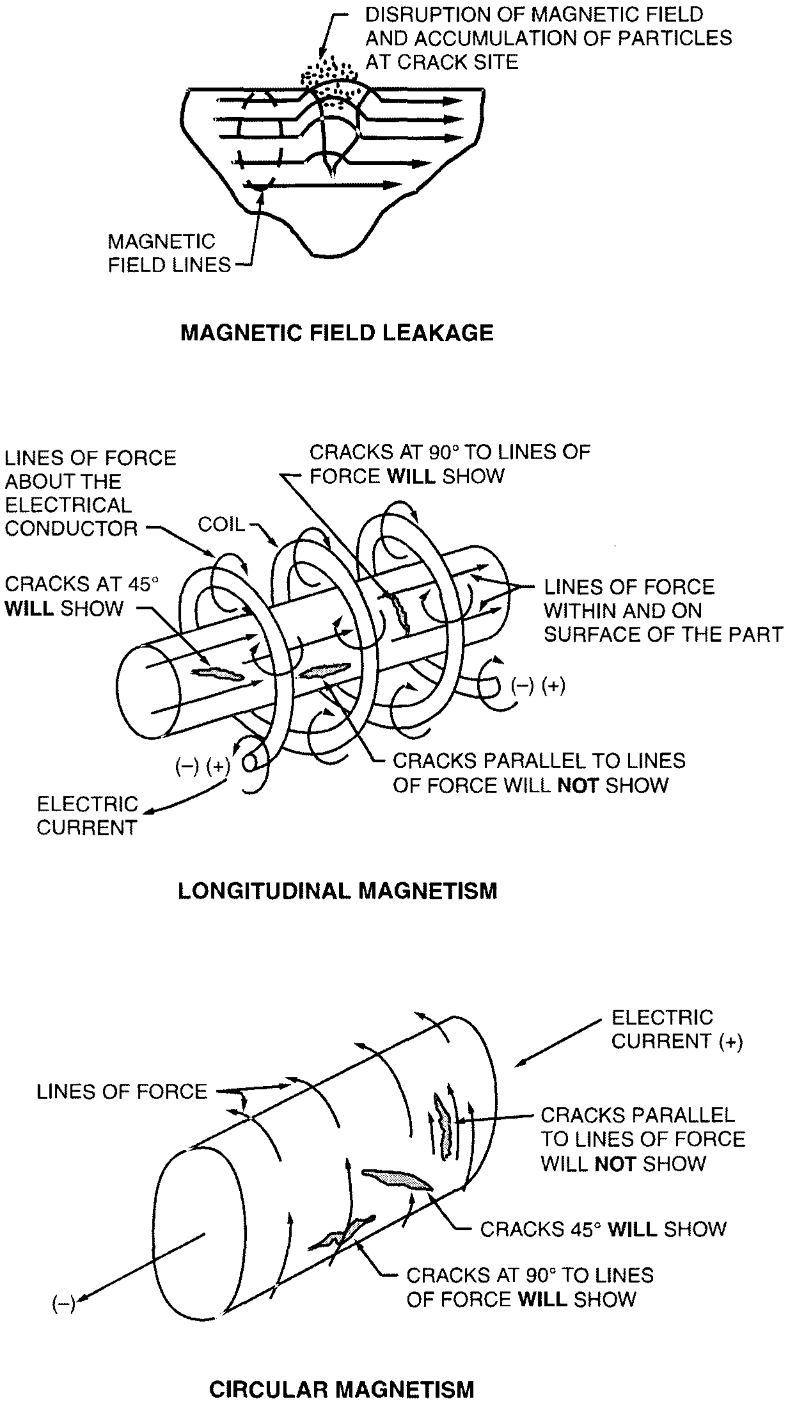


Figure 12.3—Magnetism

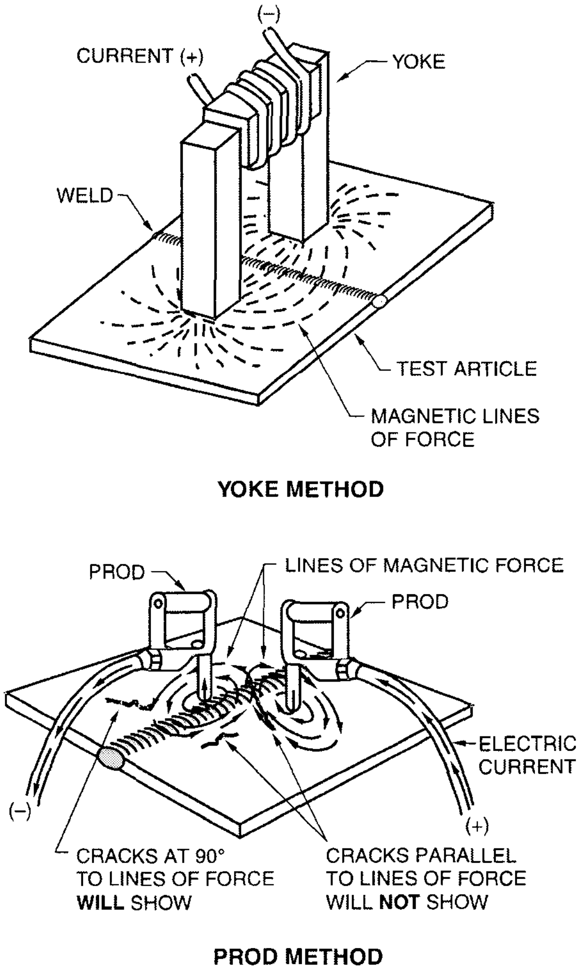


Figure 12.4—Yoke and Prod Methods

A test material or component can be magnetized either by passing electric current through it or by placing it in a magnetic field. The electric current used to generate the magnetic field may be ac, dc, or half-wave rectified direct current (hwdc). Although generally limited to the detection of surface discontinuities, the ac magnetic field tends to increase the particle mobility on the surface to result in an improvement of the test sensitivity when examining rough surfaces.

A dc magnetic field differs from the ac field in that it tends to penetrate more deeply into the test piece, which results in the ability to detect discontinuities slightly below the surface (see Figure 12.5). However, the magnetic particles do not tend to move as readily on the surface as with ac. Half-wave rectified dc combines the benefits of both types of magnetizing current: the enhanced particle mobility of ac and the deeper penetration of dc.

Uses

MT can provide a great deal of information about the quality of weldments. This method may be used to inspect welds, plate edges prior to welding, and weld repairs. MT can detect:

- Surface cracks of all kinds in the weld or base metal
- Laminations or other discontinuities on the prepared edge of the base metal
- Incomplete fusion (if at or near the surface)
- Undercut
- Subsurface cracks (if occurring near enough to the surface to cause an interruption of the magnetic field)

Advantages

The basic equipment for MT includes devices for creating a magnetic field of the proper strength and direction, in addition to controls for adjusting the current and an ammeter to indicate the amount of magnetizing current for each examination.

Compared to PT, this method has certain other advantages. MT reveals discontinuities not open to the surface or that are filled with some substance (e.g., cracks filled with carbon, slag, or other contaminants may not be detectable using penetrant testing). MT is also generally faster and more economical than PT, unless extremely large test surfaces are involved. Another advantage of MT is that the part requires less cleaning prior to examination.

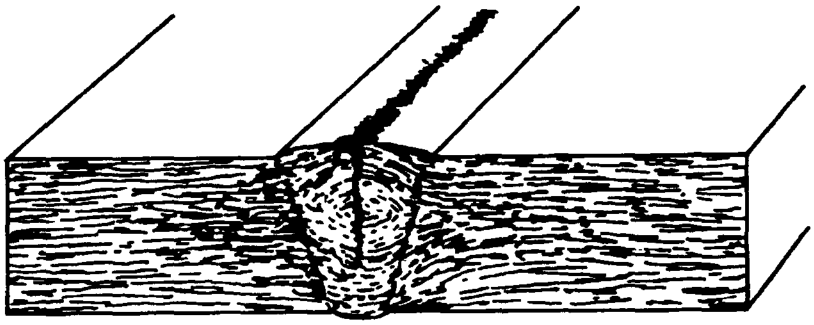
Limitations

The magnetic particle method of examination is applicable only to ferromagnetic materials in which the deposited weld metal is also ferromagnetic. This method cannot be used to examine nonferromagnetic materials such as aluminum, magnesium, or the austenitic stainless steels.

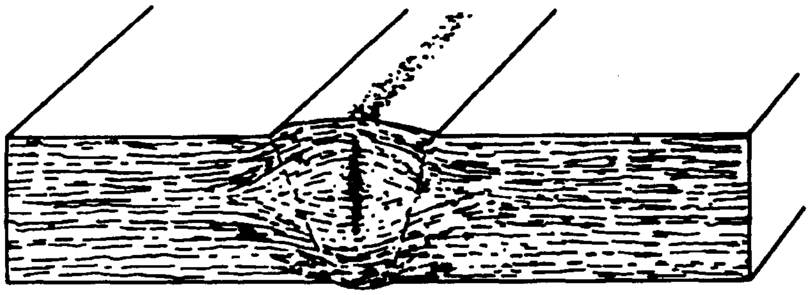
Difficulties may arise when examining weldments where the magnetic characteristics of the deposited weld metal differ appreciably from those of the base metal, or where the magnetic field is not properly oriented. Joints between metals of dissimilar magnetic characteristics may create magnetic particle indications, even though the joints themselves are sound.

It is important that the technician not expect the magnetic particle method to find deep-seated discontinuities. These discontinuities are more readily discovered using other examination methods, such as radiography or ultrasonic testing. These methods, and the visual examination of sectioned test samples, can be used to qualify the magnetic particle procedure for subsurface examination.

To discover discontinuities in all orientations, the magnetic particle test must be applied in at least two di-



SURFACE CRACKS GIVE POWDER PATTERNS THAT ARE SHARPLY DEFINED, TIGHTLY HELD, AND USUALLY BUILT UP HEAVILY. THE DEEPER THE CRACK, THE HEAVIER THE BUILD-UP OF POWDER.



SUBSURFACE CRACKS PRODUCE A LESS SHARPLY DEFINED, FUZZY PATTERN. THE POWDER IS ALSO LESS TIGHTLY ADHERENT.

Figure 12.5—Iron Powder Build-Up Reveals Discontinuity

rections, approximately 90° apart. The tester can then be assured that all discontinuities will be revealed.

Radiographic Testing (RT)

RT is suitable for all materials. However, the applicability of radiography for weld examination depends a great deal upon the weld joint location, joint configuration, and material thickness. Almost any weld thickness can be radiographed, but insufficient joint access may prevent the best use of this method. The welding inspector should keep this limitation in mind before requesting radiographic examinations.

Radiography uses X-ray or gamma radiation that penetrates through the part and produces an image on a film or plate. The density of the material in a discontinuity (i.e., air in the case of a crack, incomplete fusion, or porosity) is less than that of the solid metal. Different density materials attenuate the radiation in different amounts and consequently produce optical density differences on the film or plate.

Material density can be affected by the material itself (e.g., tungsten is much denser than steel or aluminum, therefore, it is more effective at preventing the radiation from passing through and resulting in a low density indication on the film) or by the thickness of a given material (e.g., the thicker the material, the more effective it is at stopping the radiation, and producing a lighter film image). The selection of the radiation source (energy of the emitted rays) for a particular thickness of weld is a critical factor. If the energy of the source is too high or too low for a given thickness of material, the result can be low contrast and poor radiographic sensitivity. The use of a variable light intensity viewer is helpful when viewing and analyzing radiographs.

Determining the film density at various points is also necessary, and is usually accomplished through the use of a device referred to as a *densitometer.* To indicate the acquired sensitivity of a given radiograph, a device referred to as an *image quality indicator* (IQI) is placed adjacent to the area of interest. There are two types of IQIs. The first type is a shim of a particular thickness (based on the thickness of the test part) which contains a series of holes having different diameters. The second type IQI is the wire type, which has wires of specified diameters. The sensitivity of the radiograph is determined by which one of the three holes, or wire diameter is visible on the radiograph (see Figure 12.6).

Advantages

Radiography can detect surface discontinuities (undercut, incomplete joint penetration, excessive weld reinforcement, underfill, etc.) and subsurface discontinuities that cannot be detected with visual, magnetic particle or penetrant methods, and may not be detected by the ultrasonic method.

Limitations

The cost of radiography usually increases as the joint becomes more complex, and the amount of information that can be obtained becomes more limited.

Discontinuities must be approximately aligned with the radiation beam. This is not a problem for slag or porosity because these discontinuities are usually round in cross section and are aligned with the beam from any direction. Cracks, incomplete fusion, and incomplete joint penetration, however, must be aligned with the beam to be detected. Laminations and lamellar tearing are rarely detected with radiography, due to their inherent orientation with respect to the radiation.

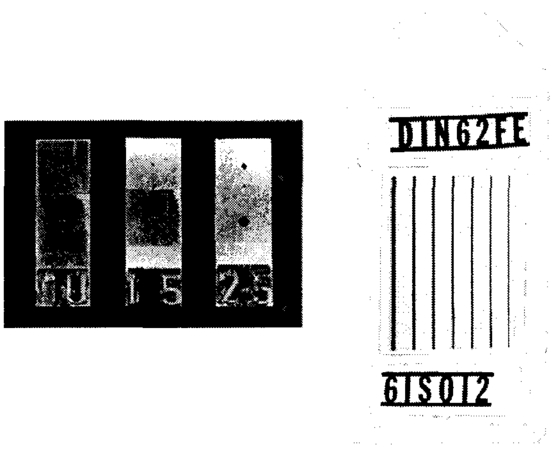


Figure 12.6—Shim and Wire Type Image Quality Indicators (Penetrameters)

The high cost of radiation sources and related equipment and facilities tends to be one of the limitations of this method. The initial setup for this type of testing requires a high capital expense.

Radiography has one negative aspect that is not associated with the other nondestructive methods—radiation hazard. Although excessive exposure to radiation from an X-ray machine or a radioactive isotope cannot be detected by any of the human senses, radiation can cause disease, permanent injury, or death. All states require that radiographers be licensed, have special training, or both. Radiography is, however, a safe operation when conducted in accordance with established procedures.

No single NDE method is the best. The discontinuity must be favorably oriented to the source of probing energy in all cases. In some cases, it may be necessary to use more than one NDE technique.

Ultrasonic Testing (UT)

UT is applicable to almost all materials. The ultrasonic method uses the transmission of mechanical energy in wave form at frequencies above the audible range. Reflections of this energy by discontinuities in metals are detected in a manner somewhat similar to the detection of reflected light waves in transparent media.

Uses

In the pulse-echo technique, a transducer transmits a pulse of high-frequency sound into and through the material; the reflected sound is then received from a discontinuity, the opposite surface, or other surfaces of the part. The reflected sound is received as an echo which, together with the original pulse, is displayed on the screen of a cathode ray tube (CRT) (see Figure 12.7).

Before testing, the instrument to be used must be calibrated against a reference standard (see Figure 12.8).

When a sound beam intercepts the plane of discontinuity at or near 90°, a maximum reflected signal will return to the transducer. In scanning welds, this is achieved by beams angled into the work, through a lucite wedge and into the work through water, oil, or similar coupling material.

When examining groove welds (which require ultrasonic testing under the AWS Structural Welding Code), the technician will find the procedures tightly specified in AWS D1.1. Both the amount of testing to be done and the equipment to be used are specified. In addition, the

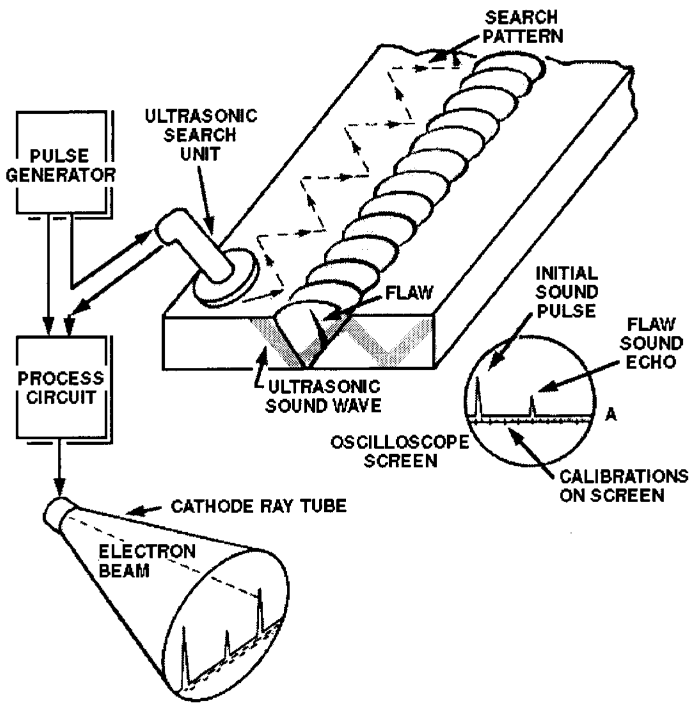


Figure 12.7—Ultrasonic Inspection

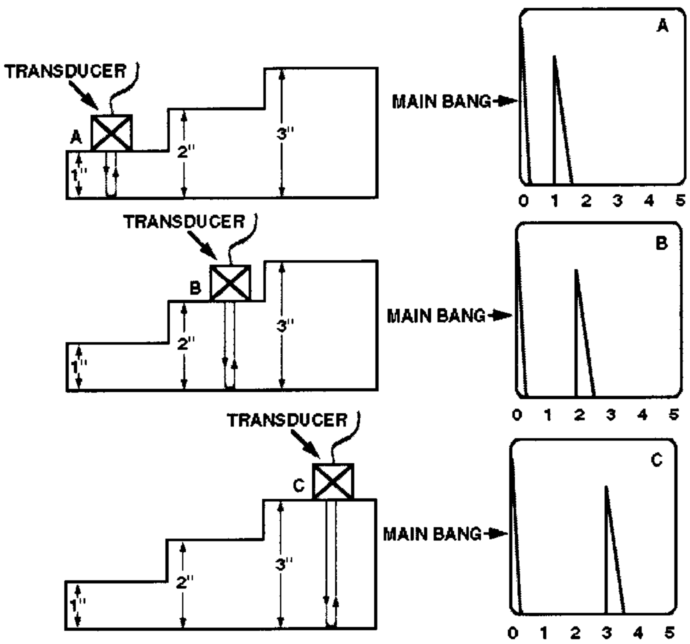


Figure 12.8—Calibration Sequence for Longitudinal Beam Transducer

equipment must be calibrated using a standard reference block, such as the International Institute of Welding (IIW) calibration block. The setup used by technicians (magnitude and location of indications on horizontal and vertical scales of the CRT) is prescribed for both straight beam and angle beam testing.

Advantages

UT can be used to detect both surface and subsurface discontinuities. For pulse-echo testing, access is necessary to only one side of the work. The size of flaws and their interface location may be determined quantitatively. This method is generally more sensitive than radiography for the discovery of planar type discontinuities, which are generally considered more critical. Laminations and lamellar tearing can be readily detected using UT.

Limitations

Welds in some materials are very difficult to examine ultrasonically. For example, welds involving materials and processes that produce large grain size tend to scatter and disperse the sound beam; penetration of the sound beam into these materials is limited and interpretation of the results can be difficult.

The scan pattern must be sufficient to pass the projected sound beam through the entire volume of the weld and heat-affected zone to permit detection of possible discontinuities.

For contact testing, the surface used for scanning with the transducer must be smooth enough so that liquid coupling may be obtained. The part can also be placed in water and the sound wave transmitted through some length of water path. This method is referred to as *immersion testing*.

Personnel performing UT must be qualified and generally require more training and experience than for most of the other NDE methods.

Eddy Current (Electromagnetic) Testing (ET)

ET requires that the part under test be subjected to the influence of an alternating electromagnetic field. This test detects surface or subsurface discontinuities in any material that is an electrical conductor. The electromagnetic field both induces eddy currents in the part and also establishes magnetic fields, if the part is magnetic (see Figure 12.9).

A complete separation of these two effects in magnetic materials is not easily accomplished. However, a high degree of differentiation can be obtained by specialized techniques. Information gathered by probe coils is transmitted to a test circuit and analyzed electronically.

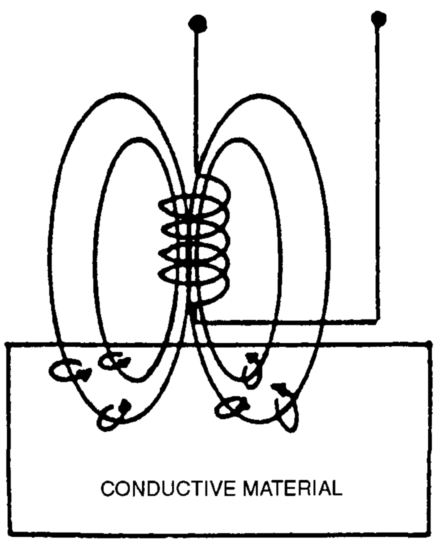


Figure 12.9—Induced Eddy Currents in Test Objects

Electromagnetic field frequencies are usually in the range of 500–5000 Hz (hertz, or cycles per second).

Uses

Since eddy currents may be induced in any electrical conductor, ET is employed on magnetic or nonmagnetic materials.

In eddy current tests, the magnitude and direction of the eddy currents are detected by the coil (or by a separate coil), which acts through electronic circuitry to register the discontinuity.

In testing of magnetic materials, the distribution of magnetic flux is affected by magnetic variables. If the variation in flux is associated with discontinuities in the material, the discontinuities are detected (see Figure 12.10).

Advantages

When compared to the other methods of testing, the following is a list of the four most significant advantages of ET:

(1) In many cases, ET can be completely automated to provide automatic examination at high speed and relatively low cost.

(2) Under certain circumstances, the indications produced are proportional to the actual size of the discontinuity; therefore, the tests can be useful for grading and classifying.

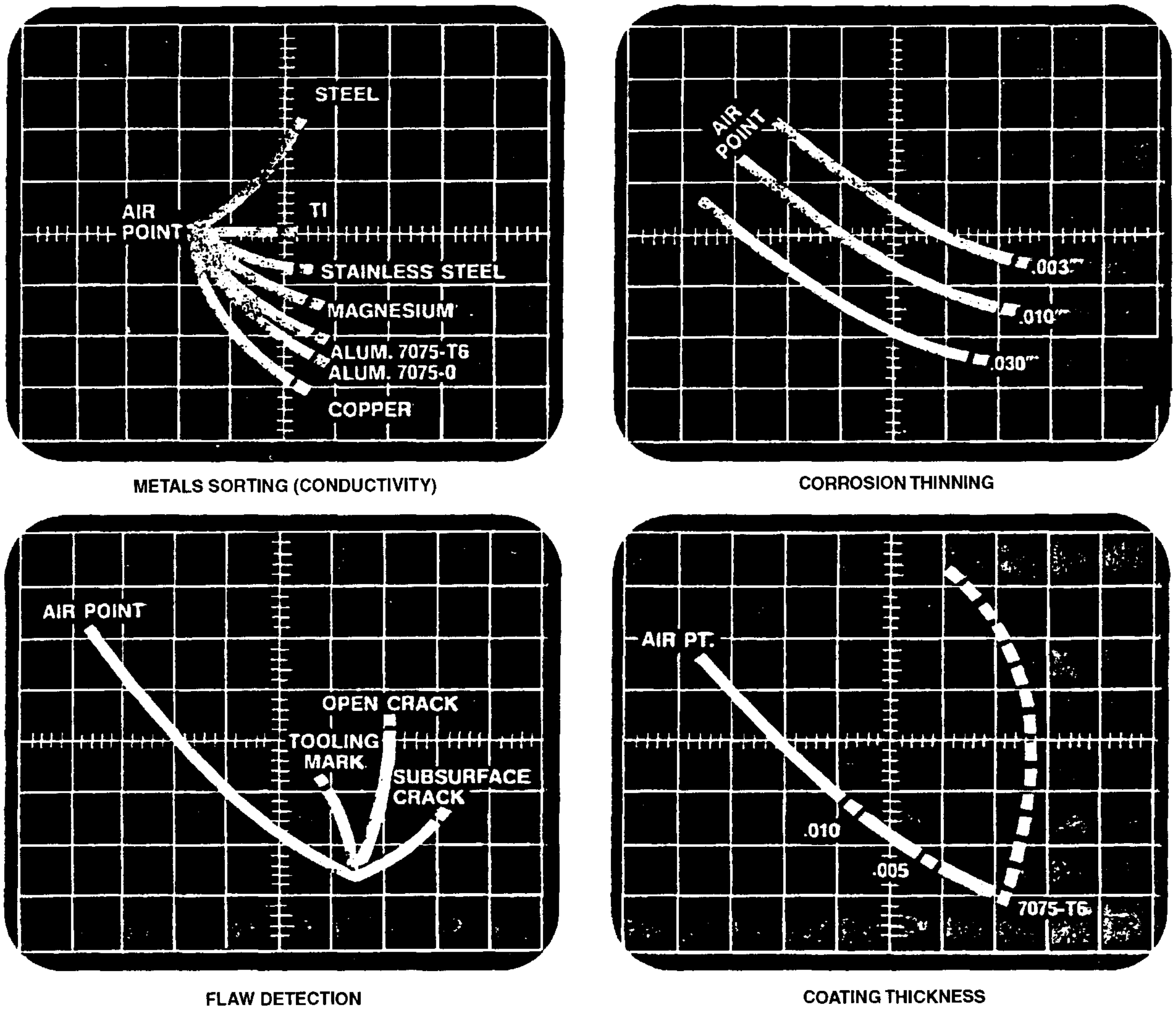


Figure 12.10—Typical CRT Displays for Eddy Current Testing

(3) Actual contact of probes with the work is unnecessary; close proximity is satisfactory.

(4) ET can detect many material characteristics, including electrical conductivity, magnetic permeability, thickness, the thickness of a nonconductive coating, alloy content, heat treatment, and the presence of discontinuities at or below the surface.

Limitations

In preparing a material to be examined, any magnetic or electrically conductive surface dirt must be removed. Before testing, the instrument to be used must be calibrated against a reference standard.

The design of the coil that produces the magnetic field must be appropriate for the shape of the component to be tested and the type of discontinuities that are sought. On welded tubular products, a coil (or coils) is commonly built to surround the material.The practical limit for penetration of eddy currents in most nonmagnetic metals is approximately 1/4 in. (6 mm) below the surface. The depth of examination below the surface of the part depends upon the frequency chosen to excite the electromagnetic field.

Acoustic Emission Testing (AET)

Atomic movements that lead to cracking are accompanied by sound bursts, which may be detected by suitable microphones (piezoelectric ceramic elements). These sounds are emitted in all directions and may be detected from any surface of the structure. By monitoring the emissions, the weld quality may be assessed during welding and cooling. Weldments with incomplete joint penetration, incomplete fusion, cracking, porosity, or various imperfections can be detected, and the regions emitting the sound can be located by triangulation from several sensors (using a computer). After the weldment has cooled, the sounds will cease, and a stimulus (mechanical loading or thermal stress) must be applied to cause further acoustic emission. Stress exceeding the maximum previously experienced by the metal causes plastic deformation at the tip of any crack and a tell-tale acoustic burst is emitted. If the discontinuities in the weldment are not affected by loading, they will not be active emitters, and the part will be recognized as structurally "sound" (soundless).

AET can be a valuable adjunct to hydrostatic pressure testing. Acoustic emissions from a lengthening crack increase in number and intensity as a function of the applied variable (displacement, load, pressure, or time). Instantaneous interpretation and location of the source can permit a repair to be made before the vessel is harmed by rupturing.

Acoustic emission is also used to monitor both in-process welding on production lines, and critical weldments in service.

Leak Tests (LT)

LT methods can be as unsophisticated as the pneumatic or gas and soap bubble test. By lightly pressurizing the component and immersing the vessel in water or brushing a soap film over the surface, the formation of bubbles can be observed at any leak (see Figure 12.11).

Open tanks are frequently tested by filling them with water that contains fluorescein, which permits ready detection of any seepage under ultraviolet illumination. The hydrostatic (or head) pressure causes the fluorescein to escape through any leaks and be detected.

Another leak test applied to storage tanks (principally floor joints) is referred to as the *vacuum box test.* In this test, the weld surface is covered with a soap solution; a transparent box with soft rubber seal is then placed over a portion of the weld length. Using a vacuum pump or compressed air, a vacuum is created in the box and any leaks will be indicated by the presence of bubbles. The leak test may use an organic halide gas on one side of the vessel and a halide torch on the other. The torch flame changes color in the presence of halogens.

The ultimate leak test, which uses helium as a tracer gas, is referred to as the *helium spectrometer leak test.* Due to their extremely small size, helium atoms can pass through the smallest leaks. These minute leaks are then detected using special instruments that sense any leakage of helium gas.

Details of the more complex tests are available from the equipment manufacturer. As stated for other testing methods, the rules for LT acceptance and rejection must be detailed in the specifications.

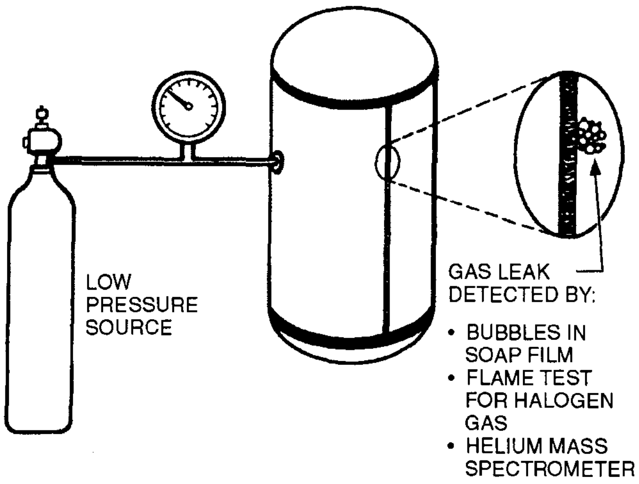


Figure 12.11—Leak Tests

Proof Tests

Proof testing may involve overloading the component or testing for leaks, or both. The hydrostatic test is one of the family of tests referred to as proof tests and is categorized as a *pressure* test. A pressure test is the "final test" that some of the weldments previously examined must pass to earn a certificate of fitness. Details of how the pressure test is to be conducted should be given in the documents governing each assembly or subassembly.

Caution must be exercised when conducting any hydrostatic test of a closed vessel; the technician must vent all air trapped within the container before permitting pressurization to begin. Liquids are essentially noncompressible, i.e., if the vessel is entirely filled with liquid, and rupture begins, the first leakage will reduce the pressure dramatically and the fracture will stop. However, if air has been trapped, its energy of compression will continue to extend the fracture explosively, resulting in great damage and danger to observers. It is also very important to vent any vessel after the hydrostatic test is completed. When draining test fluids, a vacuum may be created that may be adequate to damage the component.

Magnetic Test for Delta Ferrite

Delta ferrite is an effective crack deterrent in austenitic stainless steels. This phase, when the ferrite is in a bcc configuration, is magnetic, whereas austenite is nonmagnetic. That property is now used to measure the amount of ferrite in the weld metal—which marks a major advance for weld examination, because the alternate methods of measurement are laborious and inaccurate. For example:

- Microscopic examination checks one tiny spot at a time which may not be typical, since ferrite is not distributed uniformly; etching the phase to identify it may distort its size.
- Computations based on chemical composition ignore the effects from pre or postwelding treatments and are subject to analytical errors.

AWS recommends that delta ferrite be reported by Ferrite Number (FN), a standard measurement that is obtained from The National Institute of Standards and Technology (NIST) and is based on a comparison with magnetic chips. The testing method is explained in AWS A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal.*

Magnetic instruments such as the Magne-Gauge and other commercial devices are calibrated by measuring their response to the NIST wafers (certified samples of stainless steels). The same instrument is then used to measure the desired weld metal.

The observed FN is approximately equal to the percent ferrite that would be found by other techniques, however, the FN has the advantage of being reproducible in any laboratory in the world.

The NIST wafers have been assigned FNs depending on their thickness, which determines their magnetic response. A calibration curve is drawn showing the instrument readings plotted against FN. The curve is then used to interpret readings taken on actual weld specimens.

During the course of inspection work, the welding inspector may encounter contracts specifying delta ferrite either in FN or percent ferrite; however, all readings should be measured and reported in FN, because such measurements can be verified by NIST standards. FN readings could be labeled "percent" however, with less error than would arise from a micrographic count or from estimating the ferrite using the reported chemical analysis.

One notable difference in ferrite indications is given by an instrument referred to as a *Severn gauge* (see Figure 12.12). This is a balance beam instrument that presents the opposite ends of a bar magnet simultaneously to a known ferrite standard and to the unknown ferrite content of the weld. The operator notes which of the two metals is magnetically stronger. The test shows only that the weld had more or less ferrite than the standard, but no indication of how much the two differed. While other instruments indicate the actual FN of the weld, the Severn gauge merely gives an upper or lower limit to the FN.

That indication is sufficient for most inspections if the contract specifies "over 4 FN," or "over 4 percent ferrite." All portions of that weld should pull the magnet away from the 4 FN button. If the contract requires "4 to 10 FN," the welding inspector must also search with a 10 FN button, which should always pull the magnet away from the weld.

If delta ferrite prevents cracks, why is there concern about an upper limit to the FN? The answer is that high ferrite content increases the probability of the formation of a brittle sigma phase after heat treatment. Sigma is undesirable in stainless steel welds.

Qualification of NDE Personnel

NDE personnel also require qualification and certification. Nondestructive tests are based on indirect indications; typically, the density of photographic film is interpreted to indicate a discontinuity at the center of the weld, and an adhering line of magnetized iron powder is interpreted to reveal a subsurface crack. These may not be direct revelations of the supposed discontinuity, however, some of them may be artifacts extraneous to the subject. The individual who is evaluating such information must be qualified to accurately interpret test results.

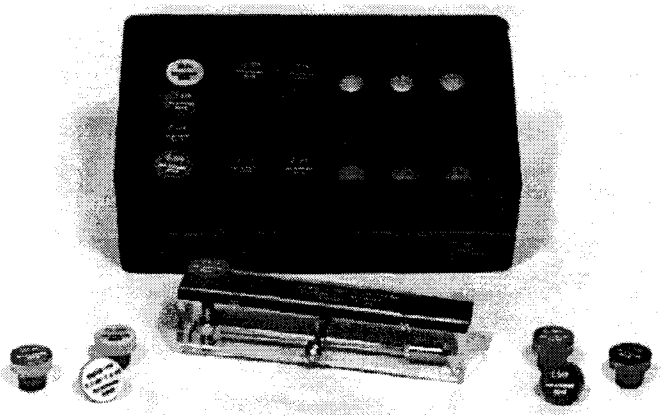


Figure 12.12—Ferrite Indicator (Severn Gauge)

The qualification procedure usually specified is the American Society for Nondestructive Testing (ASNT) Recommended Practice No. SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*. Since this is considered a recommended practice, it has relevance only when a company develops a quality control manual that refers to these recommendations.

This recommended practice provides for three levels of competence and responsibility, as shown in Table 12.1.

Note that individuals are not permitted to examine AWS D1.1 code weldments by NDE methods other than visual unless they hold SNT-TC-1A certification papers. In addition, a Level III qualified individual (able to train and examine personnel at the other levels) would not be permitted to make these tests without a Level I or Level II qualification in addition to the Level III certification.

Under the ASME code rules, the Authorized Inspector verifies the certification of NDE personnel in accordance with the applicable ASME requirements, which most likely reference SNT-TC-1A. An Authorized Inspector who questions the performance of an NDE technician has the further authority to audit the program and require requalification.

Table 12.1
SNT-TC-1A Levels of Qualification

NDT Level	Description
I	An individual qualified to perform specific calibrations, specific tests, and specific evaluations according to written instructions and to record the results; the necessary guidance or supervision from a certified NDT Level II or III individual.
II	An individual qualified to set up and calibrate equipment and to interpret and evaluate results with respect to applicable codes, standards, and specifications; responsible for on-the-job training and guidance of trainees and NDT Level I personnel; prepares written instructions, and organizes and reports NDT investigations.
III	An individual capable of, and responsible for, establishing techniques; interpreting codes, standards, and specifications; designating the particular test method and technique to be used; responsible for a complete NDT operation; establishes techniques and assists the design engineer in establishing acceptance criteria where none are otherwise available; responsible for the training and examination of NDT Level I and Level II personnel for certification.

Summary

Although the CWI will not necessarily be qualified to perform NDE other than visual, it is important for the inspector to understand the basic principles of the more common methods, which, in turn, will help the inspector to develop an understanding of the results reported by those performing the necessary tests.

In addition to a review of NDE results, the CWI may also be responsible for determining if NDE technicians are properly qualified to perform various tests in accordance with contract requirements.

Review—Chapter 12—Nondestructive Examination (NDE) Processes

Q12-1 Which of the following NDE methods do not usually require electricity?
a. eddy current
b. visible dye penetrant
c. visual
d. a and b above
e. b and c above

Q12-2 Which of the following NDE methods is limited to the detection of surface discontinuities?
a. visual
b. penetrant
c. magnetic particle
d. all of the above
e. none of the above

Q12-3 To be most effective, visual inspection should be performed:
a. before welding.
b. during welding.
c. after welding.
d. all of the above
e. none of the above

Q12-4 The time during which the penetrant remains on the surface of the part to allow it to be drawn into any discontinuities is called:
a. waiting time.
b. penetrating time.
c. soak time.
d. dwell time.
e. none of the above

Q12-5 Which type of magnetizing current provides the best combination of penetrability and particle mobility?
a. AC
b. DC
c. half-wave rectified DC
d. b and c above
e. all of the above

Q12-6 What NDE method will most likely reveal subsurface porosity?
a. PT
b. MT
c. RT
d. UT
e. all of the above

Q12-7 Which of the following statements is correct for a radiographic test?
a. A reduction in thickness will produce a light image on the film.
b. A low-density discontinuity will produce a light image on the film.
c. A high-density discontinuity will produce a light image on the film.
d. a and b above
e. b and c above

Q12-8 Which of the following discontinuities is rarely detected using RT?
a. crack
b. incomplete fusion
c. undercut
d. lamination
e. none of the above

Q12-9 What device is used during radiography to indicate the acquired sensitivity of a radiograph?
a. rate meter
b. dosimeter
c. lead screen
d. penetrameter
e. none of the above

Q12-10 Which nondestructive examination method utilizes sound energy as a probing medium?
a. VT
b. RT
c. UT
d. PT
e. ET

Q12-11 The process whereby the ultrasonic indications are related to physical distances in a test standard is referred to as:
a. setup
b. calibration
c. standardization
d. synchronization
e. none of the above

Q12-12 A test probe containing an alternating current coil is used for which NDE method?
a. RT
b. UT
c. ET
d. MT
e. both c and d above

Q12-13 Changes in electrical conductivity can be measured using which NDE method?
a. ET
b. RT
c. MT
d. UT
e. none of the above

Q12-14 Which of the following NDE methods are suitable for detecting surface cracks?
a. RT
b. VT
c. ET
d. PT
e. all of the above

Q12-15 What NDE method is most likely to reveal internal laminations in a rolled plate?
a. RT
b. UT
c. ET
d. MT
e. none of the above

Q12-16 PT is limited to the detection of those discontinuities that are:
a. near the test object surface
b. open to the test object surface
c. clean and open to the test object surface
d. all of the above
e. none of the above

Q12-17 Visible dye penetrant indications:
- a. must be observed under a black light
- b. don't have to be observed under a black light, but are more sensitive if they are
- c. must be observed under ultraviolet light
- d. must be observed under white light
- e. none of the above

Q12-18 Penetrant can be applied by:
- a. brushing
- b. spraying
- c. dipping
- d. all of the above
- e. none of the above

Q12-19 Fluorescent penetrants are generally more sensitive than visible dye penetrants because:
- a. they can flow into smaller cracks
- b. fluorescent indications are better seen by the human eye
- c. they are subject to greater capillary action
- d. a and c above
- e. b and c above

Q12-20 Which of the following cause decreased sensitivity in PT?
- a. too heavy application of the developer
- b. oily or greasy test object
- c. improper penetrant removal
- d. all of the above
- e. none of the above

Q12-21 PT is limited to test objects that:
- a. are metallic
- b. are porous
- c. are magnetic
- d. are nonporous
- e. have subsurface discontinuities

Q12-22 MT will discover:
- a. surface discontinuities
- b. slightly subsurface discontinuities
- c. underbead cracking
- d. a and b above
- e. all of the above

Q12-23 MT is most sensitive to those discontinuities that are:
- a. within 45° of perpendicular to the lines of flux
- b. within 45° of parallel to the lines of flux
- c. perpendicular to the lines of flux
- d. parallel to the lines of flux
- e. none of the above

Q12-24 MT is limited to test objects that:
- a. are metallic
- b. are porous
- c. are ferromagnetic
- d. are nonporous
- e. have subsurface discontinuities

Q12-25 UT is most sensitive to those discontinuities that are:
- a. within 45° perpendicular to the sound waves
- b. within 45° of parallel to the sound waves
- c. perpendicular to the sound waves
- d. parallel to the sound waves
- e. none of the above

Q12-26 UT uses frequencies:
- a. below the range of human hearing
- b. within the range of human hearing
- c. above the range of human hearing
- d. beside the range of human hearing
- e. none of the above

Q12-27 In UT the horizontal axis of the CRT screen gives information about:
- a. the distance the sound has traveled in the part
- b. the amount of sound energy reflected
- c. the type of discontinuity
- d. discontinuity orientation
- e. discontinuity cause

Q12-28 RT shows areas of lower density as:
- a. dark regions on the film
- b. light regions on the film
- c. light or dark regions on the film
- d. all of the above
- e. none of the above

Q12-29 RT shows areas of less thickness as:
- a. dark regions on the film
- b. light regions on the film
- c. light or dark regions on the film
- d. all of the above
- e. none of the above

Q12-30 RT shows areas of increased transmission as:
- a. dark regions on the film
- b. light regions on the film
- c. light or dark regions on the film
- d. all of the above
- e. none of the above

Q12-31 Tungsten inclusions generally appear in RT as:
- a. dark regions on the film
- b. light regions on the film
- c. light or dark regions on the film
- d. all of the above
- e. none of the above

Q12-32 Cracks generally appear in RT as:
- a. dark lines on the film
- b. light lines on the film
- c. light or dark lines on the film
- d. all of the above
- e. none of the above

Q12-33 Weld reinforcement generally appears as:
a. dark regions on the film
b. light regions on the film
c. light or dark regions on the film
d. all of the above
e. none of the above

Q12-34 Porosity generally appears in RT as:
a. dark regions on the film
b. light regions on the film
c. light or dark regions on the film
d. all of the above
e. none of the above

Q12-35 Shallow surface cracks can best be detected in type 308 stainless steel by:
a. UT
b. MT
c. RT
d. PT
e. all of the above

Q12-36 Underbead cracks can best be detected by:
a. ET
b. MT
c. UT
d. PT
e. all of the above

Q12-37 Porosity in ESW can best be detected by:
a. UT
b. MT
c. RT
d. PT
e. all of the above

Q12-38 The vertical axis of the UT CRT screen represents:
a. distance
b. time
c. reflector size
d. none of the above
e. all of the above

Q12-39 What NDE method(s) rely on the transmission of sound energy through the test object?
a. RT
b. UT
c. AET
d. a and b above
e. b and c above

Q12-40 What NDE method(s) often rely on the application of a hydrostatic pressure to a vessel?
a. pressure tests
b. leak tests
c. proof tests
d. all of the above
e. none of the above

Q12-41 What test below is applied to determine the metallurgical effects of welding on austenitic stainless steels?
a. RT
b. PRT
c. ferrite test
d. UT
e. PT

Q12-42 Application of a vacuum box to the inside surface of a steel storage tank is one form of which test?
a. VT
b. PRT
c. LT
d. all of the above
e. none of the above

Q12-43 FN is a unit of measurement with which test?
a. RT
b. PRT
c. ferrite test
d. UT
e. PT

Q12-44 NDE personnel are normally qualified in accordance with:
a. ASME Section V
b. AWS D1.1
c. ANSI SNT-TC-1A
d. ASNT SNT-TC-1A
e. ASME SNT-TC-1A

CHAPTER 13

Inspection Reports

Contents

Chapter 13—Inspection Reports

Introduction

The reporting of observations and decisions is the final step for a welding inspector. Although the welding inspector may feel responsibility only to the employer, the employer is responsible to the customer, fabricator, erector, or other related entities. Therefore, many individuals are waiting for the inspection reports.

Report Content

A good report begins with good record keeping. Good records not only protect the welding inspector; they also help the inspector to follow a policy of uniform standards.

Whether it is read today or months from now, the inspection report must be clear and concise so that others will have no difficulty understanding the decisions reached. Although concise, the report must be clearly understood by a reader unfamiliar with the product inspected.

The report must also be complete, accurate, and have the appropriate signatures. All formal reports and data forms required by the governing standard or code should be completed in ink. It should be noted that erasures are not permitted in these legal documents. Errors are to be crossed through with a single line. When such corrections are made, they should be accompanied by the inspector's initials and the date of the change. In this way, there will be no question as to who made the change and when it occurred.

Reports must include references to any other reports that the welding inspector sees and uses as tools in his own inspection process. Among the more commonly used documents are the following:

- Surveillance Reports
- Certified Material Test Reports
- Quality Reports
- Qualification Records
- Progress Reports
- Production Schedules

A welding inspector of any category should keep a set of records for each contract under surveillance that detail every inspection made and every joint in the vessel or assembly. For a small job, these records may be contained in a single file, while larger jobs may require that the records be separated into various files. This selection is often a matter of personal preference; however, some codes will stipulate how this information should be organized and maintained. The important feature is to ensure that the system used is easily understood by all appropriate individuals, not just the inspector.

Report Format

The inspector, working in accordance with a national code or standard, monitors the quality assurance program of the fabrication through his review of quality reports, qualification records, certificates of compliance, and records of examinations and tests. The inspector for the fabricator is part of the quality control organization and assists directly in preparing reports required by the quality assurance program. The governing code or standard will suggest a format for an inspection report.

AWS D1.1 Report Forms

Sample forms for in-house inspector's reports are shown in Annex E of AWS D1.1. Copies of these forms can also be found in Annex B of this manual, including forms for recording procedure qualifications and welder and welding operator qualifications. Also included are laboratory report forms for three categories of nondestructive examination data.

Variations of the sample forms are permissible, as long as all of the necessary information is provided. The AWS procedure qualification forms include versions for prequalified welding procedures, welding procedures qualified by actual testing, and welding procedures for electroslag and electrogas welding.

ASME Section IX Report Forms

The ASME code contains a number of data report forms required by the designer, the owner, the manufacturer, and the fabricator of any vessel or assembly covered by this code. Under this code, each of these parties must have a quality assurance program (documented in a Quality Assurance Manual) that details manufacturing processes, job titles, and responsibilities for inspection. The designated inspector may be expected to complete a data report form for an employer, but will not be able to sign them unless authorized.

The ASME code places all responsibility on the manufacturer or installer. Only the authorized inspector may sign or initial and date checklists of items personally witnessed on data reports. In practice, however, the in-house inspector assembles all of these reports and verifies compliance by the manufacturer.

Form N-1 for nuclear vessels is a typical ASME report. It lists the names of the manufacturer and the purchaser; the type and kind of vessel; dimensions of shell, seams, heads, jacket closure, tube sheets, and tubes; dimensions of any inner chambers (shells, seams, heads); the design pressure of jackets and inner chambers, with test data on impact resistance and pressure tests; data, when applicable, on safety valve outlets, nozzles, inspection manholes, other openings and supports; remarks, and a certification of design covering the design specifications and stress analysis report (each certified by a professional engineer). The Certificate of Field Inspection (or Field Assembly Inspection) completes this form.

In addition to these data report forms, the welding inspector will also be asked to review and verify information contained on the various forms related to welding procedure and welder qualification, including the Welding Procedure Specification (WPS), the Procedure Qualification Record (PQR) and the Welder Performance Qualification Record (WPQR).

API 1104 Report Forms

A typical API form for reporting qualification of procedures or welders for pipeline welding can be found in Annex B. Although different than those for AWS or ASME, much of the information required is similar.

Multiple Inspection

One inspector's reports may well duplicate reports by some of the other inspectors, but that is the nature of the surveillance of major weldments. An illustrative example is the multiple reporting given to the radiograph of a weld.

Many radiographs are evaluated by up to five different people—each contributing an evaluation to the inspection. The report form for radiographic examination might be used by each of them as well. Those individuals who might become involved in the radiographic evaluation for a typical scenario are listed below:

(1) The technician who exposes the film, develops it, and records the identification of the weld and the exposure details.

(2) The examiner or technician Level I or II in the radiographic department who examines the film and reports his interpretation.

(3) The SNT-TC-1A examiner for the contractor who reviews the film for acceptance.

(4) The customer's welding inspector who examines the film and makes his own evaluation.

(5) The ASME Authorized Inspector (in the employ of one of the insurance companies, or a jurisdiction such as a state) who reviews the film and the report for concurrence and acceptance.

Unstructured Reports

The major emphasis, thus far, has been on formal reports required by the code, standard or specification. However, unstructured reports will often be required of a welding inspector. This is especially true of workmanship opinions. Comments on the visual examination and repair of plate cut edges, on shrinkage and distortion, on dimensional tolerances such as straightness and flatness, camber, warpage and tilt, on the fit and straightness of intermediate stiffeners and bearing stiffeners, on weld profiles, and on the repair of unacceptable welds and difficulties that occurred—all require individual reporting. Such notes are not readily tabulated, unless accurate and complete records are kept.

The formality of an unstructured report will vary with the welding inspector's responsibility, i.e., the report of an inspector in a small company will be more informal than the report of a state inspector.

Copies of the reports and attached records should go to all who are entitled to receive them. The inspector should keep a copy for his own files. Even while performing inspections on non-code work, an inspector should keep proper records. At a minimum, such a report could be in the form of a complete set of notes.

Report Checklist

After writing the report, the welding inspector should answer the following questions to check the quality of the report:

(1) Are all the report data forms required by the governing code, standard or specification complete? Accurate? Signed?

(2) Are all supporting forms, reports, and data included or properly referenced?

(3) Are the facts stated clearly and concisely?

(4) Can the reader reach the same logical conclusions or make sound decisions from the facts and data in the report today? In two months? In six months?

(5) Does the overall organization of the report present a total picture to the reader?

(6) Does the report maintain a logical sequence? For example, does it follow the fabrication process? Procedure inspection? Acceptance process?

(7) Have the purpose and objectives of the reports been attained?

Conclusion

One should be commended for undertaking a career in the exciting and demanding field of inspection. Welding inspection is an important responsibility and it takes a special kind of individual to select this type of work.

Review—Chapter 13—Inspection Reports

Q13-1 Once inspections are completed, what important aspect of the inspector's job must be accomplished?
- a. tell the foreman that the weld is acceptable
- b. tell the supervisor that the inspection is complete
- c. fill out an inspection report detailing his findings
- d. all of the above
- e. none of the above

Q13-2 Which of the following is not normally required of inspection reports?
- a. inspector's signature
- b. an indication of only those parts which were acceptable
- c. they should be clear and concise
- d. they should be filled out in ink
- e. none of the above

Q13-3 What authorship is attached to inspection report forms?
- a. the inspector's signature
- b. the welder's signature
- c. the welding supervisor's signature
- d. Forms are anonymously presented.
- e. Forms are not signed.

Q13-4 What handy report forms are available from AWS?
- a. Annex E of AWS D1.1
- b. Annex I of AWS D1.1
- c. Annex O of AWS D1.1
- d. AWS QC 1
- e. ASME N-1 Form

Q13-5 You have made a numerical mistake on a report form. How should it be corrected?
- a. An experienced inspector will use a pencil so such errors can be erased and corrected.
- b. As an inspector-in-training, such errors need not be corrected.
- c. To keep the report legal and credible, the error should be crossed out and the correction added adjacent to the error and noted complete with initials and date of correction.
- d. The report must be completely rewritten.
- e. none of the above

Q13-6 How are errors in writing corrected in written reports?
- a. crossed out
- b. erased with an ink eraser
- c. entire page must be rewritten
- d. crossed out, corrected, initialed, and dated
- e. none of the above

Q13-7 Who is authorized to sign off ASME data report forms?
- a. the authorized inspector who performed inspection
- b. an authorized keeper of the code stamp
- c. an officer or manager of the company
- d. any of the above
- e. both a and b above

Q13-8 How are opinions on workmanship or suggestions for repair usually reported?
- a. Comments are written in chalk on the work.
- b. by unstructured reports
- c. Provisions for such comments are contained in structured reports.
- d. Inspectors are forbidden to offer such comments.
- e. none of the above

Examination Method Selection Guide

Equipment Needs	Applications	Advantages	Limitations
		Visual	
Magnifiers, color enhancement, projectors, other measurement equipment, i.e., rulers, micrometers, optical comparators, light source.	Weldments that have discontinuities only on the surface.	The method is economical and expedient, and requires relatively little training and relatively little equipment for many applications.	The method is limited to external or surface conditions only and by the visual acuity of the observer or inspector.
		Penetrant	
Fluorescent or dye penetrant, developers, cleansers (solvents, emulsifiers, etc.). Suitable cleaning gear. Ultraviolet light source if fluorescent dye is used.	Weldments that have discontinuities only on the surface.	The equipment is portable and relatively inexpensive. The inspection results are expedient. Results are easily interpreted. Requires no electrical energy except for light sources.	Surface films such as coatings, scale, smeared metal may mask or hide discontinuities. Bleed out from porous surfaces can also mask indications. Parts must be cleaned before and after inspection.
		Magnetic Particle	
Prods, yokes, coils suitable for inducing magnetism into the weld. Power source (electrical). Magnetic powders—some applications require special facilities and ultraviolet lights.	Weldments that have discontinuities on or near the surface.	The method is relatively economical and expedient. Inspection equipment is considered portable. Unlike dye penetrants, magnetic particle can detect some discontinuities slightly below the surface.	The method is applicable only to feromagnetic materials. Parts must be cleaned before and after inspection. Thick coatings may mask rejectable discontinuities. Some applications require the part to be demagnetized after inspection. Magnetic particle inspection requires use of electrical energy for most applications.
		Radiography (Gamma)	
Gamma ray sources, gamma ray camera projectors, film holders, film, lead screens, film processing equipment, film viewers, exposure facilities, radiation monitoring equipment.	Weldments that have voluminous discontinuities such as porosity, incomplete joint penetration, slag, etc. Lamellar type discontinuities such as cracks and incomplete fusion can be detected with a lesser degree of reliability. It may also be used in certain applications to evaluate dimensional requirements such as fit-up, root conditions, and wall thickness.	The method is generally not restricted by type of material or grain structure. The method detects surface and subsurface discontinuities. Radiographic images aid in characterizing discontinuities. The film provides a permanent record for future review.	Planar discontinuities must be favorably aligned with radiation beam to be reliably detected. Radiation poses a potential hazard to personnel. Cost of radiographic equipment, facilities, safety programs, and related licensing is relatively high. A relatively long time between exposure process and availability of results. Accessibility to both sides of the weld required.
		Radiography (X-Rays)	
X-ray sources (machines), electrical power source, same general equipment as used with gamma sources (above).	Same application as above.	Same as above, except that x-ray radiography can use adjustable energy levels, and it generally produces higher quality radiographs than gamma sources. The process also enjoys the same advantages as above.	High initial cost of X-ray equipment. Not generally considered portable. Also, same limitations as above.

(continued)

Examination Method Selection Guide (Continued)

Equipment Needs	Applications	Advantages	Limitations
Ultrasonic			
Pulse-echo instrument capable of exciting a piezoelectric material and generating ultrasonic energy within a weld, and a suitable cathode ray tube scope capable of displaying the magnitudes of received sound energy. Calibration standards, liquid couplant.	The method can detect most weld discontinuities including cracks, slag, and incomplete fusion. It can also be used to verify base metal thickness.	The method is most sensitive to planar type discontinuities. The test results are known immediately. The method is portable, and most ultrasonic flaw directors are battery operated. The method has high penetration capability.	Surface condition must be suitable for coupling of transducer. A liquid couplant is required. Small, thin welds may be difficult to inspect. Reference standards and a relatively skilled operator or inspector are required.
Eddy Current			
An instrument capable of inducing eletromagnetic fields within a weld and sensing the resulting electrical currents (eddy) so induced with a suitable probe or detector. Calibration standards.	Weldments that have discontinuities on or near the surface. Alloy content and heat treatment condition may affect results.	Equipment used with surface probes is generally lightweight and portable. Painted or coated welds can be inspected. The method can be partially or completely automated for a high speed, relatively inexpensive examination.	Relatively shallow depth of inspection. Many material and test variables can effect the test signal.
Leak Testing			
Leak testing requires a gas or liquid medium, a pump to apply a differential pressure to one side of a weldment and a device to contain the pressure if the weldment is not a closed structure. A detection instrument if the medium penetrating the weld cannot be detected visually may also be required.	Weldments with through thickness discontinuties	Relatively cheap and easy to do if visual detection of leaks is possible. Special mediums such as helium require more sofisticated equipment to detect. However helium leak testing is very sensitive.	Requires a source of water or other medium, a means of disposing of the medium, and the weldment may require cleaning after testing.

ANNEX B

Sample Forms

Contents

WELDING PROCEDURE SPECIFICATION (WPS) Yes ☐
PREQUALIFIED __________ QUALIFIED BY TESTING __________
or PROCEDURE QUALIFICATION RECORDS (PQR) Yes ☐

Identification # ____________________
Revision ________ Date ________ By __________
Authorized by ______________ Date __________
Type—Manual ☐ Semi-Automatic ☐
Machine ☐ Automatic ☐

Company Name ____________________
Welding Process(es) ____________________
Supporting PQR No.(s) ____________________

JOINT DESIGN USED
Type:
Single ☐ Double Weld ☐
Backing: Yes ☐ No ☐
Backing Material:
Root Opening ______ Root Face Dimension ________
Groove Angle: __________ Radius (J–U) ________
Back Gouging: Yes ☐ No ☐ Method ________

BASE METALS
Material Spec. ____________________
Type or Grade ____________________
Thickness: Groove __________ Fillet ________
Diameter (Pipe) ____________________

FILLER METALS
AWS Specification ____________________
AWS Classification ____________________

SHIELDING
Flux ______________ Gas __________
Composition __________
Electrode-Flux (Class) ______ Flow Rate __________
______________ Gas Cup Size ________

PREHEAT
Preheat Temp., Min ____________________
Interpass Temp., Min __________ Max ________

POSITION
Position of Groove: __________ Fillet: __________
Vertical Progression: Up ☐ Down ☐

ELECTRICAL CHARACTERISTICS

Transfer Mode (GMAW) Short-Circuiting ☐
Globular ☐ Spray ☐
Current: AC ☐ DCEP ☐ DCEN ☐ Pulsed ☐
Other ____________________
Tungsten Electrode (GTAW)
Size: __________
Type: __________

TECHNIQUE
Stringer or Weave Bead: ______________
Multi-pass or Single Pass (per side) ______________
Number of Electrodes ______________
Electrode Spacing Longitudinal __________
Lateral __________
Angle __________

Contact Tube to Work Distance ______________
Peening ____________________
Interpass Cleaning: ____________________

POSTWELD HEAT TREATMENT
Temp. ____________________
Time ____________________

WELDING PROCEDURE

Pass or Weld Layer(s)	Process	Filler Metals		Current		Volts	Travel Speed	Joint Details
		Class	Diam.	Type & Polarity	Amps or Wire Feed Speed			

Form E-1 (Front)

Procedure Qualification Record (PQR) # __________
Test Results

TENSILE TEST

Specimen No.	Width	Thickness	Area	Ultimate Tensile Load, lb	Ultimate Unit Stress, psi	Character of Failure and Location

GUIDED BEND TEST

Specimen No.	Type of Bend	Result	Remarks

VISUAL INSPECTION
Appearance ____________________
Undercut ____________________
Piping porosity ____________________
Convexity ____________________
Test date ____________________
Witnessed by ____________________

Radiographic-ultrasonic examination
RT report no.: __________ Result __________
UT report no.: __________ Result __________

FILLET WELD TEST RESULTS

Minimum size multiple pass Macroetch
1. ________ 3. ________
2. ________

Maximum size single pass Macroetch
1. ________ 3. ________
2. ________

Other Tests

All-weld-metal tension test

Tensile strength, psi ____________________
Yield point/strength, psi ____________________
Elongation in 2 in., % ____________________
Laboratory test no. ____________________

Welder's name ____________________ Clock no. __________ Stamp no. __________

Tests conducted by ______________________________ Laboratory

Test number ____________________

Per ____________________

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of section 4 of AWS D1.1, (__________) Structural Welding Code—Steel.
(year)

Signed ____________________
Manufacturer or Contractor

By ____________________

Title ____________________

Date ____________________

Form E-1 (Back)

WPS QUALIFICATION TEST RECORD FOR ELECTROSLAG AND ELECTROGAS WELDING

PROCEDURE SPECIFICATION

Material specification ______
Welding process ______
Position of welding ______
Filler metal specification ______
Filler metal classification ______
Filler metal ______
Flux ______
Shielding gas ______ Flow rate ______
Gas dew point ______
Thickness range this test qualifies ______
Single or multiple pass ______
Single or multiple arc ______
Welding current ______
Preheat temperature ______
Postheat temperature ______
Welder's name ______
______

VISUAL INSPECTION (Table 6.1, Cyclically loaded limitations)

Appearance ______
Undercut ______
Piping porosity ______
______
Test date ______
Witnessed by ______

TEST RESULTS

Reduced-section tensile test

Tensile strength, psi
1. ______
2. ______

All-weld-metal tension test

Tensile strength, psi ______
Yield point/strength, psi ______
Elongation in 2 in., % ______

Side-bend tests

1. ______ 3. ______
2. ______ 4. ______

Radiographic-ultrasonic examination ______
RT report no. ______
UT report no. ______

Impact tests

Size of specimen ______ Test temp ______
Ft·lb: 1. ______ 2. ______ 3. ______ 4. ______
5. ______ 6. ______ Avg. ______
High ______ Low ______
Laboratory test no. ______

WELDING PROCEDURE

Pass No.	Electrode Size	Welding Current		Joint Detail
		Amperes	Volts	
Guide tube flux ______ Guide tube composition ______ Guide tube diameter ______ Vertical rise speed ______ Traverse length ______ Traverse speed ______ Dwell ______ Type of molding shoe ______				

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of section 4 of AWS D1.1, (______) Structural Welding Code—Steel.
(year)

Procedure no. ______
Revision no. ______
Form E-3

Manufacturer or contractor ______
Authorized by ______
Date ______

WELDER, WELDING OPERATOR, OR TACK WELDER QUALIFICATION TEST RECORD

Type of Welder ________________________________
Name ________________________________ Identification No. ____________
Welding Procedure Specification No. ____________ Rev ____________ Date ____________

Variables	Record Actual Values Used in Qualification	Qualification Range
Process/Type [Table 4.10, Item (1)]		
Electrode (single or multiple) [Table 4.10, Item (8)]		
Current/Polarity		
Position [Table 4.10, Item (4)]		
Weld Progression [Table 4.10, Item (6)]		
Backing (YES or NO) [Table 4.10, Item (7)]		
Material/Spec.	to	
Base Metal		
Thickness: (Plate)		
Groove		
Fillet		
Thickness: (Pipe/tube)		
Groove		
Fillet		
Diameter: (Pipe)		
Groove		
Fillet		
Filler Metal [Table 4.10, Item (3)]		
Spec. No.		
Class		
F-No. [Table 4.10, Item (2)]		
Gas/Flux Type [Table 4.10, Item (3)]		
Other		

VISUAL INSPECTION (4.8.1)
Acceptable YES or NO _____

Guided Bend Test Results (4.30.5)

Type	Result	Type	Result

Fillet Test Results (4.30.2.3 and 4.30.4.1)

Appearance ____________ Fillet Size ____________
Fracture Test Root Penetration ____________ Macroetch ____________
(Describe the location, nature, and size of any crack or tearing of the specimen.)

Inspected by ____________ Test Number ____________
Organization ____________ Date ____________

RADIOGRAPHIC TEST RESULTS (4.30.3.1)

Film Identification Number	Results	Remarks	Film Identification Number	Results	Remarks

Interpreted by ____________ Test Number ____________
Organization ____________ Date ____________

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of section 4 of AWS D1.1, (_________) Structural Welding Code—Steel.
(year)

Manufacturer or Contractor ____________ Authorized By ____________
Form E-4 Date ____________

REPORT OF RADIOGRAPHIC EXAMINATION OF WELDS

Project ______________________________

Quality requirements—section no. ______________________________

Reported to ______________________________

WELD LOCATION AND IDENTIFICATION SKETCH

Technique

Source ____________________

Film to source ____________________

Exposure time ____________________

Screens ____________________

Film type ____________________

(Describe length, width, and thickness of all joints radiographed)

Date	Weld identification	Area	Interpretation		Repairs		Remarks
			Accept.	Reject	Accept.	Reject	

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared and tested in accordance with the requirements of AWS D1.1, (__________) Structural Welding Code—Steel.
(year)

Radiographer(s) ____________________

Manufacturer or contractor ____________________

Interpreter ____________________

Authorized by ____________________

Test date ____________________

Date ____________________

Form E-7

REPORT OF MAGNETIC-PARTICLE EXAMINATION OF WELDS

Project ____________________
Quality requirements—Section No. ____________________
Reported to ____________________

WELD LOCATION AND IDENTIFICATION SKETCH

Quantity: ________ Total Accepted: ________ Total Rejected: ________

Date	Weld identification	Area Examined		Interpretation		Repairs		Remarks
		Entire	Specific	Accept.	Reject	Accept.	Reject	

PRE-EXAMINATION
Surface Preparation: ____________________

EQUIPMENT
Instrument Make: ____________ Model: ________ S. No.: ________

METHOD OF INSPECTION
☐ Dry ☐ Wet ☐ Visible ☐ Fluorescent
How Media Applied: ____________________
☐ Residual ☐ Continuous ☐ True-Continuous
☐ AC ☐ DC ☐ Half-Wave
☐ Prods ☐ Yoke ☐ Cable Wrap ☐ Other ____________
Direction for Field: ☐ Circular ☐ Longitudinal

Strength of Field: ____________________
(Ampere turns, field density, magnetizing force, number, and duration of force application.)

POST EXAMINATION
Demagnetizing Technique (if required): ____________________

Cleaning (if required): ____________ Marking Method: ____________

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared and tested in accordance with the requirements of AWS D1.1, (________) Structural Welding Code—Steel.
(year)

Inspector ____________ Manufacturer or Contractor ____________

Level ____________ Authorized By ____________

Test Date ____________ Date ____________

Form E-8

QW-482 SUGGESTED FORMAT FOR WELDING PROCEDURE SPECIFICATIONS (WPS)
(See QW-200.1, Section IX, ASME Boiler and Pressure Vessel Code)

Company Name ______________________ By: ______________________

Welding Procedure Specification No. __________ Date __________ Supporting PQR No.(s) __________

Revision No. __________ Date __________

Welding Process(es) ______________________ Type(s) ______________________

(Automatic, Manual, Machine, or Semi-Auto.)

JOINTS (QW-402) | Details

Joint Design ______________________

Backing (Yes) __________ (No) __________

Backing Material (Type) ______________________

(Refer to both backing and retainers.)

☐ Metal ☐ Nonfusing Metal

☐ Nonmetallic ☐ Other

Sketches, Production Drawings, Weld Symbols or Written Description should show the general arrangement of the parts to be welded. Where applicable, the root spacing and the details of the weld groove may be specified.

(At the option of the Mfgr., sketches may be attached to illustrate joint design, weld layers and bead sequence, e.g. for notch toughness procedures, for multiple process procedures, etc.)

*BASE METALS (QW-403)

P-No. ________ Group No. ________ to P-No. ________ Group No. ________

OR

Specification type and grade ______________________

to Specification type and grade ______________________

OR

Chem. Analysis and Mech. Prop. ______________________

to Chem. Analysis and Mech. Prop. ______________________

Thickness Range:

Base Metal: Groove __________ Fillet __________

Pipe Dia. Range: Groove __________ Fillet __________

Other ______________________

*FILLER METALS (QW-404)		
Spec. No. (SFA)		
AWS No. (Class)		
F-No.		
A-No.		
Size of Filler Metals		
Weld Metal		
Thickness Range:		
Groove		
Fillet		
Electrode-Flux (Class)		
Flux Trade Name		
Consumable Insert		
Other		

* Each base metal-filler metal combination should be recorded individually.

This form (E00006) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300

(Source ASME B31.1, SEC IX)

QW-482 (Back)

WPS No. ________ **Rev.** ________

POSITIONS (QW-405)
Position(s) of Groove ________
Welding Progression: Up ________ Down ________
Position(s) of Fillet ________

PREHEAT (QW-406)
Preheat Temp. Min. ________
Interpass Temp. Max. ________
Preheat Maintenance ________

(Continuous or special heating where applicable should be recorded.)

POSTWELD HEAT TREATMENT (QW-407)
Temperature Range ________
Time Range ________

GAS (QW-408)

	Gas(es)	Percent Composition (Mixture)	Flow Rate
Shielding			
Trailing			
Backing			

ELECTRICAL CHARACTERISTICS 9QW-409)
Current AC or DC ________ Polarity ________
Amps (Range) ________ Volts (Range) ________

(Amps and volts range should be recorded for each electrode size, position, and thickness, etc. This information may be listed in a tabular form similiar to that shown below.)

Tunsten Electrode Size and Type ________
(Pure Tungsten, 2% Thoriated, etc.)

Mode of Metal Transfer for GMAW ________
(Spray arc, short circuiting arc, etc.)

Electrode Wire feed speed range ________

TECHNIQUE (QW-410)
String or Weave Bead ________
Orfice or Gas Cup Size ________
Initial and Interpass Cleaning (Brushing, Grinding, etc.) ________

Method of Back Gouging ________
Oscillation ________
Contact Tube to Work Distance ________
Multiple or Single Pass (per side) ________
Multiple of Single Electrodes ________
Travel Speed (Range) ________
Peening ________
Other ________

Weld Layer(s)	Process	Filler Metal Class	Filler Metal Dia.	Current Type Polar.	Current Amp. Range	Volt Range	Travel Speed Range	Other (e.g., Remarks, Comments, Hot Wire Addition, Technique, Torch Angle, etc.)

(Source ASME B31.1, SEC IX)

QW-483 SUGGESTED FORMAT FOR PROCEDURE QUALIFICATION RECORD (pqr)
(See QW-200.2, Section IX, ASME Boiler and Pressure Vessel Code)
Record Actual Conditions Used to Weld Test Coupon.

Company Name ____________________

Procedure Qualification Record No. ____________________ Date ____________________

WPS No. ____________________

Welding Process(es) ____________________

Types (Manual, Automatic, Semi-Auto.) ____________________

JOINTS (QW-402)

Groove Design of Test Coupon

(For combination qualifications, the deposited weld metal thickness shall be recorded for each filler metal or process used.)

BASE METALS (QW-403)

Material Spec. ____________________

Type or Grade ____________________

P-No. ____________ to P-No. ____________

Thickness of Test Coupon ____________________

Diameter of Test Coupon ____________________

Other ____________________

POSTWELD HEAT TREATMENT (QW-407)

Temperature ____________________

Time ____________________

Other ____________________

GAS (QW-408)

	Gas(es)	Percent Composition (Mixture)	Flow Rate
Shielding			
Trailing			
Backing			

FILLER METALS (QW-404)

SFA Specification		
AWS Classification		
Filler Metal F-No.		
Weld Metal Analysis A-No.		
Size of Filler Metal		
Other		
Weld Metal Thickness		

ELECTRICAL CHARACTERISTICS (QW-409)

Current ____________________

Polarity ____________________

Amps ____________ Volts ____________

Tungsten Electrode Size ____________________

Other ____________________

POSITION (QW-405)

Position of Groove ____________________

Weld Progression (Uphill, Downhill) ____________________

Other ____________________

TECHNIQUE (QW-410)

Travel speed ____________________

String or Weave Bead ____________________

Oscillation ____________________

Multipass or Single Pass (per side) ____________________

Single or Multiple Electrodes ____________________

Other ____________________

PREHEAT (QW-406)

Preheat Temp. ____________________

Interpass Temp. ____________________

Other ____________________

This form (E00007) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300

(Source ASME B31.1, SEC IX)

QW-483 (Back)

Tensile Test (QW-150) **PQR No.** ____________

Specification No.	Width	Thickness	Area	Ultimate Total Load lb	Ultimate Unit Stress psi	Type of Failure & Location

Guided-Bend Tests (QW-160)

Type and Figure No.	

Toughness Tests (QW-170)

Specimen No.	Notch Location	Notch Type	Test Temp.	Impact Values	Lateral Exp.		Drop Weight	
					% Shear	Mils	Break	No Break

Fillet-Weld Test (QW-180

Result - Satisfactory: Yes ____________ No ____________ Penetration into Parent Metal: Yes ____________ No ____________

Macro - Results ____________

Other Tests

Type of Test ____________
Deposit Analysis ____________
Other ____________

- -

Welder's Name ____________ Clock No. ____________ Stamp No. ____________
Tests Conducted by: ____________ Laboratory Test No. ____________
We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of Section IX of the ASME Code.

Manufacturer ____________

Date ____________ By ____________
(Detail of record of tests are illustrative only and may be modified to conform to the type and number of tests required by the Code.)

(Source ASME B31.1, SEC IX)

QW-484 SUGGESTED FORMAT FOR MANUFACTURER'S RECORD OF WELDER OR WELDING OPERATOR QUALIFICATION TESTS (WPQ)
See QW-301, Section IX, ASME Boiler and Pressure Vessel Code

Welder's name ______________ Clock number ______________ Stamp no. __________
Welding process(es) used ______________ Type ______________
Identification of WPS followed by welder during welding of test coupon ______________
Base material(s) welded ______________ Thickness ______________

Manual or Semiautomatic Variables for Each Process (QW-350)	Actual Values	Range Qualified
Backing (metal, weld metal, welded from both sides, flux etc.) (QW-402)		
ASME P-No. ________ to ASME p-No. (QW-404		
( ) Plate ( ) Pipe (enter diameter, if pipe)		
Filler metal specification (SFA): ________ Classification (QW-404)		
Filler Metal F-No.		
Consumable insert for GTAW or PAW		
Weld deposit thickness for each welding process		
Welding position (1G, 5G, etc.) (QW-405)		
Progression (uphill/downhill)		
Backing gas for GTAW, PAW, GMAW; fuel gas for OFW (QW-408)		
GMAW transfer mode (QW-409)		
GTAW welding current type/polarity		

Machine Welding Variables for the Process Used (QW-360)	Actual Values	Range Qualified
Direct/remote visual control		
Automatic voltage control (GTAW)		
Automatic joint tracking		
Welding position (1G, 5G, etc.)		
Consumable insert		
Backing (metal, weld metal, welded from both sides, flux, etc.)		

Guided Bend Test Results

Guided Bend Test Type ( ) QW-462.2 (Side) Results ( ) QW-462.3(a)(Trans. R & F) Type ( ) QW-462.3(b) (Long. R & F) Results

Visual examination results (QW-302.4) ______________
Radiographic test results (QW-304 and Qw-305) ______________
(For alternative qualification of groove welds by radiography)
Fillet Weld - Fracture test ______________ Length and percent of defects __________ in.
Macro test fusion __________ Fillet leg size ________ in. x ________ in. Concavity/covexity ________ in.
Welding test conducted by ______________
Mechanical tests conducted by ______________

We certify that the statements in this record are correct and that the test coupons were prepared, welded, and tested in accordance with the requirements of Section IX of the ASME Code.

Organization ______________

Date ______________ By ______________

This form (E00008) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield NJ 07007-2300

(Source ASME B31.1, SEC IX)

Reference: API Standard 1104, 2.2

PROCEDURE SPECIFICATION NO. ________

For ________________ Welding of ________________ Pipe and Fittings

Process ________________

Material ________________

Diameter and wall thickness ________________

Joint design ________________

Filler metal and no. of beads ________________

Electrical or flame characteristics ________________

Position ________________

Direction of welding ________________

No. of welders ________________

Time lapse between passes ________________

Type and removal of lineup clamp ________________

Cleaning and/or grinding ________________

Preheat stress relief ________________

Shielding gas and flow rate ________________

Shielding flux ________________

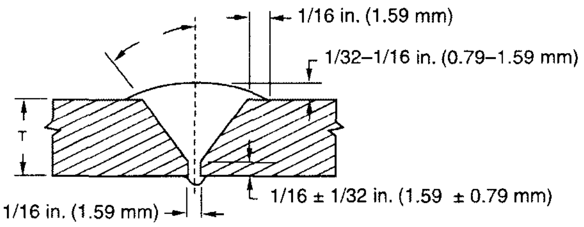
Speed of travel ________________

Sketches and tabulations attaches ________________

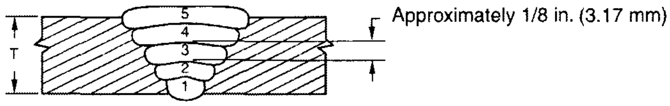
Tested ________________ Welder ________________

Approved ________________ Welding supervisor ________________

Adopted ________________ Chief engineer ________________



Standard V-Bevel Butt Joint



Sequence of Beads

NOTE: Dimensions are for reference only.

ELECTRODE SIZE AND NUMBER OF BEADS

Bead Number	Electrode Size and Type	Voltage	Amperage and Polarity	Speed

(Source API Standard 1104)

American Welding Society

Certifies that Welding Inspector

John Q Public

has complied with the requirements of Section 6.1 of the AWS Standard for Qualification and Certification of Welding Inspectors QC1-96

99999999
CERTIFICATE NUMBER

December 1999
VALID DATE

EMPLOYER: REFER TO WALLET CARD FOR VALIDITY AND EXPIRATION DATE

PRESIDENT AWS

CHAIRMAN QUALIFICATION COMMITTEE

CHAIRMAN CERTIFICATION COMMITTEE

ANNEX C

Answer Key—Review Questions for Chapters 1–13

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Annex C—Answer Key—Review Questions for Chapters 1–13

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Q10-65 a
Q10-66 a
Q10-67 e
Q10-68 c
Q10-69 b
Q10-70 c
Q10-71 a
Q10-72 d
Q10-73 d

Chapter 11

Q11-1 d
Q11-2 d
Q11-3 d
Q11-4 c
Q11-5 d
Q11-6 c
Q11-7 b
Q11-8 d
Q11-9 b
Q11-10 c
Q11-11 a
Q11-12 b
Q11-13 e
Q11-14 d
Q11-15 c
Q11-16 b
Q11-17 c
Q11-18 e
Q11-19 a
Q11-20 b

Chapter 12

Q12-1 e
Q12-2 d
Q12-3 d
Q12-4 d
Q12-5 c
Q12-6 c
Q12-7 c
Q12-8 d
Q12-9 d
Q12-10 c
Q12-11 b
Q12-12 c
Q12-13 a
Q12-14 e
Q12-15 b
Q12-16 c
Q12-17 d
Q12-18 d
Q12-19 b
Q12-20 d
Q12-21 d
Q12-22 d
Q12-23 c
Q12-24 c
Q12-25 c
Q12-26 c
Q12-27 a
Q12-28 a
Q12-29 a
Q12-30 a
Q12-31 b
Q12-32 a
Q12-33 b
Q12-34 a
Q12-35 d
Q12-36 c
Q12-37 c
Q12-38 c
Q12-39 e
Q12-40 d
Q12-41 c
Q12-42 c
Q12-43 c
Q12-44 d

Chapter 13

Q13-1 d
Q13-2 b
Q13-3 a
Q13-4 a
Q13-5 c
Q13-6 d
Q13-7 a
Q13-8 b