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# Guide for Steel Hull Welding

American Welding Society

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# Guide for Steel Hull Welding

**Superseding AWS D3.5-85**

Prepared by
AWS Committee on Welding in Marine Construction

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

## Abstract

This guide provides information to users in the marine construction industry as to the best practical methods to weld steel hulls for ships, barges, mobile offshore drilling units, and other marine vessels. This guide provides information on steel plates, shapes, castings, and forgings; their selection; and their weldability. It discusses welding processes and proper design for welding. Hull construction is presented in terms of preparation of materials, erection and fitting, and control of distortion. Qualification of procedures and personnel are outlined, and inspection methods are discussed. A common shipyard problem, stray current protection, is discussed as is the health and safety of the work force. Supplementary nonmandatory appendices are provided for informational purposes.

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This standard is subject to revision at any time by the AWS Committee on Welding in Marine Construction. It must be reviewed every five years and if not revised, it must be either reapproved or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are requested and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS Committee on Welding in Marine Construction and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS Committee on Marine Construction to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

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# Foreword

(This Foreword is not a part of ANSI/AWS D3.5-93, *Guide for Steel Hull Welding*, but is included for information purposes only.)

This guide is for reference in the construction of steel hulls by welding. It has been compiled to aid welders and supervisory personnel as well as design and construction engineers.

The first all-welded ships were built just before World War II. During that war, over 4000 welded ships, including the Liberty ships and T2 tankers, were constructed under emergency conditions. When some of these ships experienced major structural failures of the brittle-cleavage type, both government and industry undertook immediate and intensive investigation and research. Most major failures started either in a defective groove weld in the deck or bottom shell, or at a sharp structural intersection such as a square hatch corner, or some other abrupt change in structural cross-section, or lack of geometric continuity in the structure. Once started, the cracks progressed through the base metal and extended for considerable distances, in some cases across the deck and completely around the ship.

Attention was focused primarily on the influence of notches, weld quality, and the inherent notch toughness characteristics of steel and weld metal regarding both crack initiation and crack propagation. As a result of the ship research, steels having greater notch toughness were specified by regulatory agencies, and special steels having superior notch toughness were developed and specified for use in highly stressed areas. Design details were improved, and main hull welds were subjected to subsurface inspection by radiographic and ultrasonic methods.

To summarize this early research and development and to make appropriate recommendations relative to welding, the American Welding Society published D3.5-62, *Hull Welding Manual.* Because of revisions to the regulatory agencies' requirements, major developments in welding equipment and shipyard facilities, and the increased use of higher strength and superior notch-tough steels in shipbuilding, AWS D3.5-76, *Guide for Steel Hull Welding*, was prepared to replace the earlier manual. The ANSI/AWS D3.5-85 and ANSI/AWS D3.5-93 are updates of the previous Guide. The welding of aluminum in ship construction is covered in ANSI/AWS D3.7-89, *Guide for Aluminum Hull Welding*.

Much commercial building in shipyards includes special purpose ships and mobile offshore drilling units. Tankers over 30 times larger than the T2 tankers have been built. Today's container ships are as large as the largest ocean liners and have the unusual feature of having most of their strength decks open to facilitate container stowage. The large LNG (liquefied natural gas) carriers transport liquid cargo at approximately –260°F (–160°C).

For further specific details relating to welding, refer to the rules of regulatory agencies, recommendations of the steel and welding equipment manufacturers, and other related publications.

Comments and suggestions regarding this guide are welcome. These comments should be sent to the Secretary, AWS Committee on Welding in Marine Construction, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services Division, American Welding Society. A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

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## 1. Materials

This section deals with the manufacture and heat treating of steel, properties of steel, specifications for steel and welding consumables, and the weldability of steel.[1]

**1.1 Steel Manufacturing Processes.** Ship steel is made primarily in basic oxygen furnaces (BOF), open-hearth furnaces, and electric furnaces. There are only a few open-hearth furnaces operating today. Electric furnaces are used to make high-alloy specialty steels, steels for castings, and in conjunction with continuous casters they are used to make small to medium sized shapes and some flat rolled products.

**1.1.1 Plates and Shapes.** Plates are rolled in one of three types of rolling mills to produce sheared plates, universal mill plates, and continuous strip.

Sheared plates are rolled on mills which have horizontal rolls only, and are produced with irregular edges and ends which must be cut or sheared on all sides to produce a rectangular plate. Sheared plates are rolled in both directions by rotating the slab at the roughing stand of the mill. This process, called *cross rolling*, provides the plate with more uniform longitudinal and transverse properties, and sheared plates are usually specified where stringent mechanical properties are required.

Universal mill plates are rolled on mills with both horizontal and vertical rolls. The vertical rolls provide the plate with a rolled edge which does not require cutting to establish its width. Universal mill plates are not cross-rolled, and as a result, the plates may have slightly lower ductility in the transverse direction. These plates are used where a finished edge is desirable.

Continuous strip mill plates are made on a hot strip mill and can be furnished in coils or as flat rectangular products. These plates are used primarily for structural applications, cold-formed shapes, or on automated barge construction lines. Hot strip mill plates may have directional properties between those of the sheared mill and universal mill products.

Structural shapes are usually rolled on a mill similar to a universal plate mill.

**1.1.2 Chemistry.** Steel is essentially a combination of iron, manganese and carbon. The carbon content normally ranges between 0.05–1.00%, while the manganese content range is 0.25–1.00%. Many other elements are added in relatively small amounts to vary the mechanical characteristics of the steel.

Plate steels generally fall in the category of either a carbon steel or an alloy steel. Carbon steels comprise those grades where no minimum content is specified or required for aluminum, boron, chromium, cobalt, columbium (niobium), molybdenum, nickel, titanium, tungsten, vanadium, or zirconium, or any other element added to obtain a desired alloying effect. When specified, minimum copper does not exceed 0.40%. The maximum content specified for any of the following elements shall not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.

Alloy steels comprise those grades which exceed the above limits, plus any grade to which any element other than those mentioned above is added for the purpose of achieving a specific alloying effect. Carbon steels usually have a lower base price than alloy steels and therefore are much more widely applied.

For structural applications, plates normally do not exceed 0.30% carbon and 1.50% manganese.

1. Some of the information contained in this section comes from the following sources:

American Bureau of Shipping. *Rules for building and classing steel vessels.* Paraus, NJ: American Bureau of Shipping, 1990.

Bethlehem Steel Corp., *Plate selection guide, Book 1.* Bethlehem, PA: Bethlehem Steel Corporation, 1985.

**1.1.2.1 Effects of Elements.** The effects of the commonly specified chemical elements on the properties of hot-rolled and heat-treated carbon and alloy plates are discussed here by considering the various elements individually. In practice, however, the effect of any particular element will often depend on the quantities of other elements also present in the steel. For example, the total effect of a combination of alloying elements on the hardenability of a steel is usually greater than the sum of their individual contributions. This type of interrelation should be taken into account whenever a change in a specified analysis is evaluated.

Carbon is the principal hardening element in steel, with each additional increment of carbon increasing the hardness and tensile strength of steel in the as-rolled or normalized condition. For plate steels, the carbon level is generally less than 0.30%. For improved ductility, weldability, and toughness, carbon levels below 0.20% are preferred. A compromise must be maintained between higher carbon level required for tensile properties and lower carbon levels associated with improved ductility, weldability, and toughness.

Manganese is present in all commercial steels and contributes significantly to strength and hardness in much the same manner, but to a lesser extent, as does carbon. Its effectiveness depends largely upon, and is directly proportional to, the carbon content of the steel. Another important characteristic of manganese in steel is its ability to decrease the critical cooling rate during hardening, thereby increasing the hardenability. The effect of manganese in this respect is greater than that of any of the other commonly used alloying elements.

Manganese is an active deoxidizer, and shows less tendency to segregate within the ingot than do most other elements. Its presence in a steel is also highly beneficial to surface quality in that it tends to combine with sulfur, thereby minimizing the formation of iron sulfide, the causative factor of hot-shortness, or susceptibility to cracking and tearing at rolling temperatures.

Phosphorus is generally considered an impurity except where its beneficial effect on machinability and resistance to atmospheric corrosion is desired. While phosphorus increases strength and hardness to about the same degree as carbon, it also tends to decrease ductility and toughness, or impact strength, particularly for steel in the quenched-and-tempered condition. The phosphorus content of most steels is therefore kept below specified maxima, which range up to 0.04%.

In the free-machining steels, however, specified phosphorus content may run as high as 0.12%. This is attained by adding phosphorus to the ladle, commonly termed *rephosphorizing.*

Sulfur is generally considered an undesirable element except where machinability is an important consideration and resulfurized steels may be ordered. Whereas sulfides in steel act as effective chip-breakers to improve machinability, they also serve to decrease transverse ductility and impact strength. Moreover, increasing sulfur impairs weldability and has adverse effects on surface quality.

Manufacturers can produce plates with a maximum 0.010% sulfur with sulfide shape control. By controlling sulfur level, significant improvements in mechanical properties are possible. Impact properties improve. Ductility increases, especially in the through-thickness direction. Weldability and formability also improve.

Silicon is one of the principal deoxidizers used in the manufacture of both carbon and alloy steels, and depending on the type of steel, can be present in varying amounts up to 0.40% as a result of deoxidation. Silicon is also a ferrite strengthener and is sometimes added as an alloying element up to approximately 0.5% in plate steels.

Nickel is one of the fundamental steel-alloying elements. When present in appreciable amounts, it provides improved toughness, particularly at low temperatures. Nickel lowers the critical temperatures of steel, widens the temperature range for effective quenching and tempering, and retards the decomposition of austenite. In addition, nickel does not form carbides or other compounds which might be difficult to dissolve during heating for austenitizing. All these factors contribute to easier and more successful thermal treatment. Because of the tight adherent scale formed on reheating nickel-containing steels, the surface quality of plates with nickel is somewhat poorer than those without nickel.

Chromium is used in constructional alloy steels primarily to increase hardenability, provide improved abrasion resistance, and to promote carburization. Of the common alloying elements, chromium is surpassed only by manganese and molybdenum in its effect on hardenability. Chromium significantly increases the corrosion resistance of some alloys.

Chromium forms the most stable carbide of any of the more common alloying elements, giving high-carbon-chromium steels exceptional wear resistance. And, because its carbide is relatively stable at elevated temperatures, chromium is frequently added to steels used for high-temperature applications.

Molybdenum exhibits a greater effect on hardenability per unit added than any other commonly specified alloying element except manganese or boron. It is a nonoxidizing element, making it highly useful in the melting of steels where close hardenability control is desired.

Molybdenum is unique in the degree to which it increases the high-temperature tensile and creep strengths of steel. Its use also reduces the susceptibility to temper brittleness.

Vanadium is widely used as a strengthening agent in steels. Vanadium additions are normally 0.10% or lower. Vanadium-bearing steels are strengthened by both precipitation hardening and refining the ferrite grain size. Precipitation of vanadium carbide and nitride particles in ferrite can provide a marked increase in strength. Thermo-mechanical processing, for example controlled rolling, increases the effectiveness of vanadium. Vanadium is also effective in increasing the hardenability and resistance to loss of strength on tempering in the quenched and tempered steels.

Columbium (niobium) is most often used in steels that receive controlled thermo-mechanical treatment. Small additions in the range from 0.02 to 0.04% provide a significant improvement in yield strength. For a given addition, columbium is approximately two times as effective as vanadium as a strengthener. When the steel is finished below about 1700°F (927°C), columbium improves notch toughness primarily by refining grain size. At higher finishing temperatures, it may be detrimental to toughness.

Copper is added to steel primarily to improve the steel's resistance to corrosion. In the usual amount of from 0.20 to 0.50%, the copper addition does not significantly affect the mechanical properties. Copper oxidizes at the surface of steel products during heating and rolling, the oxide forming at the grain boundaries and causing a hot-shortness which adversely affects surface quality. Copper is also used in some formulations of precipitation strengthened steels in use in shipbuilding and offshore structures. ASTM A-710, *Specification for Low-Carbon Age-Hardening Nickel-Copper-Chromium-Molybdenum-Columbium and Nickel-Copper-Columbium Alloy Steels*, (and the U.S. Navy modification, HSLA 80) has copper and nickel added.[2] The steel is precipitation strengthened, has high yield strength [80 ksi (55 MPa) min], high toughness, and is more tolerant of unpreheated welding than quenched and tempered steels such as HY-80.

Boron has the unique ability to increase the hardenability of steel when added in amounts as small as 0.0005%. This effect on hardenability is most pronounced at the lower carbon levels, diminishing with increasing carbon content. Because boron is ineffective when it is allowed to combine with oxygen or nitrogen, its use is limited to aluminum-killed steels.

Unlike many other elements, boron does not increase the ferrite strength of steel. Boron additions, therefore, promote improved machinability and formability at a particular level of hardenability. It will also intensify the hardenability effects of other alloys, and in some instances, decrease costs by making possible a reduction of total alloy content.

Aluminum is used principally to control grain size and to achieve deoxidation. The fine-grained steels produced by aluminum killing show improved notch toughness over coarse-grained steels.

2. A list of document numbers and titles is at the back of this guide.

**1.1.3 Deoxidation Practices.** Entrapped gases are deleterious to mechanical properties of steel. Several techniques exist to remove oxygen from the molten steel.

In most steelmaking processes, a primary reaction involves the combination of carbon and oxygen to form carbon monoxide. Proper control of the amount of gas evolved during solidification determines the type of steel. If no gas is evolved, the steel is termed *killed* because it lies quiet in the mold. Increasing degrees of gas evolution characterize semikilled, capped or rimmed steel.

Rimmed steels are only slightly deoxidized, thereby allowing a brisk evolution of gas to occur as the metal begins to solidify. The gas is produced by a reaction between the carbon and oxygen in the molten steel which occurs at the boundary between the solidified metal and the remaining molten metal. As a result, the outer skin or "rim" of the ingot is practically free of carbon. The rimming action may be stopped mechanically or chemically after a desired period, or it may be allowed to continue until the action subsides and the ingot top freezes over, thereby ending all gas evolution. The center portion of the ingot, which solidifies after the rimming ceases, has a fairly pronounced tendency to segregate.

The low-carbon surface layer of rimmed steel is very ductile. Proper control of the rimming action will result in a very sound surface in subsequent rolling. Consequently, rimmed grades are particularly adaptable to applications involving cold forming, and where surface is of prime importance.

The presence of appreciable percentages of carbon or manganese will serve to decrease the oxygen available for the rimming action. If the carbon is above 0.25% and the manganese over 0.60%, the action is very sluggish or nonexistent. If a rim is formed, it will be quite thin and porous. As a result, the cold-forming properties and surface quality are seriously impaired. It is, therefore, standard practice to specify rimmed steel only for grades with lower percentages of these elements.

Since rimmed steels are only slightly deoxidized and generally furnished in thicknesses up to 1/2 in. (12.5 mm), their use in shipbuilding should be limited to the less important structural members in the ship.

Semikilled steels are intermediate in deoxidation between rimmed and killed grades. Sufficient oxygen is retained so that its evolution counteracts the shrinkage on solidification, but there is no rimming action. Consequently, the composition is more uniform than in rimmed steel, but there is a greater possibility of segregation than in killed steel. Semikilled steels are used where neither the surface and cold-forming characteristics of rimmed steel nor the greater uniformity of killed steels are essential requirements.

Semikilled steel is superior to rimmed steel because of less segregation. It requires less processing than killed steels and suffers less loss due to "piping." It is commonly used for weldable quality steels. Many common ship steels, both plate and structural, are semikilled.

Killed steels are strongly deoxidized and are characterized by a relatively high degree of uniformity in composition and properties. The metal shrinks during solidification, thereby forming a cavity, or "pipe," in the uppermost portion of the ingot. A refractory hot-top is placed on the mold before pouring and filled with metal after the ingot is poured. The pipe formed will be confined to the hot-top section of the ingot, which is removed by cropping during subsequent rolling. The most severely segregated areas of the ingot will also be eliminated by this cropping.

While killed steels are more uniform in composition and properties than any other type, they are nevertheless susceptible to some degree of segregation. As in the other grades, the top center portion of the ingot will exhibit greater segregation than the balance of the ingot.

The uniformity of killed steel renders it most suitable for applications involving such operations as hot-forging, cold extrusion, carburizing, and thermal treatment.

**1.1.4 Heat Treatment of Plate Steels.** The versatility of steel is attributable in large measure to its response to a variety of thermal treatments. While a major percentage of steel is used in the as-rolled condition, thermal treatments greatly broaden the spectrum of properties attainable. Heat treatments fall into two general categories: (1) those which decrease hardness and promote uniformity by slow cooling, and (2) those which increase strength, hardness and toughness by virtue of rapid cooling from above the transformation range. Annealing, normalizing, and stress relieving fall in category 1, while quenching and tempering and thermomechanical treatment are typical category 2 treatments.

**1.1.4.1** Annealing indicates a single thermal treatment intended to place the steel in a suitable condition for subsequent fabrication. Annealing may be required where machining or severe forming is involved. The steel is heated to a temperature either slightly below or above the transformation temperature followed by a slow cool. The exact temperature and cooling rate or cycle are dependent on the properties desired by the purchaser.

**1.1.4.2** Normalizing consists of heating the steel above its critical temperature range [typically 1650 to 1700°F (900 to 927°C) for plate steels] and cooling in air. This heat treatment is commonly specified to obtain uniform grain refinement and results in improved notch toughness compared to as-rolled steels. Normalizing is commonly specified for plates of pressure vessel quality for thickness over 2 in. (50 mm).

**1.1.4.3** Stress relieving consists of heating the steel to a suitable temperature after flattening or other cold working, shearing, welding, or cutting to relieve stresses induced by these operations. Stress relieving is primarily a function of temperature, with time at temperature a secondary factor. A typical stress-relieving treatment for plate steel involves heating in the range of 1000 to 1200°F (538 to 649°C) followed by slow cooling. For quenched and tempered steels, the stress relief temperature should be maintained below the original tempering temperature of the plate.

**1.1.4.4** Quenching and tempering are used to improve the strength and toughness of steel plate. The treatment consists of heating the steel to the proper austenitizing temperature [for example, 1650°F (899°C) could be used for a 0.20% carbon steel] holding it at temperature to allow complete transformation to austenite to occur and quenching in water. After quenching, the steel is tempered at an appropriate temperature normally in the range of 800 to 1200°F (427 to 649°C). The purpose of tempering is to relieve internal stresses and improve ductility and toughness.

The use of precipitation hardening and quenched and precipitation hardening steels such as ASTM A710 is on the rise. These steels (ASTM A710 and its modifications) are similar to the U.S. Navy steels HSLA 80 and HSLA 100.

**1.1.4.5 Thermomechanical Treatments**

**(1) Control Rolling.** As an alternative or substitute for heat treatments that require additional material handling and furnace facilities, improved properties can also be obtained through special processing techniques at the rolling mill. *Control rolling* is widely practiced to increase strength and improve notch toughness of plate steels. Control rolling is a plate-rolling practice that tailors the time-temperature deformation process by controlling the rolling parameters. The parameters of primary importance are (1) the temperature for start of control rolling in the finishing stand where the final rolling of the steel takes place, (2) the percentage reduction from start of control rolling to the final plate thickness, and (3) the plate finishing temperature.

As seen in Figure 1, control rolling involves deformation at much lower temperatures than hot rolling, usually in the range from 1300 to 1500°F (704 to 816°C). In contrast, a normal hot- rolling practice takes advantage of the better hot workability of the material at higher temperatures. Hot-rolled plates are finished as quickly as possible, frequently at temperatures of 1800°F (982°C) and above. For control rolling, a hold or delay is generally taken to allow time for the partially rolled slab to reach the desired intermediate temperature before start of final rolling. Control-rolling practices are designed specifically for use with microalloyed grades which take advantage

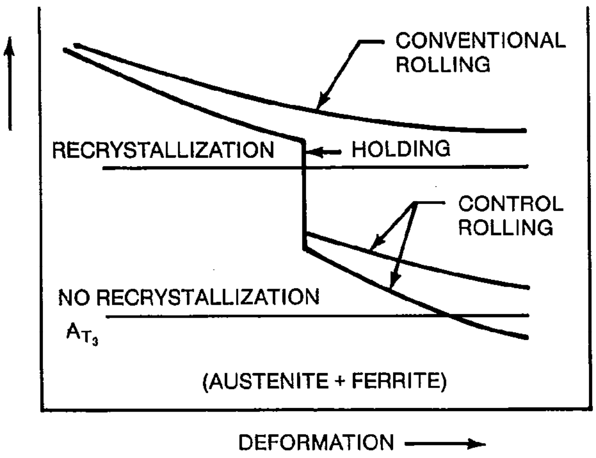



**Figure 1—Schematic Temperature Versus Deformation Plot Showing Differences Between Conventional Hot-Rolling and Control-Rolling**

of the alloying element's influence on recrystallization and grain growth in combination with the specific reduction schedule. Because of practical considerations, primarily mill load and delay times, control-rolled plates are not normally produced above about 1 in. (25 mm) thickness.

(2) **Control Finishing Temperature Rolling.** The term *control finishing temperature rolling* is used to differentiate from the term *control rolling*. The control finishing temperature rolling is a much less severe practice than control rolling and is primarily aimed at improving notch toughness for thicker plate up to 2-1/2 in. (63.5 mm) thickness. The finishing temperatures in this practice (approximately 1600°F or 871°C) are higher than required for control rolling. However, because heavier plates are involved than in control rolling, mill delays to reach the desired temperatures are still encountered. By controlling the finishing temperature, fine grain size can be obtained with resulting excellent notch toughness.

(3) **Precipitation Strengthened Steels.** Steels using this mechanism of achieving high yield strength and toughness were introduced in shipbuilding in the 1980's. In this method, the steel is heated to drive copper (1.0% to 1.3%) into solid solution in the steel matrix. Carbon is kept relatively low in content (0.07 max. for HSLA-80) which prevents formation of brittle martensite on rapid cooling. A supplementary thermal treatment from 1100 to 1300°F (593 to 704°C) is applied which allows precipitation of copper in the lattices of the matrix steel. The resulting lattice distortion is believed to be the mechanism which inhibits permanent deformation of the steel under stress with resulting increase in yield strength. Steels up to 100 ksi (690 MPa) minimum yield strength are being produced. The reduction in carbon content has allowed welding with little or no preheat and has avoided many of the problems associated with quenched and tempered steels. In addition to use in ship hull plating, HSLA-80 steels have been processed in coils on a strip mill and welded into structural beams using high frequency resistance welding at speeds of over 100 ft/min (30.5 m/min).

**1.1.5 Castings and Forgings.** The use of large steel castings and forgings is gradually declining in favor of weldments. Some ship parts are still made from forged or cast steel. Large quantities of anchor chain are furnished from both cast and forged steel. Forgings are widely used for such parts as tail shafts, rudder stocks, and anchor sections. The properties of cast and forged steels are determined by the chemical composition, heat treatment, and method of manufacture. Since most forgings and castings may be subject to welding either during initial fabrication or later during repair, the carbon content must be controlled to avoid welding difficulties.

**1.2 Higher Strength Steels.** To ensure suitable mechanical properties and adequate weldability, care must be exercised in selecting higher strength steels. Higher strength steels for commercial marine applications may be separated into two categories: the higher strength carbon steels having yield strengths of approximately 50 000 psi (345 MPa) and the low alloy steels having yield strengths ranging to approximately 100 000 psi (690 MPa).

Higher strength steels are sometimes used to reduce the steel weight of a ship and to avoid the use of exceptionally thick plates in highly stressed areas. The lighter material often provides the opportunity to increse the length and width of plates that can be ordered from the mill, and this can reduce the number of welding joints required. Alloy steels are necessary for low temperature service, below approximately –70°F (–57°C), and are used in areas where superior notch toughness is required.

When higher strength steels such as ASTM A710 or its modifications are used, those steels which attain their strength from precipitation hardening, sustained minimum preheat, and interpass temperature controls are not required. Moisture drying preheat will be required, and while heat input is not limited, the interpass temperature should not exceed 450°F (232°C) in order to control grain growth and produce adequate notch toughness.

**1.3 Notch Toughness Properties of Steel.** Notch toughness or impact resistance refers to the ability of a material, under load, to absorb energy by plastic deformation. This property allows the material to resist brittle fracture in the presence of metallurgical or mechanical cracks or notches. When little or no energy is absorbed plastically before fracture, and the break is of the cleavage type, the behavior of the material is described as brittle. Because this property of steel is strongly dependent upon temperature, transition temperature (the temperature at which the characteristics of the fracture change from ductile to brittle) has become a standard criterion of notch toughness. Depending upon material, the transition can occur over a fairly wide range. For example, the carbon steel transition region exists from –100°F (–73°C) to approximately 50°F (10°C). This is a range of 150°F (83°C).

**1.3.1 Transition Temperature.** There are a number of methods for specifying material with adequate notch toughness. The most common approaches, including Charpy testing, drop weight testing, and fracture mechanics, are described below.

Charpy V-notch testing is the most widely applied test for determining notch toughness. The Charpy test is shown in Appendix D. This specimen is notched perpendicular to the plate surface. The direction (longitudinal or transverse) of the specimen axis is selected according to the appropriate specifications for steel plate. The specimen is held for ten minutes at test temperature and then broken in the appropriate Charpy-type impact tester by a single blow of a freely swinging pendulum.

On breaking the Charpy specimen, three criterion are commonly measured. The loss of energy in the pendulum swing provides the energy in terms of foot pounds absorbed in breaking the specimen.

The fracture appearance of the broken specimen in terms of ductile and brittle failure can be rated. In addition, the lateral expansion at the base of the fracture opposite the notch can be measured. Any of these criterion can be plotted versus temperature to obtain the typical transition curve. The notch toughness will vary with specimen orientation, and requirements are generally negotiated between the customer and the supplier with a given energy at a specified temperature being the most common criteria.

During World War II, a number of Liberty ships experienced brittle fractures primarily initiating at notches in the deck plate. Service failures were never observed at temperatures at which the Charpy value was 15 ft-lb or greater. As a result, the 15 ft-lb transition temperature requirement was established and has become the most commonly used criteron in specifications. Naturally, this criteron best applies to the plain carbon steels for which it was developed. With the introduction of higher strength steels, the fracture appearance and lateral expansion values provide alternate approaches that can be considered to measure ductile performance.

The Charpy-testing approach suffers from the fact that a small specimen is tested that does not see the same conditions as the material in an actual structure. Therefore, the test results are most useful in rating material on a comparison basis.

A standard Charpy V-notch test specimen is shown in Figure 2A. A typical Charpy V-notch transition temperature curve for one particular grade of mild steel is shown in Figure 2B.

It is important to realize that the thickness and shape or geometry of the specimen or structure has a marked influence on transition temperature. Specimens with sharper notches and greater restraint will have the higher transition temperatures, and larger specimens composed of thicker material will have higher transition temperatures than similar smaller specimens. In addition to the influence of geometry, transition temperature is also influenced by the type of steel used, the general stress level, and the rate of loading. Transition temperatures increase with stress levels and loading rates.

Figure 3 shows Charpy V-notch curves for three grades of ordinary strength steel, one grade of a higher strength quenched and tempered low alloy steel, plus one grade of a quenched and precipitation-hardened steel. It should be remembered, when transition temperatures are compared, that impact energy values required for higher strength steels are usually greater than those specified for ordinary strength steels.

Drop Weight Testing is also used to determine impact toughness of steel plates and the nil-ductility-transition temperature (NDT Temp). This test is carried out in accordance with ASTM E208 as shown in Appendix D. Rectangular pieces are cut from the test plate and a crack-starter bead is deposited across the specimen. A notch is machined across the weld bead. Specimens are tested as a function of temperature. A specimen is set on an anvil, welded surface down and then struck by a guided, free-falling weight. A crack must initiate from the crack starter for the test to be valid. If the crack runs to the edge of the specimen, the specimen is considered a break (failure). The test is strictly a go or no-go result. The NDT temperature is defined as the maximum temperature at which a drop weight specimen breaks in the test. The NDT temperature is very reproducible and can be defined within 10°F (5.6°C) for a given plate.

The physical significance of the NDT value to the designer is that if a material is selected whose NDT is lower than the expected service temperature, brittle failure will not occur at a small crack subjected to yield stress levels under conditions of dynamic loading. Additionally, this (NDT) information can be used to determine tolerable crack size at lesser stress levels. This method is explained by William S. Pellini in "Principles of Fracture-Safe Design" (*Welding Journal*, March 1971).

**1.3.2 Effect of Plate Thickness.** From a metallurgical standpoint, thicker plates will be more notch sensitive than thinner plates from the same lot or heat of steel. This is due mainly to the difference in mill finishing temperatures. Increasing the plate thickness from 1/2 to 1-1/2 in.

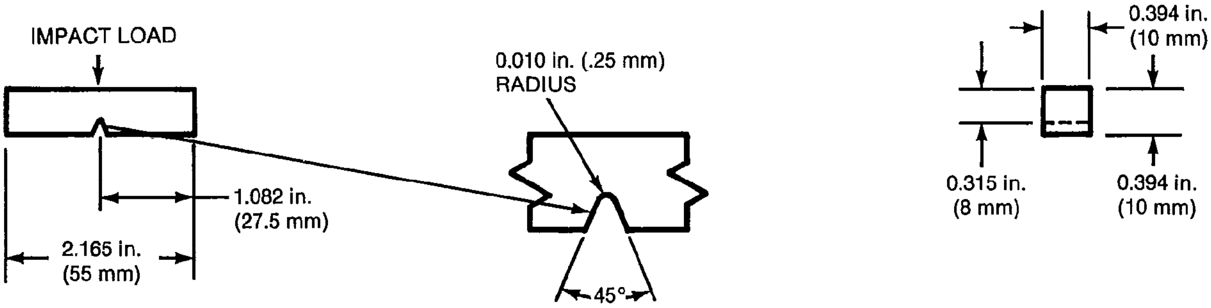
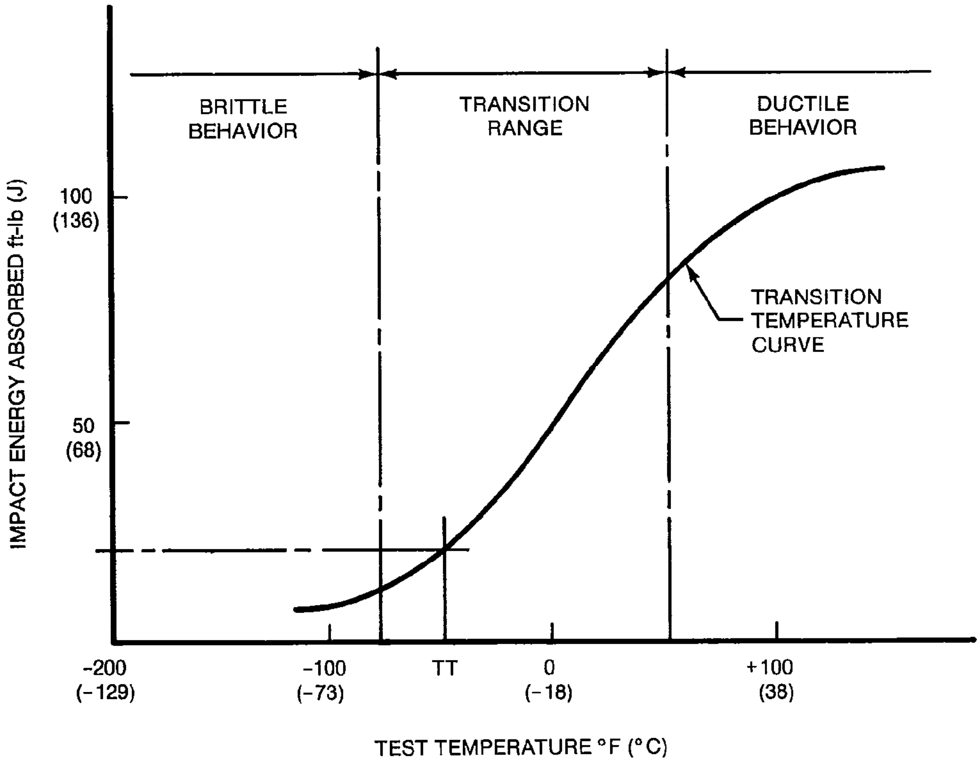



**Figure 2A—Standard Charpy V-Notch Test Specimen**




NOTE: TRANSITION TEMPERATURE (TT) IS DEFINED AS THE TEMPERATURE AT WHICH THE CURVE CROSSES A SPECIFIED ENERGY VALUE.

**Figure 2B—Typical Charpy V-Notch Transition Temperature Curve for ABS Grade D Steel**

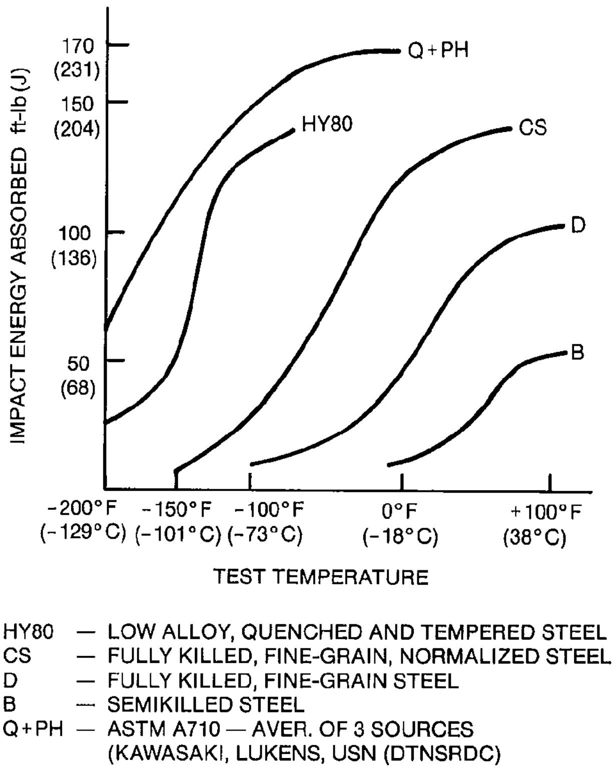



**Figure 3—Typical Charpy V-Notch Transition Temperature Curves for Several Grades of Steel**

(12 to 38 mm) has been found in some cases to raise the impact transition temperature by 50 to 68°F (28 to 38°C).

As the thickness of a plate increases, its ability to deform in the thickness direction decreases. Hence, from a geometrical standpoint, increased plate thickness in front of a notch adds restraint and increases the chance of brittle failure.

For certain critical locations, this size effect is at least partially offset by the required use of steel having greater notch toughness in the thicker plates. Regardless of location, great care should be exercised in the detailing and fabricating of structures which employ thick plates.

**1.3.3 Directional Properties of Rolled Plate.** When plates are rolled, the orientation of the constituents is elongated in the direction of rolling. As a result, the Charpy V-notch values of longitudinal specimens are greater than those of transverse specimens. It is, therefore, advisable to orient ship plates fore and aft so that the longitudinal direction of rolling is in the same direction as the primary stress.

The notch toughness of plates is even poorer in the thickness direction, that is, perpendicular to the plate surfaces. In addition, tensile strength and ductility are also reduced in the thickness direction. Therefore, it is advisable to follow the general practice of not requiring high tensile stresses to be transmitted through the thickness of a plate. Where this is unavoidable, the use of special steels with enhanced through-thickness mechanical properties should be considered.

**1.3.4 Effect of Cold Forming.** Cold forming may damage the material in several ways. Physical damage, such as surface cracking, may occur as a result of flanging or severe forming. Moderately severe cold working of the steel reduces its notch toughness and ductility. In some steels, there may be a further adverse effect from strain aging, which is usually accelerated by moderate heating.

Reduction in notch toughness due to cold forming becomes significant only when steel is stretched more than 3%. The rolling of bilge plates or rounded gunwales should not present a problem. However, the rolling of thick plates to a small radius would affect the notch toughness and, therefore, may require a stress relief heat treatment. The minimum radius for bending will vary depending upon the specifying agency or recommendations of the manufacturer in the case of proprietary grades of steel. The latest guide for forming, as set forth in *American Bureau of Shipping Rules*, should be consulted.

Strain aging of ship steel is usually of little consequence, but precautions should be taken when using rimmed-type steels for cold-formed members in any kind of structure. These steels, when strain aged, exhibit a significant reduction in ductility.

Removal by grinding of approximately 1/8 in. (3 mm) of the sheared or flame-cut edge and rounding the edge of a plate that is to be formed, particularly a thick plate, reduces the likelihood of a crack starting on the edge.

The quenched and precipitation-hardened steels offer expanded cold-forming capabilities when formed in the quenched-only condition. Since in this condition the plate has only attained 70 to 75% of its final yield strength, improvements in forming limits can be gained. The subsequent precipitation hardening produces the desired yield point as well as good notch-toughness qualities in the steel.

**1.4 Notch Toughness of Weld Metal and Heat-Affected Zone.** The primary reason for the many different grades of steels, such as those in Tables 1A, 1B, 2A, 2B and 2C, is the requirement for various degrees of notch toughness, depending on the type of structure, the plate thickness, and the service temperature.

Using selected welding conditions and consumables, it is possible to meet the minimum notch toughness properties of the base metal in both the weld and heat-affected zone. However, when high heat input welding processes are used, there is usually a degradation of impact properties. This is a main reason why the use of some welding

## Table 1A
## American Bureau of Shipping Requirements for Ordinary-Strength Hull Structural Steel Grades A, B, D, E, DS, CS 51 mm (2 in.) and Under

| Grades | A | B | D | E | DS | CS |
|---|---|---|---|---|---|---|
| Deoxidation | Semi-killed or killed steel for (in.) | Semi-killed or killed steel | Fully killed fine-grain practice (1) | Fully killed fine-grain practice | Fully killed fine-grain practice | Fully killed fine-grain practice |
| Chemical Composition (Ladle Analysis) | For all grades exclusive of Grade A shapes and bars, the sum of carbon content and one-sixth of the manganese content is not to exceed 0.40%. The upper limit of manganese may be exceeded up to a maximum of 1.65% provided this condition is satisfied. | | | | | |
| Carbon % | 0.23 max. (2) | 0.21 max. | 0.21 max. | 0.18 max. | 0.16 max. | 0.16 max. |
| Manganese % | 2.5 × carbon min. for plates over 12.5 mm (0.5 in.) | 0.80–1.10 0.60 min. for fully killed or cold flanging | 0.71–1.35 0.60 min. for thickness 25 mm (1.0 in.) and under | 0.70–1.35 | 1.00–1.35 | 1.00–1.35 |
| Phosphorus % | 0.04 max. | 0.04 max. | 0.04 max. | 0.04 max. | 0.04 max. | 0.04 max. |
| Sulphur % | 0.04 max. | 0.04 max. | 0.04 max. | 0.04 max. | 0.04 max. | 0.04 max. |
| Silicon % | — | 0.35 max. | 0.10–0.35 | 0.10–0.35 | 0.10–0.35 | 0.10–0.35 |
| Nickel % Chromium % Molybdenum % Copper % | The content of these elements is to be determined and reported, and when the amount present is less than 0.02%, these elements may be reported as < or = 0.02%. | | | | | |
| Tensile Strength | For all Grades: 41–50 kg/mm² (58,000–71,000 psi); for Grades A shapes and bars 41–56 kg/mm² (58,000–80,000 psi). For cold flanging quality: 39–46 kg/mm² (55,000–65,000 psi) | | | | | |
| Yield point, min. | For all Grades: 24 kg/mm² (34,000 psi); for Grade A and over 25.0 mm (1.0 in.) in thickness 23 kg/mm² (32,000 psi). For cold flanging quality: 21 kg/mm² (30,000 psi) | | | | | |
| Elongation, min. | For all Grades 21% in 200 mm (8 in.) (See 43.3.4d)* or 24% in 50 mm (2 in.) for specimen see Figure 43.2* or 22% in 5.65 A (A equals cross-sectional area of test specimens). For cold flanging quality: 23% in 200 mm (8 in.). | | | | | |
| Impact Test Charpy V-notch Temperature | 0°C (32°F) Over 25 mm (1.0 in.) | –10°C (14°F) | –40°C (–40°F) | | | |
| Energy Avg. min. Longitudinal Specimens | 2.8 kg-m (20 ft-lb) | 2.8 kg-m (20 ft-lb) | 2.8 kg-m (20 ft-lb) | | | |
| or Transverse Specimens | 2.0 kg-m (14 ft-lb) | 2.0 kg-m (14 ft-lb) | 2.0 kg-m (14 ft-lb) | | | |
| Heat Treatment | Normalized over 35 mm (1.375 in.) thick (4) | Normalized (6) | Normalized over 35 mm (1.375 in.) | Normalized | | |
| Marking | AB/A | AB/B | AB/D(5) | AB/EE | AB/DS | AB/CS |

**ABS Rules for Building and Classing Steel Vessels*, American Bureau of Shipping.

(1) Grade D may be furnished semi-killed in thickness up to 35 mm (1.375 in.) provided steel above 25.0 mm (1.00 in.) in thickness is normalized. In this case the requirements relative to minimum Si and Al contents and fine grain practice do not apply.

(2) A maximum carbon content of 0.26% is acceptable for Grade A plates equal to or less than 12.5 mm (0.5 in.) and all thicknesses of Grade A shapes and bars.

(3) Impact tests are not required for normalized Grade D steel when furnished fully killed fine grain practice.

(4) Controlled rolling or thermo-mechanical controlled rolling of Grade D steel may be specially considered as a substitute for normalizing.

(5) Grade D hull steel which is normalized, thermo-mechanical controlled rolled, or controlled rolled in accordance with Note 4 is to be marked AB/DN.

(6) Controlled rolling or thermo-mechanical controlled rolling of Grade E shapes and thermo-mechanical controlled rolling of Grade E plates may be specially considered as a substitute for normalizing.

### Table 1B
### American Bureau of Shipping Requirements for Ordinary-Strength Hull Structural Steel Over 51 mm (2 in.)

**Process of Manufacture: Open Hearth, Basic Oxygen, or Electric Furnace**

| Grades | A | B | D | DS | CS | E |
|---|---|---|---|---|---|---|
| Impact Test<br>Charpy V-notch<br>Temperature | 20°C*<br>(68°F) | 0°C<br>(32°F) | –10°C<br>(14°F) | –10°C<br>(14°F) | –40°C<br>(–40°F) | –40°C<br>(–40°F) |
| Energy avg. min<br>Longitudinal<br>Specimens | 2.8 kg-m<br>(20 ft-lb) | 2.8 kg-m<br>(20 ft-lb) | 2.8 kg-m<br>(20 ft-lb) | 2.8 kg-m<br>(20 ft-lb) | 2.8 kg-m<br>(20 ft-lb) | 2.8 kg-m<br>(20 ft-lb) |
| or<br>Transverse<br>Specimens | 2.0 kg-m<br>(14 ft-lb) | 2.0 kg-m<br>(14 ft-lb) | 2.0 kg-m<br>(14 ft-lb) | 2.0 kg-m<br>(14 ft-lb) | 2.0 kg-m<br>(14 ft-lb) | 2.0 kg-m<br>(14 ft-lb) |
| No. of Specimens | 3 from each* 50 tons | 3 from each 50 tons | 3 from each 50 tons | 3 from each 50 tons | 3 from each plate | 3 from each plate |
| Heat Treatment | None Required | None Required | Normalized | Normalized | Normalized | Normalized |
| Deoxidation | Fully killed | Fully killed | Fully killed fine-grain practice | Fully killed fine-grain practice | Fully killed fine-grain practice | Fully killed fine-grain practice |

*Impact tests for Grade A are not required when material is produced using a fine grain practice and normalized.

processes should not be permitted for welding joints in highly stressed areas, such as sheer strakes, where special material is required. In this respect, the large casting type of weld structure obtained by such processes as electroslag and electrogas, and some multiple wire submerged arc welding, has reduced toughness as compared to that of multiple- pass welds. Multiple-pass welds may be required in lieu of single-pass welds where superior impact properties are required. This is of particular importance when welding the higher strength steels and steels for low-temperature service.

As the impact requirements become more severe (lower-transition temperature requirements), it becomes more difficult and more costly to produce welds with impact properties to match those of the base metal, particularly for service temperatures below –20°F (–29°C) and for the higher strength steels. With some high-heat- input welding processes, procedures have not yet been developed to make welded joints that meet required impact properties.

**1.5 Fatigue.** Metal fatigue is the process by which a part, component, or structure degrades or fails when it experiences cyclic loading. Fatigue can account for as much as 90% of all failures. In general, fatigue involves two stages (1) the initiation of a crack, and (2) its subsequent growth to failure. Failure ultimately occurs when the crack is so large that the uncracked section or ligament is unable to support the applied load. The relative importance of each stage of the cracking process depends upon factors which include the presence of stress raisers (welds, holes, changes in section, etc.), the strength of the material, the applied stress range, and the size of the member. In the case of unnotched specimens, crack initiation can occupy the largest fraction of life, while propagation is the dominant stage when notches are present.

Crack initiation occurs when plastic deformation accumulates in a local region. In absence of a stress raiser, plastic deformation changes an initially flat surface to a notch-peak topography with many small cracks initiating at the base of the surface notches. As cyclic loading progresses, these small cracks join to form a larger one which can grow in response to the applied cyclic loads. In the presence of a notch (hole, weld toe, etc.), this same sequence occurs at an accelerated rate. The number of loading cycles required for crack initiation depends on the material, cyclic load range, and stress concentration factor of the notch.

Crack propagation is similar to crack initiation in that its driving force is the localized plasticity that occurs at the crack tip in response to the applied loads. As the tensile

## Table 2A
## American Bureau of Shipping Requirements for Higher Strength Hull Structural Steel Grades AH32, DH32, EH32, AH36, DH36, and EH36 51 mm (2 in.) and Under

**Process of Manufacture: Open Hearth, Basic Oxygen, or Electric Furnace**

| Grades (1) | AH32 | DH32 | EH32 | AH36 | DH36 | EH36 |
|---|---|---|---|---|---|---|
| Deoxidation | Semi-killed or Killed[4] | Killed, Fine Grain Practice[4] | Killed, Fine Grain Practice[4] | Semi-killed or Killed[3] | Killed, Fine Grain Practice[4] | Killed, Fine Grain Practice[4] |
| Chemical Composition for All Grades (Ladle Analysis) | Carbon, % | 0.18 max. | | | | |
| | Manganese, %[2] | 0.90–1.60 | | | | |
| | Phosphorus, % | 0.04 max. | | | | |
| | Sulfur, % | 0.04 max. | | | | |
| | Silicon, % | 0.10–0.50 | | | | |
| | *Nickel, % | 0.40 max. | These elements need not be reported on the mill sheet unless intentionally added. | | | |
| | *Chromium, % | 0.25 max. | | | | |
| | *Molybdenum, % | 0.08 max. | | | | |
| | *Copper, % | 0.35 max. | | | | |
| | Columbium, % (Niobium) | 0.05 max. | | | | |
| | Vanadium, % | 0.10 max. | | | | |
| | The content for any other element intentionally added is to be determined and reported. | | | | | |
| Tensile Strength | 48–60 $kg/mm^2$; 68,000–85,000 psi<br>32 $kg/mm^2$; 45,000 | | | psi 50–63 $kg/mm^2$; 71,000–90,000 psi<br>psi 36 6 $kg/mm^2$; 51,000 psi | | |
| Elongation, min. | For all Grades: 19% in 200 mm (8 in.) (see 43.3.4d)** or 22% in 50 mm (2 in.) (for specimen in Figure 43.2)** or 20% in 5.65 A (A equals cross-sectional area of test specimen). | | | | | |
| Heat Treatment | See Table 2C | | | | | |
| Impact Test Charpy V-notch Temperature | 0° (32°F) | −20°C (−4°F) | −40°C (−40°F) | 0°C (32°F) | −20°C (−4°F) | −40°C (−40°F) |
| Energy, avg. min. Longitudinal Specimens | 3.5 kg-m (25 ft-lb)[5] | 3.5 kg-m (25 ft-lb)[5] | 3.5 kg-m (25 ft-lb) | 3.5 kg-m (25 ft-lb)[5] | 3.5 kg-m (25 ft-lb)[5] | 3.5 kg-m (25 ft-lb) |
| or Transverse Specimen | (17 ft-lb)[5] | (17 ft-lb)[5] | (17 ft-lb) | (17 ft-lb)[5] | (17 ft-lb)[5] | (17 ft-lb) |
| Marking | AB/AH32 | AB/DH32 | AB/EH32 | AB/AH36 | AB/DH36 | AB/EH36 |

Notes:
1. The numbers following the Grade designation indicate the yield point or yield strength to which the steel is ordered and produced in $kg/mm^2$.
2. Grade AH 12.5 mm (0.50 in.) and under in thickness may have a minimum manganese content of 0.70%.
3. Grade AH plates to 12.5 mm (0.50 in.) inclusive and all thickness of AH shapes may be semi-killed in which case the 0.10% minimum silicon does not apply. Unless otherwise specially approved, Grade AH plates over 12.5 m (0.50 in.) are to be killed with 0.10 to 0.50% silicon.
4. Grades and EH are to contain at least one of the grain refining elements in sufficient amount to meet the fine grain practice requirement.
5. Impact tests are not required for AH, 12.5 mm (0.5 in.) and less in thickness, and aluminum treated Grade AH, 35 mm (1.375 in.) and less in thickness. Impact tests are not required for any fully killed, fine grain normalized Grade AH, or DH, 51 mm (2 in.) and less in thickness.
6. The marking AB/DHN is to be used to denote Grade DH plates which have either been normalized, thermo-mechanical controlled rolled or control rolled in accordance with an approved procedure.
7. ABS 1991 Rules include changes reflecting IACS's unified requirements for the addition of AH, DH, & EH40 to replace AH, DH, and EH36.

*These elements may be reported as < or = 0.02% when the amount present is less than 0.02%.
***ABS Rules for Building and Classing Steel Vessels*, American Bureau of Shipping.

## Table 2B
## American Bureau of Shipping Requirements for Higher Strength Hull Structural Steel Over 51 mm (2 in.)

**Process of Manufacture, Open Hearth, Basic Oxygen, or Electric Furnace**

| Grades | AH 32 and 36 | DH 32 and 36 | EH 32 and 36 |
|---|---|---|---|
| Impact Test<br>Charpy V-notch<br>Temperature | 0°C (32°F) | –20°C (–4°F) | –40°C (–40°F) |
| Energy avg. min<br>Longitudinal Specimens | 3.5 kg–m (25 ft-lb) | 3.5 kg-m (25 ft-lb) | 3.5 kg-m (25 ft-lb) |
| or<br>Transverse Specimens | 2.4 kg-m (17 ft-lb) | 2.4 kg-m (17 ft-lb) | 2.4 kg-m (17 ft-lb) |
| No. of Specimens | 3 from each 50 tons | 3 from each 50 tons | 3 from each plate |
| Heat Treatment | Normalized | Normalized | Normalized |

## Table 2C
## American Bureau of Shipping Normalizing Heat Treatment Requirements for Higher Strength Hull Structural Steels

| Grade | AH | DH[1] | EH[3] |
|---|---|---|---|
| Aluminum Treated Steels | Over 51 mm (2 in.) Thick | Over 25.5 mm (1 in.) Thick | All Thicknesses |
| Columbium[2] or Vanadium | Over 51 mm (2 in.) Thick | Over 12.5 mm (0.5 in.) Thick | All Thicknesses |

Notes:
1. Controlled rolling or thermo-mechanical controlled rolling of Grade DH may be specially considered as a substitute for normalizing.
2. When columbium (niobium) or vanadium is used in combination with each other or with aluminum, the heat treatment requirements for columbium (niobium) or vanadium apply.
3. Controlled rolling or thermo-mechanical controlled rolling of Grade EH shapes and thermo-mechanical controlled rolling of Grade EH plates may be specially considered as a substitute for normalizing.

stress is increased, the crack grows and ultimately the crack-tip is enlarged or blunted. On unloading, the crack-tip radius is resharpened for the next loading cycle. The rate at which a crack grows during one loading cycle is usually expressed in terms of the range in stress intensity factor (a function of the load range, crack length, and the specimen geometry), and is typically insensitive to the strength of the material. There are numerous references dealing with the kinetics of crack propagation, i.e., plots of crack growth rate versus the range in stress intensity factor.

### Variables Affecting Fatigue

Some of the most important variables affecting fatigue are the following:

(1) Stress range — life decreases as stress range increases

(2) Residual stresses — life decreases for tensile residual stress and increases for compressive residual stress

(3) Notches or welds — reduce fatigue life

(4) Material properties — long-life fatigue strength ($10^6$–$10^7$ cycles) increases with increasing tensile strength in absence of a notch

(5) Corrosive environment — typically degrades fatigue performance

In addition, other variables such as stress state, stress ratio, surface condition, microstructure, inclusions, grain size, heat treatment, and deoxidation practice, can play a role in the fatigue process. However, the influence of these variables is generally of secondary importance relative to those listed above.

Material effects in fatigue are primarily controlled by the tensile strength with higher strength materials having proportionally higher long-life ($10^6$ to $10^7$ cycle) fatigue resistance. In the presence of a sharp notch, fatigue life is insensitive to differences in strength level because crack propagation, the dominant phase of life in this case, is insensitive to differences in strength level. In practice, manufactured products frequently have notches or details which act like notches. Thus, it is seldom possible to achieve greater fatigue life through material selection alone.

Changing materials to increase the fracture toughness increases the critical crack length for failure under a given loading condition, and increases the margin of safety against overloads causing failure when cracks are small. However, increasing fracture toughness will not markedly lengthen fatigue life because the bulk of life is spent in crack growth when the crack is much smaller than the critical crack size.

Fracture and fatigue are best controlled by proper methods of design, fabrication, and inspection. Improved material properties and quality will not compensate for poor performance in any of the following:

(1) Every effort should be made to minimize the severity of notches, or at the least, to reduce the stress in the vicinity of the notch.

(2) In the presence of a sharp notch such as the toe of weldment, most of the fatigue life will be spent in crack propagation.

Several ways to improve the fatigue life of welded joints include the following:

(a) grinding off the groove weld reinforcement

(b) dressing fillet welds and avoiding undercut or overlap

(c) locating the weld in a low stress region

(d) avoiding joints with large variation in stiffness

(e) avoiding use of intermittent welds

(3) Initial and periodic inspections are necessary to the development of a rational plan for controlling fatigue and fracture.

(4) A thorough fatigue design will consider the possible influences of temperature and environment.

## 1.6 Specifications for Steel

**1.6.1 Ordinary and Higher Strength Steels.** The American Bureau of Shipping (ABS) and the American Society for Testing and Materials (ASTM) have issued similar requirements covering hull steels. Tables 1A, 1B, 2A, and 2B give the principal ABS requirements for ordinary strength and higher strength hull structural steels.

Unless otherwise specified, shapes and bars may be made of steel meeting the requirements of Grade A or AH quality. Other grades of steel like A36 may be used as long as the chemistry, strength, toughness, and weldability are adequate for their intended application.

Popular commercial grades of high-strength steel that have a 45 000 to 60 000 psi (315 to 420 MPa) yield strength have been used in ships for special applications involving high stress or low temperature service, i.e., such steels as ASTM A537 Class 1 and Class 2. In some instances, steels developed by the U.S. Navy, HY 80, HY 100, HSLA 80, and HSLA 100 are used. HSLA 80 is actually a modified ASTM A710, Gr A, Class 3 for structures and ASTM A736, Gr A, Class 3 for pressure vessels.

**1.6.2 Plate Thickness Limitations.** The various grades of steel plate have thickness limitations depending on the location of the plate in the structure, as given in Table 3. Note especially the thickness of plate for special applications.

**1.6.3 U.S. Navy.** The U.S. Navy has specifications for mild steel, high tensile, and low alloy high-strength steels. Specification MIL-S-22698, covering structural carbon steel for ships, is in substantial agreement with the ABS specification for ordinary strength hull steel. For thicker plates, both specifications contain specific requirements for normalizing to enhance the notch toughness.

Several strength levels of quenched and tempered steels from 50 000 to 100 000 lb/in (345 to 690 MPa) yield strength are covered by Naval Material Procurement Specifications. Development work shows promise for 130 000 to 150 000 lb/in (860 to 1035 MPa) yield-strength material for weldments of high toughness. The low alloy quenched and tempered HY80 and HY100 steels are covered in MIL-S-16216.

HSLA-80 is specified in MIL-S-24645, which also includes HSLA-100. The primary differences in chemistry between HSLA-80 and ASTM A710 are for HSLA-80 allowable sulfur has been reduced to 0.010%, and 0.06% maximum columbiumis permitted. Calcium treatment of the melt is also required for sulfide inclusion shape control. Mechanical property requirements include 80 to 99.5 ksi (55 to 69 MPa) yield strength and transverse Charpy-V-notch requirements of 35 ft/lb at –120°F (–85°C) and 60 ft/lb at 0°F (18°C).

The welding standard applicable to most current U.S. Navy surface combatant fabrication is MIL-STD-1689, *Fabrication, Welding and Inspection of Ships Structures*. This is a later document than NAVSHIPS 0900-000-1001 which may still apply under some contracted work. Both documents have extensive lists of references to applicable material specifications, Military Standards, and other relevant publications.

When requesting specifications, it is important that the proper contractual issue is obtained.

## Table 3
## Thickness Limitations for ABS Steel Grades

| Type | Grade | Ordinary I, II, III[a] Applications in. | Ordinary I, II, III[a] Applications mm | Special IV, V[a] L > 820 ft (250 m) Applications[b] in. | Special IV, V[a] L > 820 ft (250 m) Applications[b] mm |
|---|---|---|---|---|---|
| | A | 0.79 | 20 | 0.060 | 15[c] |
| | B | 0.98 | 25 | 0.79 | 20 |
| Ordinary Strength | D | 1.38 | 35 | 0.98 | 25 |
| | D | 1.57 | 40 when normalized | 1.18 | 30 when normalized |
| | DS | 1.38 | 35 | 0.98 | 25 |
| | CS | 2.00 | 51 | 2.00 | 51 |
| | E | 2.00 | 51 | 2.00 | 51 |
| Higher Strength | AH | 0.98 | 25 | 0.79 | 20 |
| | DH | 1.57 | 40 | 1.18 | 30 |
| | EH | 2.00 | 51 | 2.00 | 51 |

Notes:
a. Roman numerals I, II, III, IV, and V are ABS material classes.
b. When special material is required in the rules because of applications in bilge strake, sheerstrake, strength-deck hatch-side strake, or stringer plate.
c. Acceptable to 0.79 in. (20 mm) maximum for bilge strake with a double bottom over the full breadth and with a length less than 492 ft. (150 m).

**1.6.4 Castings and Forgings.** Castings normally conform to ASTM A27 (Grade 60-30), and forgings to ASTM A668, latest editions. See MIL-STD-1689, *Fabrication, Welding, and Inspection of Ships Structure*, for Federal and Military Specifications pertaining to castings and forgings.

**1.6.5 Requirements for Low Temperature Services.** Chapter VI of the IMO *International Code for the Construction and Equipment of Ships Carrying Liquified Gas in Bulk* (International Gas Carrier Code) is the governing document for material selection for low-temperature service. There are four general temperature ranges covering material requirements for primary cargo tanks as follows:

**1.6.5.1 Service Temperature 32°F (0°C) or Above.** See International Gas Carrier Code, Table 6.1. Steels intended for this temperature range are normally carbon manganese, fully killed steels with fine grain practice in thickness over 0.79 in. (20 mm). ABS Grades D up to 0.79 in. (20 mm) thick and E may be used subject to special agreement and additional Charpy V-notch testing. Steels should be normalized or quenched and tempered. An improved controlled rolling procedure may be substituted for normalizing.

**1.6.5.2 Service Temperatures at or above –67°F (–55°C) up to 32°F (0°C).** See International Gas Carrier Code, Table 6.2. Steels intended for this temperature range are normally carbon manganese steels furnished fully killed, fine grain, normalized.

**1.6.5.3 Service Temperatures at or Above –320°F (–196°C) up to –67°F (–55°C).** See International Gas Carrier Code, Tables 6.3 and 6.4. Steels intended for this temperature range are normally of the ferritic nickel alloy type made with fine grain practice. Austenitic steels or aluminum alloys may be used as well. In general, the following ASTM grades may be used for the temperatures listed:

| | | |
|---|---|---|
| A203, 2-1/4% Ni | –80°F (–62°C) | for Grade A |
| | –75°F (–59°C) | for Grade B |
| A203, 3-1/2% Ni | –130°F (–90°C) | for Grade D |
| | –110°F (–79°C) | for Grade E |
| A645, 5% Ni | –155°F (–105°C)[1] | |
| A353, 9% Ni | –320°F (–196°C) | |
| A553, 9% Ni | –320°F (–196°C) | |
| Austenitic Stainless Steel | –320°F (–196°C) | |
| A658, 36% Ni | –320°F (–196°C)[2] | |
| B209, Type 5083, Aluminum Alloy | –320°F (–196°C) | |

Notes:
1. 5% nickel steel may be used down to –265°F (–165°C) upon special consideration provided that impact tests are conducted at –320°F (–196°C).
2. Chemistry will be specially considered for lowering the coefficient of expansion.

For all of the specifications above, chemical composition, heat treatment, tensile, and impact properties are to conform to the requirements of the approved specification.

**1.6.5.4 Service Temperatures Below –320°F (–196°C).** Austenitic low carbon (less than 0.10%) stainless steels and aluminum alloys are to be used for these temperatures. Stainless steel types 304, 304L, and 347 and type 5083 aluminum alloy do not require toughness testing for service temperatures above –425°F (–254°C). Toughness tests for –425°F (–254°C) service temperature and below will be subject to special considerations.

For service temperatures below 0°F (–18°C), procedure qualification tests and testing of production welds should be in accordance with the International Gas Carrier Code and the appropriate regulatory body and classification society rules and regulations.

If a secondary barrier is needed, the material type will be equal to that of the primary tank plating. This affords temporary containment of any cargo leakage and prevents lowering the temperature of the surrounding ship structure to an unsafe level.

A few low-temperature products and their service temperatures are listed below for reference:

| Approximate Service Temperature | °F | (°C) |
|---|---|---|
| Vinyl Chloride | +7 | (–14) |
| Ammonia | –28 | (–33) |
| Liquified petroleum gas (LPG) | –50 | (–46) |
| Liquified natural gas (LNG) | –260 | (–162) |

**1.7 Specifications for Welding Consumables.** The many different types of electrodes, filler metals, and fluxes available are designed to produce welds with superior strength, toughness, or corrosion resistance, as the application demands. Care should be exercised in the choice of consumables to ensure that those used will be suitable for the application.

All filler metals for ship construction must be approved by regulatory agencies. For approval, ABS requires witnessed tests by the manufacturer to demonstrate that the electrodes, wire, and flux meet specified requirements. The U.S. Coast Guard accepts ABS-approved consumables and allows fabricators to obtain approval for other filler metals by passing a Weld Procedure Qualification test. The U.S. Navy has its own test and approval procedures.

Filler metals used in shipbuilding are described in a variety of specifications issued by the American Bureau of Shipping, the U.S. Navy, and the American Welding Society. The specifications most commonly used for steel hull construction are given in Table 4.

Certain electrodes and fluxes adopted for high speed, single pass welding have relatively low ductility. All filler metals and flux combinations used for welding joints in main strength members with joints made by high speed, single pass procedures should be shown by appropriate tests to demonstrate adequate mechanical properties.

**1.8 Selection of Materials.** When selecting and using a steel for a particular application, the suitability of the material will depend partly on its weldability. There are two aspects of weldability that are of concern. The first concern is the ease of joining in the shop or field while maintaining a sound joint. This aspect of weldability can be strongly influenced by the chemistry of the base metal as well as by the welding procedure and welding materials. In general, as the carbon or alloy content increases, the hardenability will also increase, and the weldability will be reduced (i.e., the weldment's resistance to cracking will decrease). The second consideration is the ability of the steel to meet the service performance requirements, such as mechanical properties, for the intended application.

Much research and development have gone into the design of modern alloy steels and into welding technology to ensure that steels can be successfully welded. As the technology of making, shaping, and treating of steels has advanced, designers and specifying agents have taken advantage of the opportunity to be more selective in their specification requirements. Although the selection of material is governed largely by requirements of regulatory agencies or classification societies, many different grades of structural steel are available for structural work. Some grades can be improved by appropriate steel making practices such as controlled rolling practices, grain refining, additions of alloying elements, and various heat treatments.

ABS ordinary and higher strength steels listed in Tables 1A, 1B, 2A, 2B and 2C are the most commonly used shipbuilding steels. Investigation of notch toughness and fatigue, in addition to tensile properties, should be made before selecting a steel for a particular application. Sometimes analysis or experimental evidence demonstrating the adequacy of the design or the material, including weld metal, is required by regulatory agencies before final approval is granted.

The selection of a material may be influenced by the possible future necessity to make repairs in remote locations of the world. Shipboard plans should show where hull steels with unusual properties have been used. Recommended repair procedures and appropriate welding procedures should be included with the plans and drawings delivered with the ship.

**1.9 Weld Cracking.** Cracks can occur in many places in a weldment, can take on various forms and sizes, can be influenced by many factors, and can form at low and high temperatures. For example, cracks can occur at elevated temperatures in the weld metal or heat-affected zone (HAZ) several hours after welding. They can be a result of an incompatibility between the steel grade and the welding procedure or due to lack of control over an otherwise acceptable welding technique.

## Table 4
## Specifications for Filler Metals

| | |
|---|---|
| | **American Welding Society** |
| A5.1 | — Covered Carbon Steel Arc Welding Electrodes |
| A5.3 | — Aluminum and Aluminum Alloy Electrodes for Shielded Metal Arc Welding |
| A5.4 | — Covered Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Electrodes |
| A5.5 | — Low-Alloy Steel Covered Arc Welding Electrodes |
| A5.9 | — Corrosion-Resisting Chromium and Chromium-Nickel Steel Bare and Composite Metal Cored and Stranded Welding Electrodes and Welding Rods |
| A5.10 | — Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods |
| A5.17 | — Carbon Steel Electrodes and Fluxes for Submerged Arc Welding |
| A5.18 | — Carbon Steel Filler Metals for Gas Shielded Arc Welding |
| A5.20 | — Carbon Steel Electrodes for Flux Cored Arc Welding |
| A5.22 | — Flux-Cored Corrosion Resisting Chromium and Chromium-Nickel Steel Electrodes |
| A5.23 | — Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding |
| A5.25 | — Consumables Used for Electroslag Welding of Carbon and High Strength Low Alloy Steels |
| A5.26 | — Consumables Used for Electrogas Welding of Carbon and High Strength Low Alloy Steels |
| A5.28 | — Low Alloy Steel Filler Metals for Gas Shielded Arc Welding |
| A5.29 | — Low Alloy Steel Electrodes for Flux Cored Arc Welding |
| | **American Bureau of Shipping** |
| | "Approved Welding Electrodes, Wire Flux and Wire and Wire Gas Combinations" |
| Appendix A | — Requirements for the Approval of Filler Metals Sections |
| 1 | — General Requirements |
| 2 | — Electrodes for Manual Arc Welding |
| 3 | — Wire Flux Combinations for Submerged Arc Welding |
| 4 | — Wire and Wire Gas Combinations for Gas Metal Arc Welding |

For a few steel grades, cracks can also occur during subsequent stress-relief of the weldment. However, the predominant type of cracking is called *hydrogen-assisted cracking*. This type of cracking is also known by various other names, such as *underbead, cold*, or *delayed cracking*. Such cracks most frequently occur in the HAZ, but may also occur in the weld metal. HAZ cracks are usually longitudinal underbead cracks, and may be initiated by stress raisers at the toe or root of the weld. Hydrogen-assisted cracks in the weld metal may occur in either a transverse or longitudinal orientation to the weld axis. These weld metal cracks may manifest themselves not only as gross cracks that are revealed at the weld joint surface, but also as fine microcracks contained entirely within the interior of the weld metal. These fine cracks are most likely when the hydrogen content is not controlled to very low levels. The probability of hydrogen-assisted cracks can be reduced with higher preheat temperatures.

Hydrogen-assisted cracking is generally the result of hydrogen embrittlement combined with stresses or strains. The major factors responsible for hydrogen-assisted cracking are the presence of hydrogen, a susceptible microstructure, and tensile stresses acting on the weld. The prevention of hydrogen-assisted cracking in practice depends on the control of one or more of these factors.

During welding, hydrogen is always present. The source may be moisture in welding flux, shielding gas, electrode covering or base plate. It is absorbed by the welding pool and can diffuse into the HAZ. This movement of hydrogen can occur at either elevated temperatures immediately following welding or at lower temperatures as the part is cooling. Diffusion becomes more difficult at temperatures below 392°F (200°C), and the hydrogen will become entrapped in the HAZ and weld nugget. Potential cracking due to the residual hydrogen may not become apparent until several hours after the weld is completed.

The susceptibility of cracking, in general, increases with harder microstructures. Softer microstructures can tolerate more hydrogen and higher stresses without cracking. Cracking is most likely to occur when the microstructure contains some martensite.

One factor contributing to the cracking susceptibility of martensite is the high level of local transformation stresses present in the phase. The microstructure produced in a weldment depends on the weld cooling rate through the transformation range and the chemical composition and hardenability of the material. Stresses developed in the weldment other than those from the martensitic transformation are caused by thermal contraction of the weldment and restraint of the weld joint. These factors are in turn influenced by the strength of the base plate and weld metal, weld size, joint design, and external restraint.

The contribution of chemical composition to hardenability and microstructure can be described generally by empirical formulae called *carbon equivalents*. One such formula which predicts the total contribution of alloyed elements for steel with approximately 0.20% carbon and higher is the following:

$$C.\ E. = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \qquad \text{(Eq. 1)}$$

For steels with lower carbon contents, below about 0.17%C, the Pcm[3] equation has been found to be a better representation of the contribution of chemical composition:

$$Pcm = C + \frac{Mn}{20} + \frac{Si}{30} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B \qquad \text{(Eq. 2)}$$

Calculations of C.E. or Pcm values provide means for comparing the weldability of various steels.

Primary measures taken to avoid cracking are controlling the material's microstructure and the hydrogen content in the HAZ and weld metal. There are several common methods of preventing hydrogen-assisted cracking, such as the use of low-hydrogen welding techniques, higher heat inputs to produce softer microstructures, and preheating.

Preheating is an effective method of preventing possible cracking and has three principal effects:

(1) A less susceptible microstructure results from a slower cooling rate through the transformation temperature range, 1472–932°F (800–500°C).

(2) It provides a longer time at elevated temperatures so hydrogen has additional time to diffuse out of the weld metal and HAZ.

(3) Reduced shrinkage stresses in the weldment results, which is of particular importance in highly restrained joints.

One additional type of cracking, namely *lamellar tearing*, deserves mention. Lamellar tearing can result when welds are made in joints that produce high stresses in the through-thickness direction from contraction occurring during solidification and subsequent cooling of the weld, such as in corner or T-joints. Lamellar tearing occurs in the HAZ or in the base plate adjacent to the HAZ in highly restrained joints when the ductility in the through-thickness direction is insufficient to accommodate the developed stains. The tearing generally initiates at nonmetallic inclusions and propagates by linking small ductile shear fractures between inclusion particles into an expanded crack, taking on a characteristic step-like appearance.

There are several fabrication techniques to minimize lamellar tearing: for example, a change in joint design to reduce the through-thickness strains, "buttering" the joint surfaces prior to welding, use of lower strength electrodes, control of hydrogen content in the weld, or use of preheating and postheating. In addition, a very effective and reliable method for minimizing lamellar tearing is the use of special steels designed to minimize the harmful effect of inclusions.

Sulfide inclusions are generally the most detrimental type inclusions, but silicate and alumina inclusions can also influence susceptibility to lamellar tearing. Special steels generally possess good ductility (> 20% reduction of area) in the through-thickness direction and can accommodate the through-thickness strains required to prevent lamellar tearing. In recent years, the steel making practice of reducing sulfur content and performing steps to inhibit aggregation of remaining sulfides has greatly reduced susceptibility of welded steel plate to lamellar tearing. These requirements can often be added to steel plate orders as an option with only nominal increases in cost.

**1.10 Service Performance of Welds.** Welded steel structures perform reliably when proper fabrication techniques are employed. Most conventional construction grades are readily weldable and possess satisfactory mechanical properties for service when care is taken in selection of welding materials and procedures. Welded joints should have sufficient strength, ductility, and notch toughness for the intended application. However, it should be kept in mind that, as the strength level of steel is increased and service requirements become more severe, greater care must be taken in choosing the welding materials and procedures.

Since the weld metal and HAZ properties are microstructure-sensitive, the properties can change with welding procedure. Generally, although not always, strength and notch toughness are adversely affected by increasing welding heat (heat input and preheat). The effect of the welding heat becomes significant as the strength of the steel increases. Fortunately, for most normalized and as-rolled steels, welding consumables are available to provide published minimum properties over a common range of welding heat inputs. However, where specific mechanical properties are required, procedure plates should be welded and tested to ensure that suitable weld metal and HAZ properties will meet with the chosen welding materials and procedure. This is particularly important when low-temperature notch toughness requirements are specified. As the heat input is increased, the grain size becomes coarser, and the microstructure continuously changes across the weld, resulting in reduced notch toughness in the weld joint.

3. Pcm is the composition parameter. See ANSI/AWS D1.1-90, *Structural Welding Code-Steel*, Appendix XI.

The effect of welding heat on properties is particularly important in quenched-and-tempered steels. The higher the welding heat (heat input or preheat), the slower the weld cooling rate, and in turn, the lower the strength of the HAZ and weld metal. For a given joint thickness and preheat temperature, the welding heat input must not exceed a specific level to maintain a microstructure with suitable mechanical properties. If the preheat temperature is increased or the joint thickness decreased, then the heat input must be decreased to maintain the required microstructure. The maximum heat input for thicker plate is higher than for thinner plate, since the welding heat is dissipated faster for the thicker plate.

However, at the other end of the heat input spectrum (i.e., low heat input), typical of small, high-speed welds on relatively cool, thick plate, and typical of small tack welds or arc strikes, creates localized embrittlement of the heat-affected zones and the welds which can lead to cracking.

As the number of modern constructional-steel grades increases and as the mechanical property requirements for new steels become more severe, the success in fabricating welded structures depends more and more on design and effective use of expanding welding technology. Some practical welding suggestions are presented below for consideration, particularly when welded joints are subject to severe conditions:

(1) Avoid arc striking on the surface of the base plate. Always strike the arc in the groove or on the area to be welded.

(2) Tack welds are particularly prone to weld cracking. Preheating prior to tack welding is sometimes required, and the preheat temperature necessary to prevent cracking can be higher than for the normal weld. The tack welds should be a minimum of about 4 in. (100 mm) in length when possible, and care should be exercised to fill craters. The use of low-hydrogen electrodes is desirable.

The single most important precaution in preventing cracks in tack welds may be the utilization of low-strength electrodes to provide good weld metal ductility and low residual stresses in the weld joint. The use of low-strength electrodes should be restricted when the tack welds cannot be fully penetrated by the subsequent welding or removed by back gouging.

(3) Particular attention should be given to welding sequence to control unnecessary welding stress. For example, back-stepping techniques can be used sometimes to lower the risk of cracking. Also, by controlling the sequence of welding, excessive rotation of one workpiece relative to the other workpiece can be minimized, further reducing the tendency toward cracking.

(4) It is good practice to clean carbon-arc gouged grooves with a grinder prior to welding to remove high-carbon-content material.

(5) Hot bending or straightening of welded plate in quenched and tempered and control-rolled steels should be avoided, since the microstructure and the resulting plate strength may be altered.

(6) Stress raisers at the toe of fillet welds must be avoided by maintaining a smooth contour from the toe of the fillet weld to the base material. In groove welds, excessive weld reinforcement must be avoided.

(7) Notch extension cracking is defined as transverse weld metal cracking which may occur as a result of welding over back-up strip discontinuities or other notches. High-strength steels are particularly prone to this type of cracking. The cracking initiates at the notch or discontinuity and propagates up through the weld under the action of high welding stresses. Cracking will be most extensive at low-heat input. It should be emphasized that welding over discontinuities such as cracks is an undesirable practice that must be avoided, particularly when welding higher strength steels. Where backing bars are required, they should be made continuous.

(8) For higher strength steels and particularly quenched and tempered steels, excessive heat inputs should be avoided. For example, a stringer bead welding technique is preferable over a wide bead weaving technique.

(9) At the other extreme, care should be taken, particularly with higher strength steels, to prevent heat inputs from being so low that the weld metal ductility is reduced to where bend test requirements could not be met or cracking could occur.

In the traditional sense, fast cooling rates can lead to high- hardness microstructures that are susceptible to hydrogen-assisted cracking. Recent research from the Ukraine indicates that fast cooling rates can lead to microcracking which can serve as sites for initiation of hydrogen-assisted cracking. An article in *Automatic Welding*, No. 3, 1988, Paton Welding Institute, puts forth the following:

Increased cooling rates during the thermo-deformation welding cycle result in the intensification of plastic deformation during the phase transformation and pushes this process into a range of lower temperature (for some steel the reduction may be more than 100°C). The high speed of deformation at lower temperatures makes it difficult to accommodate microdeformation inside the grains. All relaxation takes place at austenite grain boundaries, and some boundaries collapse, becoming a spot from which cold cracks can start or are susceptible to starting.

(10) To prevent hydrogen-assisted cracking difficulties, the hydrogen content of the weld should be kept to a minimum. The following are common sources of hydrogen:

(a) Manual shielded metal-arc electrode coatings. Low and extra-low-hydrogen electrodes, as well as moisture-resistant electrodes, are available for manual welding of high-strength steels. These electrodes should always be properly stored and dried prior to welding. Low-hydrogen electrodes should not be exposed to the atmosphere for lengths of time longer than that suggested by the manufacturer.

(b) Moisture, oil, paint, or rust on the plate.

(c) Submerged-arc welding flux that has been improperly stored or dried.

(d) Certain flux-cored wire. Actual hydrogen content of the wire is strongly dependent on the manufacturing techniques.

(e) Moisture contamination in shielding gas.

**1.11 Welding of Higher Strength and Low-Temperature Service Steels.** Compared to welding ordinary strength steels, special precautions regarding electrodes, preheat, and interpass temperatures are necessary in welding higher strength steels. Low-hydrogen electrodes of matching strength should be used for all important members, and preheat should generally be used. Interpass temperature and heat input control may be required, depending on the type of steel.

When ordinary strength steels are welded to higher strength steels, it is advisable to use low-hydrogen electrodes, but it is not necessary to match the strength of the higher strength material. Under conditions of high restraint, it is preferable to use electrodes giving lower strength weld deposits. However, electrode moisture content restrictions suitable for the higher strength steel should be applied.

**1.11.1 Low-Temperature Service.** Ordinary or higher strength steels, intended for low-temperature service below 0°F (–18°C), are required to meet certain notch toughness requirements at 10°F (5.5°C) below the minimum expected service temperature. The weld metal and HAZ must meet the same notch toughness requirements. To meet these requirements, welding procedures using controlled rates of heat input are usually necessary. Consequently, a greater number of weld passes may be needed than for ordinary steel applications, and interpass temperature control may become important.

**1.11.2 Quenched and Tempered Low Alloy Steels.** The welding of quenched and tempered steels requires special welding procedures. Low-hydrogen electrodes are necessary. The base material heat-affected zone may experience some degradation, due to high welding heat inputs, and therefore, may exhibit both reduced notch toughness values and loss of strength. Submerged arc welding may be used on quenched and tempered steels, but only with carefully controlled heat input and after special procedure qualifications are met. It is most important to follow welding specifications and the steel manufacturer's recommendations as previously stated.

It is suggested that tempering passes be used in critical areas. The tempering passes are considered effective in reducing the tendency for cracking at the toe of finish passes (see Figure 4). Tempering passes are no longer required by the Navy for surface ships.

When joints are prepared by air carbon arc gouging, a dark discoloration may form on the joint surfaces if the process is improperly applied. This discoloration is a carbon deposit that should be removed by grinding the surfaces to bright metal.

**1.12 Welding of Clad Steel.** Structural tanks that carry certain chemicals are often made of clad steel to provide the required corrosion resistance. The cladding, such as stainless steel or nickel alloys, is very thin and is normally 1/16 to 1/8 in. (1.6 to 3 mm) thick. When clad steel is welded, great care must be taken to prevent contamina-

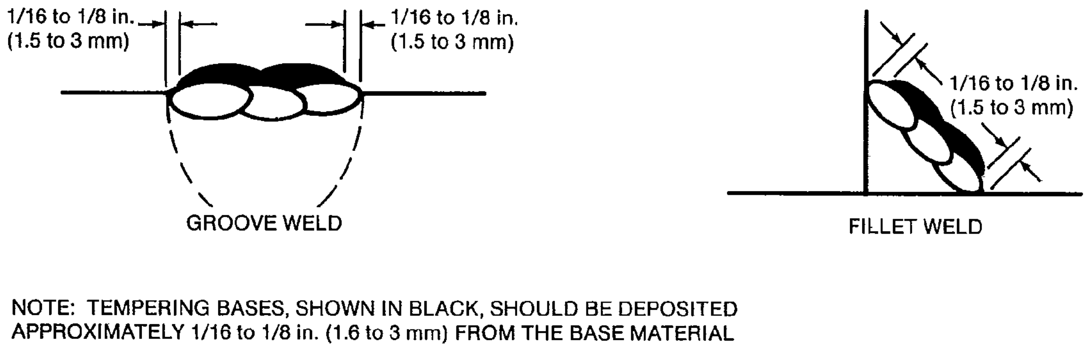



**Figure 4—Tempering Passes**

tion of the clad surface welds by iron pickup from the structural carbon steel backing.

Ordinary carbon-steel electrodes must never be used to weld to the cladding or to the clad weld metal. The steel backing is welded first with ordinary steel electrodes, and then the clad side is welded with the appropriate electrode for the cladding. A typical detail is shown in Figure 5. Generally, gas metal arc and submerged arc welding can be applied successfully for welding the clad side.

An alternate approach would be to weld the entire joint by using filler metal appropriate for the cladding. Undercutting should be avoided because it could destroy the effectiveness of the thin cladding.

It is often necessary to take samples of surface weld metal to ensure that the iron pickup is not above the maximum allowed. If there is excessive iron pickup, the surface welding must be removed, usually by grinding, and a new layer of clad weld metal deposited. Often multiple layers of weld are required to minimize dilution.

Extreme care in material handling, cutting, welding, and maintaining cleanliness is required in the fabrication of clad steel plates, but it is possible here only to mention that this fabrication calls for special overall planning.

**1.13 Explosion Bonded Transition Joints.** The problem of welded transition joints between aluminum and steel has been approached by the use of an explosion bonded aluminum to steel coupling. These transition joints are used extensively in joining aluminum deck houses to steel decks. Recently, improvement in the strength of the transition have been produced by inserting a strip of titanium between the aluminum and steel prior to explosion bonding.

## 2. Welding Processes

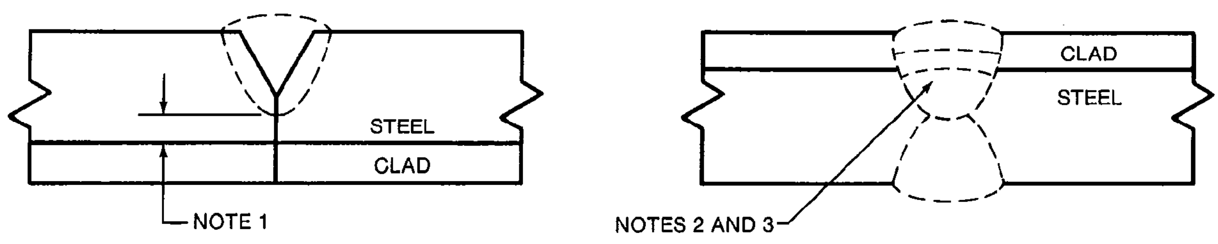
**2.1 Introduction.** Manual shielded metal arc, semiautomatic flux cored arc, and mechanized submerged arc welding are the major welding processes used in ship construction. However, other automatic and semiautomatic processes are being used successfully in specialized operations. Such processes include submerged arc, gas metal arc, flux cored arc, electroslag, and electrogas. Processes such as electroslag and electrogas enable heavy-section welds to be made in one pass. Special submerged arc welding techniques have been successfully applied in making one-side butt welds in long lengths. In the future, new processes such as electron beam welding and laser beam welding may find application in shipbuilding. Significant features of the processes currently employed in shipbuilding are outlined in this section.

Selection of the process and filler metal to be used depends on many factors: material to be welded, welding position limitations, joint accessibility, joint design, accuracy of edge preparation, prescribed procedures and sequencing of the work, suitability of welding equipment, and welder skill. To ensure welder skill, thorough training regarding the characteristics of the various types of electrodes, and the preferable welding techniques for each is essential. A process and filler metal should be selected so that the weld deposit will be compatible with the base metal and will have mechanical properties similar to those of the base metal. Generally, there are no prequalified procedures, and procedures usually may not be transferred from one shipyard to another.

Regulatory agency codes require Welding Procedure Qualification and Welding Performance Qualification prior to performing any production welding. These qualifications are normally required for each shipyard.

Table 5 indicates applicable ABS/AWS filler metal designations for different welding processes for the various ABS ordinary and higher strength hull structural steel base metal.

**2.2 Shielded Metal Arc Welding (SMAW).** Several grades of electrodes exhibit low ductility compared with other electrodes of the same strength level. These low




NOTES:
1. WELD BACKING STEEL WITHOUT PENETRATING THE CLADDING.
2. BACK GOUGE TO SOUND METAL.
3. WELD THE CLAD SIDE WITH MATCHING FILLER METAL USING MULTIPLE PASSES TO CONTROL DILUTION FROM THE STEEL.

**Figure 5—Typical Detail for Groove Welding Clad Plating**

## Table 5
## Applicable Filler Metal (ABS Grade and AWS Classification) — Base Plate Combinations

| Filler Metal Properties | Ordinary Strength | | | Higher Strength | | |
|---|---|---|---|---|---|---|
| Tensile strength (psi) (a) | 58,300–95,000 (402–655 MPa) | | | 71,000–95,000 (490–655 MPa) | | |
| Yield point, min (psi) | 44,100 (304 MPa) | | | 54,000 (372 MPa) | | |
| Elongation in (2 in.), min % | 22 | | | 20 | | |
| ABS filler metal grade | 1 (b) | 2 (b) | 3 (b) | 1Y (b) | 2Y (b) | 3Y (b) |
| Charpy V-impacts ft-lb @ °C | | | | | | |
| Manual and semiautomatic | 35 @ 20 | 35 @ 0 | 35 @ –20 | 20 @ 0 | 20 @ –20 | 20 @ –40 |
| Automatic | 25 @ 20 | 25 @ 0 | 25 @ –20 | 20 @ 10 | 20 @ –10 | 20 @ –30 |
| Equivalent AWS classification Covered electrodes (SMAW) | E6010, E6011, E6027, E7015, E7016, E7018, E7027, E7048 [E7028] | | | [E7015, E7016, E7028, E7018 E7048,] | | E8016-C3 E8018-C3 E7016-1, E7018-1 |
| Wire-flux (SAW) (c) | F6A2X, F7A2X [F6A0X] | F6A4X, F7A4X [F7A0X] | F6A6X F7A6X | F7A2X, F8A2X, [F7A0X,] | F7A4X, F8A4X, [F8A0] | F7A6X, F7A4X, F7A2X, F8A2X, F8A4X |
| Wire-gas (GMAW) | ER70S-2, ER70S-6, ER70S-7, [ER70S-3] | | | [ER70S-2, ER70S-3, ER70S-6, ER70S-7] | | ER80S-Ni1 |
| Flux-cored (FCAW) | E6XT-5, E6XT-6, E6XT-8, E7XT-6, E7XT-8, E7XT-5 [E6XT-1, E7XT-1] | | | [E7XT-1, E7XT-5, E7XT-6 E7XT-8] | | |
| Applicable ABS Base plate Material grades | A to 1/2 in. (12.5 mm) inclusive | A over 1/2 in. (2.5 mm) B, D, DS | CS, E | AH to 1/2 in. (12.5 mm) inclusive | AH over 1/2 in. (12.5 mm), DH | EH |

[shaded box] Suitable for grades 1, 2, or 1Y, 2Y as indicated.
Remainder Suitable for grades 1, 2, 3, or 1Y, 2Y, 3Y as indicated.
(a) (psi x 6.895) ÷ 1000 = MPa
(MPa x 1000) ÷ 6.895 = psi
(b) Ref: ABS publication: "Rules for Welding Electrodes, Wire Flux and Wire Gas Combinations."
(c) X represents electrode chemistry designation such as EL8, EM15K, etc.

ductility electrodes (E6012, E6013, E7014, E7024) are not approved for joints in main strength members such as strength decks, shell, and tank tops.

In gravity feed welding, electrodes having specially formulated high iron oxide and iron powder coatings are used to make fillet welds without manipulating the electrodes. The electrodes are approximately 25 to 30 in. (635 to 760 mm) long, and one welding operator can handle four to six electrodes simultaneously by using special electrode holders (see Figure 6). Because of space requirements for setting up the tripod holder, gravity welding in many closely confined areas may be accomplished with specially designed holders. These holders and electrodes generally must be imported into the United States.

To avoid contamination, damage, or undue moisture pick-up, electrodes must be stored in a clean, dry place. The various types of electrodes require different moisture content control. The E6010 and E6011 types require some moisture in the coatings for satisfactory operation and generally should not be redried after manufacture unless wet or exposed to extreme humidity for a considerable time. The redrying temperature should not exceed 150°F (66°C).

Low-hydrogen electrodes, however, must be dry. Most are supplied prebaked in hermetically sealed containers in which they should be stored until shortly before use. Those not supplied in hermetically sealed containers, or not prebaked, should be baked before use in accordance with

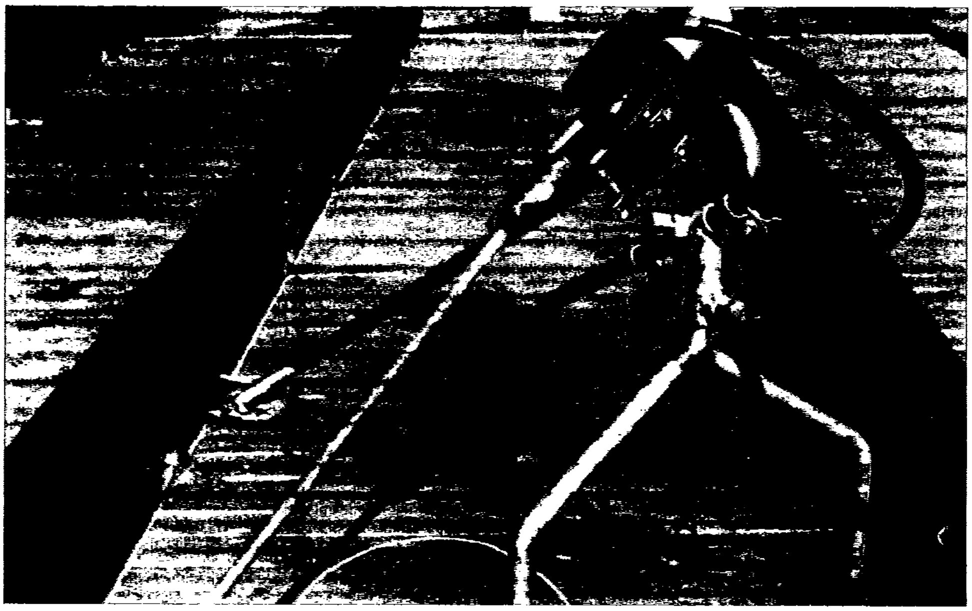


**Figure 6—One Type of Gravity Feed Welding**

the manufacturer's recommendations and the welding specifications covering the work. Once baked or removed from hermetically sealed containers, they should be placed in holding ovens at 150 to 300°F (65 to 150°C). Prolonged exposure to the atmosphere after removal from the welding ovens requires rebaking at 700 to 800°F (371 to 427°C). When higher strength steels and highly restrained ordinary strength steels are welded, it may be advantageous to rebake the electrodes to ensure that a low level of hydrogen is obtained. The electrode specifications and electrode manufacturers define the baking requirements with regard to time and temperature.

At ambient temperatures, the coatings of low-hydrogen electrodes pick up moisture from the air. Exposure time is usually limited to between 4 and 9 hours, depending on temperature and humidity conditions, type of electrode, and application. For more critical applications or for welding some of the higher strength steels, the maximum time could be much less than 4 hours, especially in humid weather. Portable ovens operating at approximately 250°F (120°C) should be used for such applications during inclement (higher humidity) weather conditions. Rebaking at temperatures as high as 800°F (427°C) is normally required when electrodes have been exposed to moist conditions beyond 9 hours. The exact procedure should be in accordance with the fabrication/welding specifications and manufacturer's instructions. Some manufacturers, however, offer low-hydrogen electrodes which are highly resistant to moisture, and some are offered at extremely low-moisture content. When these are used, special handling procedures should be developed by the user.

**2.3 Submerged Arc Welding (SAW).** The submerged arc welding process is widely used for welding butts and seams in flat plate assemblies (decks, bulkheads and flat sections of bottom and side shells) and for fillet welding in the flat or horizontal position. Horizontal groove welds can be accomplished with special equipment.

In shipboard welding, when the machine travel is in a downhill direction, the angle of decline should not exceed one degree in single-pass welding of a butt joint in plates 3/4 in. (19 mm) thick or greater and should not exceed three degrees in multiple-pass welding of groove or fillet welds. Many welds, however, are made in the uphill direction.

It is advisable that each yard adopt standard welding procedures and joint details for various plate thicknesses. Factors to be controlled are type and size of the electrode, moisture content of the flux, grade, and mesh of the flux, current, voltage, and travel speed. Welding personnel should know what deviation from the standard control data may be made to meet variations in root opening and other unusual conditions. Plate edge preparation and fit-up require more attention than in manual welding.

Tack welds should be only large enough to preclude their cracking. They should be short and closely spaced to hold the plates securely together. Cracked tack welds should be removed if they cannot be remelted and incorporated in the finished weld. Flux must be removed from the tack welds prior to submerged arc welding.

Temporary steel run-off tabs should be provided at both ends of the joint to be welded. The tabs should be securely welded to the plating to prevent them from spreading apart under the heat of welding. Grooves should be made in the run-off tabs to conform to the groove contour of the joint. Each pass should be started as near the outer edge of the run-off tab as possible so that welding conditions will be stabilized when the weld head reaches the weld joint. In some cases, the weld pass is stopped before the opposite end of the joint is reached. The machine is then moved out to start on the opposite run-off tab and run back along the weld joint to the point of previous stopping. In other cases, the welding is continued, without stopping, until it is run well out onto the run-off tab at the end of the joint.

A backstep type of sequence for welding together two plates minimizes distortion and chances of hot cracking at the finish end of the weld. The first 6 to 8 ft (2 to 2-1/2 m) of the seam is back stepped with the submerged arc machine. Then the weld is completed by welding from the opposite end onto the original start.

The most commonly employed equipment is mounted on a carriage which travels along a track positioned parallel to the weld joint. Although single-arc systems are most common, multiple-arc systems employing two or three electrodes are often used to increase deposition rates. In addition to multiple-arc systems, special methods such as hot wire and powdered metal additions (which require special procedure qualification by most code issuing bodies) have been employed to further increase the deposition rate.

When steels, particularly higher strength steels, are welded for low-temperature service, it is often necessary to employ a greater number of passes than normal to keep heat inputs low. This will help retain the weld metal and base-metal toughness.

One-side automatic submerged arc welding has been developed so that reliable welds can be made with minimal repair on the opposite side. One of many methods used for backing is illustrated in Figure 7. It must be capable of withstanding high-heat inputs and must contain the molten weld metal so that an acceptable bottom weld contour will be formed.

The copper bar holding the flux is usually grooved from 19/32 to 25/32 in. (15 to 20 mm) wide and 1/16 in. (1.6 mm) deep, and is held against the flux with air pressure or other means. The steel plates to be welded are held in place by mechanical means or by magnets.

Fillet welds can be made automatically where the members being joined are held rigidly in place, (see Figure 8).

The flux, if not stored in a hermetically sealed container, should be stored in a dry place to prevent moisture pickup. The flux, which provides a low-hydrogen-type shield during welding, may need to be baked and stored in a heated container before it is used if its moisture content becomes too high.

**2.4 Gas Metal Arc Welding (GMAW).** In the gas metal arc welding process, a continuous solid electrode is fed to the arc region with the arc shielded by gas. The operation may be automatic or semiautomatic. In the semiautomatic method, the wire and gas are fed to a hand-held arc welding gun through a flexible conduit and hose. Various gases are used for shielding, including argon, carbon dioxide, or mixtures of argon and carbon dioxide, oxygen, and helium.

The coiled wire should be stored in a dry place so that a clean, bright surface will be maintained on the wire.

Some of the advantages of gas metal arc welding, compared to the SMAW welding processes, are as follows:

(1) Concentration of arc heat limits distortion

(2) Deep penetration can be obtained

(3) Deposition rates and welding speed (for a given weld size) are higher

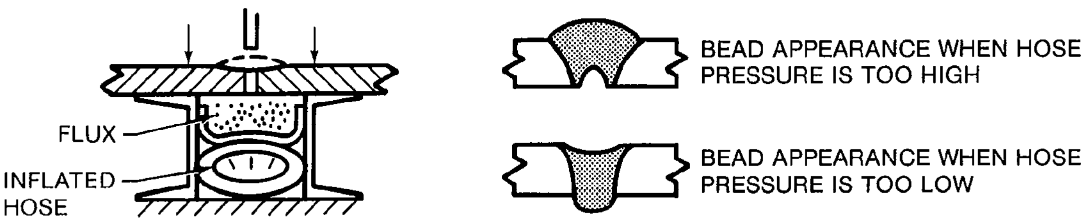
(4) Less skill is required for welders

Because of these features, the GMAW process is used for subassembly welding and for hull construction in unlimited thicknesses.

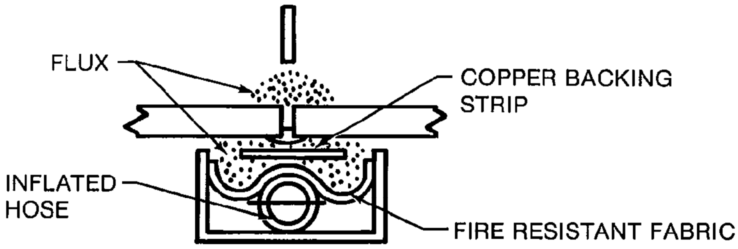
This arc welding process is used for welding aluminum, titanium, and other nonferrous metals as well as steel. It is also useful for welding low alloy steels with a yield point of 80 000 psi (550 MPa) or higher because of the very low level of hydrogen in the arc region and the excellent notch toughness of the finished welds.

The type of metal transfer across the welding arc depends on a combination of process parameters such as current, shielding atmosphere, voltage, and electrode extension. Variations of the gas metal arc welding (GMAW) process include pulsed gas metal arc welding (GMAW-P), short circuit gas metal arc welding (GMAW-S), arc spot welding, and electrogas welding (EGW). These variations and the basic process also encompass several modes of weld metal transfer, including axial spray transfer, globular transfer, and short circuiting transfer.

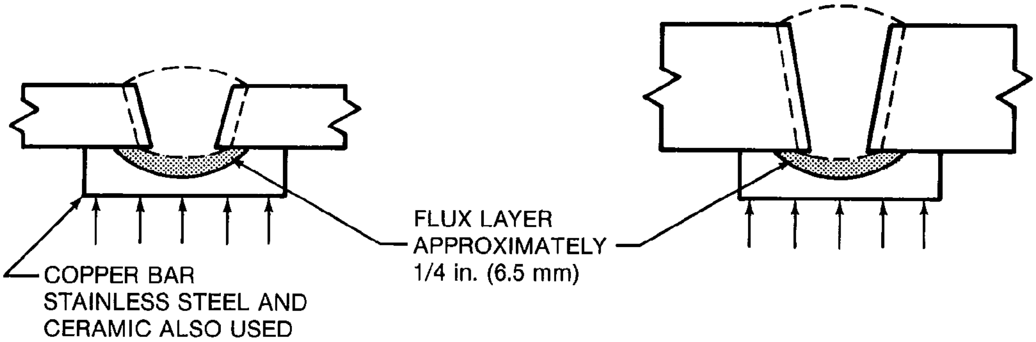
In short circuiting transfer, the electrode makes physical contact with the workpiece, creating an electrical short circuit. The molten end of the electrode is drawn into the workpiece by surface tension, without requiring high amperage and voltage. Variations in welding parameters can create excessive spatter and fusion defects. The reduced heat input enables the process to be used in welding thin metal and in welding positions other than flat and horizontal. Due to its relatively low penetration characteristics, this technique is generally not applicable to structural welding of thicknesses over 1/4 in. (6.3 mm). It should be noted that some codes do not permit the use of GMAW short arc welding. The low-heat input may lead




**(A) TYPICAL SCHEME FOR ONE SIDE SINGLE PASS WELDING OF PLATES UP TO 5/16 in. (8 mm) IN THICKNESS**




**(B) TYPICAL SCHEME FOR ONE SIDE WELDING OF PLATE THICKNESSES RANGE OF 5/16 to 5/8 in. (8-16 mm)**




**(C) TYPICAL JOINT DETAILS FOR ONE SIDE SUBMERGED ARC WELDING**

**Figure 7—Typical Joint Details and Backing Material Positioning for One-Side Submerged Arc Welding**

to lack of fusion type defects; therefore, it must be carefully controlled.

The spray transfer variation, usually shielded with a minimum of 80% argon, transfers metal across the arc in the form of axially directed small droplets. The spray variation offers the greatest operator appeal, weld quality, and metal deposition efficiency. Penetration is deeper than that obtained with the SMAW process, but less than can be obtained with the globular transfer mode of GMAW, with carbon dioxide shielding. The spray mode is characterized by high-current density which makes spray transfer possible.

In the pulsed arc variation, the power source provides two current levels: a steady background level, too low to produce any metal transfer, and a pulsed peak current metal transfer that can be regulated independently of heat input by pulse parameter adjustment (level, shape, and frequency). This variation of GMAW may be used for applications where higher heat inputs cannot be tolerated. Strict adherence to appropriate established welding parameters is very important in order to prevent incomplete fusion defects in the heavier thicknesses, but it is not as critical as with short circuiting arc GMAW. Pulsed arc can be used for all position welding, and its use is particularly advantageous when joining thin plates of steel, aluminum, and copper alloys. Since its heat input is similar to that of short-arc but with less tendency towards defects, and since there is very little spatter, pulsed gas metal arc welding (GMAW-P) is quickly gaining favor.

In globular metal transfer, usually shielded with carbon dioxide, the molten metal at the end of the electrode, when transferred across the arc to the molten weld pool, forms

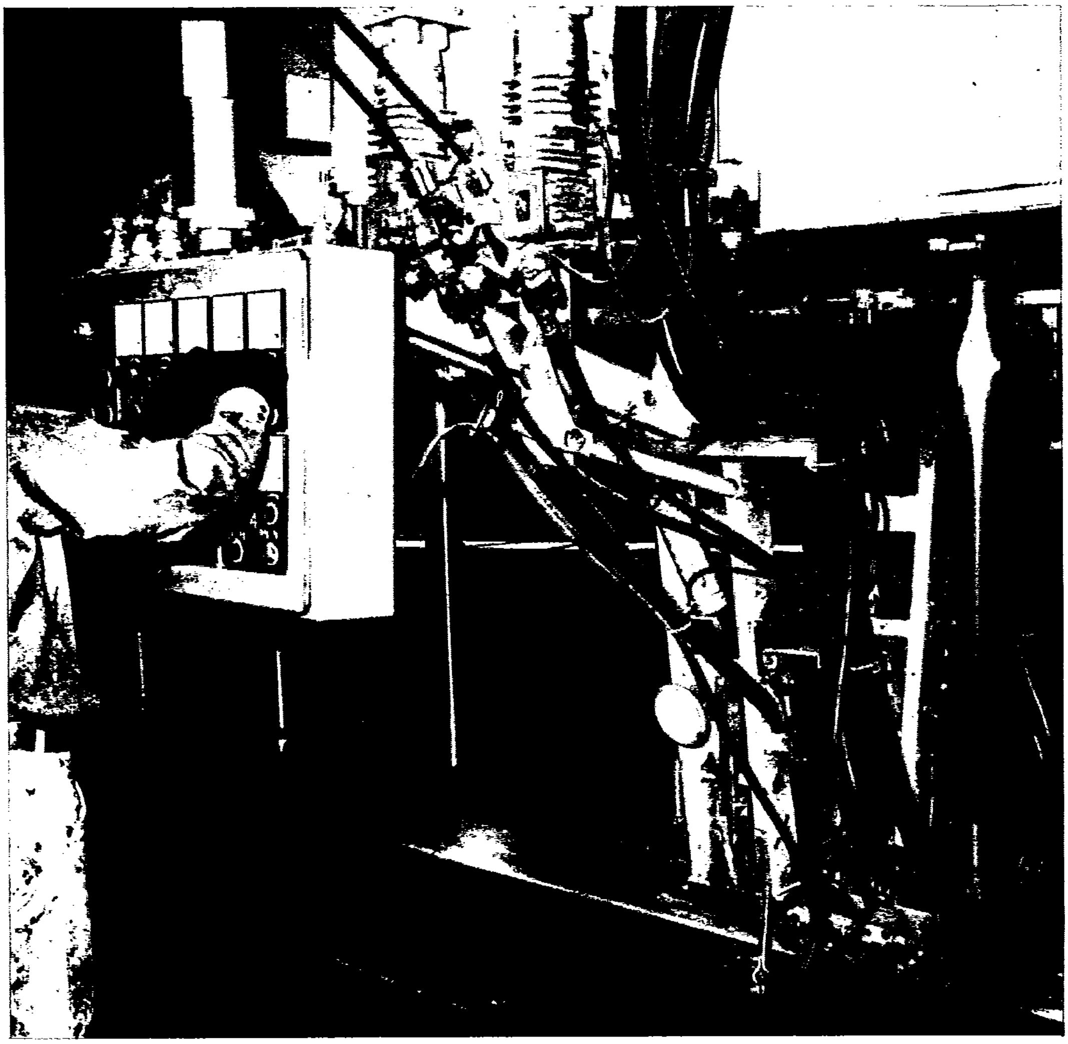


**Figure 8—Automatic Fillet Welding of Stiffeners to Plate Panel—Welds are Being Made Simultaneously on Both Sides of Stiffener**

comparatively large irregular globules, resulting in a rough bead appearance (ripple effect) and spatter. The weld bead profile exhibits extremely deep penetration.

AWS classifications of GMAW carbon and low alloy electrodes are listed in Table 6. The information shown in Table 6 is extracted from AWS A5.28-79, *Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding* and AWS A5.18-79, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding.*

Some shipyards are making use of tractor systems for mechanization of GMAW-P and FCAW in all positions. Hull and deck plating is particularly suited to this.

**2.5 Flux Cored Arc Welding (FCAW).** The flux cored arc welding process is similar to the gas metal arc process except that the wire has a core containing flux or alloying additions, or both. Shielding gas is required for some electrodes to operate correctly. However, the flux does change both the arc action and metallurgical reactions in the weld pool, making them similar to the action and reactions of conventional covered electrodes. These changes make this process more tolerant to surface contaminants and weather than the gas metal arc process, and thus more adaptable to outdoor shipyard welding. Vertical and overhead welds can be made with certain gases and types of wire.

The fluxes vary and are selected to suit metallurgical requirements and operations with or without gas shielding. Generally, gas shielding is beneficial from the point of view of notch toughness and minimizing defects. Powdered metal alloys may also be added to produce deposits with increased strength, toughness, or hardness.

## Table 6
## Carbon and Low Alloy Steel Solid or Composite Electrodes and Rods

| AWS Classification | Weld Metal Composition[a, b] | | | | | | | | | | | | | Minimum Charpy V-notch Impact Properties[c] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | P | S | Ni | Cr | Mo | V | Cu | Ti | Zr | Al | ft-lb | °F | J | °C |
| ER70S-2 | 0.07 | 0.90–1.40 | 0.40–0.70 | 0.025 | 0.035 | — | — | — | — | 0.50 | 0.05–0.15 | 0.02–0.12 | 0.05–0.15 | 20 | –20 | 27 | –29 |
| ER70S-3 | 0.06–0.15 | 0.90–1.40 | 0.45–0.70 | 0.025 | 0.035 | — | — | — | — | 0.50 | — | — | — | 20 | –0 | 27 | –18 |
| ER70S-6 | 0.07–0.15 | 1.40–1.85 | 0.80–1.15 | 0.025 | 0.035 | — | — | — | — | 0.50 | — | — | — | 20 | –20 | 27 | –29 |
| ER70S-7 | 0.07–0.15 | 1.50–2.00 | 0.50–0.80 | 0.025 | 0.035 | — | — | — | — | 0.50 | — | — | — | 20 | –20 | 27 | –29 |
| ER80S-Ni1 | 0.12 | 1.25 | 0.40–0.80 | 0.025 | 0.025 | 0.80–0.10 | 0.15 | 0.35 | 0.05 | 0.35 | — | — | — | 20 | –50 | 27 | –46 |
| ER80S-Ni2[d] | 0.12 | 1.25 | 0.40–0.80 | 0.025 | 0.025 | 2.00–2.75 | — | — | — | 0.35 | — | — | — | 20 | –80 | 27 | –62 |
| ER80S-Ni3[d] | 0.12 | 1.25 | 0.40–0.80 | 0.025 | 0.025 | 3.00–3.75 | — | — | — | 0.35 | — | — | — | 20 | –100 | 27 | –73 |
| E80C-Ni1 | 0.12 | 1.25 | 0.60 | 0.025 | 0.035 | 0.80–1.10 | — | 0.65 | 0.05 | 0.35 | — | — | — | 20 | –50 | 27 | –46 |
| E80C-Ni2[d] | 0.12 | 1.25 | 0.60 | 0.025 | 0.030 | 2.00–2.75 | — | — | — | 0.35 | — | — | — | 20 | –80 | 27 | –62 |
| E80C-Ni3[d] | 0.12 | 1.25 | 0.60 | 0.025 | 0.030 | 3.00–3.75 | — | — | — | 0.35 | — | — | — | 20 | –100 | 27 | –73 |
| ER80S-D2 | 0.07–0.12 | 1.60–2.10 | 0.50–0.80 | 0.025 | 0.025 | 0.15 | — | 0.40–0.60 | — | 0.50 | — | — | — | 20 | –20 | 27 | –29 |
| ER100S-1 | 0.08 | 1.25–1.80 | 0.20–0.60 | 0.010 | 0.010 | 1.40–2.10 | 0.30 | 0.25–0.55 | 0.05 | 0.25 | 0.10 | 0.10 | 0.10 | 50 | –60 | 68 | –51 |
| ER100S-2 | 0.12 | 1.25–1.80 | 0.20–0.60 | 0.010 | 0.010 | 0.80–1.25 | 0.30 | 0.20–0.55 | 0.05 | 0.35–0.65 | 0.10 | 0.10 | 0.10 | 50 | –60 | 68 | –51 |
| ER110S–1 | 0.09 | 1.40–1.80 | 0.20–0.55 | 0.010 | 0.010 | 1.90–2.60 | 0.50 | 0.25–0.55 | 0.04 | 0.25 | 0.10 | 0.10 | 0.10 | 50 | –60 | 68 | –51 |
| ER120S-1 | 0.10 | 1.40–1.80 | 0.25–0.60 | 0.010 | 0.010 | 2.00–2.80 | 0.60 | 0.30–0.65 | 0.03 | 0.25 | 0.10 | 0.10 | 0.10 | 50 | –60 | 68 | –51 |

Notes:

a. Chemical composition of solid electrodes is based on as-manufactured composition. Chemical requirements for composite electrodes are based on undiluted weld metal in the as-welded condition deposited using shielding gases specified in Table 4 of A5.28.

b. Single values are maximum.

c. As-welded condition.

d. Postweld heat treated in accordance with Table 12 of A5.28.

(Refer to AWS A5.18, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*, and AWS A5.28, *Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding*.)

A new generation of small diameter rutile type (AWS A5.20, T-1) gas shielded flux cored wires offers the most competitive challenge to SMAW electrodes. These wires retain all position welding characteristics with low-temperature toughness properties, and low weld-metal hydrogen levels. For welding carbon-manganese steels in plate with thicknesses up to 1 in. (25 mm), these small diameter rutile wires provide a joint completion rate at least 50% higher than solid wire GMAW processes and 100% higher than an SMAW process. This same wire offers cost savings of 20–25% over GMAW processes and 17–50% over SMAW processes.

Flux cored electrodes (wires) of plain carbon steel are covered in AWS A5.20, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*. The chemical compositions and mechanical properties of weld deposits made with some flux cored electrodes are listed in Table 7.

Flux cored electrodes (wires) with consistently high quality are available with alloys added to meet the strength and toughness requirements for welding the higher strength steels. However, the hydrogen content of these electrodes is quite variable. Some manufacturers supply electrodes with a hydrogen content low enough to prevent cracking in higher strength steels, but the user must be careful to select proper types and suitable brands. These electrodes are in AWS A5.29, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*.

Basic slag type (AWS A5.20, T-5) flux cored electrodes are available which provide low-hydrogen content in weld metal, and permit the welding of higher strength steels. However, these electrodes do not perform well in all positions.

The E7XT1 type, a general purpose electrode for making single-or multiple-pass welds, is somewhat more sensitive to surface contaminants than E7XT2 which is intended for single-pass welding.

The E7XT5 type produces welds with the best notch toughness of any of the plain carbon steel cored electrodes. However, because it has less operational appeal than E7XT1 or E7XT2 electrodes, it is not generally used unless maximum notch toughness is required.

The E7XT8 type can be manufactured as a carbon steel electrode or a low alloy steel electrode for flux cored arc welding. These electrodes are designed for all position welds with good impact qualities. The low alloy steel electrodes provide excellent impact values and are especially applicable when CTOD (crack tip opening displacement) testing is a requirement of the project specifications.

**2.6 Electroslag Welding (ESW) and Electrogas Welding (EGW).** Electroslag and electrogas welding are mechanized processes for fusion welding metals in the vertical position. These processes are most suitable for the joining of plates over 1-1/2 in. (40 mm) thick, but may be used for plating as thin as approximately 3/4 in. (19 mm) thick.

Although the use of electroslag and electrogas welding in the fabrication of ship hulls has been limited, these processes have been used to weld vertical shell joints. The vertical joint in the sheerstrake and bilge may be welded by the electroslag process only if the requirements for toughness in the weld and heat-affected zone, as well as other mechanical properties, can be met.

**2.6.1** In electroslag welding, the current runs from the welding electrode through the molten slag to the melt. The wire is fed into the groove that forms a continuous casting between the two base metals (see Figure 9). Water-cooled copper sliding shoes are positioned on each side of the groove to contain the molten metal, and move continuously upward as the molten metal solidifies at the bottom.

In electrogas welding, flux cored or solid wire electrode is fed into an arc generally shielded by $CO_2$ or other gases, or it may be self-shielded depending on the type of base metal. The operation is similar to the electroslag process except that the weld pool is shielded by gas instead of a flux (see Figure 9). See ANSI/AWS A5.25 and A5.26 for electroslag and electrogas filler metal requirements.

**2.6.2 Consumable Guide Tube Method.** Short lengths of vertical welds can be made by a variation of the electroslag process with a fixed dam or shoe used around the groove (see Figure 10). The dam is usually made of heavy copper, and is water cooled. A consumable guide tube, placed into the groove, guides the wire into the groove. The guide tube is coated with flux to insulate the steel tube from the side walls and to supply needed flux as welding progresses. A small amount of iron powder and flux may be added before the weld is started. This method is used for making relatively short groove welds in the vertical webs of longitudinal framing.

When applying the consumable guide tube to a long vertical butt, several tubes are fastened together end to end. In this case, the copper shoes are generally moved upward in a leap frog fashion as indicated in Figure 10 or a single, long, stationary shoe may be provided.

**2.7 Stud Welding.** Two types of stud welding guns are available: arc and capacitor discharge. The capacitor discharge gun is particularly suited for welding small diameter fasteners, because the weld time is so short, 1 to 6 milliseconds, and no ferrule or fluxing is required.

In the arc system, studs require a flux on the arcing end for deoxidizing and arc stabilization. The fluxing agent is permanently affixed to the end of the stud. Ceramic ferrules are also placed around the ends to concentrate the heat, to reduce oxidation, and to confine the molten metal.

Stud welding requires thoroughly trained personnel who are familiar with the machine settings needed for each size of stud, position of welding, and variable job

## Table 7
## Carbon and Low Alloy Steel Flux Cored Electrodes (Wires)

| AWS Classification[a] | External Shielding Gas | Chemical Composition of Weld Deposit[b] | | | | | | | | | | Charpy V-notch Impact Strength | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C | Mn | Si | P | S | Cr | Ni | Mo | V | Al | ft-lb | °F | J | °C |
| E70T1 | $CO_2$ | (c) | 1.75 | 0.90 | 0.04 | 0.03 | 0.20 | 0.50 | 0.30 | 0.08 | — | 20 | 0 | 27 | –18 |
| E70T5 | $CO_2$ | (c) | 1.75 | 0.90 | 0.04 | 0.03 | 0.20 | 0.50 | 0.30 | 0.08 | — | 20 | –20 | 27 | –30 |
| E70T6 | None | (c) | 1.75 | 0.90 | 0.04 | 0.03 | 0.20 | 0.50 | 0.30 | 0.08 | 1.8 | 20 | –20 | 27 | –30 |
| E70T8 | None | (c) | 1.75 | 0.90 | 0.04 | 0.03 | 0.20 | 0.50 | 0.30 | 0.08 | 1.8 | 20 | –20 | 27 | –30 |
| E71T8-Ni1 | None | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | 0.15 | 0.80–1.10 | 0.35 | 0.05 | 1.8 | 20 | –20 | 27 | –30 |
| E80T1-Ni1 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | 0.15 | 0.80–1.10 | 0.35 | 0.05 | — | 20 | –20 | 27 | –30 |
| E81T1-Ni1 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | 0.15 | 0.80–1.10 | 0.35 | 0.05 | — | 20 | –20 | 27 | –30 |
| E80T5-Ni1 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | 0.15 | 0.80–1.10 | 0.35 | 0.05 | — | 20[d] | –60 | 27[d] | –51 |
| E71T8-Ni2 | None | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | — | 1.75–2.75 | — | — | 1.8 | 20 | –20 | 27 | –30 |
| E80T1-Ni2 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | — | 1.75–2.75 | — | — | — | 20 | –40 | 27 | –40 |
| E81T1-Ni2 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | — | 1.75–2.75 | — | — | — | 20 | –40 | 27 | –40 |
| E80T5-Ni2 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | — | 1.75–2.75 | — | — | — | 20[d] | –75 | 27[d] | –60 |
| E90T1-Ni2 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | — | 1.75–2.75 | — | — | — | 20 | –40 | 27 | –40 |
| E91T1-Ni2 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | — | 1.75–2.75 | — | — | — | 20 | –40 | 27 | –40 |
| E80T5-Ni3 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | — | 2.75–3.75 | — | — | — | 20[d] | –100 | 27[d] | –73 |
| E90T5-Ni3 | $CO_2$ | 0.12 | 1.50 | 0.80 | 0.03 | 0.03 | — | 2.75–3.75 | — | — | — | 20[d] | –100 | 27[d] | –73 |
| E91T1-D1 | $CO_2$ | 0.12 | 1.25–2.00 | 0.80 | 0.03 | 0.03 | — | — | 0.25–0.55 | — | — | 20 | –40 | 27 | –40 |
| E90T5-D2 | $CO_2$ | 0.15 | 1.65–2.25 | 0.80 | 0.03 | 0.03 | — | — | 0.25–0.55 | — | — | 20[d] | –60 | 27[d] | –51 |
| E100T5-D2 | $CO_2$ | 0.15 | 1.65–2.25 | 0.80 | 0.03 | 0.03 | — | — | 0.25–0.55 | — | — | 20[d] | –40 | 27[d] | –40 |
| E90T1-D3 | $CO_2$ | 0.12 | 1.00–1.75 | 0.80 | 0.03 | 0.03 | — | — | 0.40–0.65 | — | — | 20 | –20 | 27 | –30 |
| E80T5-K1 | $CO_2$ | 0.15 | 0.80–1.40 | 0.80 | 0.03 | 0.03 | 0.15 | 0.80–1.10 | 0.20–0.65 | 0.05 | — | 20 | –40 | 27 | –40 |
| E70T4-K2 | None | 0.15 | 0.50–1.75 | 0.80 | 0.03 | 0.03 | 0.15 | 1.00–2.00 | 0.35 | 0.05 | 1.8 | 20 | 0 | 27 | –18 |
| E71T8-K2 | None | 0.15 | 0.50–1.75 | 0.80 | 0.03 | 0.03 | 0.15 | 1.00–2.00 | 0.35 | 0.05 | 1.8 | 20 | –20 | 27 | –30 |
| E80T1-K2 | $CO_2$ | 0.15 | 0.50–1.75 | 0.80 | 0.03 | 0.03 | 0.15 | 1.00–2.00 | 0.35 | 0.05 | — | 20 | –20 | 27 | –30 |
| E90T1-K2 | $CO_2$ | 0.15 | 0.50–1.75 | 0.80 | 0.03 | 0.03 | 0.15 | 1.00–2.00 | 0.35 | 0.05 | — | 20 | 0 | 27 | –18 |
| E91T1-K2 | $CO_2$ | 0.15 | 0.50–1.75 | 0.80 | 0.03 | 0.03 | 0.15 | 1.00–2.00 | 0.35 | 0.05 | — | 20 | 0 | 27 | –18 |
| E80T5-K2 | $CO_2$ | 0.15 | 0.50–1.75 | 0.80 | 0.03 | 0.03 | 0.15 | 1.00–2.00 | 0.35 | 0.05 | — | 20 | –20 | 27 | –30 |
| E90T5-K2 | $CO_2$ | 0.15 | 0.50–1.75 | 0.80 | 0.03 | 0.03 | 0.15 | 1.00–2.00 | 0.35 | 0.05 | — | 20 | –60 | 27 | –51 |
| E100T1-K3 | $CO_2$ | 0.15 | 0.75–2.25 | 0.80 | 0.03 | 0.03 | 0.15 | 1.25–2.60 | 0.25–0.65 | 0.05 | — | 20 | 0 | 27 | –18 |
| E110T1-K3 | $CO_2$ | 0.15 | 0.75–2.25 | 0.80 | 0.03 | 0.03 | 0.15 | 1.25–2.60 | 0.25–0.65 | 0.05 | — | 20 | 0 | 27 | –18 |
| E100T5-K3 | $CO_2$ | 0.15 | 0.75–2.25 | 0.80 | 0.03 | 0.03 | 0.15 | 1.25–2.60 | 0.25–0.65 | 0.05 | — | 20 | –60 | 27 | –51 |
| E110T5-K3 | $CO_2$ | 0.15 | 0.75–2.25 | 0.80 | 0.03 | 0.03 | 0.15 | 1.25–2.60 | 0.25–0.65 | 0.05 | — | 20 | –60 | 27 | –51 |
| E110T5-K4 | $CO_2$ | 0.15 | 0.20–2.25 | 0.80 | 0.03 | 0.03 | 0.20–0.60 | 1.75–2.60 | 0.30–0.65 | 0.05 | — | 20 | –60 | 27 | –51 |
| E111T1-K4 | $CO_2$ | 0.15 | 1.20–2.25 | 0.80 | 0.03 | 0.03 | 0.20–0.60 | 1.75–2.60 | 0.30–0.65 | 0.05 | — | 20 | –60 | 27 | –51 |
| E120T5-K4 | $CO_2$ | 0.15 | 1.20–2.25 | 0.80 | 0.03 | 0.03 | 0.20–0.60 | 1.75–2.60 | 0.30–0.65 | 0.05 | — | 20 | –60 | 27 | –51 |
| E61T8-K6 | None | 0.15 | 0.50–1.50 | 0.80 | 0.03 | 0.03 | 0.15 | 0.40–1.10 | 0.15 | 0.05 | 1.8 | 20 | –20 | 27 | –30 |
| E71T8-K8 | None | 0.15 | 0.50–1.50 | 0.80 | 0.03 | 0.03 | 0.15 | 0.40–1.10 | 0.15 | 0.05 | 1.8 | 20 | –20 | 27 | –30 |
| E101T1-K7 | $CO_2$ | 0.15 | 1.00–1.75 | 0.80 | 0.03 | 0.03 | — | 2.00–2.75 | — | — | — | 20 | –60 | 27 | –51 |

Notes:

a. Unless manufacturer recommends otherwise, all ele5ctrodes operate with dcep, except the EXXT8-X electrodes which operate on dcen.

b. Single values are maximum.

c. Carbon content to be determined and reported.

d. Test plate given post weld heat treatment in accordance with paragraph 3.6 of AWS A5.20, *Specification for Low Alloy Steel Electrodes[1] for Flux Cored Arc Welding*. All other specimens were tested in the "as-welded" condition.

(Refer to AWS A5.20 and AWS A5.29, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*.)

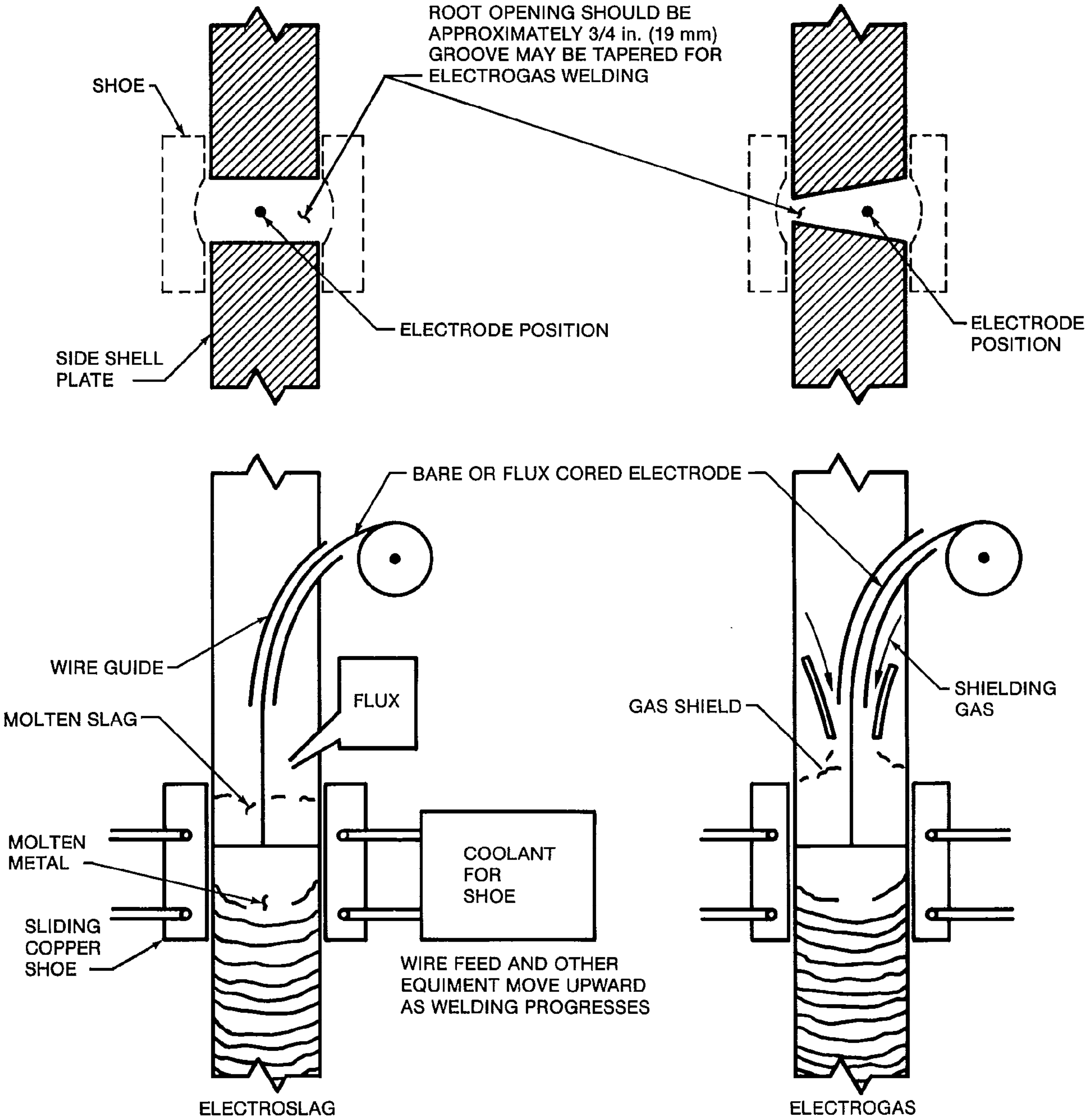



**Figure 9—Vertical Electroslag and Electrogas Welding**

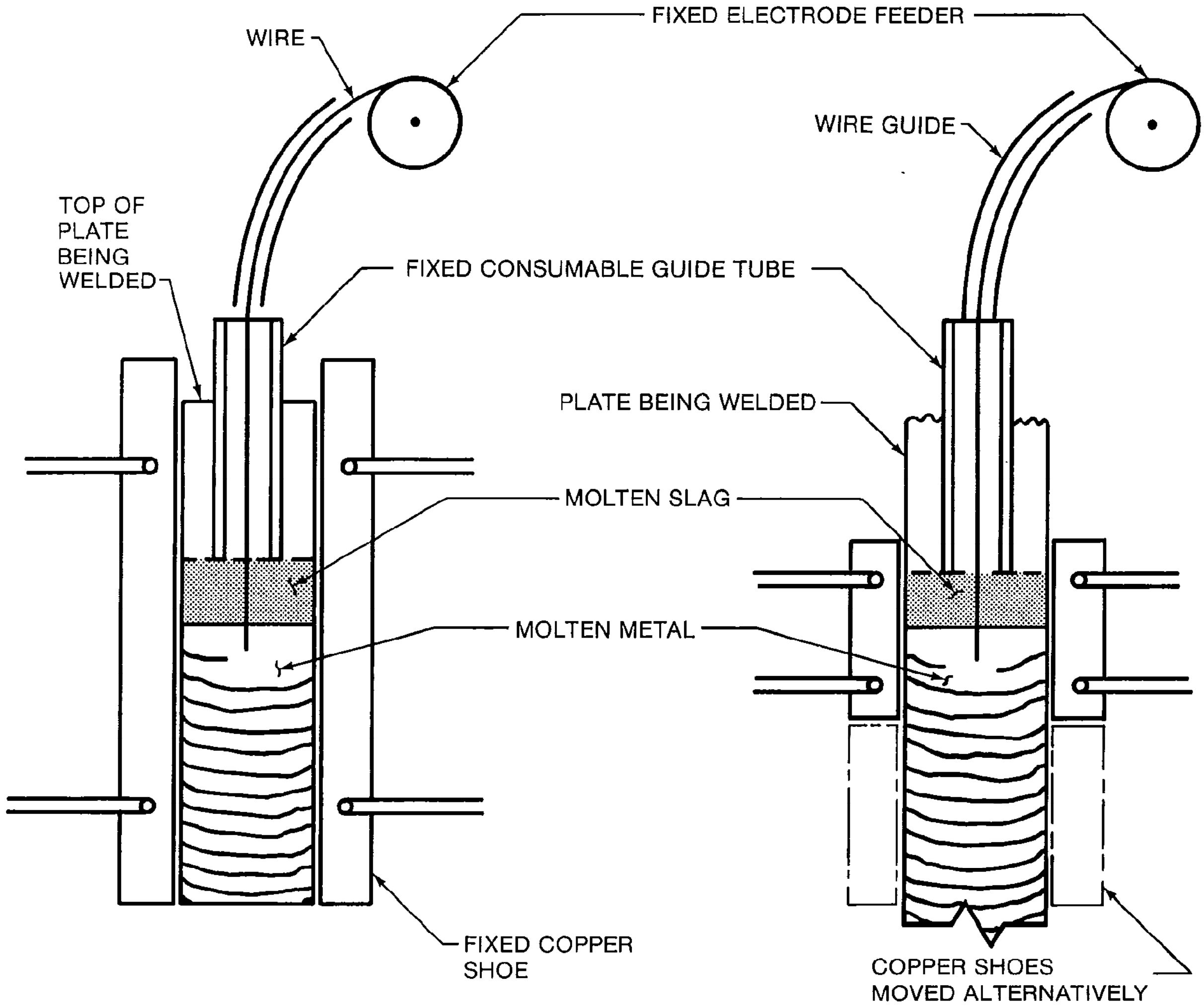



**Figure 10—Consumable Guide Tube Welding**

conditions. The operating procedures must be based on trials to determine the required voltage, amperage and timer setting.

Best results will be obtained when a jig is used to locate the studs properly and to ensure that the studs are applied exactly perpendicular to the surfaces to which they will be attached. The area where the stud is to be welded should be cleaned to bare, bright, dry steel. For large size studs, adherence to the proper settings is essential.

It is desirable that at the start of each job, and periodically during production welding, sample stud welds be made on scrap plate and tested by hammering the studs over until they lie practically flat on the plate. This check will show whether proper welding conditions are being maintained. Other types of tests, such as partial bend or torque tests using special equipment, are sometimes specified.

**2.8 Thermit Welding.** Although now seldom used, thermit welding has been employed for joining heavy sections of stern frames, rudder post forgings, and castings.

A chemical reaction produces both heat for welding and the weld metal. A mixture of aluminum and iron oxide is ignited out of contact with the air. While a crucible holds the mixture in place, the molten metal runs into the mold surrounding the joint. Risers are provided to clear the slag from the mold. An important part of the procedure is to thoroughly preheat the steel parts to be joined.

**2.9 Removable Backing Materials for Welding.** Many of the flat, horizontal, and vertical joints in plate which are not welded by the submerged arc process are welded with flux cored or pulsed arc processes against a flexible ceramic-tape backing to avoid second-side gouging and welding. Various types of removable backing materials for welding from one or both sides have been developed for making groove- and fillet-type weld joints. These backings are available in different types of materials of various sizes and shapes.

The backing material may be held in place by pressure-sensitive tape, magnets, or any device that will hold the backing material against the weld joint. Since these materials are nonconductors, the joint fit-up and welding conditions should be such that the welding arc can be maintained at the leading edge of the weld pool.

In the flat position, some welding procedures use metal powders in the joint to maintain the arc on poor fit-up and to accomplish a one-side, one-pass weld on materials to about 3/8 in. (9.5 mm) thick. For multiple-pass welding, manual or semiautomatic welding is used for root passes, and then, when possible, fill passes are made with mechanized processes. Some of the weld joints and backing types are shown in Figure 11.

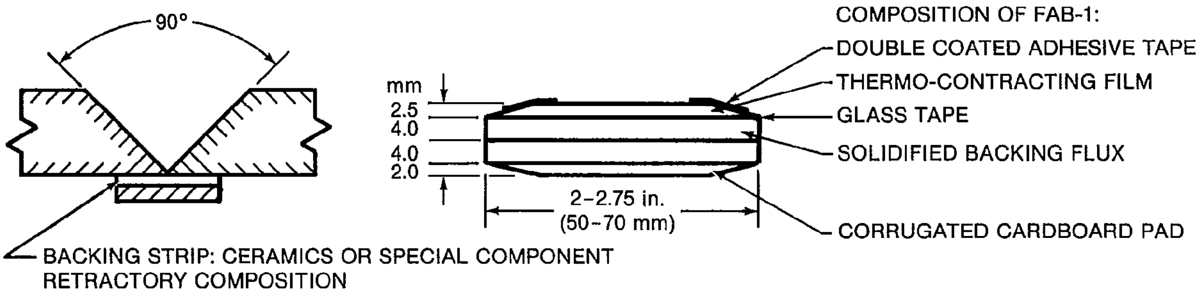
# 3. Design

**3.1 Introduction.** This chapter highlights the importance of design details rather than to recommend any particular detail. Details will be considered primarily from the point of view of resistance to brittle failure, and it is reasonable to say that details showing good resistance to brittle failure will also show good resistance to fatigue failure.

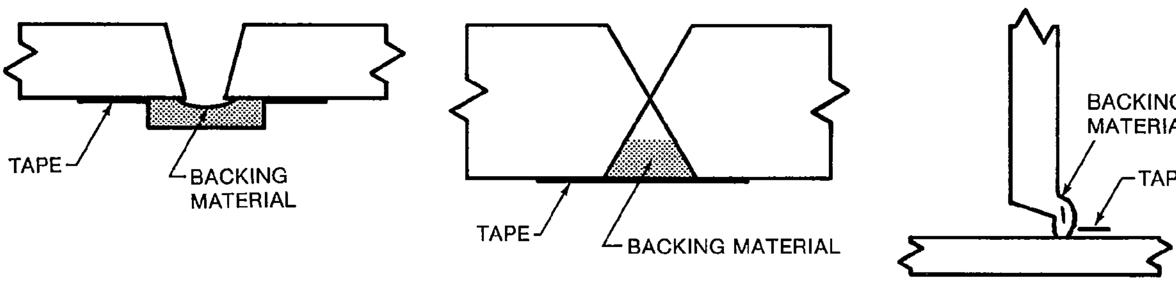
Since there is no easy way to determine the stress mechanism at notches and stress concentrations, the designer must rely on experience and research to determine the type of structural detail that will give satisfactory service performance.

Although the development of structural details is primarily the responsibility of the designer, the fabricator should cooperate in working out suitable welding details and fabricating procedures.

**3.2 Main Strength Members.** Main strength members, such as deck, shell, and longitudinal girders, resist the bending moments experienced by the ship as a whole. These bending moments, caused by the action of waves and by the distribution of cargo, fuel, and ballast, are maximum near midships. The most highly stressed areas of the hull girder are the upper deck and bottom shell within the midship half-length (see Figure 12). In these areas, efforts should be especially concentrated to avoid questionable design details and defects in workmanship.




(A) TYPICAL SCHEME FOR ONE SIDE WELDING OF PLATES OF UNLIMITED THICKNESSES




(B) BACKING MATERIAL AND TAPE

**Figure 11—Typical Joint Details for One-Side Welding**

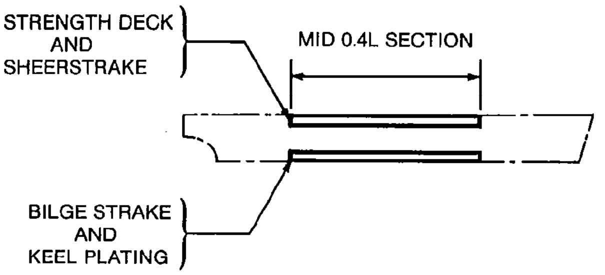



**Figure 12—Most Highly Stressed Areas of Hull Girder**

**3.3 Secondary Strength Members.** A secondary member may be attached to a main strength member in a critical, highly stressed area. Some examples are bilge keels, bulwarks, deckhouses, hatch coamings and foundations for rigging and mooring fittings. When a long, secondary member, such as a bilge keel or bulwark, is attached to the main hull, that member will be stressed just as severely as the main hull. Therefore, the details of these members must be developed and inspected with the same care as the details of the main hull.

Whenever possible, it is wise to keep the top of the sheerstrake clear of welded attachments, including temporary attachments, such as hangers for welding boxes, etc., which hang over the side during construction. If this practice is not feasible, the attachment should be carefully faired into the sheerstrake.

Although internal decks, bulkheads and web frames may be called secondary structures, they often experience "nuisance" cracks which can prove serious to a ship owner. Thus, even in secondary structures, both structural and welding details must be carefully engineered.

**3.4 Design Details.** In section 1, it was pointed out that transition temperature is influenced by several factors: geometry, type of steel, stress level, and rate of loading. The role which design details can play is discussed in the following paragraphs.

**3.4.1 Notches.** Apart from the characteristics of the material and temperature, the most important factor influencing brittle behavior is the notch effect. The influence of notches is clearly illustrated in Figure 13 which compares the tensile and transition temperature characteristics of an unnotched plate with those of a mildly and a sharply notched plate. Figure 13 shows the loss of ductility for each specimen as the temperature is lowered. Note that the transition temperature curves in Figure 13 are similar in shape to the transition temperature curve in Figure 2B.

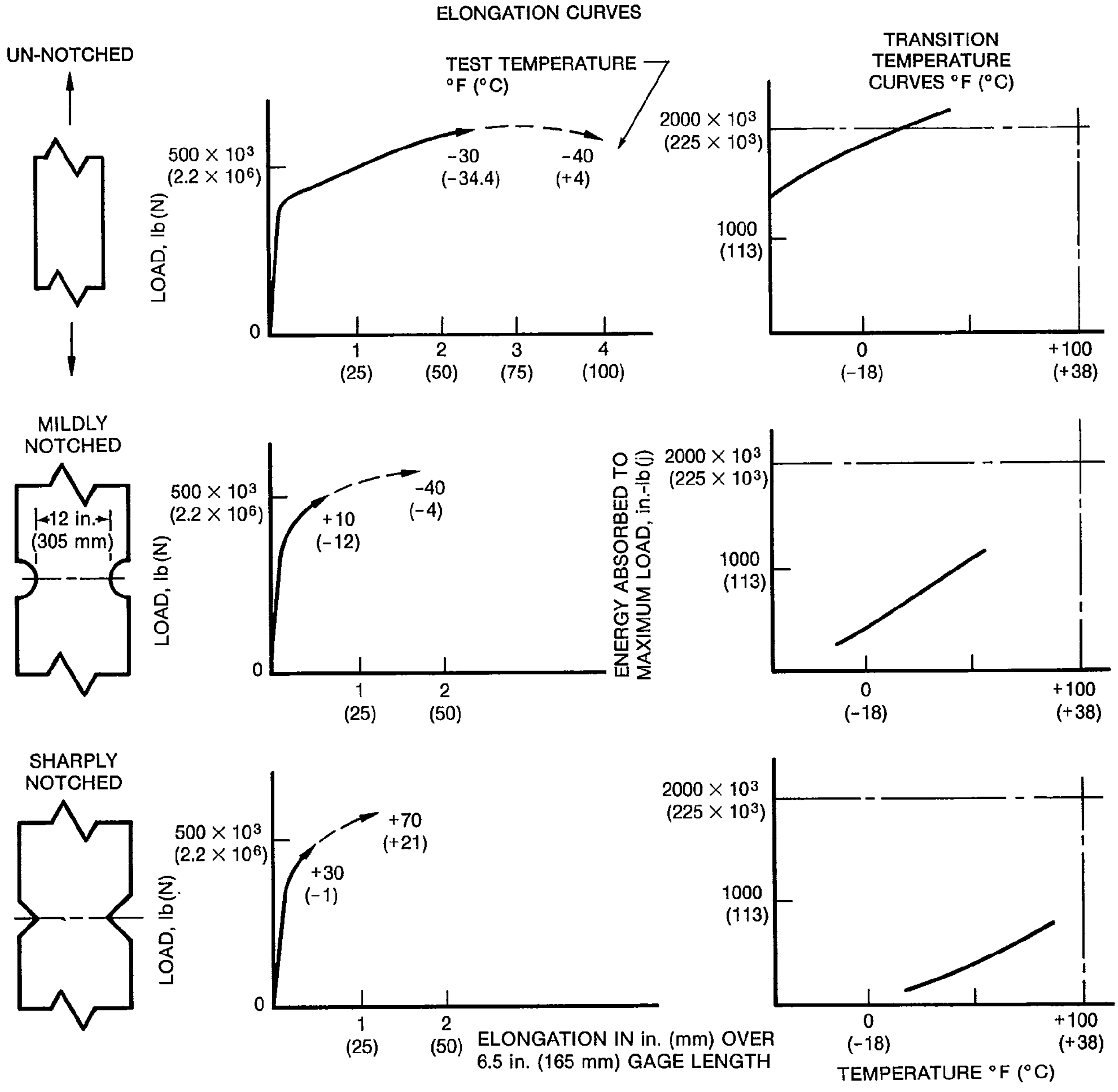
**3.4.2 Structural Discontinuities.** As used here, *structural discontinuity* means any abrupt change in the general contour of the structure other than a sharp notch or crack. These discontinuities (also called *stress raisers*) increase the stress level of the adjacent area well above the average stress level. The stress intensity at the edge of a circular opening, for example, is approximately three times the average intensity. It is particularly dangerous, therefore, to have sharp notches or defects in areas having abnormally high stress levels. It is important to eliminate, wherever practicable, such design details as groove welds, small insert plates, and drain holes in the vicinity of larger structural discontinuities. Special control over workmanship is recommended in these areas.

Two examples of troublesome places where notches were superimposed on stress raisers are the square ending of a fashion plate which was welded to the top of the sheerstrake, Figure 14, and the original World War II Liberty Ship hatch corner, Figure 15. To avoid making a difficult welded connection, such as the ones shown in Figure 14, many bulwarks are not welded directly to the sheerstrake but are supported independently from deck brackets.

In addition to the square corner, Figure 15 shows a small, thick doubler which would add considerable constraint without actually strengthening the joint. Also, because of the design of the corner, it was practically impossible to make a good fit and a sound weld at the corner joints. Naturally, this design created many problems. Figure 16 shows an improved, trouble-free hatch corner design used on the World War II Victory Ships, which followed the Liberty Ships.

In locating openings, such as hatches, access and ventilation openings, and piping, it is important to avoid having holes or openings close together in line across the deck or shell. The breaks in the upper strength decks of the liners Majestic and Leviathan occurred at places where several large openings were directly in line across the deck. It is equally important to avoid placing staggered openings too close together so that each opening tends to augment the stress concentration caused by the others. Because of the increase in stress level around openings, considerable effort is made to round corners and, if necessary, to reinforce openings.

**3.4.3 Radius Corners and Reinforcement of Openings.** Regardless of the type of reinforcement used at openings, a generous radius should be provided. For large hatch openings, it is suggested that the corner radius be approximately 1/24th the hatch width, with a minimum radius of 12 in. (300 mm). In the case of container ships, the corner radius must be as small as possible so that the lost space around the containers at each end of the hold be minimized. A typical corner detail is shown in Figure 17. In some cases, a higher grade of steel may be required at the hatch corners.




NOTE: CURVES DERIVED FROM DATA IN SHIP STRUCTURE COMMITTEE REPORT SSC-51, PRE-WORLD WAR II TYPE OF STEEL.

**Figure 13—Load-Elongation and Transition Temperature Curves for Specimens With Oxygen-Cut Edges**

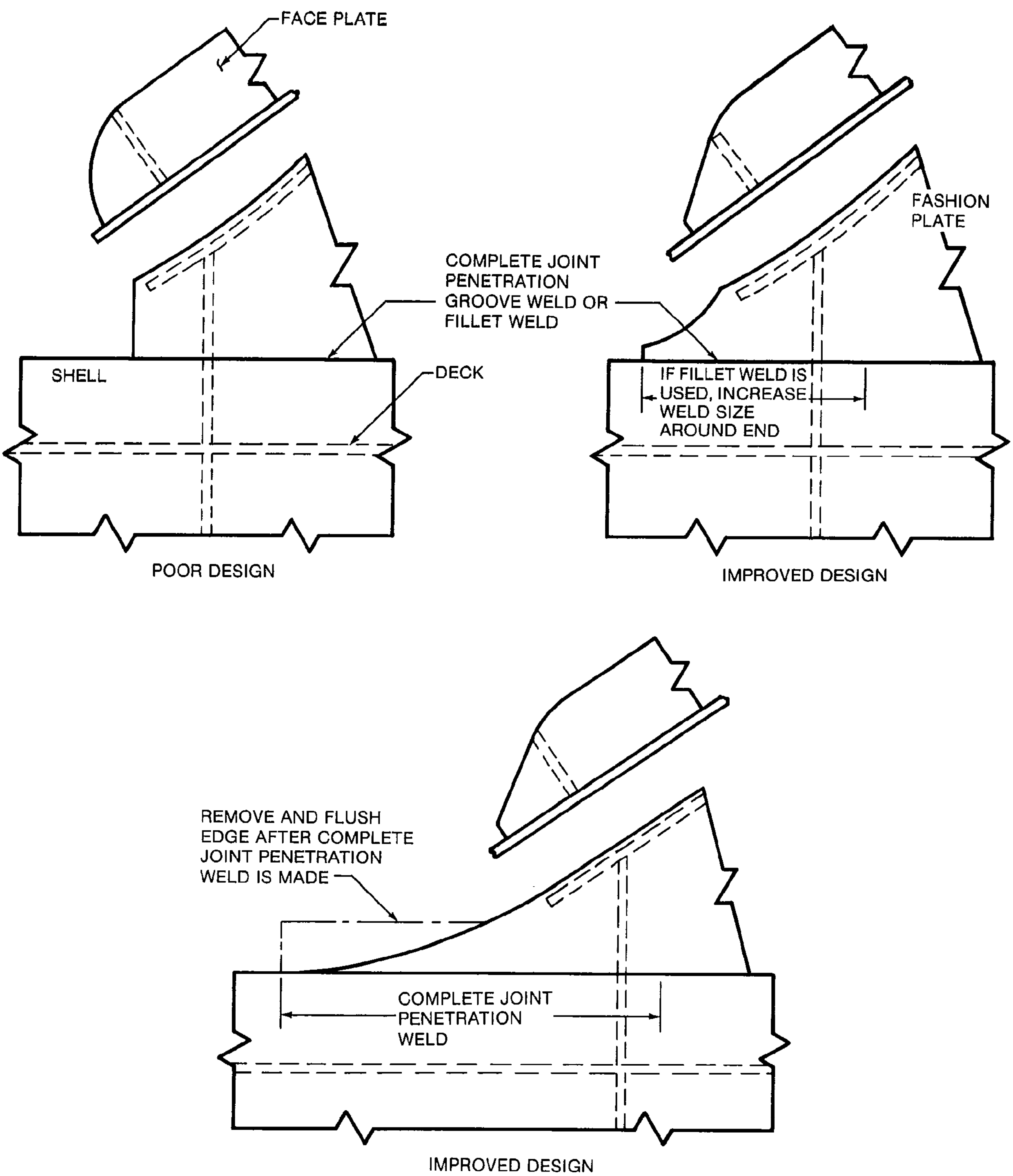



**Figure 14—Ending of Bulwark Fashion Plate Welded to Top of Sheerstrake**

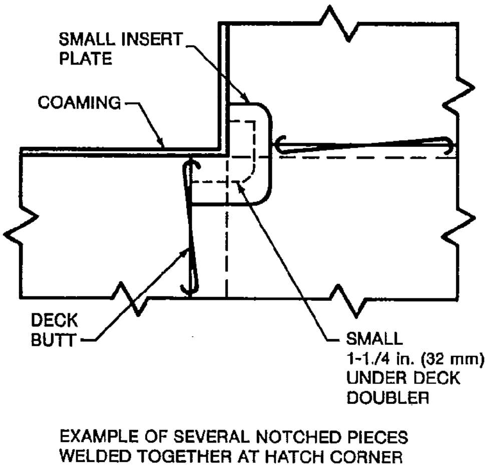



**Figure 15—Original Design of Hatch Corner on Liberty Ship**

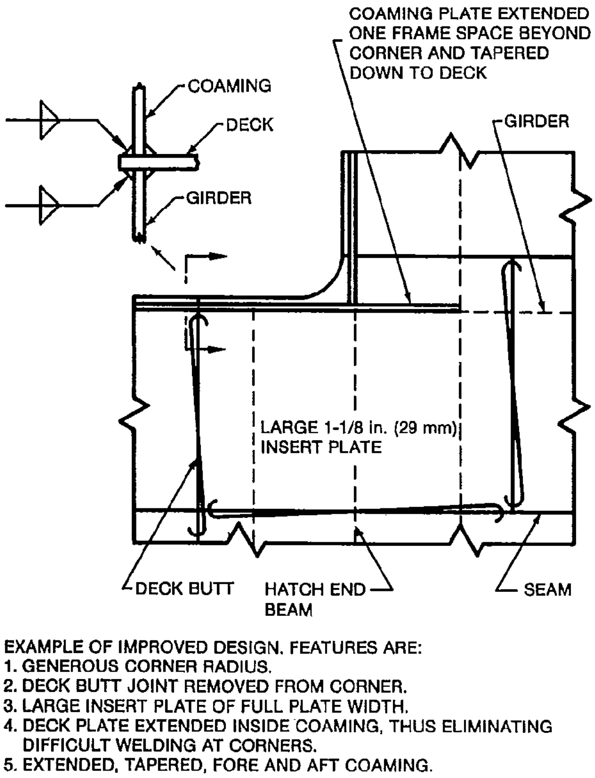



**Figure 16—Design of Hatch Corner on Victory Ship**

Because of a more favorable stress flow pattern, elliptical rather than radial cuts are being used more frequently for hatch corners, large drain holes, etc. (see Figure 18).

For small openings around trunks, stairways, etc., a radius of 6 in. (150 mm) is generally used. Well rounded cuts, in superstructure or deckhouse sides, for windows and doors also are essential, particularly near the ends of long superstructures. Avoidance of sharp irregularities in cutting these corners is of equal importance.

A common reinforcement at the corner of a large opening is a large insert plate. The best method of incorporating the insert is to include it as part of the deck or shell plating. Small insert pieces are not recommended. Figures 15 and 16 are examples of bad and good hatch corner reinforcement, respectively. Doubler plates are not used unless excessively thick plates would otherwise be required.

Where an opening up to approximately 10 ft (3 m) wide must be reinforced by a coaming plate or insert plate, or both, it is usually unnecessary for the reinforcement to compensate for more than 40 to 50% of the opening. In some cases, excessive reinforcement could be harmful.

**3.4.4 High Restraint.** The welding of small, thick insert plates has been a source of much trouble because of restraint against weld shrinkage. The principal danger here is the cracking of the welds during welding. Therefore, the use of small inserts for reinforcement of openings should be discouraged. Section 4 under Welding Sequence explains special welding precautions which are necessary when insert pieces or patch plates cannot be avoided.

A different form of restraint and discontinuity occurs when a rigid member terminates abruptly in the middle of a plate panel which is inherently flexible. The plate panel, restrained from its natural flexing at the point (hard spot) where the rigid support terminates, produces a point of high stress concentration (see Figure 19).

The flexing of a plate panel at a hard spot will often cause the immediate plate surface to be stressed beyond the yield point. When this stress occurs in a corrosive medium (salt water, for example), the cyclic flexing action will cause spalling of the surface scale or rust. This spalling causes local, accelerated corrosion because it continually exposes fresh steel surfaces.

Another place where cracking of this type has been reported is at the intersection of two planes (for instance, a longitudinal bulkhead and deck) where a primary stress is transferred from one plane to the other as indicated in Figure 20. To remedy this situation, long connecting brackets should be installed in each plane to provide a transition area for reasonably smooth stress flow.

**3.5 Details for Manual Welding.** In most cases, decisions regarding arrangement, location, and details of joints must be made in the design stage. However, the

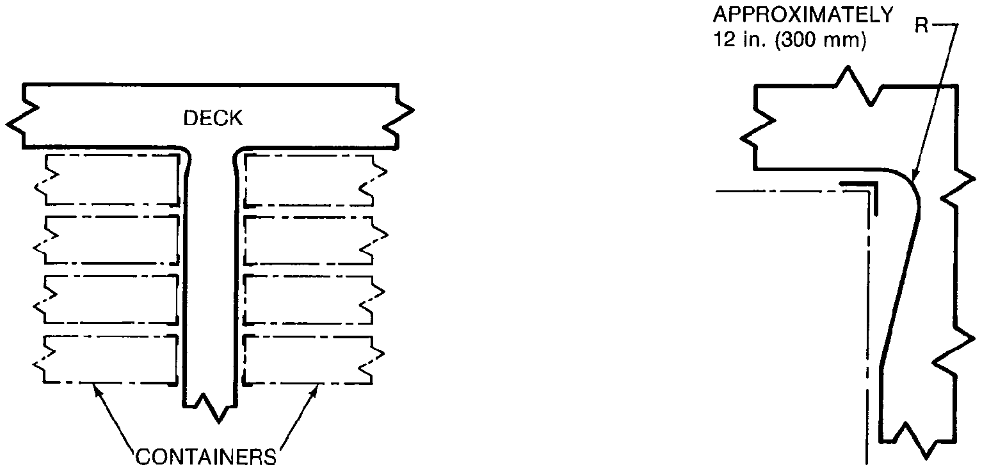
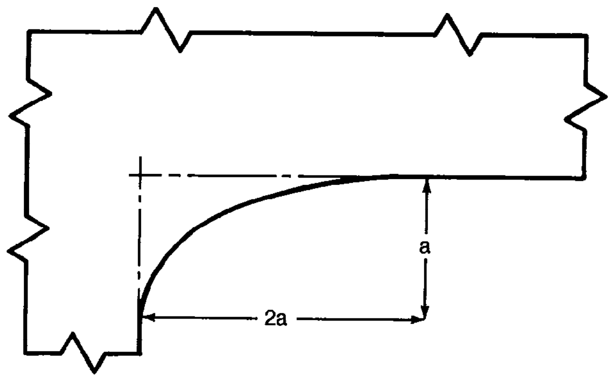



Figure 17—Typical Hatch Corner in Way of Container Guides on Container Ship




"a" EQUALS APPROXIMATELY 12 in. (300mm)
MINIMUM FOR LARGE HATCHES

Figure 18—Typical Elliptical Hatch Corner

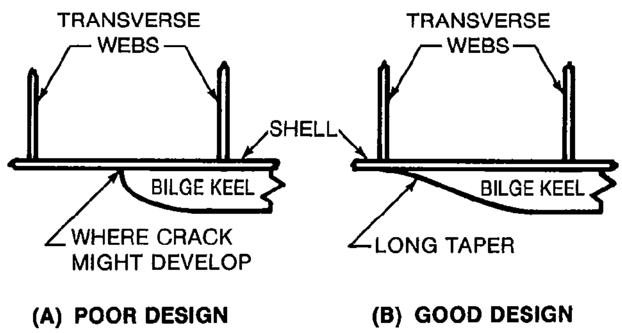



Figure 19—Bilge Keel Endings

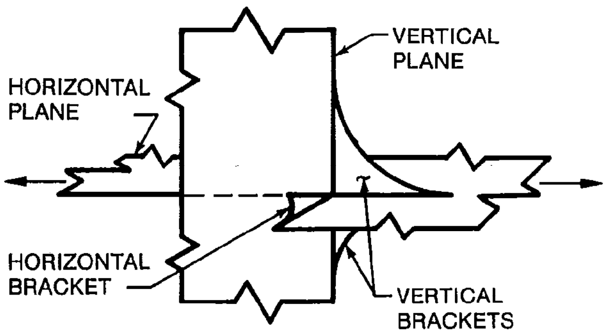



**Figure 20—Stress Concentration at Intersecting Planes Eased by Brackets**

designer must account for the actual position in which a specific joint will be when it is welded, and what process will be used to make the weld before these joint details are developed. Otherwise a change later on could be costly. The following are essential to provide good weld quality:

(1) Provide for reasonable ease of joint preparation and back chipping or gouging of roots where required

(2) Provide for reasonable ease of the welding operation so that the welder can properly position and manipulate the electrodes and can clean the intermediate passes

### 3.5.1 Groove Welds Made From One Side Only

**3.5.1.1 One-Side Welding With Permanent Backing.** Welds made from one side against a permanent backing may be used in the construction of rudders, bilge keels, welded joints in way of riveted seams, and stern frames. However, they should be minimized and reserved primarily for welds where the backside is inaccessible unless continuous fillets can be made to seal the crevice between the backing and the structure. The selection of root opening and included angles will depend primarily on the welding process employed and the thickness of the plates being welded. The root opening must be large enough so that complete joint penetration can take place at the root.

Unless the joint groove is backed by the main structure, a backing bar must be provided. Splices in permanent backing should be welded with complete joint penetration welds prior to making the primary weld. Where a landing bar is being fit for a bilge keel, special care must be exercised in making the complete joint penetration weld in the landing bar splice so that the splice to the shell plate is not welded. The root opening generally should not be less than 3/16 in. (5 mm) as indicated in Figure 21. Square grooves may be used to join thin plate, 1/4 in. (6 mm) thick and less, with root openings not less than the thickness of the material.

To minimize weld shrinkage and its effect on distortion, and for best economy, the groove weld detail should require the least amount of weld metal necessary for making a sound weld joint.

Where a groove angle less than 60 degrees is desired, as in thick plate, the root opening should be increased so that the electrode may be positioned properly. The groove angle may be reduced to approximately 20 degrees when the root opening is increased. For example, in a 2 in. (51 mm) plate, a 20 degree groove angle is usually satisfactory if the root opening is 1/2 in. (12.5 mm), see Figure 21. Due to deeper penetration of SAW, GMAW and FCAW processes, groove angles used for joints with these processes can be reduced in comparison to SMAW.

Where a groove weld crosses a flat member, such as a plate lap or coaming plate, that portion of the weld in the overlap area must be made from one side only. There are two methods of preparing the groove in the overlap area. One method is to prepare the entire groove as a single-V and later remove sufficient material from the plate edges in the overlap area so that complete fusion to the underlying plate can be accomplished. This method is satisfactory for thin plates (see Figure 22, Method 1). The second method, for thick plates, is to prepare the joint for a double-V-groove weld in the main portion of the butt joint and a single-V-groove weld in the lap joint area (see Figure 22, Method 2). The transition from double- to single-V groove weld should be gradual.

**3.5.1.2 One-Side Welding Without Permanent Backing Bars.** Several United States shipyards routinely weld plates up to 3/4 in. (19 mm) thick using a series submerged arc procedure with multiple arcs in tandem. The series arc was found to be needed in order to achieve large root-pass deposition rates, easy removal of flux and good control of back-side weld contour. Elimination of the need to flip plates over for additional grinding and welding has proved to be a useful productivity advancement. A flux covered copper backing bar is used to support the back side of the weld with this process.

**3.5.2 Transition from Welding to Riveting in a Seam.** Although rivets in new ship construction are essentially nonexistent, riveted connections are often encountered when repairs or alterations are made to older ships. In such cases, the transition from welding to riveting in a seam must be carefully planned so that a sharp notch will not be left at the end of the weld. One method of eliminating the notch at a flush seam weld is to drill and ream a hole in sound weld metal a short distance back from the end of the weld (see Figure 23). Near a lap seam weld, the usual practice is to terminate the riveting as shown in Figure 24.

**3.5.3 Groove Welds in Shapes.** Groove weld details of bulb angles, heavy rolled sections, and built-up shapes

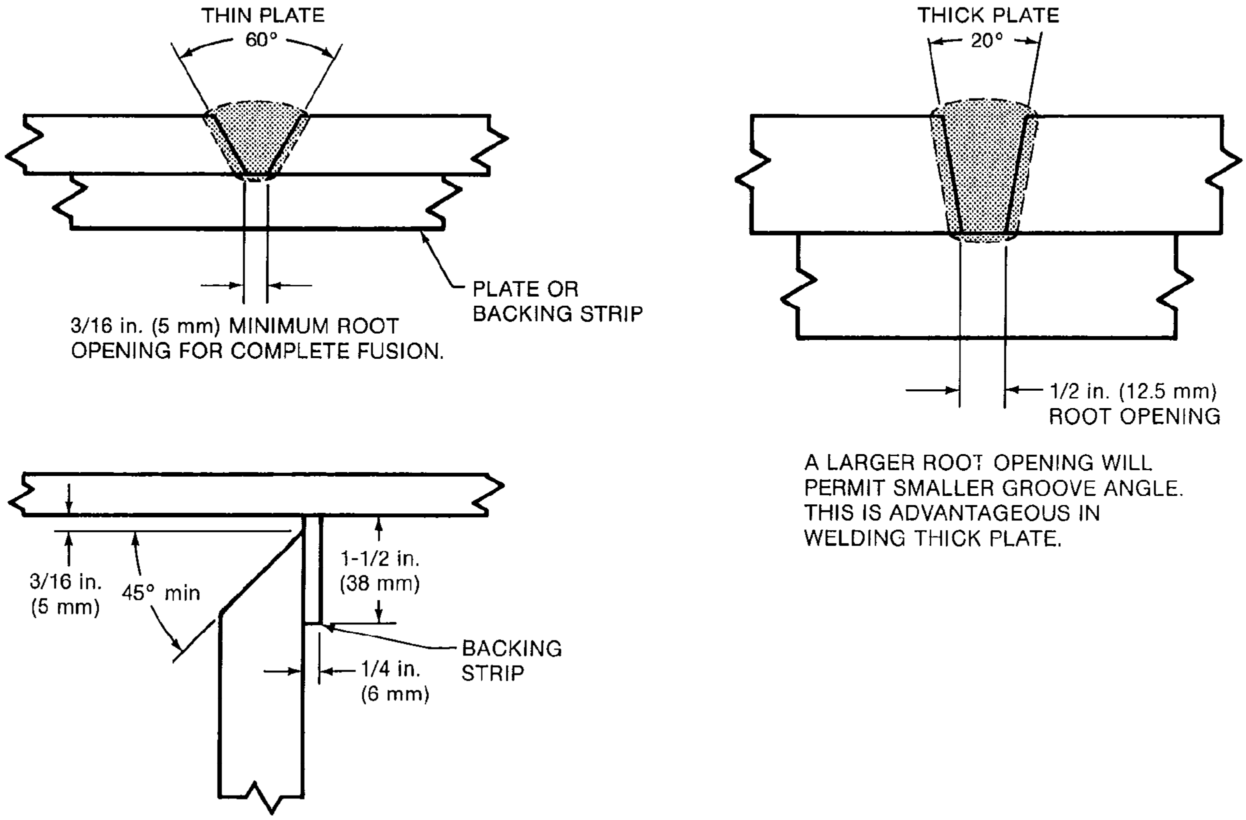



**Figure 21—Typical Weld Details for Welding From One Side Only, Permanent Backing**

are particularly important, especially where the application involves main-strength members. The thickness at a bulb or at the heel of an angle or channel may be as much as four times greater than the leg or web thickness. Experience has shown that unless the joint is well prepared, cavities are very likely to be left in the thicker portions of these members.

**3.5.4 Plug and Slot Welds.** Except where absolutely necessary, plug and slot welds should not be used. When required, an elongated slot weld is preferred to a circular plug weld. In general practice, the width of the slot is usually at least 1-1/2 times the plate thickness and the length approximately 3 times the width. Plugs or slots should be spaced no more than 18 times the plate thickness between centers in both directions. Sometimes the slot is completely filled with weld metal to make the surface flush.

One method that meets general approval is to deposit a fillet weld in the slot. The slot is cut large enough so that a fillet weld can be made around the inside periphery. Usually the remaining portion of the slot is filled with a compound to provide a smooth, flush surface.

**3.5.5 Welded Oil and Water Stops.** Oil and water stops in fillet welded T- or lap joints are of the welded type, although in the area of riveted joints, impregnated canvas stops may be used. An effective stop at intersecting members is the complete joint penetration weld (full penetration weld) stop (see Figure 25). Another accepted method is to simply make a small scallop cut of approximately 1-1/2 in. (40 mm) as indicated in Figure 25.

For riveted or fillet welded lap seams, a complete joint (full) penetration single-V-groove weld stop is generally used (see Figure 26). This second type is generally used in riveted seams in place of canvas stops.

**3.5.6 Scallops and Small Cutouts.** The trend is away from the widespread use of scallops because an improperly cut scallop is potentially dangerous. Scallops are invariably used where a groove weld of a stiffener or girder is made after the members have been assembled in place, as in the case of a longitudinal stiffener or bilge keel (see Figure 27). Scallops are also used for drain and vent holes. However, they are not recommended in stiffening members, girders, or bilge keels in way of completed shell or deck butts; rather, it is recommended that the weld

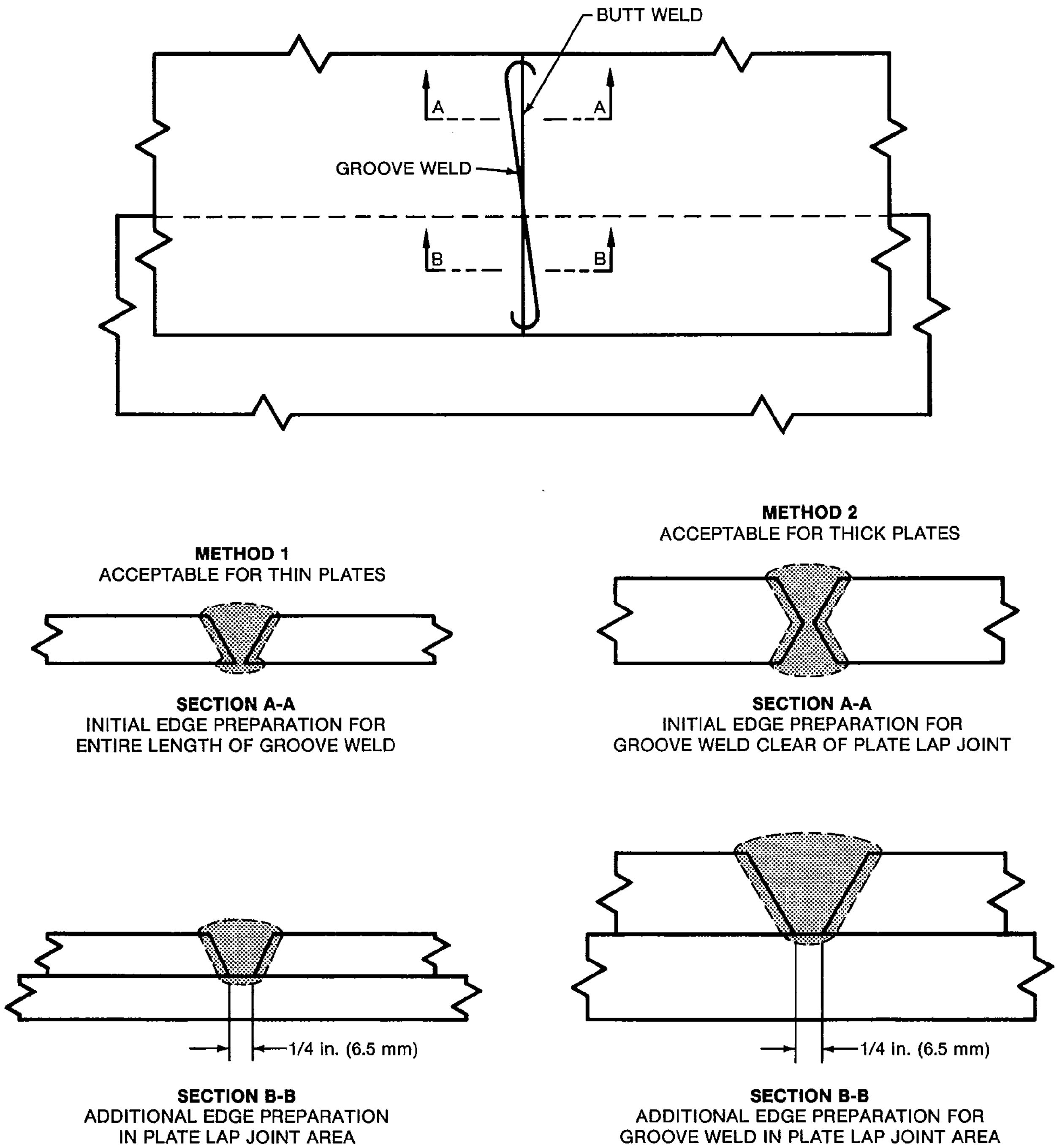



**Figure 22—Two Methods of Edge Preparation for Groove Welds Near Plate Laps**

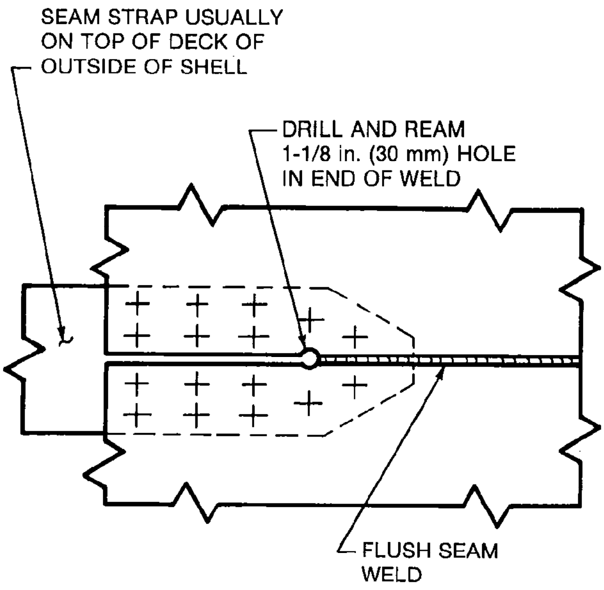



**Figure 23—Transition From Riveting to Welding in Flush Seam**

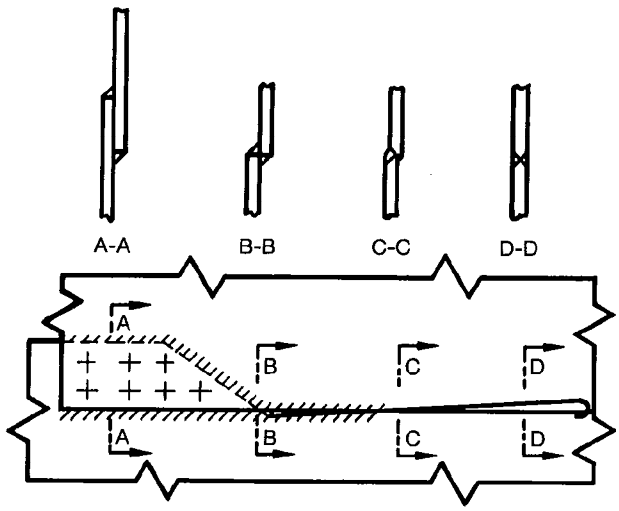



**Figure 24—Transition From Riveting to Welding in Lap Seam**

reinforcement be removed where crossed by the stiffener, girder or bilge keel. Finally, scallops should not be cut near the ends of brackets.

Since most shipyards are equipped for automatic cutting of some kind (such as numerical tape control), small cutouts and scallops are generally quite smooth. When manual cutting is done, it is essential that an even, smooth cut be provided. Normally, the cutout should not be smaller than 1-1/2 in. (38 mm) radius, unless it is to be temporary, to be filled with deposited metal after completing the crossing seam. Temporary scallops should have a 1/2 to 3/4 in. (12.5 to 19 mm) radius.

**3.5.7 Joining Plates of Different Thickness.** ABS Rules indicate that where plates to be joined differ in thickness and have an offset on either side of more than 1/8 in. (3 mm), a suitable transition taper is to be provided. For transverse joints in bottom shell plates, sheerstrake, and strength deck plating within the midship portion of the hull, and other joints which may be subject to comparatively high stress, the transition taper length is to be not less than three times the offset. The transition may be formed by tapering the thicker member or by specifying a weld joint design which will provide the required transition.

**3.5.8 Skewed Joints.** A special condition exists when members come together at an angle other than 90 degrees and fillet welds are used to make the connection. Ordinary specifications for the fillet weld leg at some joint angles could result in excessive waste of weld metal, along with difficulty in depositing the weld on the acute (closed) side of the joint. Fillet welds may be used in skewed T-joints having a dihedral angle of not less than 60 degrees nor more than 135 degrees, (see Figure 28). In these instances, the following guidelines are recommended. Angles smaller than 60 degrees are permitted; however, in such cases, the weld is considered to be a partial joint penetration groove weld. The root opening shall not exceed 3/16 in. (5 mm) except in cases involving either shapes or plates 3 in. (76 mm) or greater in thickness if, after straightening in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 5/16 in. (8 mm) is acceptable, provided a backing weld or other suitable backing is used. The backing weld may be by means of shielded metal arc welding root passes deposited with low-hydrogen electrodes, or other arc welding processes may be used. The other backing types may be flux, glass tape, iron powder, or similar materials.

Refer to Figure 28 and Table 8. Table 8 is a tabulation showing equivalent fillet weld leg-size factors for the range of dihedral angles between 60 degrees and 135 degrees, assuming no root opening. Root openings 1/16 in. (2 mm) or greater, but not exceeding 3/16 in. (5 mm), shall be added directly to the leg size. The required leg size for fillet welds in skewed joints is calculated using the equivalent leg size factor for correct dihedral angle.

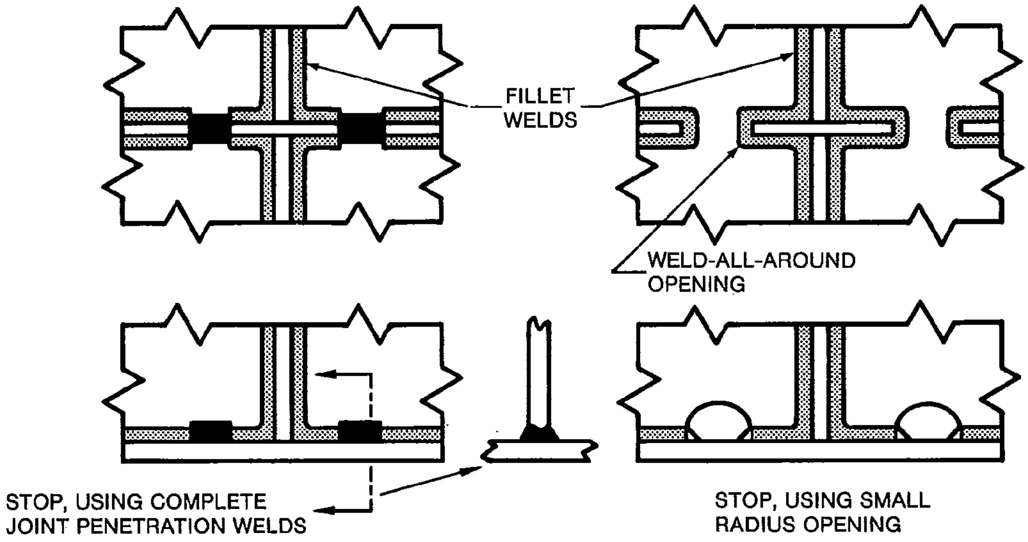



**Figure 25—Welded Water- or Oil-Stops at Intersecting Members**

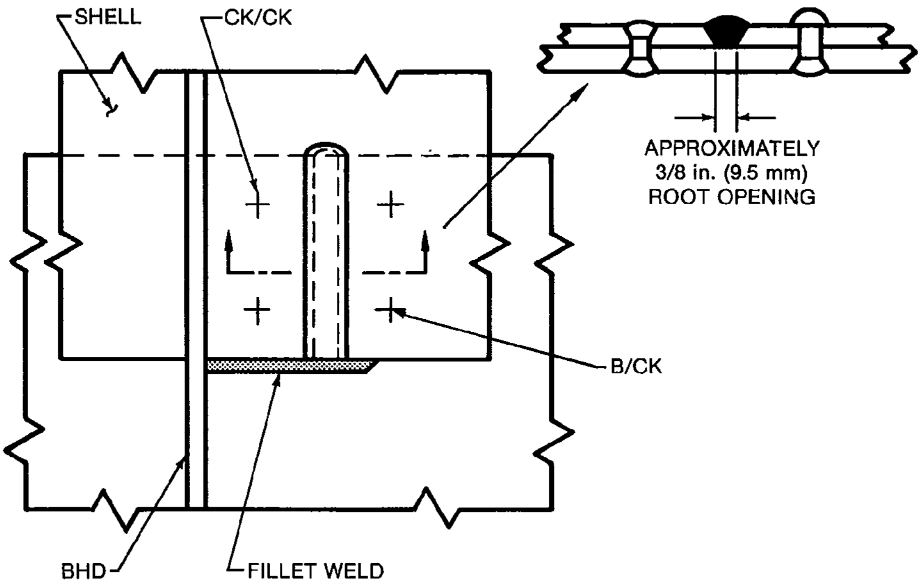



**Figure 26—Welded Stops at Riveted Seam Lap**

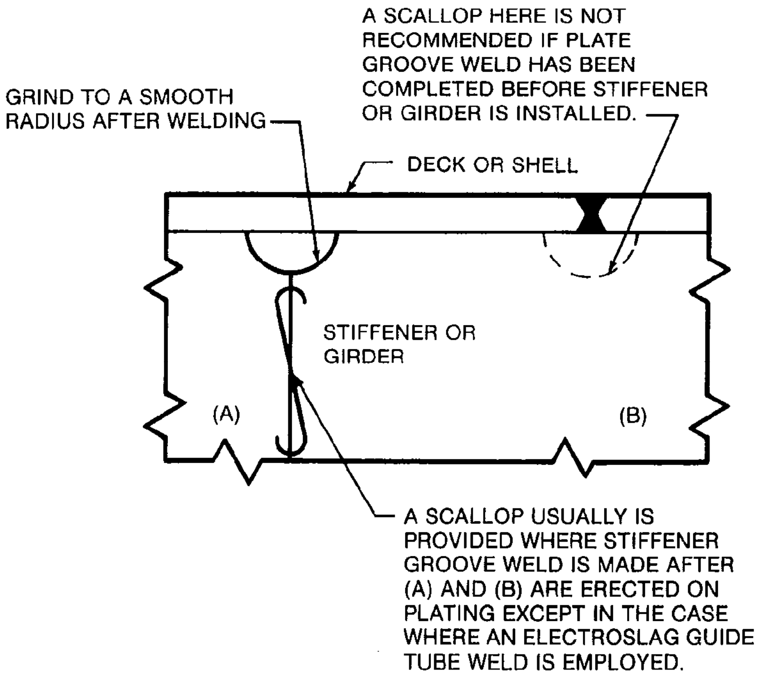
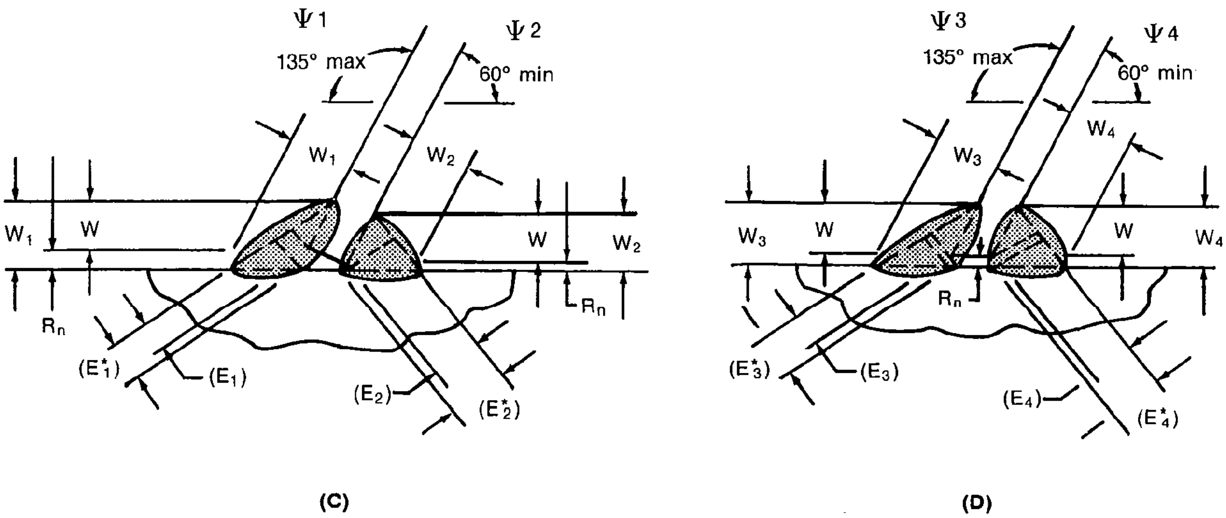



**Figure 27—Scallops**




SKEWED T-JOINTS

NOTE: $(E)_{(A)}$, $(E)_{(A)}^2$ EFFECTIVE THROATS DEPENDENT ON MAGNITUDE OF ROOT OPENING $(R_n)$.
SUBSCRIPT (n) REPRESENTS 1, 2, 3, OR 4.

ANGLES SMALLER THAN 60 DEGREES ARE PERMITTED: HOWEVER, IN SUCH CASES, THE WELD IS CONSIDERED TO BE A PARTIAL JOINT PENETRATION GROOVE WELD.

**Figure 28—Details for Skewed T-Joints**

**Table 8**
**Equivalent Fillet Weld Leg Size Factors for Skewed T-Joints**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dihedral Angle | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 |
| Comparable fillet weld size for same strength | 0.71 | 0.76 | 0.81 | 0.86 | 0.91 | 0.96 | 1.00 | 1.03 |
| Dihedral angle | 100 | 105 | 110 | 115 | 120 | 125 | 130 | 135 |
| Comparable fillet weld size for same strength | 1.08 | 1.12 | 1.16 | 1.19 | 1.23 | 1.25 | 1.28 | 1.31 |

| Example (U.S. customary units) | | (SI units) |
|---|---|---|
| Given: | Skewed T-joint, angle: 75 deg; | |
| | root opening: 1/16 (0.063) in. | 1.6 mm |
| Required: | Strength equivalent to 90 deg. | |
| | fillet weld of size: 5/16 (0.313) in. | 8.0 mm |
| Procedure: | (1) Factor for 75 deg. from Table : 0.86 | |
| | (2) Equivalent leg size, w, of skewed joint, without root opening: | |
| | w = 0.86 x 0.313 = 0.269 in. | |
| | | w = 0.86 x 8.0 = 6.9 mm |
| | (3) with root opening of: 0.063 in. | 1.6 mm |
| | (4) Required leg size, w, of skewed fillet weld: | |
| | (2) + (3) = 0.322 in. | 8.5 mm |
| | (5) Round up to a practical dimension: w = 3/8 in. | w = 9.0 mm |

For fillet welds having equal measured legs ($w_n$), the distance from the root of the joint to the face of the diagrammatic weld ($t_n$) may be calculated as follows:

For root openings > 1/16 in. and < 3/16 in., use

$$t_n = W_n \frac{-R_n}{2sin} \frac{\Psi}{2} \qquad \text{(Eq. 3)}$$

For root openings 1/16 in., use

$$R_n = 0 \text{ and } t_n = W_n \qquad \text{(Eq. 4)}$$

Where the measured leg of such fillet weld ($W_n$) is the perpendicular distance from the surface of the joint to the opposite toe, and ($R$) is the root opening, if any, between parts.

Also note that each fillet in a double fillet weld must be sized separately in skewed joints.

For welding skewed tubular joints, refer to the latest edition of ANSI/AWS D1.1, *Structural Welding Code—Steel,* for the applicable section covering tubular connections.

# 4. Hull Construction

## 4.1 Introduction

**4.1.1 Fabrication.** The fabrication of the hull consists primarily of assembling precut plates and shapes into subassembly units. The greatest possible use is made of automatic and flat position welding. Several small assembly units may be assembled together into a much larger unit before being erected on the ship. Some of these large erection units weigh 100 tons or more. If the fit-up of members being joined is not accurate, corrective measures can be extremely costly.

**4.1.2 Workmanship.** The quality of welding is affected by many factors and is not restricted only to the work done by the welder. Before welding, all of the earlier steps such as layout, plate edge preparation, and fitting should have been planned with regard to securing good workmanship.

The welder must be considered. For reasonable comfort and consistently good workmanship, those who must wear shields or helmets, respirators, and heavy, cumbersome clothing require adequate ventilation, especially in confined spaces, and good accessibility. Both production and workmanship are affected by these factors.

From the standpoint of comfort as well as weld soundness, adequate shelter from the elements must be provided during welding operations. Welding with shielded metal arc and any of the gas shielded processes where high winds prevail will likely produce excessive porosity because of the disturbance of the arc shielding. Welding under rainy conditions is equally bad. Some leeway for judgement may be allowed regarding shelter when ordinary strength steels are welded. However, since the welding of higher strength materials usually involves the application of low hydrogen electrodes, preheat and interpass temperature control, it will probably be necessary to provide additional shelter for this welding.

**4.2 Preparation of Material.** In order for the assembly parts to be prepared and located accurately, several methods are used in "lofting" or laying out the work full size.

Most shipyards today utilize computerized lofting methods, especially in new ship construction. These computerized methods have a direct or indirect (tape or disc) link with numeric-control cutting machines for plates and some shape cutting. Optical templates and the traditional manual lay down lofting methods are still used, especially in ship repair.

**4.2.1 Optical Detailing.** Optical detailing consists of drawing structural members 1/10 full size, photographing the drawing on a glass negative, and then projecting the negative to full size on the steel plate. The projected outline is transferred to the plate by center punching, scribing and marking. In the ratio control cutting system, however, the torches for full-scale cutting are applied directly from a scale drawing or glass negative with no laying out required.

**4.2.2 Numerical Tape Detailing.** Numerical tape detailing consists of transferring information from either basic lines and structural calculations or 1/10 size drawings directly to a tape which, in turn, is used to guide the torches of a tape-controlled oxyfuel gas or plasma arc cutting machine. No laying out is necessary.

**4.2.3 Plate Edges.** Plate edges prepared by machine oxyfuel gas cutting are usually smooth and require no further preparation. Manual oxyfuel gas cutting (OFC), if carefully done, produces an edge satisfactory for welding. If the cutting is not carefully done, the resulting irregularities along the cut edge may require smoothing off by welding or grinding, or both. Plate edges prepared by plasma arc cutting are usually smooth and require no further preparation. However, plasma arc cut edges may be slightly rolled or slightly beveled which may interfere with submerged arc welding where plates are butted tightly with supposedly no gap. This may lead to burn through while welding the first side. Where edges are square, it is generally satisfactory to shear relatively thin plate for welding. However, shearing should not be permitted on an exposed edge of a highly stressed plate, such as the top of a sheerstrake, unless the sheared edge is removed by OFC or by some other method.

**4.2.4 Fabrication of Subassemblies.** It is normal procedure to lay the plates on skids or platens to facilitate flat position welding. The seams are welded on one side, the plate assembly turned over, and the seams finish welded on the second side. Some shipyards do their assembly work on elevated platens or in special jigs or fixtures to allow placement of ceramic backing for single-sided welding. Where plates of varying thickness are employed, the second side will be smooth; this smoothness will facilitate placing and welding stiffeners and frames. In modern shipyards, all flat plate seams and many of the stiffening members are automatically welded.

In an alternative procedure, the seams are welded on the first side, and then the stiffeners and frames are installed and welded to that first side before the assembly is turned over to complete the welding of the seams on the second side. This alternative procedure does not adequately control distortion because plate edges cannot be dogged down to the platen while the second side is being welded.

Plate seams can be automatically welded from one side with special procedures and equipment as described in section 2. With seam welds made from one side, the assembly would not have to be turned over during fabrication. It may be necessary to do some repair of seam welds on the second side.

If manual welding of butts and seams is used, it is advantageous to backstep the first or root bead. In subsequent passes, back stepping or other deposition sequences such as a "wandering" block are often used to control distortion.

To arrive at the proper overall dimensions, the subassembly is treated by one of two methods. In one method, the plates may be cut to finish size before they are welded into the assembly. In this case an allowance must be made for shrinkage during the subsequent welding. In the other method, the plates can be prepared with stock for trimming, usually 1 to 2 in. (25 to 50 mm) around the periphery of the finished assembly. Then, following welding, the subassembly may be trimmed accurately to size in the shop, or the unit may be sent to the ways with trimming to be done in place. Depending upon the location and design of the assembly, either of these methods can be used.

**4.3 Erection and Fitting.** The subassemblies should be set as accurately as possible with the crane and, while still hanging, jacked or pulled to make up at the "set" lines marked on the structure. Then, before the crane is released, the sections are secured by such methods as strongbacking, cabling, and tacking in the joint. Additional tack welding and supports may be required to make the structure safe for subsequent erection. Since most of the assemblies weigh in excess of 30 tons and some as much as 500 tons, this operation must be performed carefully.

After the assembly has been set and secured, the entire joint is aligned and tack welded. Within the midship section, if fillet connections in longitudinal and principal transverse members are not aligned to within 1/3 thickness of members, then the fillet weld should be increased in size by 10%. If misalignment is 1/2 or greater than the thickness of the members, the members should be realigned. Butt joints are fitted by matching the plate surfaces while allowing for the proper root opening. Then the plates are tack welded. The usual root opening for manually welded deck and shell butt joints is 1/8 in. (3 mm), with a tolerance of plus or minus 1/16 in. (1.6 mm). Usually the alignment is maintained by strongbacks as indicated in Figure 29. The strongbacks in Figure 29(A) and 29(B) permit some-

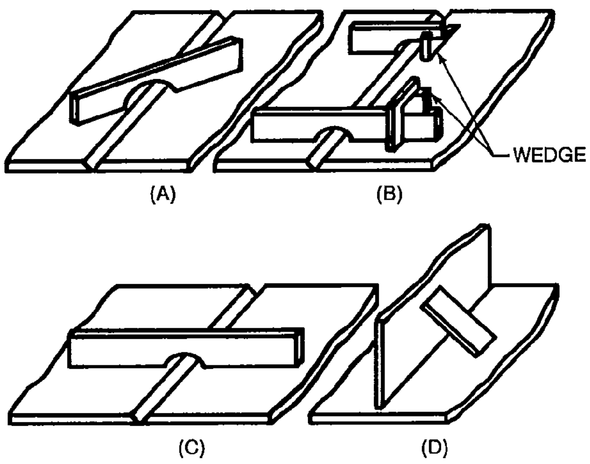



**Figure 29—Typical Strongbacks**

what more movement of plate during welding than the strongback in (C). Actually, where thick plates are involved, none of these strongbacks can exert much resistance to weld shrinkage across the weld.

Strongbacks and erection clips should be removed with minimum scarring of plates (see 5.6).

Fillet welded joints with minimum root opening are aligned and secured by means of tack welds in the joint. To prevent angular distortion in final welding, temporary supports or strongbacks, as shown in Figure 29(D), may be necessary.

Tack welds must be of high quality. In most instances, tack welding in the final welding groove is acceptable. It is important to follow tack welding with final welding as soon as possible, although the sections are supported so that danger from collapse (a result of tack weld failures) is practically negligible. No more tack welds than necessary should be applied, and cracked tack welds must be removed or repaired before incorporation into the finished weld.

Where large assembly units are joined together using automatic welding machines, such as submerged arc or electroslag, the line of welding must be cleared so that the machine can be maneuvered continuously along the joint. In connection with a vertical-side shell groove weld made using electroslag or electrogas, cutouts in longitudinal members crossing that butt are provided to allow the inboard sliding shoe, cables and hoses to pass through the longitudinal members (see Figure 30). These cutouts are usually small and need not be patched after welding unless a small stiffener requires reinforcing to maintain the strength requirements. Welding machines for automatic welding of horizontal seams also require similar details.

In connection with submerged arc welding of seams or butts in plating on which bulkheads or framing is already in place, openings in vertical members crossing the seam or butt must be provided to permit the welding machine to pass through. These openings will be fairly large and invariably will need to be filled in by insert or patch plates.

Where the root opening of a groove weld is under the specified minimum, it should be opened to specification by oxyfuel gas cutting, arc gouging, or chipping. The groove angle must be maintained.

When the root opening is over the specified maximum, correction may be made by buildup of one or both plate edges as shown in Figure 31(A). This buildup should be an operation separate from, not integral with, the joint welding procedure. The plate edges should be built up to within the specified maximum root opening before welding with the joint welding procedure. The buildup should be deposited to maintain the joint bevel and need only be cleaned of slag and unacceptable discontinuities. Chipping or grinding should be applied only as necessary to meet cut edge roughness standards and plate metal thickness dimensions.

The ABS Rules provide for approval of welding procedures for edge buildup of each member that does not exceed one-half the thickness of the thinner member or 1/2 in. (12.5 mm) whichever is the lesser. Acceptance of edge buildup in excess of the above is on a case-by-case basis.

A temporary backing strip is sometimes used where the root opening exceeds the specified maximum, as shown in Figure 31(A). The backing strip is removed and after back chipping or gouging, the weld can be completed.

Where the gap is considered too large for building up the plate edges by welding, an insert plate may be used. The recommended minimum width of an insert plate may vary, depending upon the particular application and location in the ship. In most cases, such as internal decks and bulkheads and in all framing members, the minimum width of an insert would generally be 12 to 18 in. (300 to 450 mm). However, in main-strength plating such as shell and main-deck plating, the minimum width of an insert would normally extend the full width of the plate and the length should be equal to or exceed the width, and cross at least three frames. New butts and seams should provide approximately 3 in. (76 mm) clearance to existing fillet welds. In any case, particular attention should be given to the welding sequence so that distortion and cracking during welding will be avoided.

Typical details for closures at small and large openings are covered in 4.4.1.

Care must be taken to use proper plate material. Moreover, in a critical, highly stressed plate area such as a sheerstrake, the rolling direction of the insert plate should be the same as that of the original plating.

Where fillet welded joints have root openings in excess of approximately 1/16 in. (1.6 mm), it is required that the fillet size be increased by the amount of the opening as

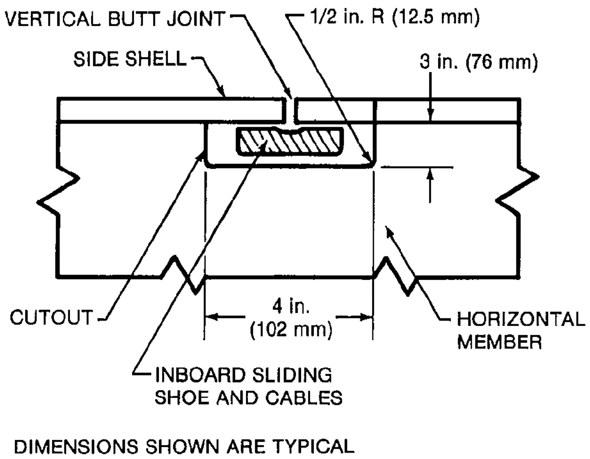



**Figure 30—Cutout of Member to Permit Passage of Inboard Sliding Shoe and Cables**

shown in Figure 31(B). However, where openings are considered too wide to be bridged or built up by welding, one of the methods suggested in Figure 31(C) may be used, when allowed by the contracting or regulatory agency.

**4.4 Welding Sequence.** The overall welding sequence should be considered primarily from the point of view of minimizing distortion and facilitating fabrication. The welding sequence can be important, especially when thick plates and castings are welded, if cracking is to be avoided during welding. In small insert pieces, tensile stresses will be built up within the insert plating. Thus, cracking of the boundary welds during welding is likely unless a suitable welding procedure and welding sequence is followed.

A welding sequence should be simple because it may be ignored if it is too complicated to understand. Likewise, the welding sequence must be practical so that more than one welder can be put to work at the same time. Figure 32 illustrates two basic ways to weld at an intersection of a plate butt and seam:

(1) Tie in plates which are relatively free to draw together.

(2) Do not weld across an unwelded butt or seam.

When these ways are applied to a plate structure, the welding sequence may be as shown in Figure 33. On a broader scale, the sequence with staggered butt arrangement takes an orderly form as shown in Figure 34. Note that several joints can be welded at the same time. Although staggered butts are seldom used now, Figure 34 is excellent for illustrating a good welding sequence. Figure 35 shows a typical sequence where butts are in line.

In Figure 36, the basic sequence as given in Figure 33 has been complicated by internal structure. It is possible to first weld the plates together as shown in Figure 33 and then weld the internals to the plating. This latter method is used in subassembly or panel shop work where several plates are welded together with automatic welding before the framing is installed.

**4.4.1 Sequence For Joining Panels.** Where vertical butts in plate panels are in line, as shown in Figure 37, a panel section may be treated as a shop assembly with all internal framing welded to within approximately 9 in. (230 mm) of the panel edges. When two adjacent panels are complete, they may be welded together. After the butt between the panels is welded, the unwelded portions of the framing across the butt can then be fit up and welded as shown in Figure 38. Girders and framing should not be welded to the plating too far in advance of welding the butts and seams. The regulatory agencies should be consulted before any deviation from this general sequence is attempted.

When a ship butt or seam in heavy plate is manually welded, it is always desirable, especially in cold weather, to assign a sufficient number of workers to the job to complete the joint in one shift. Welding should be carried out on both sides of the joint after the root has been back gouged and welded.

Where it is necessary to weld sections of plating under restrained conditions, as in repair work, the sequence should be similar to that shown in Figure 38. The seams, which usually will be common with the existing structure, should be cut back approximately 9 in. (230 mm) to reduce restraint when the vertical butts are being welded. Likewise, any framing left in the old structure should be released approximately 9 in. (230 mm) clear of the opening.

**4.4.2 Access Holes and Inserts.** Figure 39(A) shows several methods of closing small openings. Generally, a back-step cascade sequence of welding is recommended.

Where openings are relatively large, rectangular insert plates with radius corners are often used. With a rectangular insert, the edge of the cutout may coincide with existing butts or seams, or both, as shown in Figure 39(B), (E) and (F).

Some of the weld grooves should be extended approximately 9 in. (230 mm) to eliminate weld starts and stops at a weld intersection, (see Figures 32 and 38). Where this step is impracticable, the corners should have a generous radius, as shown in Figure 39(C) and (D). However, a lap joint rather than an insert may be used quite satisfactorily in places such as internal decks and bulkheads.

**4.5 Weld Distortion.** Although much theoretical work has been done on weld distortion, only that work substantiated by experiment and experience is reliable. Basically, there are just two principles, as illustrated in Figure 40, to consider regarding distortion from welding, namely:

(1) The weld metal, with shrinkage stresses of near yield point magnitude along the weld, exerts tensile weld stresses which must be equalized by compressive stresses

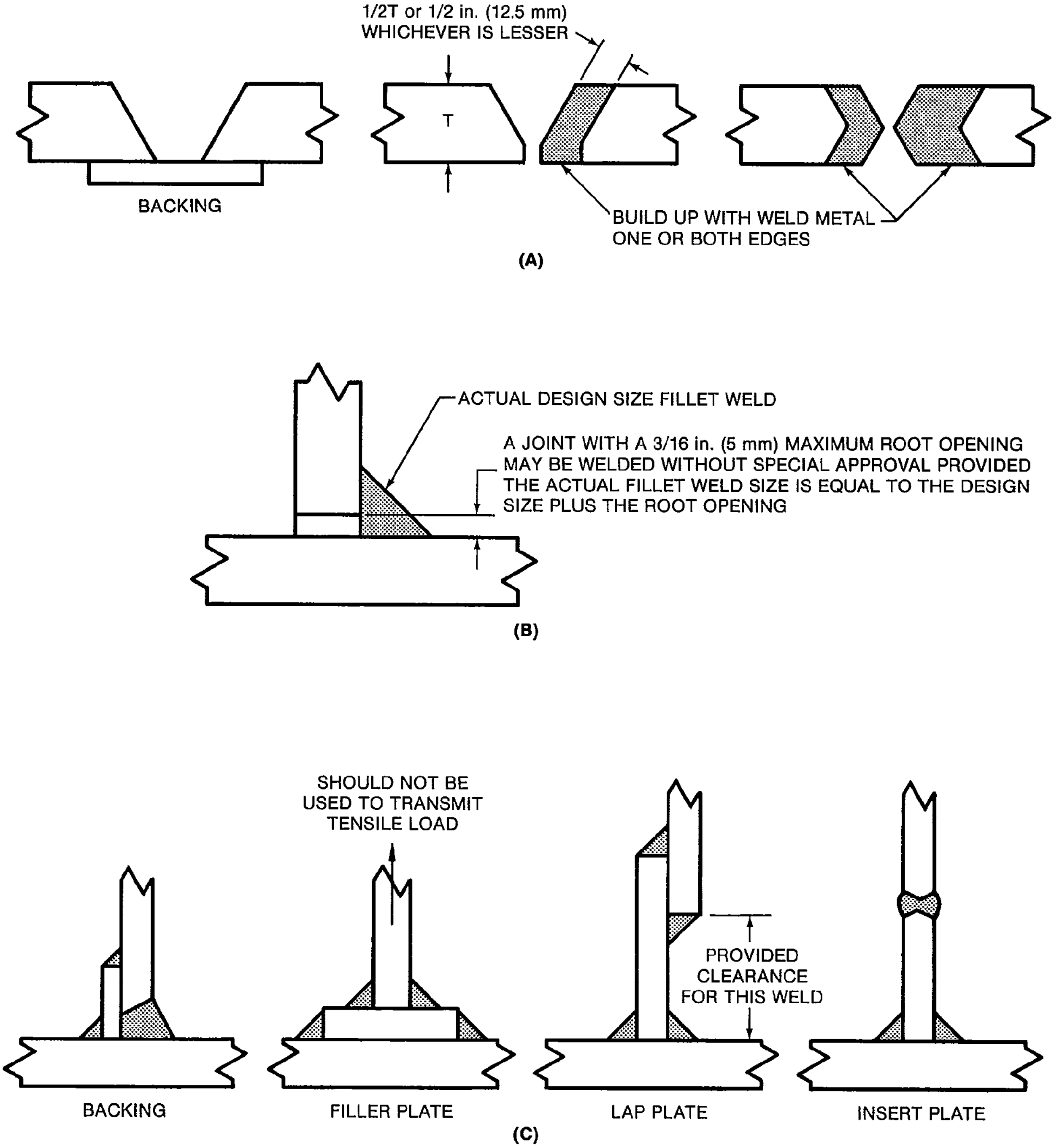
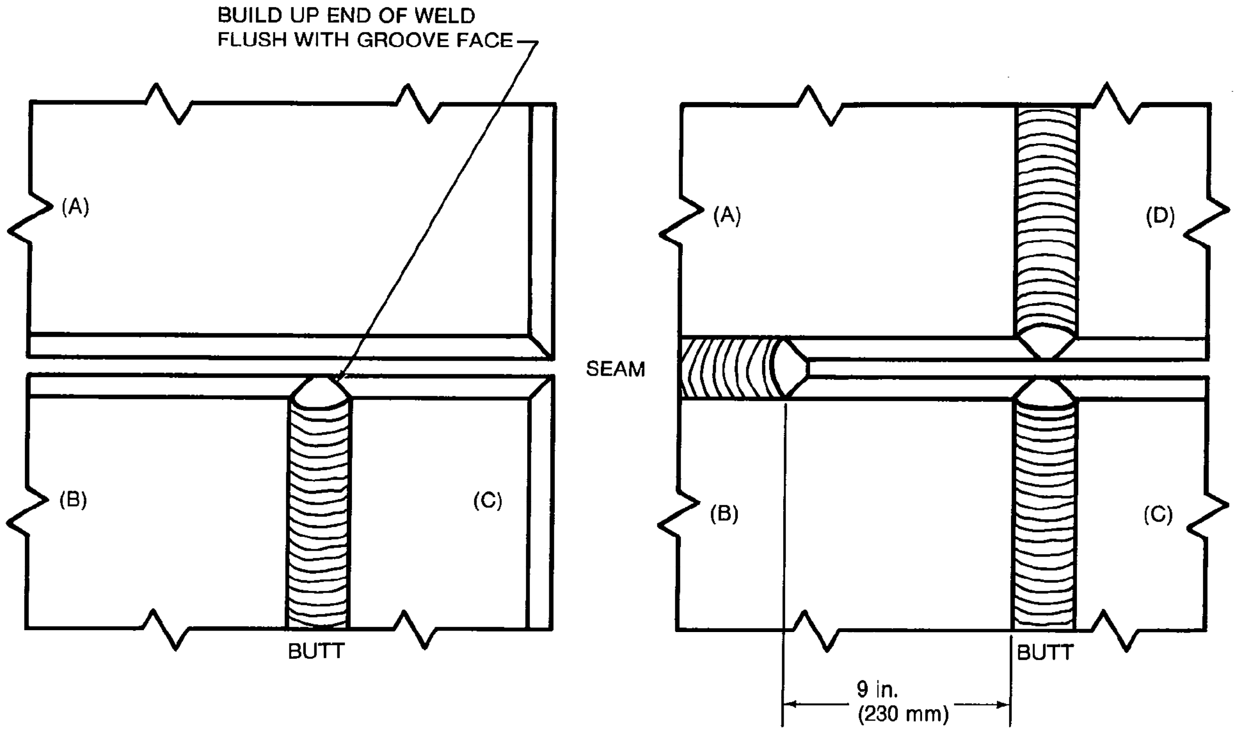



**Figure 31—Correction of Poor Fit-Up**




1. WELD BUTT BETWEEN (B) AND (C)
2. WELD SEAM BETWEEN (A) AND (B)

1. WELD SEAM BETWEEN (A) AND (B) TO WITHIN 9 in. (230 mm) OF BUTT JOINT
2. WELD BUTT BETWEEN (B) AND (C)
3. WELD BUTT BETWEEN (A) AND (D)
4. COMPLETE WELDING SEAM BETWEEN (A D) AND (B C)

**Figure 32—Welding Sequence at Intersection of Butt and Seam**

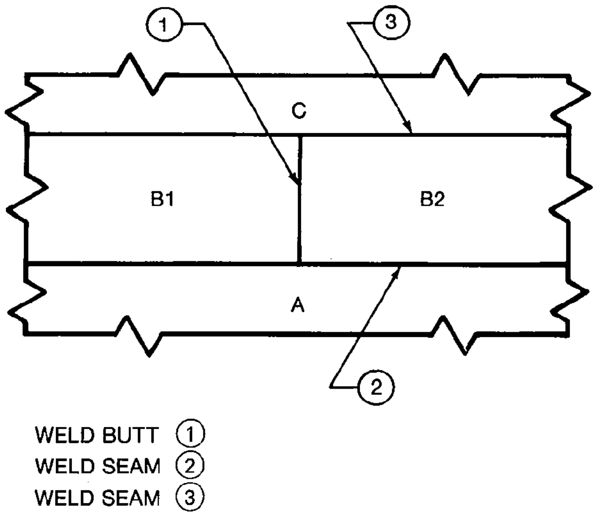



**Figure 33—Welding Sequence for Plate Butt and Adjacent Seams**

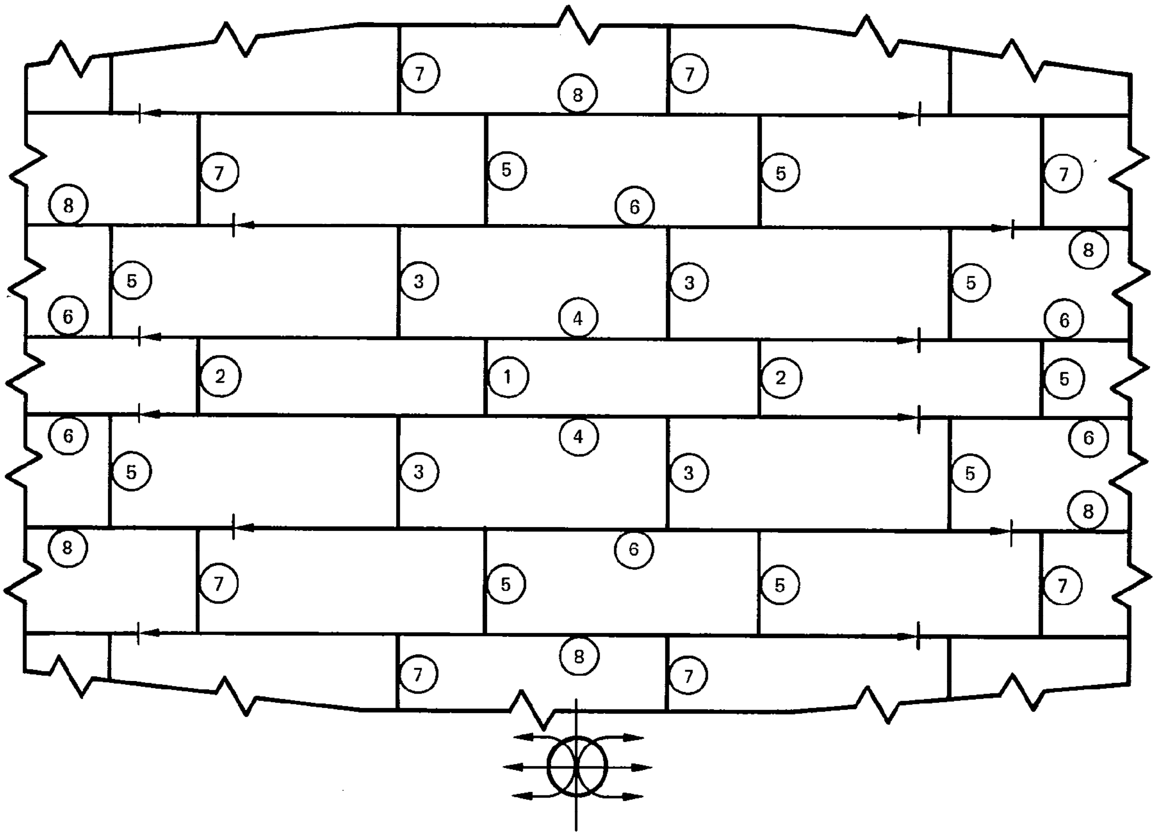



Figure 34—Typical Welding Sequence For Plate Butts and Seams Where Butts are Staggered

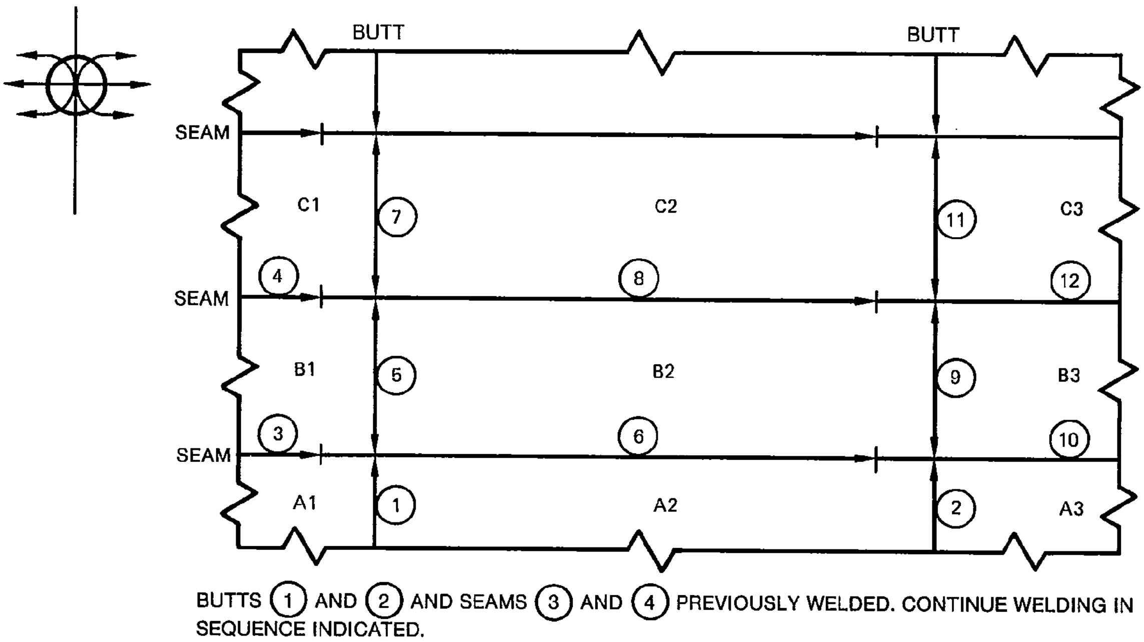
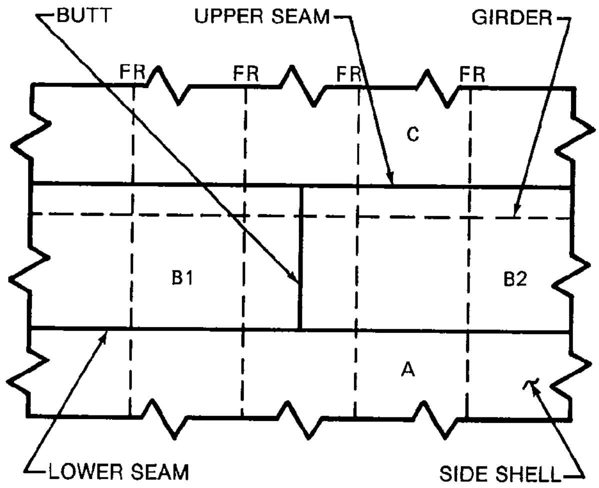
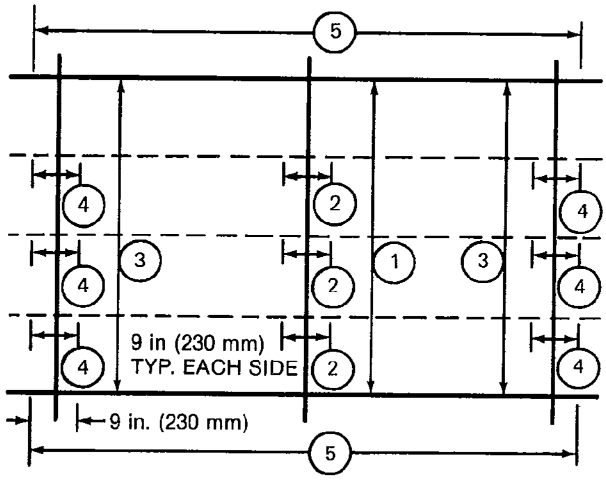



Figure 35—Typical Welding Sequence for Plate Butts and Seams Where Butts are in Line



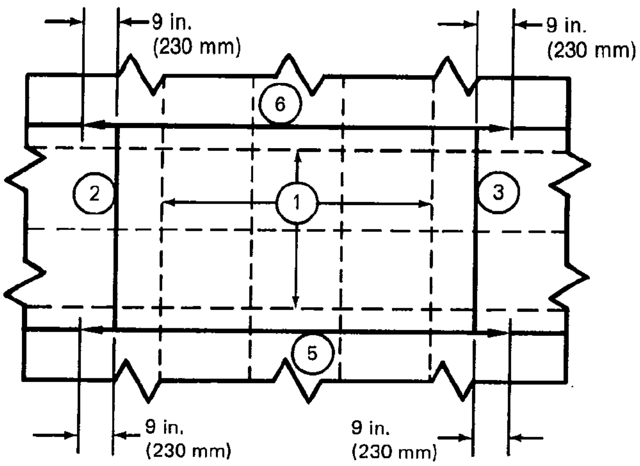

1. Weld frames and girder to plates within 9 in. (230 mm) of all unwelded butts and seams.
2. Weld butt
3. Weld unwelded portion of girder, in way of butt.
4. Weld lower seam to point 9 in. (230 mm) from next butt.
5. Weld unwelded portion of rames in way of lower seam.
6. Weld upper seam to point 9 in. (230 mm) from next butt.
7. Weld unwelded portion of frames in way of upper seam.
8. Complete seams.

**Figure 36—Typical Welding Sequence for Plate Butt and Adjacent Seams Where Internal Framing is Attached**




1. Panels 1 and 2 are complete with internals welded to within 9 in. (230 mm) of edges of panel.
2. Gouge ends of welds 1 and 3 prior to welding 5 as required.

**Figure 37—Typical Welding Sequence for Large Subassembled Plate Panels**




Note that a release length of 9 in. (230 mm) is provided in the horizontal seams at each corner of the insert plate.

Weld in this sequence:

Framing to within 9 in. (230 mm) of unwelded butts and seams.

Vertical butt (2) complete.

Vertical butt (3) complete.

Unwelded framing in way of vertical butts.

Horizontal seam (5) including release lengths.

Horizontal seam (6) including release lengths.

Unwelded framing in way of horizontal seams.

**Figure 38—Welding Sequence for Side Shell Plate Repair**

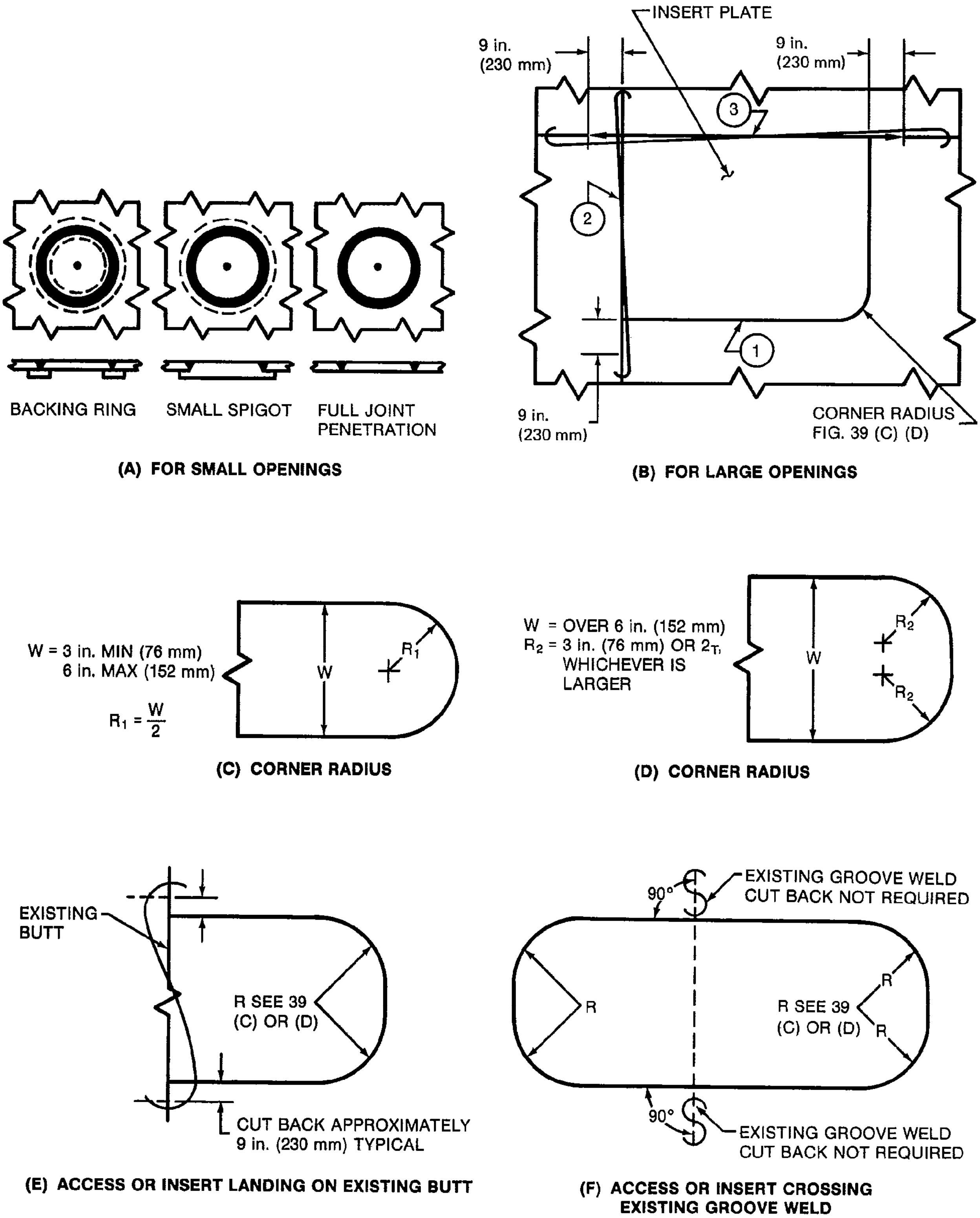



**Figure 39—Closure of Small and Large Openings**

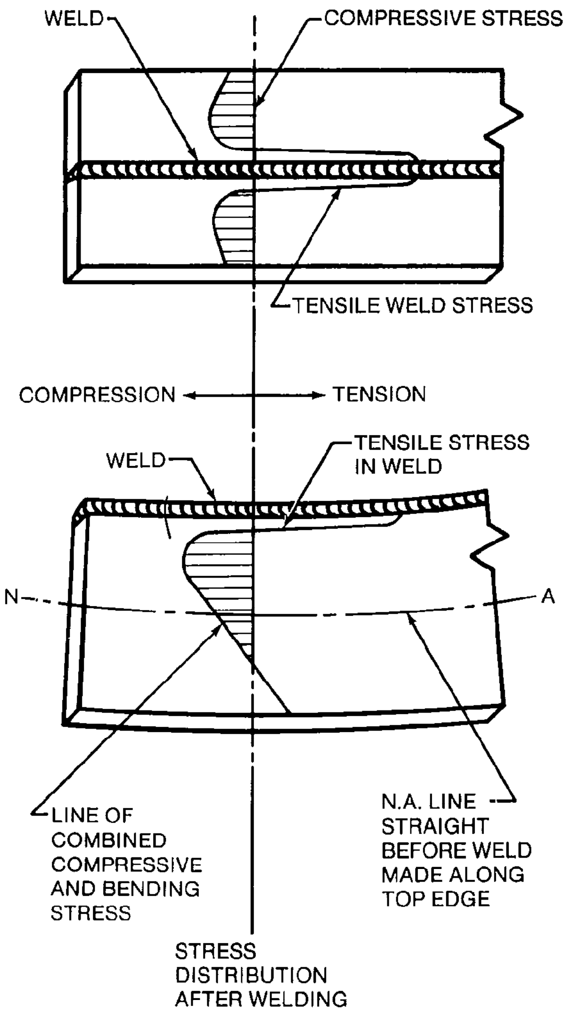



**Figure 40—Residual Welding Stresses**

in the adjacent plating or structure. Of course, shrinkage also takes place across the weld.

(2) If the tensile weld stresses are not exerted at the neutral axis of the structure, the structure will react by bending. When bending occurs in two planes, twisting results.

These two principles may be used to explain both local distortion at the welded joint itself and overall distortion in the structure. The greater the inertia of the structure to resist bending, the smaller will be the bending distortion. Also, the greater the overall restraint offered, the smaller will be the distortion.

**4.5.1 Distortion at Welded Joints.** Typical distortions are illustrated in Figure 41. For a given weld size, the greater the number of weld passes used, the greater will be the angular distortion. In this respect, automatic welding with higher arc heat concentration, higher deposition rates, faster travel speed, and possibly smaller groove angles or square groove joints will usually cause less distortion than manual welding. Also, the smallest practicable fillet welds and the smallest groove angles should be specified.

The angular distortion caused by welding stiffeners to plating often results in the familiar washboard effect (see Figure 42). Another form of angular distortion occurs when two plates or assemblies are being welded together starting at one end and progressing toward the other. If the weld is made slowly with little heat input, as with multiple pass manual welding, the welding tends to draw the unwelded portion of the joint closer together as shown in Figure 43(A). To offset this tendency, a block welding sequence is sometimes used in manual welding.

However, if the weld is made fairly rapidly with higher heat input, as with submerged arc or electroslag welding, the heating pattern produced in the plating adjacent to the welding may cause the unwelded portion of the joint to remain fairly stable or to open as shown in Figure 43(B). If the welding is stopped before completing the joint, the joint will close up. With submerged arc, tack welds can help maintain alignment. With electroslag, no tack welds are used. Instead, stiffening members are employed to help maintain alignment.

The amount of opening or closing of the unwelded portion of the joint will depend on many factors including plate size, welding process, speed of welding, cooling rate, and heat input. In some cases, it is helpful to initially provide a larger gap at the top of the joint than at the bottom to compensate for a closing tendency. Experience, however, is the only reliable guide.

**4.5.2 Distortion of Structure.** The welding of butts and seams in plate panel assemblies and the welding of stiffeners to the plating will compress the plating and warp the stiffeners. These distortions result from a combination of compressive reaction stresses caused by weld shrinkage and bending stresses caused by stiffener eccentricity. In addition, the result sometimes produces twisting.

If the compressive stresses are relatively high, buckling may take the form of natural buckling deflections (waves) along the plate or across the plate (see Figure 44). This condition is usually quite noticeable in light plating.

The same principles, as noted above, also apply to large assembly units and even to the ship itself. If welding is applied to the top of a long shallow unit, the unit will deflect upward at the ends. In such welding, the bows and sterns of ships have been observed to lift off the keel blocks several inches.

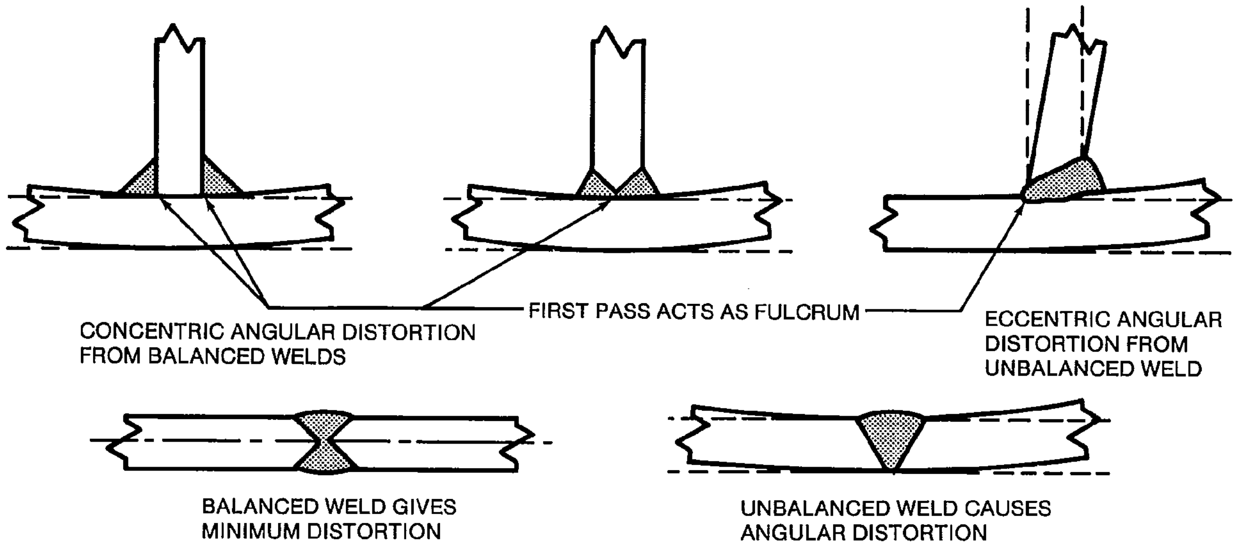



**Figure 41—Typical Distortion of Welded Joints**

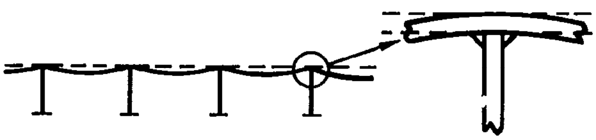


**Figure 42—Angular Deflection Due to Welding Stiffeners to Plate (The Washboard Effect)**

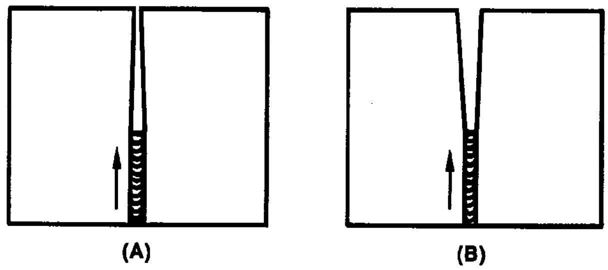



**Figure 43—Angular Distortion Tendencies in Making Groove Welds**

**Figure 44—Natural Buckling Deflection**

On the other hand, if the unit is relatively deep and stiff, there will be less tendency to deflect upward at the ends. Also, if an upper unit can be installed and tack welded in place before welds are made on the lower unit, the top unit will provide added restraint and thus further reduce the deflection.

Ideally, the welding should start along the midline of the assembled units and progress upward and downward, forward and aft, port, and starboard. However, with the very large assemblies now being used, the overall deflection problem is much less than when ships were built with small assemblies or plate by plate.

For manually welded seam and butt joints, a backstep or wandering block sequence often helps to minimize overall distortion. The effect on distortion control is much greater for the initial passes than for subsequent passes.

**4.5.3 Control of Distortion.** One method of holding overall dimensions is to make proper shrinkage allowances. By allowing extra length or width to compensate for the shrinkage, the final measurement will be correct. This method will provide good results if the operations of trimming, fitting, and tack welding are done uniformly on duplicate pieces. Shrinkage estimates given in Table 9 provide some benefit when data based on experience with a particular assembly are unavailable. However, considerable variation from these estimates can be expected.

The judicious use of temporary stiffeners, jigs, and strongbacks will help to minimize distortion. Sometimes presetting or prebending is useful. When the member is welded, it is expected to deform to the correct or desired shape. With higher strength steels, it is helpful to use the lowest yield-strength electrode compatible with the design.

There are several ways to correct distortion, but all methods are less desirable than preventive measures. One of the most common corrective measures is torch heating and accelerated cooling either by heat shrinking spots in a regular pattern or by line heat shrinking. Nevertheless, there are limitations on the use of accelerated cooling, as noted later in this section.

In straightening a plate panel, line-heat shrinking may be used along the back of frames and stiffeners, slightly beyond the toe of the weld, or in combination with either spot or line heating in between. Line or spot heating the flanges of stiffeners is sometimes used to straighten bowed frames if the flange is along the convex side. The deposition of weld beads along the hump of a buckle or bend is much less efficient than torch heating.

On light deck plating, additional stiffening in the form of flat bar headers, intermittently welded to the plating, are effective. However, they are generally used only as a last resort to prevent as well as correct distortion. Sometimes it is expedient to cut in new butts to remove excess material. In these cases, new butts are cut normal to the direction of the excess length of material.

Fairing by heating or flame shrinking and other methods of correcting distortion or defective workmanship in fabrication of main-strength members within the midships portion of the vessel and other plating which may be subject to high stresses is to be carried out only with the express approval of the classification society's surveyor or the owner's inspector.

Shrinking by the alternate use of heat and water-spray cooling is not permitted on main strength members by most codes and fabrication specifications. Decks, bottom shell, side shell, and other main-strength members, regardless of the grade of steel, may be faired either by heating (sometimes accompanied by jacking) or by releasing all restraint and then cold straightening. On the higher strength steels, heat straightening should be kept to an absolute minimum.

On some low alloy steels, not even heating is permitted. Refairing should be done by the releasing of adjacent joints or the making of new joints, fairing by strong backing only and then the rewelding of the joints.

Since plate unfairness is often unavoidable, some consideration should be given to the structural importance of the part. Figure 45 shows acceptable steel plate tolerances given in MIL-STD-1689 covering fabrication, welding, and inspection of ship hulls as amended.

Intermittent fillet welding instead of continuous welding will reduce distortion. However, intermittent welding is not advisable if maximum strength is required. Nor is it advisable in locations where damaging corrosion is likely to occur along the unwelded surfaces. It is recommended wherever buckling distortion in thin plate panels is to be minimized. Any intermittent fillet welding should have continuous welds both at the ends of the members and at the intersection of these members with main-support members. The minimum required length of continuous fillet welding at these places is normally specified by regulatory agencies. Wherever possible, staggered welds should be used. Weld segments should be 1-1/2 in. (38 mm) minimum and the maximum unsupported length should not exceed 12 times the thickness of the plate (see Figure 46).

## 4.6 Stress Relief

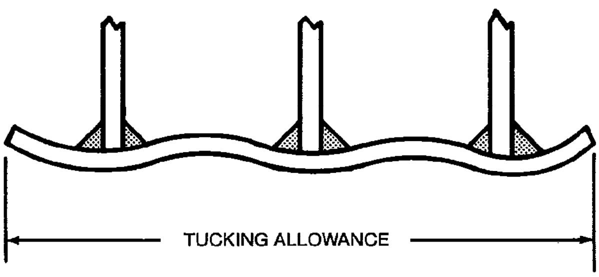
**4.6.1 Postweld Heat Treatment.** After joining or after repairs have been completed, a postweld heat treatment is sometimes required of heavy weldments, usually those incorporating castings that will be in highly stressed portions of the structure.

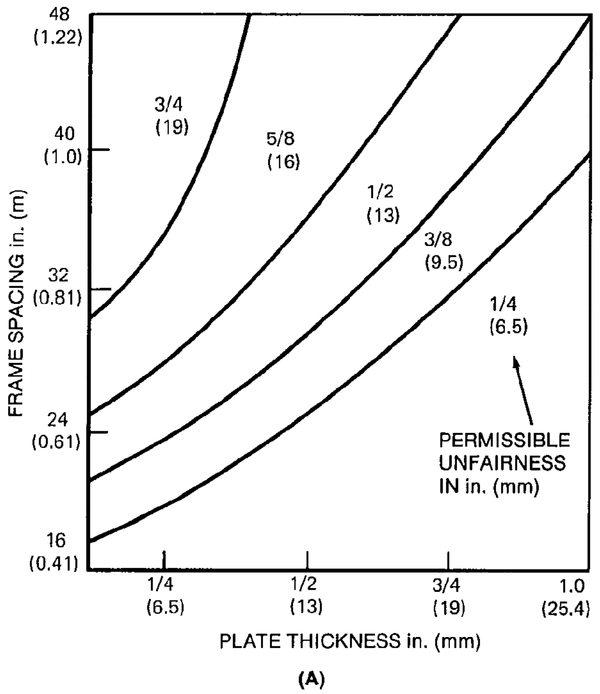
Examples are rudders, rudder posts, and stern frame weldments. Heat treating may be necessary to maintain dimensional stability before or at some time during machining of heavy weldments. If the material is plain carbon steel, a treatment temperature of 1150° ± 50°F (620° ± 28°C), held for one hour per inch of maximum thick-

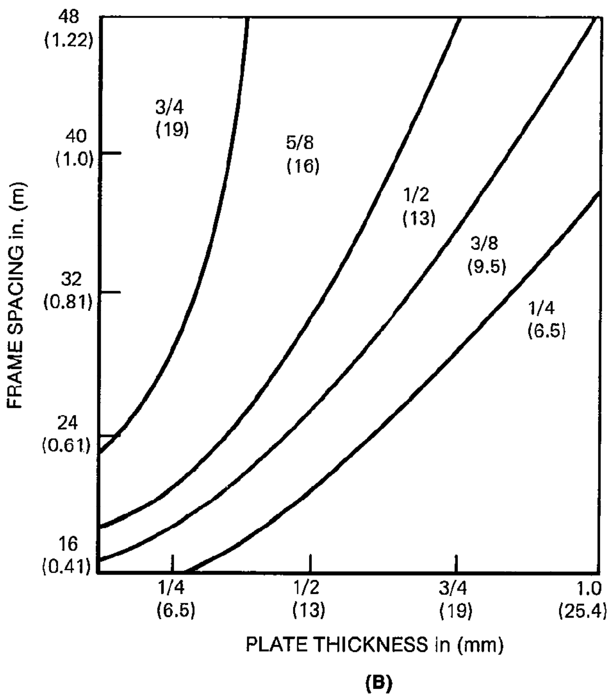
## Table 9
## Weld Shrinkage Allowances

| | |
|---|---|
| **Groove Welds** | |
| Transverse | 1/16 to 3/32 in. (1.6 to 2.4 mm) for all thicknesses |
| Longitudinal | |
| Over 1/2 in. (12.5 mm) thick | 1/32 in. (0.8 mm) in 10 ft (3 m) |
| 3/8 to 1/2 in. (9.5 to 12.5 mm) thick | 1/32 to 1/16 in. in 10 ft (0.8 to 1.6 mm in 3 m) |
| 1/4 to 3/8 in. (6.5 to 9.5 mm) thick | 1/16 to 3/32 in. in 10 ft (1.6 to 2.4 mm in 3 m) |
| 1/4 in. (6.5 mm) and thinner | 1/16 to 1/8 in. in 10 ft (1.6 to 3.2 mm in 3 m) |
| **Fillet Welds** | |
| Tucking Allowances | |
| Over 1/2 in. (12.5 mm) thick | No allowance |
| 3/8 to 1/2 in. (9.5 to 12.5 mm) thick | 1/64 in. (0.4 mm) each stiffener |
| 1/4 to 3/8 in. (6.5 to 9.5 mm) thick | 1/32 in. (0.8 mm) each stiffener |
| 1/4 in. (6.5 mm) and thinner | 1/16 in. (1.6 mm) each stiffener |

Note: Tucking allowance (see Figure below) was developed for use on flat plates with continuously welded stiffeners. Intermittent welding will result in about one-half the tucking tabulated above when the weld lengths and spacings conform to the requirements for shipbuilding. Tucking allowance refers to the amount of distortion and subsequent loss of plate length or width, which will be encountered due to welding.






(A) To be used for: shell, uppermost strength deck, bulwarks; exterior superstructure bulkheads; and within midships 3/5 length the longitudinal strength structure including tank top and the deck next below uppermost strength deck if continuous above machinery spaces.

For transversely framed ships, reduce the tolerances by 1/8 in. (3 mm) for all members stated above except bulwarks and exterior superstructure bulkheads.

(B) To be used for the following areas, except where "A" governs: Structural bulkheads forming a boundary of a living space and contiguous passageways, decks within the hull and superstructure in way of living spaces, decks exposed to weather, tank and main transverse bulkheads and inner bottom plate longitudinals and transverses.

For other structural bulkheads and decks, the unfairness as permitted by above curves, as applicable, may be increased by 1/8 in. (3 mm).

**Figure 45—Permissible Unfairness in Steel Welded Structures as Used for Guidance by U.S. Navy**

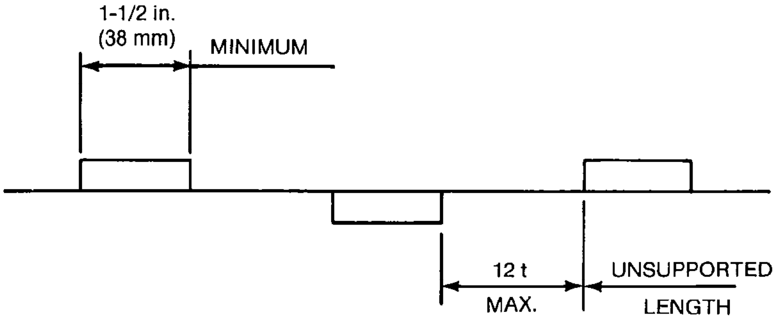



**Figure 46—Control of Distortion in Thin Plate By Intermittent Welding**

ness of section, is usually specified. However, if assemblies are welded in a proper sequence with preheat and low hydrogen electrodes, they may not require postweld heat treatment.

Many low alloy steels, particularly the quenched and tempered steels which may suffer a loss in strength and impact resistance, perform better when not postweld heat treated. In any case, the treatment temperature should always be lower than the tempering temperature.

**4.6.2 Mechanical Stress Relief of Welds.** When postweld heat treatment is impossible, mechanical stress relieving of welds is sometimes used to reduce high welding stresses in large pressure vessels and cylindrical tanks. This method involves subjecting the tank to hydrostatic pressure about 1-1/2 times the design pressure to plastically stretch the weld metal. Thus, the residual welding stresses will be reduced when the internal pressure is removed. The pressure, which should not stress the tank to more than 90% of the yield point, is maintained for a minimum of approximately two hours. Applications and limitations of mechanical stress relief are covered in *U.S. Coast Guard Marine Engineering Regulations*, Title 46 of Federal Regulations Subchapter F. Generally, this method of stress relief is not permitted on materials where the yield point is greater than 80% of the ultimate tensile strength.

**4.6.3 Vibrational Stress Relief.** Mechanical vibration at frequencies and intensities designed specifically for the part has been shown to be effective at stabilizing dimensions but has little known effect on residual stress. It is therefore not recognized by most regulatory agencies. It has been used successfully, however, to relieve stresses induced by excessive transportation vibration and induced by having been dropped or having fallen from an elevated position.

**4.6.4 Peening.** In some cases, peening will effectively reduce distortion or loss of dimension. Generally, the first and last layers are not peened; the first layer because it does not have sufficient strength to resist the blows and the last layers because no subsequent weld passes are deposited to reheat and refine the peened material. Peening of single-pass fillet welds has been shown to be quite effective in reducing angular distortion in thin plate. Care should be taken that peening operations do not close up undercuts, incomplete fusion, or other defects. Such defects should be removed before peening. Peening should be done immediately after the weld pass is made, or after any repairs are made.

**4.7 Preheat.** The benefit of preheat results primarily from the reduction of the cooling rate during welding. The slower cooling helps to reduce the concentration of shrinkage stresses and the hardness of the weld and heat-affected zones. In that way, the slower cooling may help to prevent the formation of cracks and may increase the notch toughness of the welded joint. Preheating during cold weather is usually specified, especially for the welding of thick plates.

Regardless of ambient temperature, preheat is advisable on heavy weldments and castings. Although preheat as high as 400°F (200°C) is considered desirable in some cases, practical considerations usually dictate lower preheat temperatures of approximately 150° to 200°F (65° to 90°C) and the use of low hydrogen welding processes. In some higher strength steels, however, a higher preheat, together with low-hydrogen welding processes, may be necessary.

Sometimes preheating is unnecessary because the use of a high-heat input welding process may bring about a sufficient retardation of cooling. Continuous welding operations, together with the maintaining of a specified temperature, are highly desirable when heavy units or highly restrained structures, such as castings or small insert plates, are welded. Sometimes, when an insert is welded in a heavy plate, only the minimum amount of preheat required for adequately retarding the cooling should be used, because the plate shrinkage from the preheated areas adjacent to the weld, when these areas cool, will be added to the weld shrinkage and increase the tendency toward shrinkage cracking.

Preheat may be necessary before tack welding when the members to be joined are highly restrained. When higher strength steels (particularly those that are quenched and tempered) are fabricated, the same preheats specified in the welding procedures should be used when any type of weld or tack is made.

Holding the weldment at the preheat temperature for a period of up to twenty-four hours after welding can be an effective measure against delayed cracks. This allows entrapped hydrogen to diffuse out of the weld area.

**4.8 Barge Construction for Inland Waterways.** River barges are built to provide the maximum possible cargo tonnage within given dimensions, consistent with adequate structural strength and towing efficiency. In shape, barges are usually of semi-integrated (one square end and one shaped end) or box (two square ends) construction. Many barge yards are highly automated, and they take advantage of many labor saving details in the construction process.

Steel plating is purchased from the mill as sheared flat plates or in coils. Coil storage and uncoiling operation at the shipyard are shown in Figure 47. After it is uncoiled, the plating is side trimmed and sheared to length. Coil plate thicknesses vary between No. 10 gauge 9/64 in. (3.5 mm) and 5/8 in. (16 mm). When plate butts are welded, maximum use is made of automatic submerged arc welding with flux backing for welding plates up to

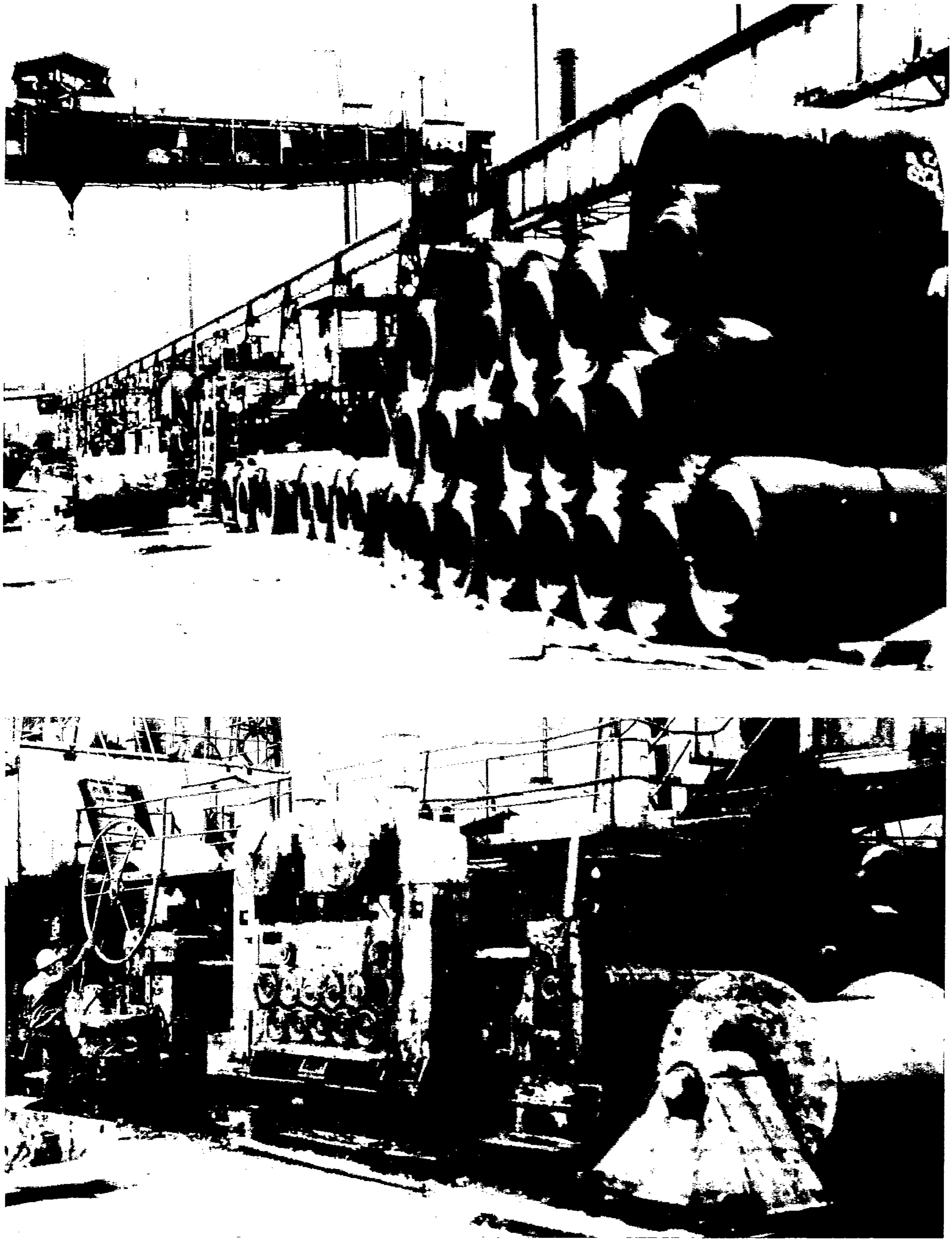


Figure 47—Coil Storage (Top) and Uncoiling Operation (Bottom)

1/2 in. (12.5 mm) thick in a single pass from one side only. Stiffeners are normally welded to plating by the use of manual shielded metal arc welding, or semiautomatic flux cored arc welding or both.

Subassemblies with standardized details are widely used (1) to gain the maximum labor efficiency, (2) to take advantage of positioning for flat welding, and (3) to minimize construction time. The only size limitation is that of crane capacity.

Steel plate in coil form to ABS requirements may be produced only as Grade A. The steel on the outside of the coil will have a slightly higher tensile strength than the steel on the inside of the coil because of the coiling process after rolling. This difference in tensile strength is due to a difference in cooling rates when the steel is coiled.

Figure 48 shows barge assembly units being placed into position.

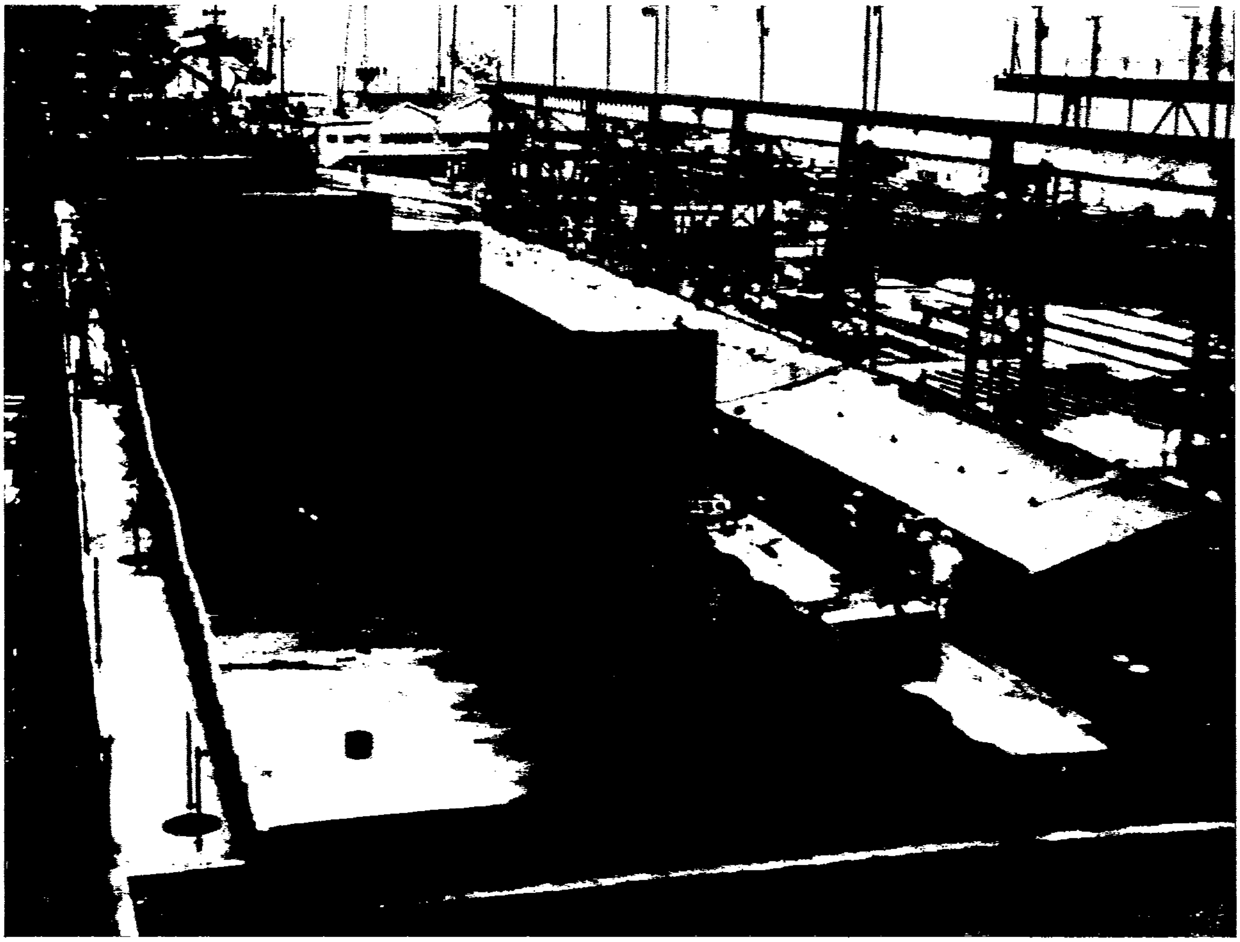


**Figure 48—Barge Construction Showing a Side Shell Unit (at right) in Horizontal Position Ready to be Erected Into Final Vertical Position**

# 5. Inspection and Qualification

**5.1 Introduction.** The maintenance of good weld quality depends on the organization of welding operations as well as on the methods of inspection. Subsurface inspection is not infallible as a means of controlling quality nor does it minimize the need for a high standard of workmanship or supervision. A close liaison among tradesmen, supervisors, welding engineers, and designers is therefore essential to creating conditions suitable for producing sound welds.

Quality assurance in an organization starts at the top and the responsibility for it lies with the shipyard's top management. Quality cannot be inspected into a product. Trained personnel and appropriate procedures must be in place prior to the start of work. The proper materials for base metals and suitable consumables, electrodes, and flux must be selected. Suitable and properly working equipment must be available, and the correct processes and procedures must be selected. Finally, properly trained welders and welding operators must be available.

Quality control starts with the qualification of the welding and nondestructive testing procedures required by the design of the hull and its components. Once these procedures are in place, welders, welding operators, and inspector/testers must be trained and qualified.

The use of various welding processes and techniques will produce different types of defects which are usually associated with a given process or technique. For instance, in submerged arc welding, the flux cover which precedes the electrode may produce pockets of entrapped slag, whereas with welding processes using only gas for shielding, this type of defect would not be likely to occur. It is important to consider how the change in variables and techniques of a welding procedure can affect the probability of certain types of defects. Each of the regulatory agencies and classification societies require the shipbuilder to inspect the hull and its components by various inspection methods to meet stated acceptance standards. Alternative inspection methods may be approved upon request of the shipbuilder, but each request will be evaluated on a case-by-case basis and the alternative method must provide equal or better detection of the type of defects probable with the welding procedure used.

Naval vessels and some merchant ships are now using increasing amounts of higher strength, low alloy steels. Initial qualification of both the welding procedure and the welders is required for these materials.

**5.2 Welding Procedure Qualifications.** Most regulatory agencies and classification societies do not recognize any prequalified welding procedures for shipbuilders; therefore, welding procedure qualification is required for all ship welding construction. Such tests are conducted to determine the shipyard's or fabricator's capability in applying the proposed filler metal to the base metal. The extent of such tests may vary depending upon the intended application, but they generally consist of transverse tensile and bend tests, as a minimum.

However, procedure qualification for special applications, such as the use of high-heat input electroslag and electrogas processes and the welding of steels for low-temperature service, usually requires additional Charpy V-notch tests.

**5.3 Welder Qualification.** The details of specimens to be prepared and also the tests to be carried out for welder qualification in shipbuilding are included in the rules and specifications of the U.S. Navy, the U.S. Coast Guard, and the American Bureau of Shipping. The tests are designed to show whether the welder can make sound welds using approved materials and procedures. Each welder should be qualified for the welding process, the material thicknesses, and welding positions to be used in production.

Since the turnover in welders is large, new welders must be trained on a regular basis. Beginners are taught the fundamentals and practice of making welds; first in the less difficult flat and horizontal positions, then in the vertical and overhead positions. Welders must pass a qualification test before they are permitted to undertake production welding. It must be recognized that successful completion of a qualification test weld is not an accurate measure of a welder's skill. Many areas of ship construction present extremely difficult welding conditions which can only be completed by highly skilled people with a great deal of experience.

After normal performance qualification is completed, it is recommended that further training on job related materials, thicknesses, and access constraints be conducted before the welder is released to production. Continuation of this training to supplement on-the-job training is also recommended. Fortunately, more and more ship welding is done on subassemblies in the shop or on platens, where the less experienced welders can be assigned to work in less difficult positions and under more direct supervision. These areas are often used for on the job training where the welder's supervisors will learn whether or not a person can become a skilled welder.

It must be understood that welders who can successfully complete a test weld do not necessarily know or understand the sundry requirements imposed by codes, contract specifications, or welding procedure specifications. Clear communication of special data must occur so that welders perform properly on the job.

Welding supervisors should be sure that all welding personnel are qualified by their ability to exhibit an adequate knowledge of (1) the welding process, (2) the equipment used, and (3) the techniques involved. Likewise, welding personnel should be able to demonstrate their ability by making sound welds with the equipment involved.

Requalification of welding personnel is required when certain changes are made in procedure or when welding personnel have not been employed in welding for a specified length of time, three consecutive months in some cases. Welding supervisors should make certain that only qualified welders are assigned to production work.

**5.4 Inspection Methods.** Surface inspection is generally performed by using three methods, visual (VT), liquid penetrant (PT), and magnetic particle (MT). These methods may be designated by the designer, by the code or inspection specification, or by the local surveyor or inspector. These methods are used to locate and identify defects on the surface of the weld metal or base metal. Some methods of magnetic particle inspection can detect discontinuities slightly below, approximately 1/8 in. (3 mm), the surface of the metal.

The interiors of welds may be examined by radiography (RT), gamma ray or x-ray, and by ultrasonic testing (UT). These methods are used to locate and identify discontinuities below the surface of the weld metal in welds which are in highly stressed locations, e.g., the shearstrake, bilge, hatch corners and deck inserts within mid 3/5 length of the hull. Other locations are weld intersections, column joints, and connections on mobile offshore drilling units or at specific locations designated by the local surveyor or inspector.

With low alloy steels where delayed cracking is often a problem, nondestructive testing should be performed no sooner than 48 hours after the completion of welding.

**5.4.1 Visual Inspection.** Visual inspection (VT) is generally satisfactory for completed fillet welds. Such inspection should be accompanied by periodic checks of joint fit-up. A smooth weld surface, proper shape of fillets, lack of sharp undercuts at the toes, and freedom from craters at the ends of welds are good evidence that the fillet welds are satisfactory. The welds should also be checked for size, with gages where accuracy is important.

Groove welds in plates cannot be effectively judged solely by their surface appearance. However, inspecting the joint before it is welded can be effective in requiring the following items to be satisfactory: edge smoothness, cleanliness, plate alignment, groove angles, root opening, and root faces.

During welding, supervision is required to ensure that proper slag removal and cleaning are carried out between weld passes, by the welders.

In most joints of hull plates, the weld is deposited from both sides with the root of the first side chipped or gouged. In this case, visual inspection of the joint after back gouging will reveal any unfused areas, slag inclusions, or other root defects that may remain because of the failure to gouge deep enough.

**5.4.2 Subsurface Inspection.** This inspection is accomplished by radiography (RT) or by ultrasonic testing (UT). Inspection is concentrated in the more highly stressed deck and bottom shell areas. Generally, the number of locations inspected on a ship is 200 to 400 with more inspected locations on special purpose ships and other marine vessels.

**5.4.3 Radiography.** Radiographic testing (RT) is a widely accepted method for nondestructive examination. There are two basic sources of radiation: gamma rays, emitted by radioactive materials such as iridium 192 or cobalt 60, and x-rays. In either case, the rays pass through the weld and are recorded on a special film as a shadow picture. Only relative densities of the material are shown on the developed film. Cracks, porosity, slag inclusions, and incomplete fusion areas are indicated by darker areas, contrasting with the lighter areas which depict more dense, sound metal.

Inspection of plates up to approximately 1-1/2 in. (40 mm) thick is usually carried out with portable x-ray equipment and recorded on film 4-1/2 by 17 in. (115 by 430 mm) or 10 by 10 in. (250 by 250 mm). The immediate surrounding area must be roped off and conspicuously posted to keep workers from walking through the radiation zone.

Inspection of castings and plates over 1-1/2 in. (40 mm) is carried out by the use of gamma ray. The resulting radiographs have less contrast than x-ray results. Safety precautions are more stringent than those required for x-ray inspection.

Radiographic inspection evaluates porosity and entrapped slag more readily than does ultrasonic inspection. Therefore, radiography is preferred when discontinuities of this type are suspected. Ultrasonic inspection evaluates linear discontinuities more effectively than does radiography. Therefore, UT is preferred in evaluating this type of defect. Each inspection method has its advantages, and the shipbuilder in consultation with the customer and regulatory agency should agree on the appropriate inspection methods.

For ship-hull work, one exposure at a location is sufficient. However, in unusual cases, two may be employed, one being taken at right angles and the other inclined to the plate surface in line with the weld fusion line. Thus, fine cracks which may not show on one film can usually be detected on the other.

Numerous variables affect the resultant shadow picture. Some of these are radiation source, x-ray voltage, film type, material thickness, and the presence of weld reinforcement. All of these variables must be understood to interpret radiographs of production welds and evaluate the importance of any indication of a discontinuity.

In all cases, a penetrameter is used. A penetrameter is a strip of metal having a thickness of approximately 2% of the weld that is being inspected and is provided with drilled holes whose diameters are certain multiples of the thickness of the penetrameter. The image of the penetrameter is used to evaluate the sharpness of the image and the contrast between the image and the background of the film.

Typical shipyard x-ray equipment includes a transformer and control panel as well as an x-ray tube in a protective housing connected to the transformer by high-voltage cables. Additional equipment may be required to cool the tube. The x-ray tube is placed on one side of the weld. On the other side, the film is placed in its holder together with intensifying screens which increase the effectiveness of the technique.

Interpretation is usually left to the quality-control engineer and the regulatory agencies. Radiographs can be retained as a permanent record during the construction period and can be examined as desired.

Hull-weld radiographic acceptance standards have been established by the U.S. Navy and the American Bureau of Shipping. The U.S. Navy requirements are contained in the NAVSEA 0900-003-9000, *Radiographic Standards for Production and Repair Welds.* The ABS requirements are contained in its publication, *Rules for Nondestructive Inspection of Hull Welds.*

**5.4.4 Ultrasonic Testing.** In the past, ultrasonic testing (UT) was generally used in conjunction with radiography. Now, ultrasonic testing is increasingly used instead of radiography, and in some cases, has replaced radiography in the inspection of hull welds. Occasionally, a radiograph of a questionable area is taken for verification of ultrasonic testing results. Because interpretation of ultrasonic testing is rather difficult, it must be made by highly qualified personnel. Ultrasonic testing also helps to determine the extent of plate laminations, when present.

In radiography, a flat discontinuity, such as a crack, parallel to the plate surface can be picked up less easily, if at all, than a similar discontinuity perpendicular to the surface. Whereas this type of defect is readily detectable by ultrasonic testing, radiography is not used for detecting plate laminations.

The advantages of ultrasonic testing are that it may be done during regular working hours without having to clear the area of people to avoid radiation hazard thus not disrupting production, results are immediately available and work need not be delayed waiting to find out if rework is necessary.

The ABS requirements for ultrasonic inspection are contained in its *Rules for Nondestructive Inspection of Hull Welds*. The U.S. Navy has standards for ultrasonic testing in NAVSEA 0900-006-3010, *Ultrasonic Inspection Procedure and Acceptance Standards for Hull Structure Production and Repair Welds.*

**5.4.5 Magnetic Particle.** The magnetic particle (MT) method of inspection is used effectively after back gouging for the inspection of the roots of groove welds, although it is not as effective on the face of a weld where the weld surface is rather rough. This method is employed in the inspection of heavy welds in castings, and during casting repairs. It is also used in the examination of joint preparations in heavy weldments, castings, intermediate passes of multiple-pass welds, and surface conditions on castings, forgings, and plates. The magnetic particle method cannot be used on nonmagnetic materials.

In magnetic particle inspection, a magnetic field, established temporarily by the passage of an electric current, is interrupted by discontinuities at or very close to the surface of the magnetized material. Two large, metal prods, connected to an ac or dc power source, are placed on the surface to create the magnetic field. When fine magnetic particles are dusted on the surface, they will arrange themselves in the pattern of the magnetic field, outlining any interruptions in the magnetic field caused by discontinuities, located 1/8 in. (3 mm) or less from the metal surface.

**5.4.6 Liquid Penetrant.** Liquid penetrant testing is another method used to look for surface defects. It is used for the inspection of smooth surfaces such as machined parts, ship propellers, piping, and on parts made with nonmagnetic materials. Due to the portability of the materials used in this method of inspection, it is often used in relatively inaccessible areas of the ship or for inspections where the ship is in a remote location outside of a shipyard or port area.

Liquid-penetrant methods can be divided into two major groups; fluorescent penetrant testing and visible penetrant testing. Fluorescent means that the penetrant glows when illuminated by ultraviolet or "black light". The visible method uses a brightly colored dye that contrasts against a white developer background. Both offer good sensitivity when properly applied; however, if you can get the right conditions, fluorescent may have greater sensitivity.

**5.4.7 Other Methods.** There are several other methods of nondestructive testing which can be used although not often in shipbuilding. Eddy current testing (ET) is primarily used for testing piping and tubulars. It can be used on ferromagnetic and austenitic steels, copper alloy and nickel alloy tubular products. A common application is checking boiler tubes.

Acoustic emissions testing (AET) can detect crack formation during loading or thermal stressing of metals. It is used for the in-process monitoring of continuous or spot welding and for monitoring welds during proof testing.

Proof testing includes many of the common shipyard tests: hydrostatic testing, pneumatic testing, hose testing, chalk testing, etc. Leak testing can be done acoustically, with leak detection instruments called *calibrated sniffers*, with low-viscosity penetrating oils, or with vacuum boxes.

**5.4.8 Nondestructive Testing Personnel.** Qualification of personnel is one of the most important aspects of nondestructive testing. Qualification assures that the person performing the test method has proper knowledge and experience to apply the test and interpret the results. Most nondestructive testing personnel are qualified in accordance with the American Society for Nondestructive Testing (ASNT), *Recommended Practice No. SNT-TC-1A*. This document establishes the guidelines for education, training, experience, and testing requirements for various levels of competence.

The American Welding Society conducts examinations to determine the proficiency of welding inspectors and associate welding inspectors in accordance with AWS QCI, *Standard for Qualification and Certification of Welding Inspectors*. This qualification verifies that the inspectors of weldments have the knowledge to properly apply various codes and specifications.

**5.5 Welding Discontinuities.** The following are principal discontinuities found in welded joints:

(1) Inadequate joint penetration
(2) Incomplete fusion
(3) Undercut
(4) Slag inclusions
(5) Porosity
(6) Cracking
(7) Overlap

**5.5.1 Inadequate Joint Penetration.** Inadequate joint penetration describes the failure of the filler metal and base metal to fuse at the root of a welded joint. The following are causes of this type of discontinuity:

(1) Root face too great
(2) Root opening too small
(3) Groove angle of the weld too small
(4) Use of too large an electrode
(5) Insufficient welding current
(6) Insufficient back gouging

Careful back gouging is very important, as it can usually overcome all other causes of inadequate root penetration. Still, only a nominal amount will be required if skill and supervision are employed during welding.

Back gouging is usually accomplished by arc gouging or chipping. The use of ceramic backing usually eliminates back gouging and the defects associated with it, even in joints welded from both sides such as double V groove joints.

**5.5.2 Incomplete Fusion.** Incomplete fusion describes the failure of the weld metal to fuse at the root or sides of joints and may also occur between adjacent layers of weld metal.

Incomplete fusion is usually caused by poor fit-up, too low welding current, or mislocation of the arc. The arc provides heat for fusion, so if the arc is not sufficiently intense or is not brought sufficiently close to the joint sidewalls by the welder, incomplete fusion is likely to result. This condition is more likely to occur if only one side of the groove is beveled, with the other side remaining square. Inadequate removal of slag and weld spatter from the surfaces may also contribute to incomplete fusion, but it is seldom considered the primary cause.

**5.5.3 Undercut.** Undercut is a groove melted into the base metal adjacent to the toe or root of a weld that is left unfilled by weld metal. While slight undercut can be tolerated, excessive undercut must be repaired and is usually due to carelessness or lack of skill of the welder. Some types of electrodes show a greater tendency to undercut than others. With a given electrode, the tendency to undercut will be increased by too high a current or too long an arc. Surface undercut can usually be corrected by the deposition of additional metal. Undercut of the weld-groove sidewalls is normally filled up as the successive passes of weld metal are deposited. Excessive undercut in the sidewalls may lead to incomplete fusion and slag inclusion.

**5.5.4 Slag Inclusions.** Slag inclusions are nonmetallic material entrapped in weld metal or between weld metal and base metal in a welded joint and are usually associated with incomplete fusion of the underlying metal. Slag inclusions may occur along the bottom of crevices, along deep undercuts, or at sharp corners which interrupt the continuity of the welding operation. Accordingly, the factors which contribute to incomplete fusion also contribute to slag inclusions. These factors include inadequate skill in shaping and placing weld passes, low amperage, too narrow a groove, and insufficient cleaning of preceding weld passes. Small, widely dispersed slag inclusions are generally not considered detrimental.

**5.5.5 Porosity.** Porosity is the term used to describe the blow holes, voids, or gas pockets sometimes found in welds. A small amount of fine and widely scattered porosity does not have a serious effect on the mechanical properties of a welded joint. The prime source of porosity is a lack of cleanliness. Be sure the joint is clean before welding.

Porosity may be minimized by using proper welding current, travel speeds, and arc lengths. When using low-hydrogen electrodes, the welder should use relatively high welding currents and shorter arc lengths. The arc should be struck quickly and accurately, then immediately reduced to the required short length. Otherwise, cluster porosity will result at that point. Also, moisture content of the electrode covering must be kept low, and the weld areas must be dry and clean to keep porosity to the minimum.

Normally, the presence of a very thin coat of special priming paint is not objectionable. When the submerged arc process or low hydrogen electrodes are used, some specifications prohibit paint on the surfaces to be welded or require welding procedures to be qualified.

**5.5.6 Cracking.** Cracking of welded joints is a result of high, localized stress. Cracks may arise from various types of welding discontinuities, or improper welding conditions, such as too rapid cooling from the welding temperature, or unfavorable joint geometry. Additional precautions must be taken to avoid cracking under conditions involving thick sections of plates and highly restrained joints. Unless precautions are taken, cracking is more likely to occur during cold weather. Some precautions are the use of low-hydrogen electrodes, preheat, heat-confining procedures (such as cascade or backstep welding), and postheat.

Failure to back gouge adequately and clean the root pass of a groove weld will leave slag or voids in the weld, which weaken the joint and may cause cracking. To permit complete joint penetration, the root should be cleaned to sound weld and base metal. When the root opening is too great, the large amount of weld metal required to fill the root and the resultant excessive shrinkage may cause cracking. Metal should be built up on one or both sides to reduce the gap before the joint is bridged. Build up of plate edges in out-of-position welds in thin material can create defects. Metal backing, removed after welding, or ceramic backing should be used to provide support for root passes on gaps up to 1/4 in. (6 mm). In other cases, where multiple build-up passes are required, metal or ceramic backing is recommended. Cracked tack welds can also be a source of trouble if they are not removed.

Several types of cracks, classified by location and orientation, are shown in Figure 49. Weldment cracks may be classified by their location in the weldment. The different locations are weld metal, fusion line, and heat-affected zone. Weld metal cracks can be further classified as crater cracks, root cracks, or centerline cracks. The term *root crack* is also applied to heat-affected-zone cracks located at the root of the weld. A second specific type of heat-affected zone crack is an *underbead crack*, which is located in the heat-affected zone close to the fusion line and generally does not extend to the surface.

*Lamellar Tearing*, as shown in Figure 49, refers to a type of cracking which occurs within the plate below the weld and heat-affected zone. Lamellar tearing is associated with strains (created by welding shrinkage) which tend to pull the plate apart in the thickness direction, the

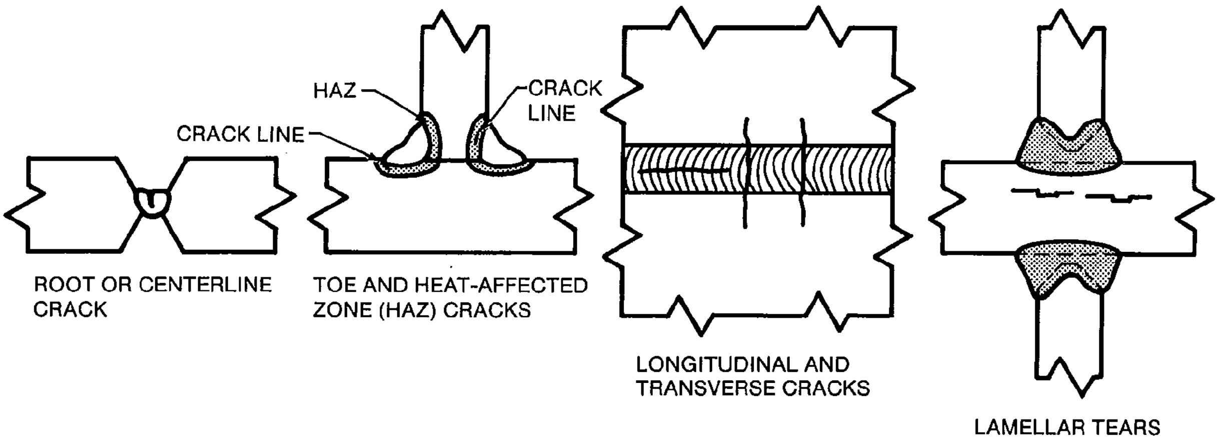



**Figure 49—Typical Weldment Cracks**

weakest direction of the plate. The cracks are parallel to the plate surface and have a characteristic stepped, lamellar appearance. Usually, these cracks develop during welding of highly restrained thick plates. The use of lower sulfur steel in recent years and introduction of nonmetallic inclusion shape control in the steel making process has greatly reduced the susceptibility of lamellar tearing in welded structures.

**5.5.7 Overlap.** Overlap is a sharp surface connected discontinuity that forms a severe mechanical notch, because the weld metal protrudes or flows beyond the toe or face of the weld without fusion. It is usually caused by incorrect welding procedures, wrong selection of welding materials, or improper preparation of the base metal prior to welding. If lightly adhering oxides on the base metal interfere with fusion, overlap will result along the toe, face, or root of the weld. Welds shall be free from overlap. It can be repaired by removing excess weld metal and carefully restoring an acceptable weld profile.

**5.6 Repair of Defects.** Extensively cracked sections of plating may need to be removed and replaced. The removal of large sections of plates or entire plates because of a small crack or defect is not justified. However, a larger area of plate should be renewed where fatigue is indicated by multiple fractures, star shaped fractures, or the fracture surface appears to have chevrons running along the surface. If proper welding procedures are followed in the repair, there is no need to renew more than approximately 3 ft (1 m) of plate near a defect, provided the remainder of the plate is sound.

If a plate crack is discovered, especially when the ship is afloat, a carefully located hole should be drilled immediately at the end of the crack to arrest its progress. Unless an inspection method such as magnetic particle or x-ray determines the end of the crack, the hole is usually drilled slightly beyond the visual crack on the surface since the portion of the crack at the plate mid-thickness may extend a short distance beyond the end portion of the crack as seen on the surface. A general rule of thumb for the drilled hole size is 1/2 the plate thickness, but not less than 3/8 in. (9.5 mm). The defective area should then be repaired with complete joint penetration groove weld.

Peening should not be used for correcting defective welds because it will not remove the defect's potential danger as a crack starter. Any crack found in a weld should be completely removed before repair is made.

Deep scars must be repaired by welding and grinding flush. Shallow scars can be faired in by grinding, provided the thickness is not reduced below acceptable limits. Scars left by removing clips with a maul can be troublesome, especially in the higher strength steels. The deep scars are created by the clip weld metal pulling out a portion of the plate surface. It is much better to remove clips by chipping or air arc gouging and grinding flush. Sometimes, clips or temporary pads are simply cut off approximately 1/8 in. (3 mm) from the plate surface without further treatment.

**5.7 Air Carbon Arc Process.** Although used for other purposes, the air carbon arc process is often used in the repair of welds and cracks in ship structure. The principle of the air carbon arc process is the striking of an electric arc between a carbon graphite electrode held in a specially designed torch, and the simultaneous removal of the molten metal by a blast of compressed air from nozzles contained in the head of the torch. (See Figure 50.)

The major applications for the process are (1) removal of cracked welds, (2) gouging out cracks in ships' structures, (3) "U" groove preparation of seams for welding, and (4) back gouging the roots of welds. Another common use is the removal of fillet welds from pad eyes, strong backs, and other temporary fabrication aids.

Most of the work is done with manual torches and 3/16 in. (5 mm), 1/4 in. (6 mm), 5/16 in. (8 mm). and some 3/8 in. (9 mm) diameter pointed dc electrodes (see Figure 50). AC electrodes are available, if required. Automatic torches capable of producing "U" grooves with a depth tolerance of 3/64 in. (± 1 mm) can be mounted on heavy-duty carriages for flat work, such as deck plates, or on all position travel carriages for vertical, horizontal, and overhead applications (see Figure 51). Standard ac and dc constant current power sources can be used for all electrode sizes, whereas dc constant voltage power sources are recommended for 1/4 in. (6 mm) and larger electrode diameter sizes.

Figure 50—Air Carbon Arc Torch

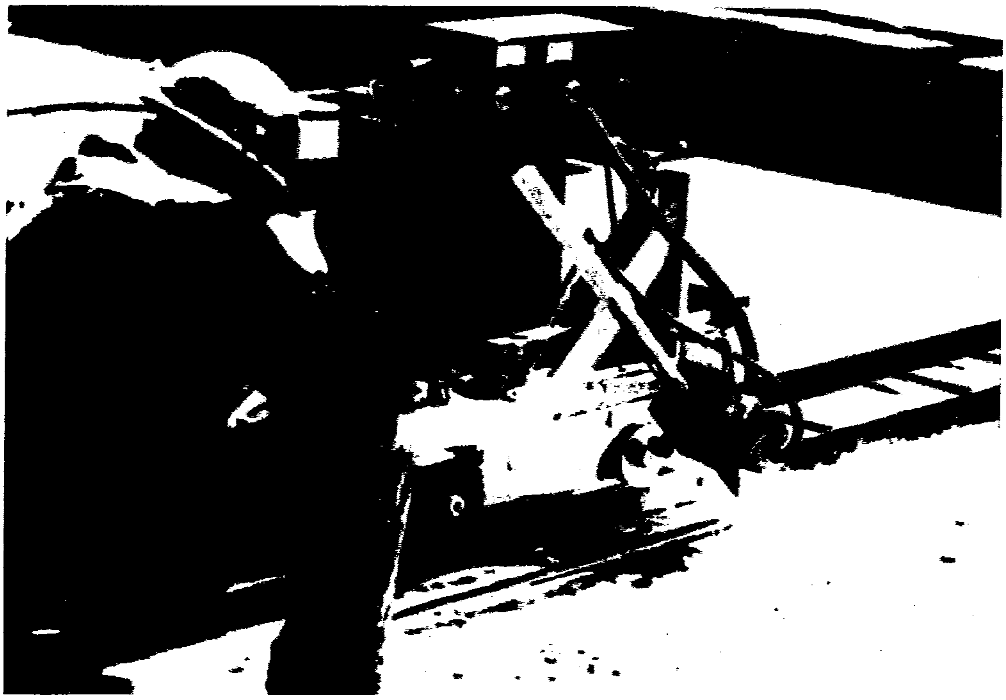


Figure 51—Air Carbon Arc Torch Mounted on Carriage for Flat Work

# 6. Stray Current Protection[4]

## 6.1 Underwater Corrosion

**6.1.1** Underwater hull and shaft corrosion is mainly attributable to improper hookup of welding leads while work is being performed on ships which are waterborne. Corrosion resulting from improper weld-lead hookup is induced through electrolytic action by stray electrical currents.

**6.1.2** Corrosion of a ship hull may result from other sources of direct currents. If a grounded neutral (negative ground in Edison 3-wire system) leg of a three-wire direct current system, used to supply power to the ship, is grounded permanently or accidently on the ship, current flow will result, as shown in Figure 52.

**6.2 Current Flow.** Current flow is caused by the difference in electrical potential between any two localities. Even though the path through water offers greater resistance to current flow than adjoining electric ground (work lead) cable, water still will carry a fraction of the current and create an undesirable condition. See Figure 53.

**6.3 Welding Equipment Requirements.** To prevent possible serious damage to electrical and ordnance equipment, and pitting of ship structure, special requirements for welding on ships, both waterborne and in dry or floating docks, shall be used. The requirements are as follows:

(1) Each ship should have a separate welding current power source.

(2) Work lead of any welding generator shall never be connected to anything but the ship the generator is serving.

(3) Work and electrode leads shall be completely insulated and not permitted to drop overboard into the water.[5]

(4) The frame or case of the welding machine shall be connected to a safety electric ground cable according to the methods prescribed in the National Electrical Code (primary side). This is shown in Figures 56–60 as the equipment ground and shall be electrically isolated from the ground (work lead) terminal on the generator or rectifier.

**6.4 Grounding (Work Lead) Connections.** Historically, the term *ground* has been used to refer to the work lead and its connections; this is unfortunate. The use of the term to mean work lead or work connections is misleading. *Ground* in the National Electrical Code means "...a conducting connection, whether intentional or accidental, between an electrical circuit and the earth, or some conducting body that serves in place of the earth." American National Standard Z49.1 states, in part, in 11.3.2.1, "...The work lead is not the ground lead." Shipyard jargon continues to perpetuate the misleading usage of the term *ground.* We have attempted to correct this situation in the following paragraphs.

**6.4.1 Cable Lugs.** Grounding (work lead) cable lugs shall be secured tightly to grounding (work lead) plates. The lug contact area shall be cleaned thoroughly to base metal. Resistance of the connection should be a maximum of 125 micro-ohms for each connection; voltage drop across the connection should be a maximum of 62.5 millivolts for a current of 500 amps except as outlined in paragraph 6.4.2.

**6.4.2** Electrical measurement at lug contact area need not be made on board ships which are part of the forces afloat, provided welding is to be accomplished using a single-operator dc machine using shipboard power. All other rules of grounding (work lead connection) given in 6.3 through 6.4 shall be strictly enforced.

**6.4.3 Cable Size.** Cross-sectional areas of return ground cable (work lead) should be one million circular mils minimum for each 1000 amps for each 100 feet. One or more cables, connected in parallel, may be used to meet the minimum cross-sectional area requirement. A nomograph showing required cable size for ground (work lead) return leads is presented in Figure 54.

**6.4.4** Manufacturers' recommendations for electrode lead-cable size shall be used. Lead-cable size is approximately 500 000 circular mils for each 1000 amps for each 100 feet. A nomograph showing copper electrode lead-cable size is presented in Figure 55.

**6.4.5 Resistance.** Resistance between welding (work lead) ground cable and the welding machine case should not be less than 0.1 megohms when the machine is not connected to the ship. Resistance less than 0.1 megohms will indicate improper insulation of the welding (work lead) ground cable, or a need to clean the welding machine.

**6.4.6 Welding Unit Arrangements.** Combinations of welding unit arrangements with correct and incorrect grounding (work lead) connections are shown in Figures 56 through 60. These figures represent common arrangements and errors in making welding machine connections.

4. These data are excerpted from NAVSEA S9086-CH-STM-010/CH-074 VI.

5. The return side of the circuit, called the *ground connection* in shipbuilding, is the *work lead,* so defined in ANSI/AWS A3.0, *Standard Welding Terms and Definitions.*

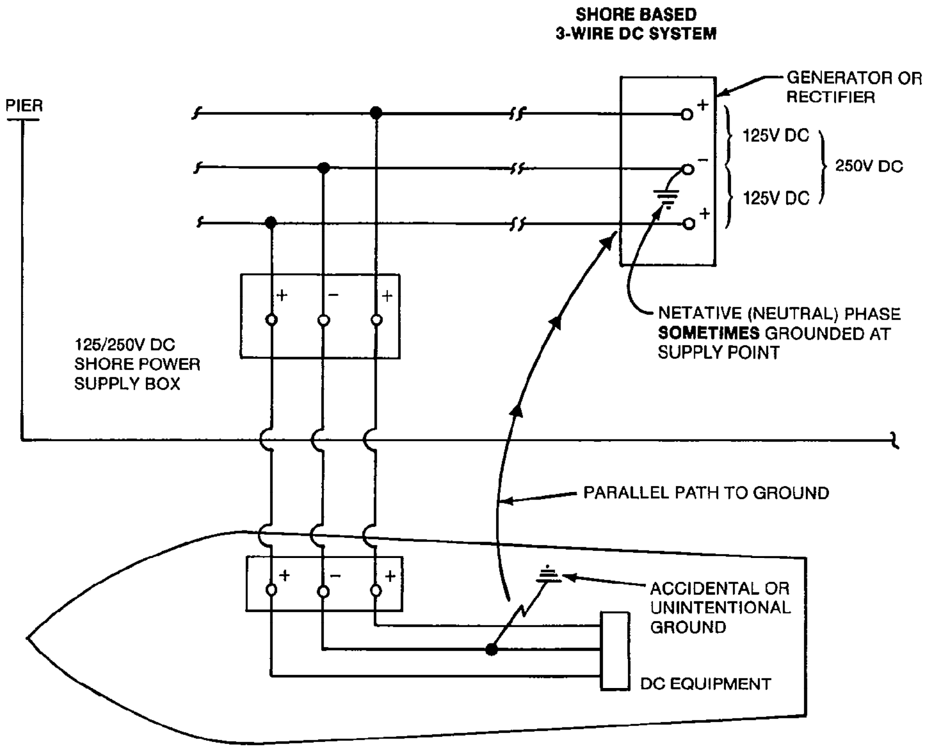



**Figure 52—Potential Source of Direct Currents Causing Corrosion Due to Accidental or Unintentional Ground on Vessel**

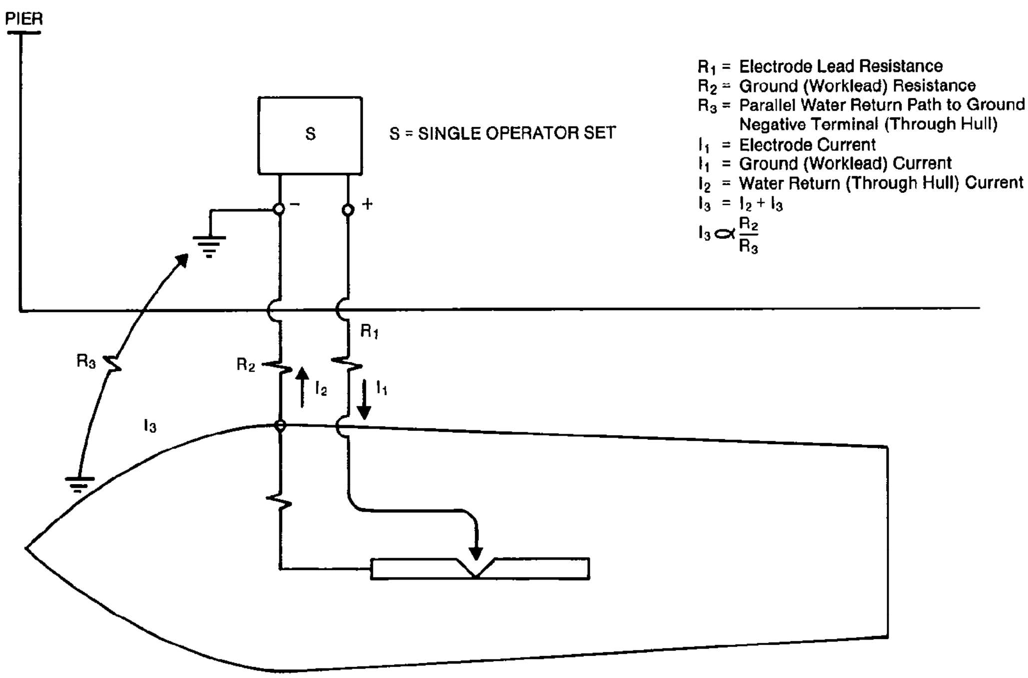
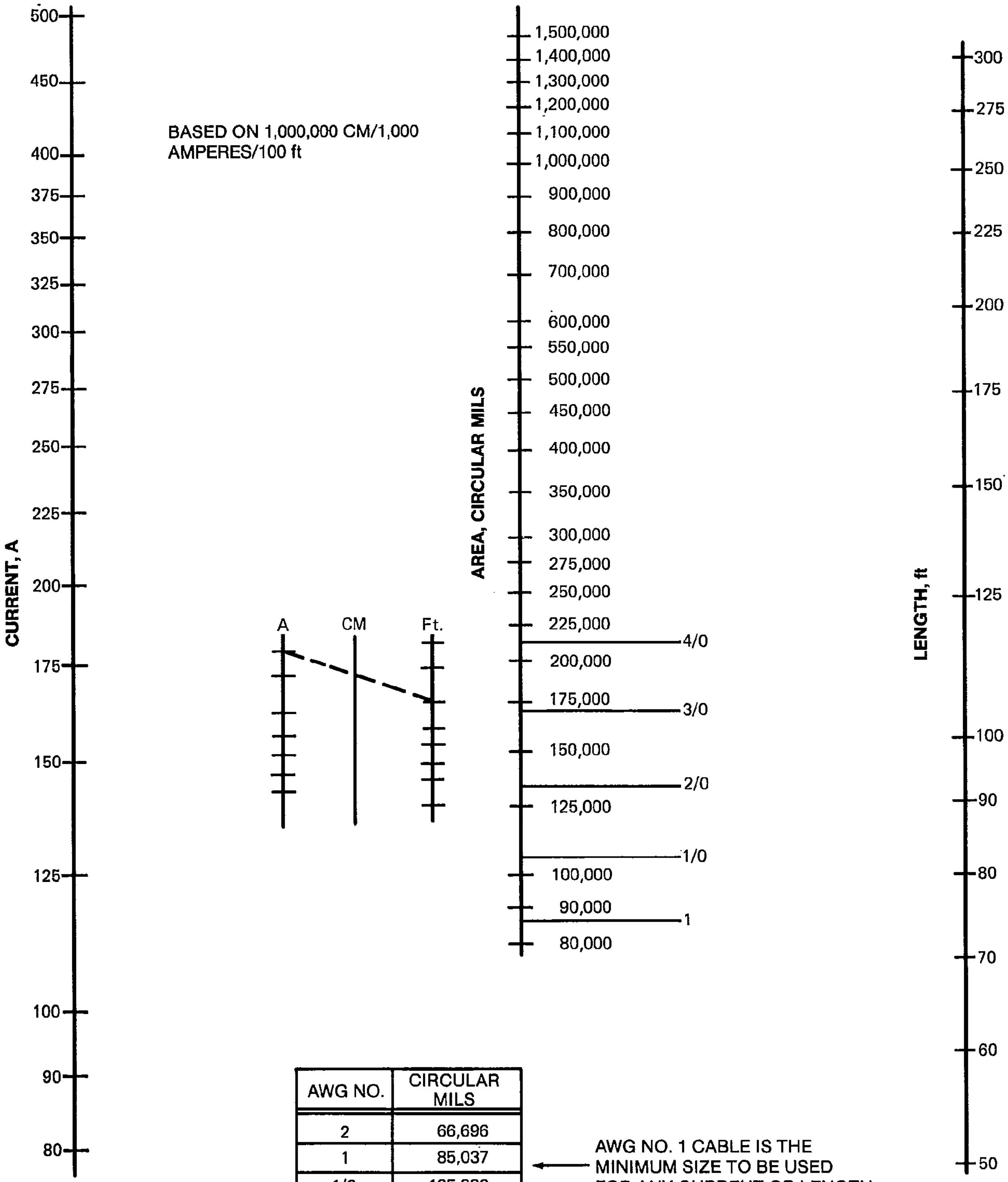


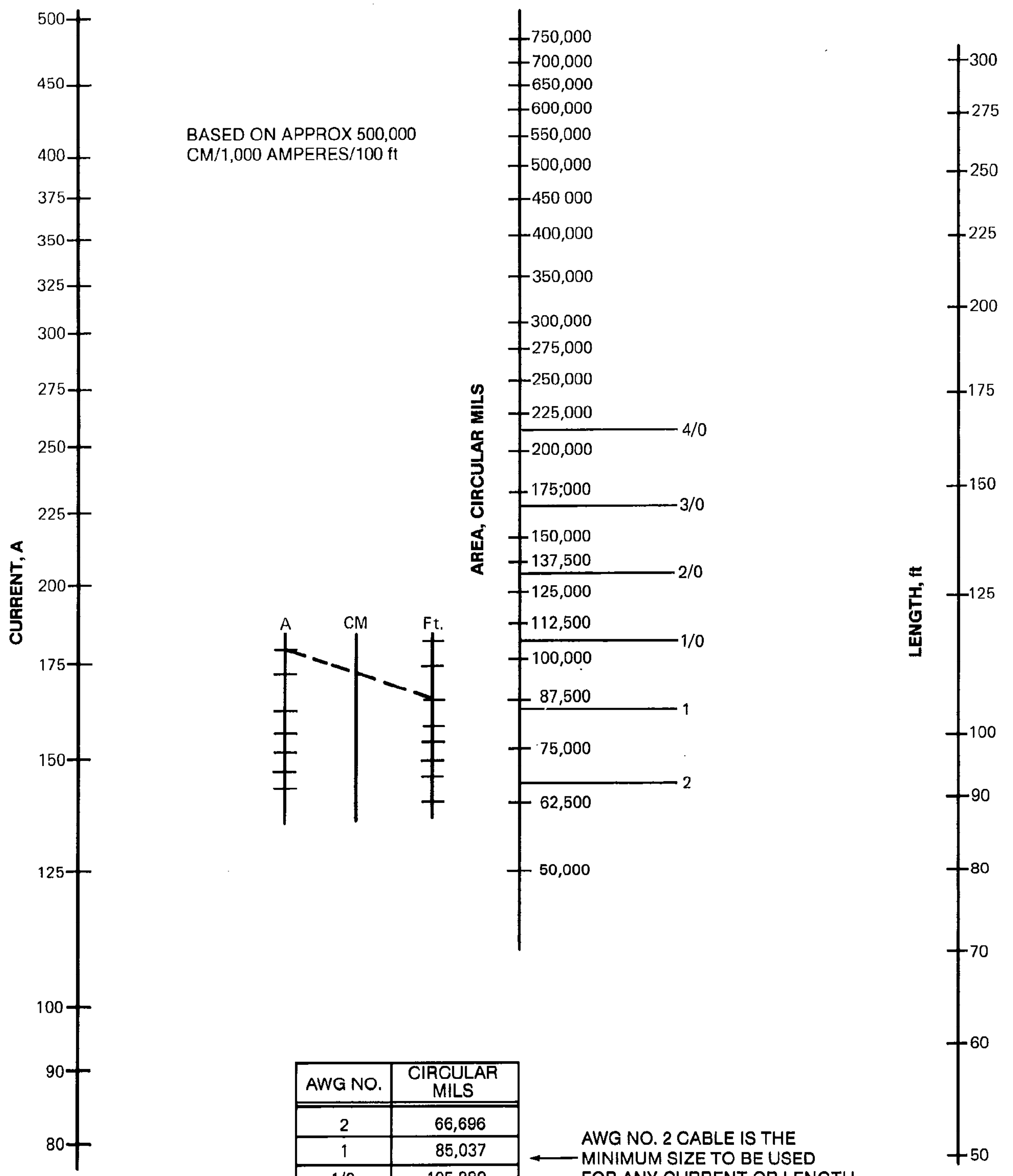

**Figure 53—Equivalent Circuit for Improperly Connected Generator or Rectifier**




| AWG NO. | CIRCULAR MILS |
|---|---|
| 2 | 66,696 |
| 1 | 85,037 |
| 1/0 | 105,880 |
| 2/0 | 133,392 |
| 3/0 | 169,519 |
| 4/0 | 212,594 |

← AWG NO. 1 CABLE IS THE MINIMUM SIZE TO BE USED FOR ANY CURRENT OR LENGTH

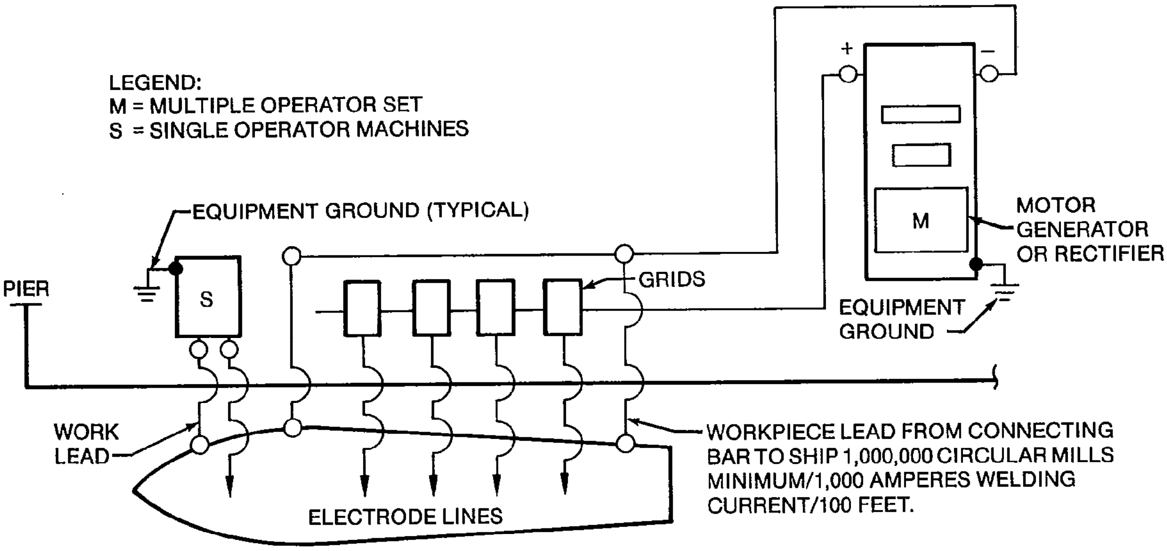
**Figure 54—Nomograph for Copper Ground (Work Lead) Wire Size**




| AWG NO. | CIRCULAR MILS |
|---|---|
| 2 | 66,696 |
| 1 | 85,037 |
| 1/0 | 105,880 |
| 2/0 | 133,392 |
| 3/0 | 169,519 |
| 4/0 | 212,594 |

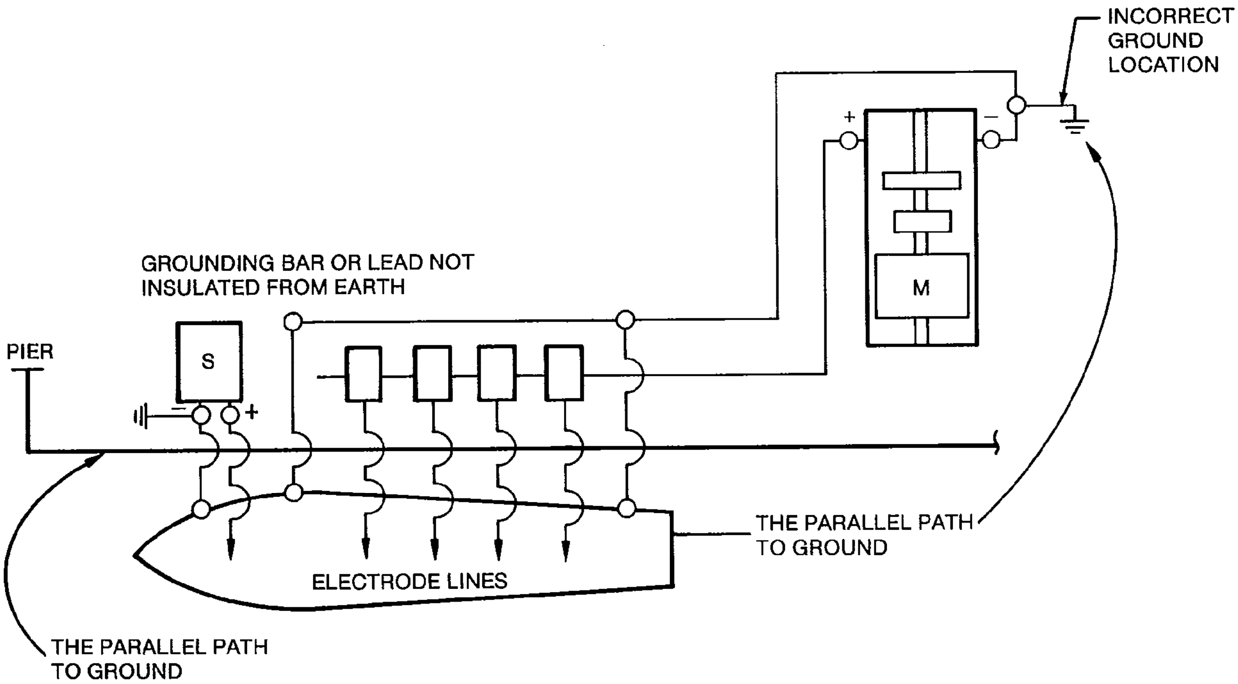
AWG NO. 2 CABLE IS THE MINIMUM SIZE TO BE USED FOR ANY CURRENT OR LENGTH

**Figure 55—Nomograph for Copper Electrode Lead Cable Size**




NOTE: CONNECTING BAR OR LEAD SHALL BE INSULATED FROM EARTH, CASE OF MACHINE, AND OTHER STRUCTURES, BE OF SUFFICIENT CROSS-SECTIONAL AREA TO CARRY THE WELDING CURRENT, AND SHOULD REMAIN ABOVE WATER WITH TIDE CHANGES OR SHIP MOVEMENTS.

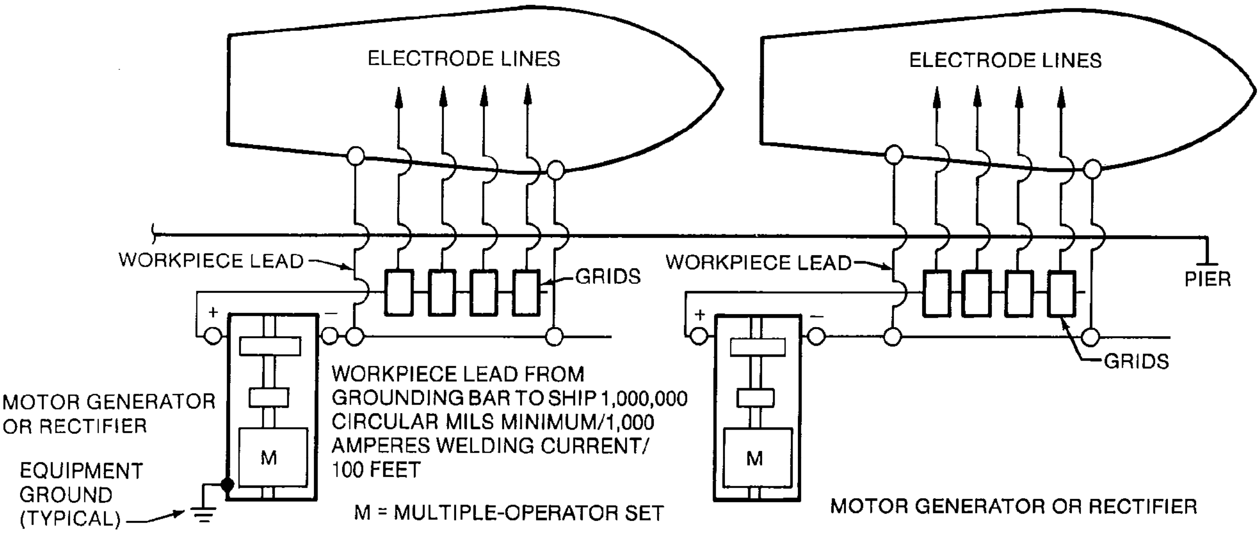
**CORRECT**




NOTE: WITH NEGATIVE SIDE OF GENERATOR OR RECTIFIER GROUNDED, PART OF THE WELDING CURRENT FLOWS FROM THE SHIP'S HULL TO THE WATER AND EVENTUALLY REACHES THE NEGATIVE SIDE OF THE GENERATOR OR RECTIFIER.

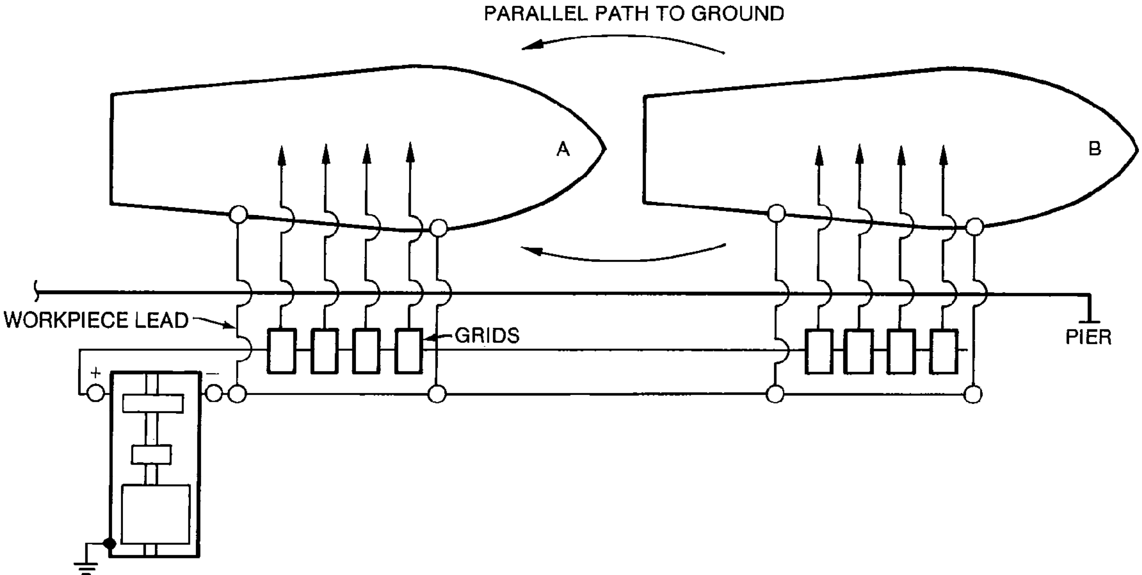
**INCORRECT**

**Figure 56—Hookup for Single Ship at Pier**




NOTE: WELDING ON TWO OR MORE SHIPS (IN CASE OF MULTIPLE-OPERATOR MACHINE) SHOULD NOT BE PERFORMED WITH THE SAME GENERATOR OR RECTIFIER.

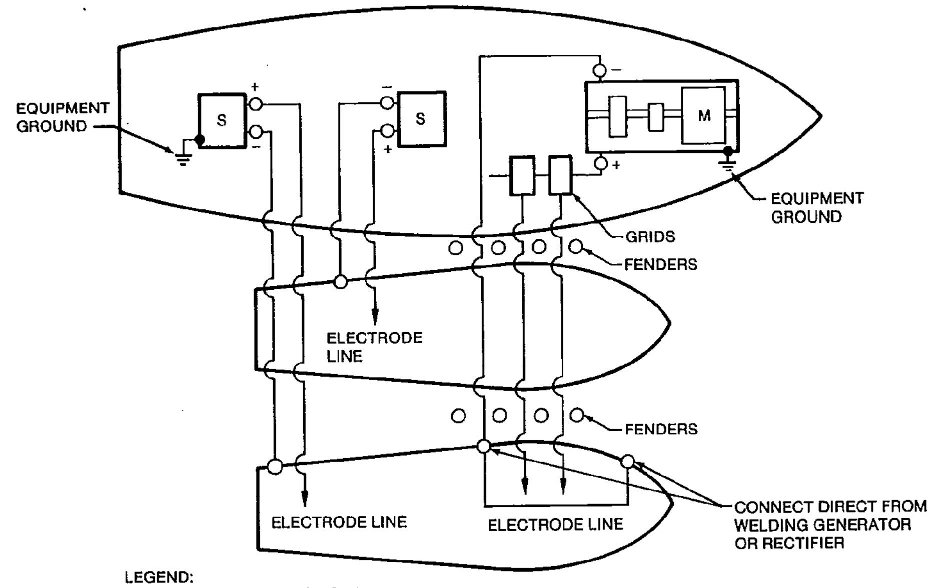
**CORRECT**




NOTE: WHEN TWO SHIPS ARE CONNECTED TO THE SAME GENERATOR OR RECTIFIER, THE RESISTANCE OF THE NEGATIVE RETURN BETWEEN THE SHIPS CANNOT BE MADE LOW IN COMPARISON WITH THE RESISTANCE THROUGH THE WATER. SOME OF THE CURRENT USED ON SHIP B FLOWS THROUGH THE WATER, CORRODING METAL OFF SHIP B AND POSSIBLY BLISTERING PAINT ON SHIP A.

**INCORRECT**

**Figure 57—Hookup for Two Ships at Pier**

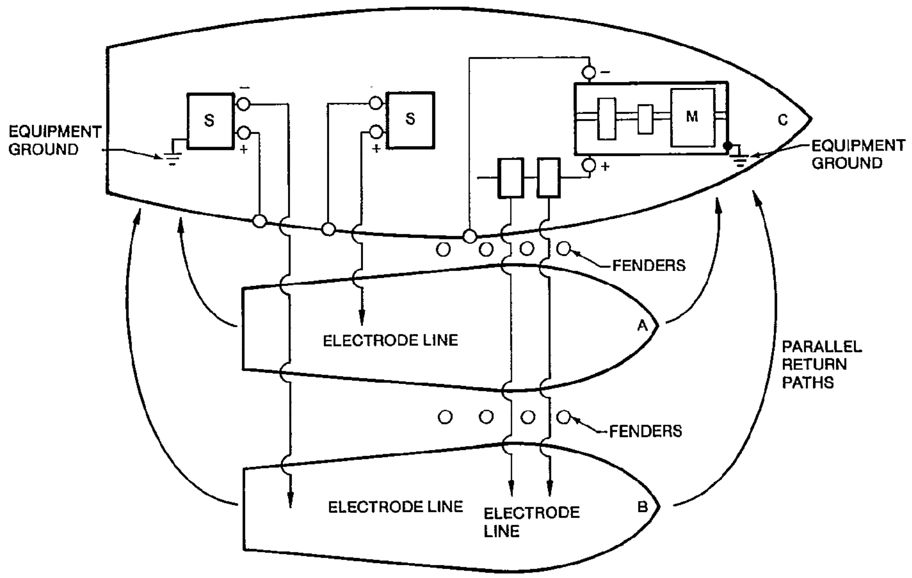



LEGEND:
M = MULTIPLE-OPERATOR SET
S = SINGLE-OPERATOR SET

NOTES:
1. FOR SINGLE OPERATOR MACHINES, ATTACH THE WORKPIECE LEAD AS CLOSE AS PRACTICAL TO STRUCTURE OR COMPONENT TO BE WELDED.
2. WELDING ON TWO OR MORE SHIPS (IN CASE OF A MULTIPLE-OPERATOR MACHINE) SHOULD NOT BE PERFORMED WITH THE SAME GENERATOR OR RECTIFIER.

CORRECT

**Figure 58—Hookup for Ships Afloat (Sheet 1 of 2 Sheets)**




LEGEND: M = MULTIPLE-OPERATOR SET
S = SINGLE-OPERATOR SET

NOTE: WHEN THE GENERATOR OR RECTIFIER ON ONE SHIP GROUNDED TO THAT SHIP IS USED TO WELD ON ANOTHER SHIP WHICH IS WITHOUT A WORK LEAD GROUND OR IS IMPROPERLY GROUNDED, ALL OR PART OF THE WELDING CURRENT RETURNS FROM SHIPS A AND B TO SHIP C THROUGH THE WATER.

INCORRECT

**Figure 59—Hookup for Ships Afloat (Sheet 2 of 2 Sheets)**

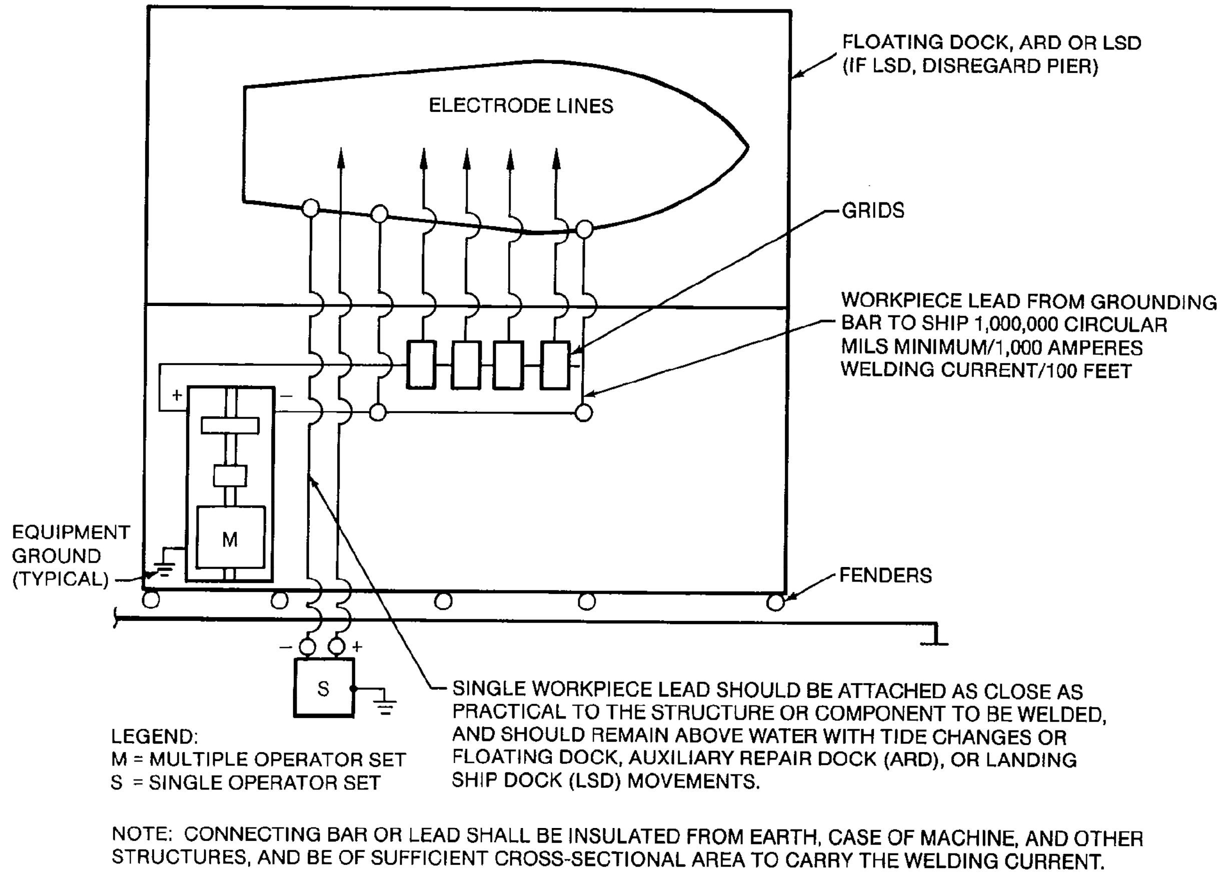



**Figure 60—Hookup for Ship in Floating Docks or ARD or LSD**

**6.4.7** Details for making provisions for welding (work lead) grounding connections on steel surface ships and submarines are shown in Figures 61 and 62.

**6.4.8** These minor modifications for welding grounding (work lead) connections can be accomplished when authorized by the U.S. Navy supervisors. Because electrical currents have the tendency of running to structural points, two grounding (work lead) cables should be used when multiple operator sets are being used or welding is necessary in several locations throughout the vessel. The grounding (work lead) cables should be located as close to the bow and stern as practical.

**6.4.9** For ships constructed of nonmagnetic materials, ground-return (work lead) cable shall be connected directly to the component being welded. Work lead cables shall be located as close to the weld zone as possible.

**6.5 Special Precautions**

*Note: For welding on or near electrical equipment, machinery, or ordnance equipment, special precautions shall be observed. Precautions listed in 6.5.1 through 6.5.5 shall be followed for welding equipment electrical connections when welding on or near electrical or loaded ordnance equipment.*

**6.5.1 Welding Current.** Electrical equipment (case) grounding straps on electrical equipment, machinery, and ordnance equipment have not been designed for, and shall not be used as, welding ground (work lead) returns. Welding current shall not be allowed to pass through bearings (ball, roller, or brushing type) to return to grounds such as gun mounts, motors, and lathes.

**6.5.2 Splitting Ground-Return (Work Lead) Cables.** When welding on piping which leads into loaded

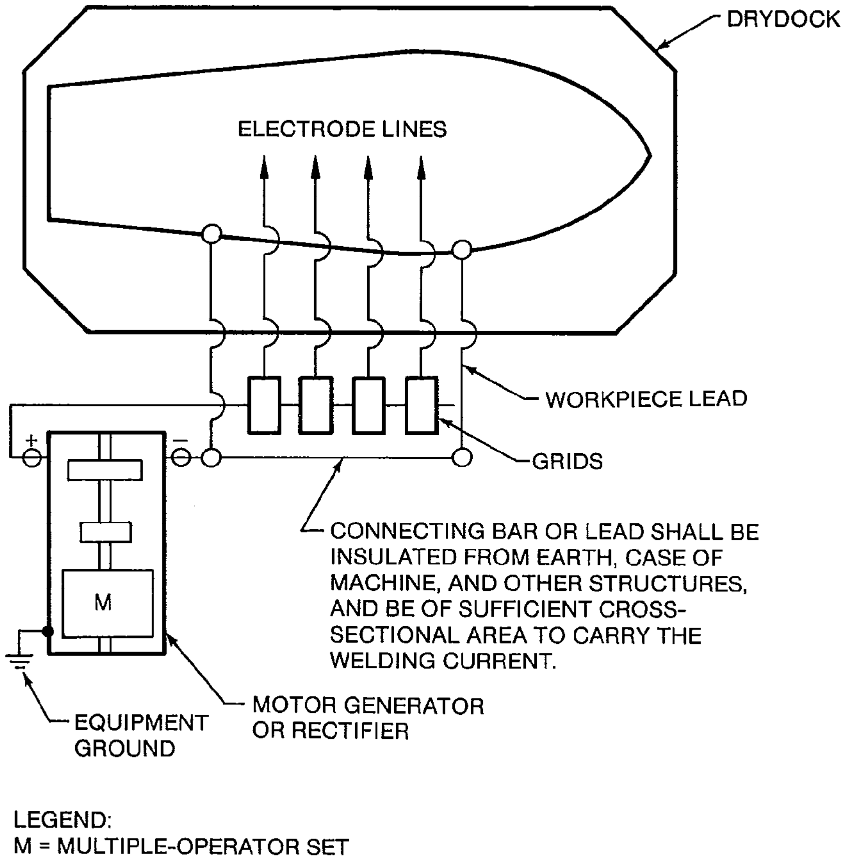



**Figure 61—Hookup for Ships in Dry or Graving Dock**

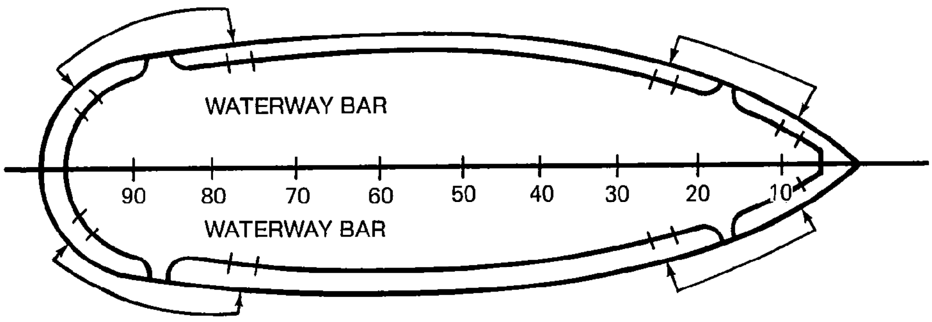
ordnance equipment areas, ground-return (work lead) cables should be split into two equal ground-return cables, connected to the pipe on each side of the welding areas, and located as close to the area as possible. If pipe hangers or branch pipes are located between the dual ground (work lead) connections, additional split-ground connections should be provided to such items. A maximum distance of 10 feet should be maintained between connectors and work. See ANSI/ASC Z49.1, *Safety in Welding and Cutting*, latest edition, for additional restrictions.

**6.5.3 Resistance Checks.** Ensure adequacy of ground-return (work lead) cable connections between ship hulls and power source by checking resistance of the connection, which shall be a maximum of 125 micro-ohms for each connection, or the voltage drop across the connection should be a maximum of 25 millivolts for a current of 200 amps.

**6.5.4** Ensure that ground-return (work lead) cables are adequate for amperage and distance involved (see Figure 54).

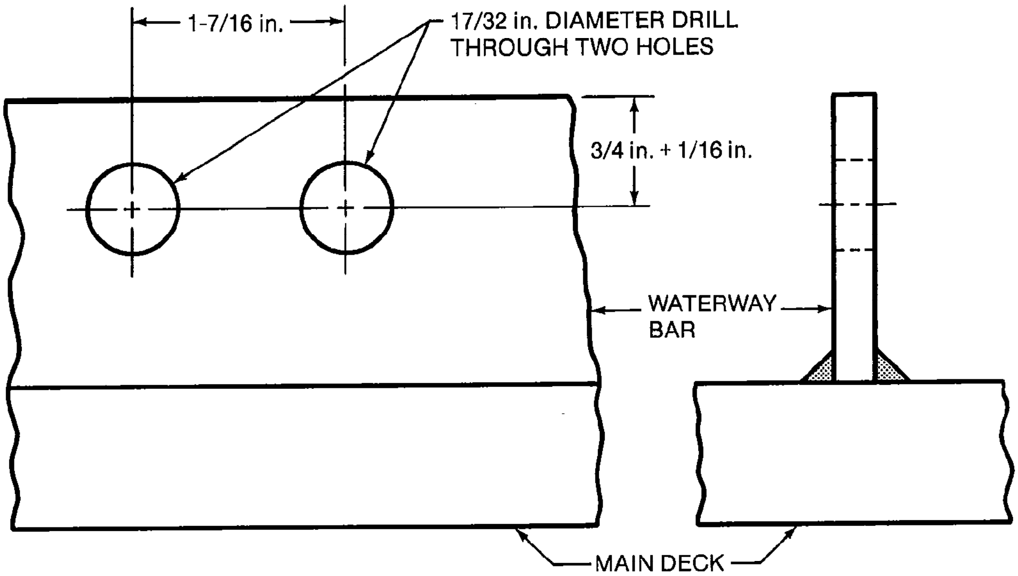
**6.5.5** Precautionary measures outlined in manufacturers' equipment manuals and other documents should be observed when welding on or near electrical equipment. These measures should be observed because the induced magnetic field produced by welding may damage electrical equipment.

**6.5.6 Location of Ground-Return (Work Lead) Cables.** When welding on systems such as piping, pressure vessels, or machinery, the ground-return (work lead) cable connection should be located as close to the work as possible. This ensures that welding current does not flow through bearings, threaded joints, and other areas where arcing could occur. Cable connections should be no farther than 10 feet from work.




MAIN DECK STEEL HULL

NOTES:
1. LOCATE HOLES IN AREAS INDICATED BY ARROWS.
2. ON STEEL HULLS WITH NO WATERWAY BAR, DRILL HOLES IN DECK COAMINGS.
3. CLEAN LUG CONTACT AREA TO BARE METAL WHEN WORKPIECE CONNECTIONS ARE MADE. (WHEN WORKPIECE CONNECTIONS ARE BROKEN, THE AREA SHALL BE PAINTED TO MATCH THE SURROUNDING DECK.)
4. WITHIN 6 INCHES OF LUG CONTACT AREA, PAINT IN BLACK, 3/4 INCH HIGH LETTERS: WORKPIECE CONNECTION AREA.




TYPICAL HOLE SPACING, GROUNDING LUG ATTACHMENT

NOTES:
1. HOLES ARE TO BE DRILLED AT LOCATIONS SHOWN ABOVE.
2. WHERE POSSIBLE, MODIFY AND UTILIZE EXISTING HOLES IN WATERWAY BARS.

**Figure 62—Grounding (Work Lead) Connections on Steel Surface Ships**

# 7. Safety

**7.1 Introduction.** In welding, safety precautions always apply to the process being used, the equipment, the welder's physical and mental condition, the type and condition of the welder's clothing, shop or yard conditions, and other factors. Welding safety also is affected by the material being welded which may generate hazardous fumes and gases.

Before starting to weld, be sure the area is well ventilated, and the welder has the correct personal protective equipment including respirator, eye, ear and body protection as required by government regulations or company safety procedures, or both, and that the welder is wearing this equipment properly. Protect the welder and those who are in or who could enter the work area.

When welding or other hot-working operations are to be performed in areas not normally assigned for such operations or in or adjacent to spaces where hot work could cause a fire or explosion, a hot-work permit system and a trained fire watch should be used. The purpose of this system is to alert supervisors and workers to an extraordinary danger of fire and explosion that can exist at a particular time and place. The system should have a check list of precautions that should include an examination of the area or space by a marine chemist, as outlined in 29 CFR 1915, Subpart B — Explosive and other Dangerous Atmospheres, or other cognizant party to determine that hot work can take place. A notice that hot work is permitted should be prominently displayed in the area or at the entrance to the space. Safety instructions should also be given to personnel in the area who are not involved in the hot work.

**7.2 Fumes and Gases.** Many welding, cutting and allied processes produce fumes and gases which may be harmful to health. Fumes are solid particles which originate from welding consumables, the base metal, and any coatings present on the base metal. Gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. The amount and composition of these fumes and gases depend upon the composition of the filler metal and base material, welding process, current level, arc length and other factors.

The possible effects of over-exposure range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever. The possibility of more serious health effects exists when especially toxic materials are involved. In confined spaces, the gases might displace breathing air and cause asphyxiation.

Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases from the breathing zone and general area. In some cases, natural air movement will provide enough ventilation. Where ventilation may be questionable, air sampling should be used to determine if corrective measures should be applied. The welder should at all times endeavor to keep his head out of the fume plume.

Refer to the following sources for more detailed information on fumes and gases produced by the various welding processes:

(1) The permissible exposure limits required by OSHA can be found in CFR Title 29, Chapter XVII, Part 1910, OSHA General Industry Standards, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

(2) The recommended threshold limit values for these fumes and gases may be found in *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*, published by the American Conference of Governmental Industrial Hygienists (ACGIH), 6500 Glenway Avenue, Building D-5, Cincinnati, Ohio 45211.

(3) The results of an AWS-funded study are available in the report entitled *Fumes and Gases in the Welding Environment*, published by the American Welding Society, 550 N.W. LeJeune Rd., Miami, FL 33126.

**7.3 Radiation.** Welding, cutting and allied operations may produce radiant energy (radiation) harmful to health.

Radiant energy may be ionizing (such as x-rays) or nonionizing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage, depending on the radiant energy's wavelength and intensity, if excessive exposure occurs.

The intensity and wavelengths of nonionizing radiant energy produced depend on many factors such as the process, welding parameters, electrode and base metal composition, fluxes, and any coating or plating on the base material. Most arc welding and cutting processes (except submerged arc when used properly), laser welding and torch welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Protection from possible harmful effects caused by nonionizing radiant energy from welding include the following measures:

(1) Do not look at welding arcs except through welding filter plates which meet the requirements of Z87.1, *Practice for Occupational and Educational Eye and Face Protection*, published by American National Standards Institute.

(2) Protect exposed skin with adequate gloves and clothing as specified in ANSI Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society.

(3) Beware of reflections from welding arcs, and protect all persons from intense reflections. (Note: Paints

using pigments of substantially zinc oxide or titanium dioxide have a low reflectance for ultraviolet radiation.)

(4) Avoid exposing passersby to welding operations by use of screens, curtains, or adequate distance from aisles, walkways, etc.

(5) Safety glasses with UV protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

**7.4 Electrical Hazards.** Electric shock can kill. However, it can be avoided. Do not touch live electrical parts. Read and understand the manufacturer's instructions and recommended safe practices. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

Ground all electrical equipment and the workpiece. The work lead is not a ground lead. It is used only to complete the welding circuit. A separate connection is required to ground the workpiece. Do not mistake the work lead for a ground connection.

Use the correct cable size, since sustained overloading will cause cable failure and result in possible electrical shock or fire hazard. Make sure all electrical connections are tight, clean and dry. Poor connections can overheat and even melt. Further, they can produce dangerous arcs and sparks. Do not allow water, grease or dirt to accumulate on plugs, sockets, or electrical units. Moisture can conduct electricity. To prevent shock, keep work area, equipment, and clothing dry at all times. Wear dry gloves, rubber soled shoes, or stand on a dry board or insulated platform.

Keep cables and connectors in good condition. Improper or worn electrical connections may set up conditions that could cause electrical shock or short circuits. Do not use worn, damaged, or bare cables. Avoid open circuit voltage.

When several welders are working with arcs of different polarities, or when a number of alternating current machines are being used, the open circuit voltages can be additive. The added voltages increase the severity of the shock hazard.

In case of electric shock, turn off the power. If the rescuer must resort to pulling the victim from the live contact, use nonconducting materials. If the victim is not breathing, administer cardiopulmonary resuscitation (CPR) as soon as contact with the electrical source is broken. Call a physician and continue CPR until breathing has been restored or until a physician has arrived. Treat electrical burns as thermal burns; that is, apply clean, cold (iced) compresses. Prevent contamination and cover with a clean, dry dressing. Call a physician.

**7.5 Fire Prevention.** Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause fire or explosion if precautionary measures are not used.

Many of the fires associated with welding, cutting, and applied processes have been caused by sparks which can travel up to 35 ft (10.7 m) in a horizontal direction from the work area. Sparks can pass through or become lodged in cracks, clothing, pipe holes, and other small openings in floors or partitions. (Note: sparks and molten metal can travel greater distances when falling.)

Typical combustible materials commonly involved in the fires are floors, partitions, roofs, and building contents such as wood, paper, clothing, plastics, chemical and flammable liquids and gases. Outdoors, the combustible materials involved are dry leaves, grass, and brush. Explosions have occurred where welding or cutting has been performed in spaces containing flammable gases, vapors, liquids, or dusts.

Remove any combustible material from the work area. Where possible, move the work to a location well away from combustible materials. If neither action is possible, protect combustibles with a cover of fire resistant material. Remove or make safe all combustible materials for a radius of 35 ft (10.7 m) around the work area. All open doorways, windows, cracks, and other openings should be covered or blocked with fire resistant material.

If possible, enclose the work area with portable fire resistant screens. Protect combustible wall, ceilings, etc. from sparks and heat with fire resistant covers. If work is to be performed on a metal wall, ceiling, etc., prevent ignition of combustibles on the other side by moving the combustibles to a safe location. If this cannot be done, designate someone to serve as a fire watch, equipped with a fire extinguisher during the welding operation and for one half-hour after welding is completed. At the expiration of one half-hour after completion of welding, an inspection of the area should be made.

Welding or cutting should not be performed on material having a combustible coating or combustible internal structure, as in walls or ceilings, without an approved method for eliminating the hazard. Do not dispose of hot slag in containers holding combustible material. Keep a fire extinguisher nearby. Make a thorough examination for evidence of fire. Remember that easily visible smoke or flame may not be present for some time after the fire has started.

Overloading and improper sizing can cause overheating of electrical equipment. Be sure all electrical equipment and wiring is installed properly with recommended circuit protection.

Be sure the work cable is connected to the work as close to the welding areas as practical. Work cables connected to locations some distance from the welding area increase the possibility of the welding current passing through lifting chains, crane cables or other alternate circuits. This can create fire hazards or overheat lifting chains or cables until they fail.

Do not weld or cut in atmospheres containing dangerously reactive or flammable gases, vapors, liquids, or dust. Do not apply heat to a container that has held an unknown substance or a combustible material whose contents when heated knee produce flammable or explosive vapors. Heat should not be applied to a workpiece covered by an unknown substance or whose coating can produce flammable, toxic, or reactive vapors when heated. Adequate procedures should be developed and proper equipment used to do the job safely. Provide adequate ventilation in work areas to prevent accumulation of flammable gases, vapors, or dusts. Clean and purge containers before applying heat.

Closed containers, including castings, should be vented before preheating, welding or cutting. Venting will prevent the buildup of pressure and possible explosion due to the heating and the resultant expansion of gases.

**7.6 OSHA Regulations.** The OSHA regulations that govern shipbuilding, ship breaking, and ship repairing safety practices are found in the *Code of Federal Regulations*, Title 29, Chapter XVII, Part 1915, *Shipyard Employment Safety Standards (Proposed) 1988*, which covers all occupational safety and health standards for shipyard employment, and Subpart D deals with welding, cutting, and heating in situations involving shipyard personnel. Title 29CRF 1910–Subpart Q, *Welding, Cutting and Brazing for General Industry* no longer applies to shipyard work, but it is applicable to the manufacture of shipyard components in other manufacturing plants.

This technical document does not address all welding safety and health hazards. However, pertinent information can be found in Appendix C and in the following documents:[6]

(1) *National Electric Code*, published by the National Fire Protection Association.

(2) *Practice for Occupational and Educational Eye and Face Protection*, ANSI Z87.1, published by the American National Standards Institute.

(3) *Safety in Welding and Cutting*, ANSI Z49.1, published by the American Welding Society.

(4) *Standard for the Installation and Operation of Oxygen-Fuel Gas Systems for Welding and Cutting*, NFPA No. 51, published by the National Fire Protection Association.

(5) *Standard for Fire Prevention in the Use of Cutting and Welding Processes*, NFPA No. 51B, published by the National Fire Protection Association.

(6) *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*, published by the American Conference of Governmental Industrial Hygienists.

(7) *Standard Welding Terms and Definitions*, AWS A3.0, published by the American Welding Society.

(8) Manufacturers' safety literature on equipment and materials.

(9) Other pertinent documents as appropriate.

These documents shall be referred to and followed as required.

Each shipyard, welding contractor, and the owners must determine independently whether or not the safety precautions referenced in the publications identified in section 7 and Appendix C are adequate.

6. The locations of document publishers are listed in Appendix A.

# Appendix A

## Codes and Specifications

(This Appendix is not a part of ANSI/AWS D3.5-93, *Guide for Steel Hull Welding*, but is included for information purposes only.)

Agencies publishing codes and specifications, recommended practices, materials standards, weld tests, and other documents applicable to welded steel ship structure, including safety and health information, are listed below:

American Bureau of Shipping
45 Eisenhower Drive
P.O. Box 910
Paramus, NJ 07653-0910

American Conference of Governmental Industrial Hygienists
6500 Glenway Avenue — Building D-5
Cincinnati, OH 45211

American National Standards Institute
1430 Broadway
New York, NY 10018

America Optometric Association
243 N. Lindbergh Blvd.
St. Louis, MO 63141

American Society for Metals
Metals Park, OH 44073

American Society for Mechanical Engineers
345 East 47th Street
New York, NY 10017

American Society for Nondestructive Testing
4153 Arlingate Plaza
Columbus, OH 43228

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

American Welding Society
550 N.W. LeJeune Road
P.O. Box 351040
Miami, FL 33135

Contact Lens Association of Opthomologists
3620 Jena Street
New Orleans, LA 70115

National Fire Protection Association
Batterymarch Park
Quincy, MA 02169

National Institute for Occupational Safety and Health
4676 Columbia Parkway
Cincinnati, OH 45226

National Safety Council
444 N. Michigan Ave.
Chicago, IL 60611

Society of Naval Architects and Marine Engineers
601 Pavonia Avenue
Jersey City, NJ 07306

Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

Commandant (G-MTH)
United States Coast Guard
2100 Second Street, S.W.
Washington, DC 20593

U. S. Federal Food and Drug Administration
5600 Fishers Lane
Rockville, MD 20857

United States Navy
Naval Sea Systems Command
NAVSEA 05M2 Crystal City
Washington, DC 20362

Pertinent governmental and commercial specifications and references are given in the following comprehensive, but not necessarily complete, list:

**Military**

| | |
|---|---|
| MIL-STD-248 | Welding and Brazing Procedure and Performance Qualification |
| MIL-STD-271 | Nondestructive Testing Requirements for Metals |
| MIL-STD-410 | Nondestructive Testing Personnel, Qualification and Certification |
| MIL-STD-0022 | Welded Joint Design |
| MIL-STD-1689 | Fabrication, Welding and Inspection of Ships Structure |
| MIL-R-45774 | Radiographic Inspection, Weld Soundness Standards |
| MIL-S-16216 | Steel Plate, Alloy, Structural, High Yield Strength (HY-80 and HY-100) |
| MIL-S-24113 | Steel Plates and Shapes, Welding Ordinary Strength and Higher Strength: Hull Structural |
| MIL-W-10430 | Preparation for Delivery of Welding Rods and Electrodes |
| NAVSEA 0900-003-9000 | Radiograph Standards for Production and Repair Welds |

**Governmental or Industrial Specifications**

| | |
|---|---|
| ASME Boiler and Pressure Vessel Code, Section IX | Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators |
| **American Bureau of Shipping** | ABS Rules for Nondestructive Inspection of Hull Welds |
| | ABS Rules for Building and Classing Steel Vessels |
| | ABS Approved Welding Electrode, Wire Flux, and Wire Gas Combinations |

**American Welding Society**

| | |
|---|---|
| AWS B2.1 | Welding Procedure and Performance Qualification |
| AWS A2.4 | Standard Symbols for Welding. Brazing and Nondestructive Examination |
| AWS A3.0 | Standard Welding Terms and Definitions |
| AWS B4.0 | Standard Methods for Mechanical Testing of Welds |
| AWS D10.9 | Standard for Qualification of Welding Procedures and Welders for Piping and Tubing |
| U.S. Coast Guard | Title 46 Code of Federal Regulations |

# Appendix B

# Glossary

(This Appendix is not a part of ANSI/AWS D3.5-93, *Guide for Steel Hull Welding*, but is included for information purposes only.)

### Shipbuilding Terms

**beam.** Any main member supporting deck plating. Beams usually run from side to side of a vessel and are fastened to the frames.

**bulb angle.** A rolled structural steel member with a large mconcentration of metal, or a "bulb" at the toe of one leg of the angle. When used as a plate stiffener, the leg with the bulb is usually the outstanding leg. It has a high moment of inertia-to-weight ratio.

**bilge.** The rounded portion of a vessel's shell which connects the bottom with the sides.

**bulkhead.** A term applied to any of the partition walls used for subdividing the interior of a ship or marine vessel into the various compartments. Some serve as strength members of a ship's structure and as a barrier to liquids or fluids passing from one compartment to another.

**bulwark.** A term applied to the strake of shell plating above a weather deck.

**butt.** The end of a plate, structural shape, or pipe which comes squarely against the end of another plate, structural shape, or pipe or the joint thus formed. A **BUTT** is a transverse or vertical plate edge connection in the shell, bulkhead or deck plating. A **BUTT** is perpendicular to a seam (see also **butt joint** and **seam**).

**butt joint.** In United States shipbuilding the term **butt joint** is used as defined in ANSI/AWS A3.0: A joint between two members aligned approximately in the same plane. In shipbuilding the term *butt weld* is applied both to ends of plates (butts) and to lengthwise edge joints of plating (seams).

**coamings, hatch.** Raised framework about deck openings. Coamings prevent water from running below, and strengthen the deck around the hatch.

**deck.** A deck corresponds to a floor in a building.

**fashion plate.** A transition piece used to avoid abrupt structural discontinuities where high stresses in decks and strakes must be transferred to ship's main hull girder as in transfer from super structure to main deck or sheerstrake.

**floor.** A plate placed vertically in the bottom of a ship, usually on every frame running from bilge to bilge.

**frame.** A term used to designate one of the transverse members that make up the riblike part of the skeleton of a ship.

**girder.** On ships, this term is generally applied to continuous beams running in a fore and aft direction under the decks which support deck beams and decks.

**hold.** Space or compartment below decks allotted for the storage of cargo.

**hull.** The structural body of a ship including shell plating, framing, decks, bulkheads, etc.

**hull girder.** That part of the hull structural material effective in the longitudinal strength of the ship as a whole, which may be treated as analogous to a girder.

**innerbottom.** Plating forming the top of the double bottom also called the tank top.

**intercostal.** The opposite of continuous, usually applied to the member which is cut at the intersection of two members.

**keel.** A centerline strength member running fore and aft along the bottom of the ship.

**longitudinal.** Fore and aft member attached to the underside of decks or flats or to the inboard side of shell plating.

**seam.** Fore and aft butt joint of shell plating, deck and tank top plating, or a lengthwise edge joint of any plating. A **seam** is perpendicular to a **butt**; (see also **butt**, **butt joint**, and **seam weld**).

**seam weld.** (From ANSI/AWS A3.0) 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 surface of one member. The continuous weld may consist of a single weld bead or a series of overlapping spot welds.

**stanchion.** Vertical column supporting decks, flats and girders.

**strake.** A continuous row of shell, deck, bulkhead or other plating, for example:

**bilge strake.** A strake of the outside plating running in way of the bilge.

**sheer strake.** The strake of shell plating that runs along the level of the main deck.

**strength deck.** The deck that is designed as the uppermost part of the main hull longitudinal strength girder.

**strongback.** A piece of plate or special tool used to align the edges of plates to be welded together.

### Steel Terms

**alloy steel.** Steel is considered to be an alloy steel when either (1) the maximum of the range given for the content of alloying elements exceeds one or more of the following: manganese 1.65, silicon 0.60, copper 0.60; or (2) a definite range or definite minimum quantity of those elements considered as alloys is specified.

**annealing.** A thermal cycle involving heating to and holding at a suitable temperature and then cooling at a suitable rate for such purposes as reducing hardness, improving machinability, facilitating cold working, producing a desired microstructure, or obtaining desired mechanical or other properties.

**carbon steel.** By common custom, steel is considered to be carbon steel when no minimum content is specified or required for aluminum, boron, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium or any other element added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40%; or when the maximum content specified for any of the following elements does not exceed the percentages: manganese 1.65, silicon 0.60, copper 0.60. Small amounts of alloying elements may be present and are considered as incidental.

**controlled cooling.** A process by which steel is cooled from an elevated temperature in a predetermined manner to avoid hardening, cracking, or internal damage, or to produce desired microstructure or mechanical properties.

**control rolling.** A rolling practice that improves mechanical properties by controlling the related parameters of time-temperature and deformation.

**creep.** A time-dependent deformation of steel occurring under conditions of elevated temperature accompanied by stress intensities well within the apparent elastic limit for the temperature involved.

**ductility.** The ability of a material to deform plastically without fracturing, usually measured by elongation or reduction of area in a tension test, or, for flat products such as sheet, by height of cupping in an Erichsen test.

**elastic limit.** The greatest stress that a material can withstand without permanent deformation.

**elongation.** A measure of ductility, determined by the amount of permanent extension achieved by a tension-test specimen, and expressed as a percentage of that specimen's original gage length (such as 25% in 2 in.).

**full annealing.** A thermal treatment for steel with the primary purpose of decreasing hardness. It is accomplished by heating above the transformation range, holding for the proper time interval, and controlled slow cooling to below that range. Subsequent cooling to ambient temperature may be accomplished either in air or in the furnace.

**grain size number.** An arbitrary number which is calculated from the average number of individual crystals, or grains, which appear on the etched surface of a specimen at 100 diameters magnification.

**hardness.** The resistance of a material to plastic deformation. Usually measured in steels by the Brinell, Rockwell, or Vickers indentation-hardness test methods.

**high strength, low alloy steels.** A specific group of steels with chemical compositions especially developed to impart higher mechanical properties and in certain instances improved atmospheric corrosion resistance relative to conventional carbon steel. It is not considered to be an alloy steel as previously described even though utilization of any intentionally added alloy content would technically qualify it as such.

**impact test.** A test for determining the ability of a steel to withstand high-velocity loading, as measured by the energy, in ft-lb, which a notched-bar specimen absorbs upon fracturing.

**mechanical properties.** Properties which reveal the reactions, elastic and inelastic, of a material to applied forces. Sometimes designated erroneously as "physical properties." Physical properties are the structure-insensitive properties such as density, thermal conductivity, electrical conductivity, etc. Mechanical properties are structure-sensitive properties such as tensile strength, yield strength, Charpy V-notch energy, etc.

**notch toughness.** An indication of a steel's capacity to absorb energy when a stress concentrator or notch is present.

**normalizing.** A thermal treatment consisting of heating to a suitable temperature above the transformation range and then cooling in still air. Usually employed to improve toughness or machinability, or as a preparation for further heat treatment.

**quenching and tempering.** A thermal process used to increase the hardness and strength of steel. It consists of austenitizing, then cooling at a rate sufficient to achieve partial or complete transformation to martensite. Tempering should follow immediately, and involves reheating to a temperature below the transformation range and then cooling at any rate desired. Tempering improves ductility and toughness but reduces the quenched hardness by an amount determined by the tempering temperature used.

**reduction of area.** A measure of ductility determined by the difference between the original cross-sectional area of a tension test specimen and the area of its smallest cross section at the point of fracture. Expressed as a percentage of the original area.

**strain aging.** Deformation of rimmed or capped steel followed by storage of several days at slightly higher than room temperature for the purpose of increasing the yield and tensile strengths.

**stress relieving.** A thermal cycle involving heating to a suitable temperature, usually 1000° to 1200°F, holding long enough to reduce residual stresses from either cold deformation or thermal treatment, and then cooling slowly enough to minimize the development of new residual stresses.

**tensile strength.** The maximum tensile stress in pounds per square inch which a material is capable of sustaining, as developed by a tension test.

**thermal treatment.** Any operation involving the heating and cooling of a metal or alloy in the solid-state to obtain the desired microstructure or mechanical properties.

**toughness.** An indication of a steel's capacity to absorb energy that is related to the area under the true stress-strain curve.

**transformation ranges.** Those ranges of temperatures within which austenite forms during heating and transforms during cooling.

**transformation temperature.** The temperature at which a change in phase occurs. The term is sometimes used to denote the limiting temperature of a transformation range.

**yield point.** The minimum stress at which a marked increase in strain occurs without an increase in stress as indicated by a sharp knee in the stress-strain curve.

**yield strength.** The stress at which a material exhibits a specified deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain, and in the offset method, usually a strain of 0.2 percent is specified.

### Welding Terms

**active flux.** (submerged arc welding). A flux which contains small amounts of manganese or silicon, or both, added to improve the weld in certain single-pass applications. Change in arc voltage or the number of weld passes can significantly change weld-metal chemistry and mechanical properties.

**alloy flux.** (submerged arc welding). A flux which contains alloy ingredients intended to modify the weld metal chemistry. Changes in arc voltage can significantly change weld metal chemistry.

**all-weld-metal test specimen.** A test specimen with the reduced section composed wholly of weld metal.

**arc gouging.** An arc cutting process variation used to form a bevel or groove.

**as-welded.** The condition of weld metal, welded joints, and weldments after welding, but prior to any subsequent thermal, mechanical, or chemical treatments.

**back gouging.** The removal of weld metal and base metal from the other side of a partially welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.

**backing.** A material or device placed against the back side of the joint, or at both sides of a weld in electroslag and electrogas welding, to support and retain molten weld metal. The material may be partially fused or remain unfused during welding and may be either metal or nonmetal.

**backing weld.** Backing in the form of a weld.

**complete fusion.** Fusion which has occurred over the entire base material surfaces intended for welding and between all adjoining weld beads.

**complete joint penetration.** A penetration by weld metal for the full thickness of the base metal in a joint with a groove weld.

**complete joint penetration groove weld.** A groove weld which has been made from both sides or from one side on a backing having complete penetration and fusion of weld and base metal throughout the depth of the joint.

**consumable guide electroslag or electrogas welding.** An electroslag or electrogas process variation in which filler metal is supplied by an electrode(s) and its (their) guiding member(s).

**continuous weld.** A weld that extends continuously from one end of a joint to the other. Where the joint is essentially circular, it extends completely around the joint.

**crater.** A depression at the termination of a weld bead.

**defect.** A discontinuity or discontinuities that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability.

**discontinuity.** An interruption of the typical structure of a weldment such as a lack of homogeneity in the mechanical or metallurgical or physical characteristics of material or weldment. A discontinuity is not necessarily a defect.

**electrogas welding (EGW).** An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode, and the weld pool and work. Molding shoes are used to confine the molten weld metal for vertical position welding. The electrodes may be either flux cored or solid. Shielding may or may not be obtained from an externally supplied gas or mixture.

**electroslag welding (ESW).** A welding process that produces coalescence of metals with molten slag that melts the filler metal and the surfaces of the workpieces. The weld pool is shielded by this slag which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc that heats the slag. The arc is then extinguished by the conductive slag, which is kept molten by its resistance to electric current passing between the electrode and the workpieces.

**flat position.** The welding position used to weld from the upper side of the joint when the face of the weld is approximately horizontal.

**flaw.** A near synonym for discontinuity, but with an undesirable connotation.

**flux.** A material used to hinder or prevent the formation of oxides and other undesirable substances in molten metal and on solid metal surfaces, and to dissolve or otherwise facilitate the removal of such substances.

**flux cored arc welding (FCAW).** An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work. Shielding is provided by a flux contained within the tubular electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.

**fusion.** The melting together of filler metal and base metal (substrate), or of base metal only, which results in coalescence.

**gas metal arc welding (GMAW).** An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the workpiece. Shielding is obtained entirely from an externally supplied gas.

**groove angle.** The total included angle of the groove between workpieces.

**heat-affected zone.** That portion of the base metal which has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, or cutting.

**horizontal position**

**fillet weld.** The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.

**groove weld.** The position of welding in which the weld axis lies in an approximately horizontal plane and the weld face lies in an approximately vertical plane.

**intermittent weld.** A weld in which the continuity is broken by recurring unwelded spaces.

**interpass temperature.** In a multipass weld, the temperature of the weld before the next pass is started.

**joint.** The junction of members or the edges of members that are to be joined or have been joined.

**joint root.** 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, a line, or an area.

**joint welding procedure.** The materials and detailed methods and practices employed in the welding of a particular joint.

**neutral flux (submerged arc welding).** A flux which will not produce significant changes in weld metal chemistry as a result of large changes in arc voltage.

**overhead position.** The position in which welding is performed from the underside of the joint.

**overlap.** The protrusion of weld metal beyond the weld toe or weld root.

**partial joint penetration.** Joint penetration that is intentionally less than complete.

**peening.** The mechanical working of metals using impact blows.

**porosity.** Cavity-type discontinuities formed by gas entrapment during solidification.

**postweld heat treatment.** Any heat treatment after welding.

**preheating.** The application of heat to the base metal immediately before welding, brazing, soldering, thermal spraying, or cutting.

**procedure qualification.** The demonstration that welds made by a specific procedure can meet prescribed standards.

**shielded metal arc welding (SMAW).** An arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the workpiece. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

**shielding gas.** Protective gas used to prevent atmospheric contamination.

**spatter.** The metal particles expelled during fusion welding that do not form a part of the weld.

**stringer bead.** A type of weld bead made without appreciable weaving motion.

**submerged arc welding (SAW).** An arc welding process that produces coalescence of metals by heating with an arc or arcs between a bare metal electrode or electrodes and the workpieces. The arc and molten metal are shielded by a blanket of granular, fusible material on the workpieces. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

**tack weld.** A weld made to hold parts of a weldment in proper alignment until the final welds are made.

**T-joint.** A joint between two members located approximately at right angles to each other in the form of a T.

**tubular.** Tubular products is a generic term for a family of hollow section products of various cross-sectional configuration. The term *pipe* denotes cylindrical products to differentiate from square and rectangular hollow-section products. However, a tube or tubing can also be cylindrical.

**tubular connection.** A connection in the portion of a structure that contains two or more intersecting members, at least one of which is a tubular member.

**tubular joint.** A joint in the interface created by one tubular member intersecting another.

**undercut.** A groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

**vertical position.** The position of welding in which the axis of the weld is approximately vertical.

**weave bead.** A type of weld bead made with transverse oscillation.

**weld.** A localized coalescence of metals or nonmetals produced either by heating the materials to the welding temperature, with or without the application of pressure, or by the application of pressure alone and with or without the use of filler metal.

**weldability.** The capacity of a material to be welded under the imposed fabrication conditions into a specific, suitable designed structure and to perform satisfactorily in the intended service.

**welder certification.** Certification in writing that a welder has produced welds meeting prescribed standards.

**welder performance qualification.** The demonstration of a welder's ability to produce welds meeting prescribed standards.

**weld face.** The exposed surface of a weld on the side from which welding was done.

**welding operator.** One who operates machine or automatic welding equipment.

**welding procedure.** The detailed methods and practices including all joint welding procedures involved in the production of a weldment.

**welding sequence.** The order of making the welds in a weldment.

**weldment.** An assembly whose component parts are joined by welding.

**weld pass.** A single progression of welding or surfacing along a joint or substrate. The result of a pass is a weld bead, layer, or spray deposit.

**weld reinforcement.** Weld metal in excess of the quantity required to fill a joint.

**weld root.** The points, as shown in cross section, at which the back of the weld intersects the base metal surfaces.

**weld size**

**fillet weld size.** For equal leg fillet welds, the leg lengths of the largest isosceles right triangle which 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 within the fillet weld cross section.

**groove weld size.** The minimum distance between the weld root and the surface of the weld exclusive of reinforcement in partial joint penetration welds; the thickness of the thinner part joined in complete joint penetration welds.

*Note: When one member makes an angle with the other member greater than 105 degrees, the leg length (size) is of less significance than the effective throat which is the controlling factor for the strength of a weld.*

**weld toe.** The junction of the weld face and the base metal.

# Appendix C

# Safety

(This Appendix is not a part of ANSI/AWS D3.5-93, *Guide for Steel Hull Welding*, but is included for information purposes only.)

## C1. Fumes and Gases

Many welding, cutting and allied processes produce fumes and gases which may be harmful to health. Fumes are solid particles which originate from welding consumables, the base metal, and any coatings present on the base metal. In addition to shielding gases that may be used, gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. You — the reader — should acquaint yourself with the effects of these fumes and gases. The amount and composition of these fumes and gases depend upon the composition of the filler metal and base material, welding process, current level, arc length and other factors.

The possible effects of over-exposure range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever. The possibility of more serious health effects exist when highly toxic materials are involved. In confined spaces, the gases might displace breathing air and cause asphyxiation.

Keep your head out of the fume plume. Use enough ventilation exhaust at the arc, or both, to keep fumes and gases from your breathing zone and general area. In some cases, natural air movement will provide enough ventilation. Where ventilation may be lacking corrective measures should be applied.

Refer to the following sources for more detailed information on fumes and gases produced by the various welding processes:[1]

(1) The permissible exposure limits (PEL) required by OSHA can be found at CFR Title 29, Chapter XVII, Part 1910. The OSHA General Industry Standards are available from the Superintendent of Documents, U.S. Government Printing Office.

(2) The recommended threshold limit values for these fumes and gases may be found in *Threshold Limit Values (TLV®) for Chemical Substances and Physical Agents in the Workroom Environment* published by the American Conference of Governmental Industrial Hygienists (ACGIH).

(3) The results of AWS-funded study are available in the report entitled *Fumes and Gases in the Welding Environment* available from the American Welding Society.

(4) For specific information, refer to the applicable Material Safety Data Sheet (MSDS).

## C2. Radiation

Welding, cutting, and allied processes may produce radiant energy (radiation) harmful to health. You should acquaint yourself with the effects of this radiant energy.

Radiant energy may be ionizing (such as x-rays) or nonionizing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage, depending on the radiant energy's wavelength and intensity, if excessive exposure occurs.

**C2.1 Ionizing Radiation.** Ionizing radiation is produced by the electron beam welding process. It is ordinarily

1. See Appendix A for list of agencies and their locations.

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controlled within acceptable limits by use of suitable shielding enclosing the welding area.

**C2.2 Nonionizing Radiation**. The intensity and wavelengths of nonionizing radiant energy produced depend on many factors such as the process, welding parameters, electrode and base metal composition, fluxes, and any coating or plating on the base material.

Some processes such as resistance welding and cold pressure welding ordinarily produce negligible quantities of radiant energy. However, most arc welding and cutting processes (except submerged arc when used properly), laser welding and torch welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Protection from possible harmful effects caused by nonionizing radiant energy from welding include the following measures.

(1) Do not look at welding arcs except through welding filter plates which meet the requirements of ANSI Z87.1, *Practice for Occupational and Educational Eye and Face Protection*, published by American National Standards Institute. *Note: Transparent welding curtains are not intended as welding filter plates, but rather are intended to protect passersby from incidental exposure.*

(2) Protect exposed skin with adequate gloves and clothing as specified in ANSI/ASC Z49.1, *Safety in Welding and Cutting*, published by American Welding Society.

(3) Beware of reflections from welding arcs, and protect all persons from intense reflections. *Note: Paints using pigments of substantially zinc oxide or titanium dioxide have a low reflectance for ultraviolet radiation.*

(4) Avoid exposing passersby to welding operations by use of screens, curtains, or adequate distance from aisles, walkways, etc.

Safety glasses with UV protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

References sources on ionizing radiation include the following:

(1) American Welding Society. ANSI/AWS F2.1, *Recommended safe practices for electron beam welding and cutting*. Miami, Florida: American Welding Society, 1978.

(2) Manufacturer's Product Information literature.

Information sources on nonionizing radiation include:

(1) American National Standards Institute. ANSI Z136.1, *Safe use of lasers*. New York, New York: American National Standards Institute.

(2) ————. ANSI Z87.1, *Practice for occupational and educational eye and face protection*, New York, New York: American National Standards Institute.

(3) American Welding Society. ANSI Z49.1, *Safety in welding and cutting*. Miami, Florida: American Welding Society, 1988.

(4) Hinrichs, J. F. "Project committee on radiation — summary report." *Welding Journal*, January 1978.

(5) Moss, C. E. and Murray, W. E. "Optical radiation levels produced in gas welding, torch brazing and oxygen cutting." *Welding Journal*, September 1979.

(6) Moss, C. E. "Optical radiation transmission levels through transparent welding curtains." *Welding Journal*, March 1979.

(7) National Technical Information Service. Nonionizing Radiation Protection Special Study No. 42-0053-77, *Evaluation of the potential hazards from actinic ultraviolet radiation generated by electric welding and cutting arcs*. Springfield, Virginia: National Technical Information Service.

(8) ————. Nonionizing Radiation Protection Special Study No. 42-0312-77, *Evaluation of the potential retina hazards from optical radiation generated by electric welding and cutting arcs*. Springfield, Virginia: National Technical Information Service.

(9) "Optical radiation levels produced by air-carbon arc cutting processes." *Welding Journal*, March 1980.

## C3. Noise

Excessive noise is a known health hazard. Exposure to excessive noise can cause a loss of hearing. The loss of hearing can be either full or partial, and temporary or permanent. In welding, cutting, and allied operations, noise may result from the process, the power source, or other equipment. Air carbon arc cutting and plasma arc cutting are examples of processes which are frequently noisy. Engine-driven generators may also be quite noisy.

Excessive noise adversely affects hearing capability. This adverse effect in hearing capability may be a temporary threshold shift from which the ears may recover if removed from the noise source. However, if a person is exposed to this same noise level for a longer time, the loss of hearing may become permanent. The time required to develop permanent hearing loss depends upon factors such as individual susceptibility, noise level, and exposure duration. In addition, there is evidence that excessive noise affects other bodily functions and behavior.

A direct method to protect against excessive noise is to reduce the intensity of the source. Another method is to shield the source, but this has limitations. The acoustical characteristics of a room will also affect the level of noise. When engineering control methods fail to reduce the noise, personal protective devices such as ear muffs or ear plugs may be employed. Generally, these devices are only accepted when engineering controls are not fully effective.

The permissible noise exposure limits can be found in CFR Title 29, Chapter XVII, Part 1910. This is available from the U.S. Government Printing Office. Additional information may be found in *Threshold Limit Values*

*(TLV®)for Chemical Substances and Physical Agents in the Workroom Environment,* Published by the American Conference of Governmental Industrial Hygienists.

A recommended method for measuring noise emitted by arc welding processes may be found in ANSI/AWS F6.1-88, *Method for Sound Level Measurement of Manual Arc Welding and Cutting Processes,* Published by American Welding Society.

## C4. Chromium and Nickel in Welding Fume

Compounds of chromium, including hexavalent chromium, and of nickel may be found in fume from welding processes. The specific compounds and concentrations will vary with the composition of the base metals, the welding materials used, and the welding processes. Immediate effects of overexposure to welding fumes containing chromium and nickel are similar to the effects produced by fume from other metals. The fumes can cause symptoms such as nausea, headaches, and dizziness. Some persons may develop a sensitivity to chromium or nickel which can result in dermatitis or skin rash.

Chronic (long term) effects of exposure to chromium and nickel in welding fume are unknown. However, the National Institute for Occupational Safety and Health (NIOSH) has concluded that some forms of hexavalent chromium and nickel and their inorganic compounds should be considered occupational carcinogens. These conclusions were published in NIOSH Criteria Document 76-129 and 77-164 listed below. The conclusions were based on data from the chromate producing industry and from nickel ore-refining processes. No determination has yet been made concerning the health effects on welders or users of chromium- or nickel-containing alloys. Nevertheless, consideration must be given to the NIOSH conclusions.

To protect against the effect of overexposure to chromium and nickel in welding fume plume, do not breathe fumes and gases, and the welder should keep his or her head out of the fume plume. Use enough ventilation or exhaust at the arc or both to keep fumes and gases from your breathing zone and general area. In some cases, natural air movement will provide enough ventilation. Where ventilation may be questionable, air sampling should be used to determine if corrective measures should be applied.

The following are references for more detailed information on welding fumes which may contain chromium and nickel compounds.


(1) American Conference of Governmental Industrial Hygienists. *Threshold limit values for chemical substances and physical agents in the workroom environment.* Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists (ACGIH).

(2) American Welding Society. AWS Report, *Fumes and gases in the welding environment.* Miami, Florida: American Welding Society.

(3) National Institute for Occupational Safety and Health. NIOSH Publication No. 76-129, *Criteria for a recommended standard-occupational exposure to chromium* (VI). Cincinnati, Ohio: National Institute for Occupational Safety and Health.

(4) ————. NIOSH Publication No. 77-164, *Criteria for a recommended standard-occupational exposure to inorganic nickel.* Cincinnati, Ohio: National Institute for Occupational Safety and Health.

(5) Occupational Safety and Health Administration (OSHA). Standard 29 CFR 1910, Section 1910.1000. Washington, DC: Superintendent of Documents, U.S. Government Printing Office.

(6) For specific information, refer to the applicable Material Safety Data Sheets (MSDS).


The following references include the specific precautionary methods which can be used to protect against exposure to fumes and gases:


(1) American Welding Society. ANSI/ASC Z49.1-88, *Safety in welding and cutting.* Miami, Florida: American Welding Society, 1988.

(2) National Institute for Occupational Safety and Health. NIOSH Publication No. 78-138, *Safety and health in arc welding and gas welding and cutting.* Available from the National Institute for Occupational Safety and Health. This is also available from the U.S. Government Printing Office.

(3) Occupational Safety and Health Administration (OSHA) Standard 29 CFR 1910, Section 1910.252. Washington, D.C.: Superintendent of Documents, U.S. Government Printing Office.


## C5. Electrical Hazards

Electric shock can kill. However, it can be avoided. Do not touch live electrical parts. Read and understand the manufacturers' instructions and recommended safe practices. Faulty installations, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

Ground all electrical equipment and the workpiece. The work lead is not a ground lead. It is used only to complete the welding circuit. A separate connection is required to ground the workpiece. Do not mistake the work lead for a ground connection.

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Use the correct cable size, since sustained overloading will cause cable failure and result in possible electric shock or fire hazard. Make sure all electrical connections are tight, clean, and dry. Poor connections can overheat and even melt. Further, they can produce dangerous arcs and sparks. Do not allow water, grease, or dirt to accumulate on plugs, sockets, or electrical units. Moisture can conduct electricity. To prevent shock, keep the work area, equipment, and clothing dry at all times. Wear dry gloves, rubber soled shoes, or stand on a dry board or insulated platform.

Keep cables and connectors in good condition. Improper or worn electrical connections may set up conditions that could cause electrical shock or short circuits. Do not use worn, damaged or bare cables. Do not touch live electrical parts.

When several welders are working with arcs of different polarities, or when a number of alternating current machines are being used, the circuit voltages can be additive. The added voltages increase the severity of the shock hazard.

In case of electric shock, turn off the power. If the rescuer must resort to pulling the victim from the live contact, use nonconducting materials. If the victim is not breathing, administer cardiopulmonary resuscitation (CPR) as soon as contact with the electrical source is broken. Call a physician and continue CPR until breathing has been restored, or until a physician has arrived. Treat electrical burn as thermal burn; that is, apply clean, cold (iced) compresses. Prevent contamination and cover with a clean, dry dressing. Call a physician.

Follow recognized safety standards such as ANSI Z49.1. Also follow the National Electrical Code NFPA 70, available from the National Fire Protection Association.

## C6. Fire and Explosion Prevention

Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause fire or explosion if precautionary measures are not used.

Many of the fires associated with welding, cutting, and allied processes have been caused by sparks which can travel up to 35 feet in a horizontal direction from the work area. Sparks can pass through or become lodged in cracks, clothing, pipe holes, and other small openings in floors or partitions. *(Note: Sparks and molten metal can travel greater distances when falling.)*

Typical combustible materials commonly involved in fires are floors, partitions, roofs, and building contents such as wood, paper, clothing, plastics, chemicals and flammable liquids and gases. Outdoors, the combustible materials involved are dry leaves, grass, and brush. Explosions have occurred where welding or cutting have been performed in spaces containing flammable gases, vapors, liquids, or dusts.

Remove any combustible material from the work area. Where possible, move the work to a location well away from combustible materials. If neither action is possible, protect combustibles with a cover of fire resistant material. Remove or make safe all combustible materials for a radius of 35 feet around the work area. All open doorways, windows, cracks, and other openings should be covered or blocked with fire resistant materials. If possible, enclose the work area with portable fire resistant screens.

Protect combustible walls, ceilings, etc. from sparks and heat with fire resistant covers. If work is to be performed on a metal wall, ceiling, etc. prevent ignition of combustibles on the other side by moving the combustibles to a safe location. If this cannot be done, designate someone to serve as a fire watch, equipped with a fire extinguisher during the welding operation and for one half-hour after welding is completed.

Welding or cutting should not be performed on material having a combustible coating or combustible internal structure, as in walls or ceilings, without an approved method for eliminating the hazard. Do not dispose of hot slag in containers holding combustible material. Keep a fire extinguisher nearby. Make a thorough examination for evidence of fire. Remember that easily visible smoke or flame may not be present for some time after the fire has started.

Overloading and improper sizing can cause overheating of electrical equipment. Be sure all electrical equipment and wiring is installed properly with recommended circuit protection.

Be sure the work cable is connected to the work as close to the welding area as practical. Work cables connected to the building framework or other locations some distance from the welding area increase the possibility of the welding current passing through lifting chains, crane cables, or other alternate circuits. This can create fire hazards or overheat lifting chains or cables until they fail.

Do not weld or cut in atmospheres containing dangerously reactive or flammable gases, vapors, liquids, or dust. Do not apply heat to a container that has held an unknown substance or a combustible material whose contents when heated can produce flammable or explosive vapors. Heat should not be applied to a workpiece covered by an unknown substance or whose coating can produce flammable, toxic, or reactive vapors when heated. Adequate procedures should be developed and proper equipment used to do the job safely. Provide adequate ventilation in work areas to prevent accumulation of flammable gases, vapors or dusts. Clean and purge containers before applying heat.

Closed containers, including castings, should be vented before preheating, welding, or cutting. Venting will prevent the buildup of pressure and possible explosion due to the heating and the resultant expansion of gases.

Refer to the following for more detailed information on fire hazards from welding and cutting operations:

(1) American Welding Society. ANSI/ASC Z49.1-88, *Safety in welding and cutting*. Miami, Florida: American Welding Society, 1988.

(2) American Welding Society. ANSI/AWS F4.1, *Recommended safe practices for the preparation for welding and cutting containers that have held hazardous substances*. Miami, Florida: American Welding Society.

(3) National Fire Protection Association. NFPA Standard 51B, *Cutting and welding processes*. Quincy, MA: National Fire Protection Association.

(4) Occupational Safety and Health Administration. *Code of federal regulations,* Title 29, Labor, Chapter XVII, Part 1910, OSHA General Industry Standards. Washington, D.C.: U.S. Government Printing Office.

## C7. Burn Protection

Molten metal, sparks, slag, and hot work surfaces are produced by the welding, cutting, and allied processes. These can cause burns if precautionary measures are not used.

Workers should wear protective clothing made of fire resistant material. Do not wear pant cuffs or have open pockets or other places on clothing that can catch and retain molten metal or sparks. Wear high-top shoes or leather leggings and fire-resistant boots. Use helmets or hand shields that provide protection for the face, neck, and ears, and wear a head covering to protect the head. In addition, appropriate eye protection should be used.

When welding overhead or in confined spaces, wear ear plugs to prevent weld spatter from entering the ear canal and goggles or equivalent to give added eye protection. Keep clothing free of grease and oil. Do not carry combustible materials in pockets. If any combustible substance has been spilled on clothing, change to clean fire-resistant clothing before working with open arcs or flame. Use aprons, cape-sleeves, leggings, and shoulder covers and bibs designed for welding service. Where usually heavy welding or cutting is involved, sheet metal shields should be used for extra protection. Mechanization of highly hazardous processes or jobs should be considered.

Other personnel in the work area should be protected by the use of noncombustible screens or by the use of appropriate protection as described in the previous paragraph. Before leaving a work area, mark hot workpieces to alert other persons of this hazard. Do not attempt to repair or disconnect electrical equipment under load. Disconnecting under load produces arcing of the contacts and may cause burns or shocks. *(Note: Burns can be caused by touching hot equipment such as electrode holders, tips, and nozzles. Therefore, insulated gloves should be worn when these items are handled unless an adequate cooling period has been allowed before touching.)*

Refer to the following for more detailed information on personal protection:

(1) American National Standards Institute. ANSI Z87.1, *Practice for occupational and educational eye and face protection*. New York, NY: American National Standards Institute.

(2) ————. ANSI Z41, *Safety — toe footwear.* American National Standards Institute.

(3) American Welding Society. ANSI/ASC Z49.1-88, *Safety in welding and cutting*. Miami, FL: American Welding Society, 1988.

(4) Occupational Safety and Health Administration. *Code of federal regulations*, Title 29 Labor, Chapter XVII, Part 1910, OSHA General Industry Standards. Washington, DC: the U.S. Government Printing Office.

## C8. Mechanical Hazards

The use of or the proximity to mechanical equipment can present hazards to the welder. A knowledge of the proper use of power tools, such as grinders, chippers, drills and various hand tools, is important to welder safety. Know and understand the safe limits and proper use of cranes, positioners, and other material handling equipment, and use the appropriate guards and personal protective equipment.

The following recommendations are made concerning frequently encountered mechanical hazards in welding:

**C8.1** Adhere to grinding wheel speed limitations. Don't grind on the side of a wheel not designed for such service. When starting a new wheel, stand to the side until it reaches speed and correct any abnormalities noted. Be sure guards are in place and used.

**C8.2** Wear proper eye and hand protection. Use face shields, safety glasses and goggles as appropriate. Watch out for sharp objects, pinch points, and moving objects.

**C8.3** Avoid wearing items that can be caught in machinery such as rings, necklaces, bracelets, long hair, loose clothing, etc.

**C8.4** Use the right tool for the job. Keep a firm grip on tools to prevent their slipping away. Do not overload or force a tool beyond its expected capabilities. Foresee results of unexpected occurrences such as tools getting away, binding, or coming loose from their handles. Any tool that has become jammed or otherwise overstressed should be checked for damage before reuse. Anticipate the reactive force from tools.

**C8.5** When using tools that involve weights and spring tension, be certain that all pressures are released in a safe manner. Anticipate what might happen to a component that is to be loosened or unbolted from its working position.

**C8.6** Follow lock-out procedures for equipment and tools specifying such a procedure. Intermittent or bypassed interlocks create a definite hazard and such acts should be avoided.

For additional information on the safe operation and guarding of mechanical equipment, refer to the manufacturers' safe operating procedures for the equipment being used and the following publications:

(1) American National Standards Institute. ANSI Z244.1, *Safety requirements for the lockout/tagout of energy sources.* New York, NY: American National Standards Institute.

(2) American Welding Society, 1988. ANSI Z49.1-88, *Safety in welding and cutting.* Miami, FL: American Welding Society.

(3) National Institute for Occupational Safety and Health. NIOSH publication No. 78-138, *Safety and health in arc welding and gas welding and cutting.* Cincinnati, OH: National Institute for Occupational Safety and Health.

(4) Occupational Safety and Health Administration. *Code of federal regulations,* Title 29 Labor, Chapter XVII, Part 1910, OSHA General Industry Standards. Washington, D.C.: U.S. Government Printing Office.

## C9. Confined Spaces

Welding, cutting and heating operations can take place in a variety of locations. Some of these locations may be considered "confined spaces" having characteristics such as the following:

(1) Limited space, entry, or exit

(2) Unfavorable ventilation which could contain or trap hazardous air contaminants or prevent replenishment of safe breathing air, or both

Typical confined spaces include small rooms, storage tanks, compartment of ships, process vessels, pits, silos, vats, degreasers, reactor vessels, boiler, ventilation and exhaust ducts, sewers, tunnels, underground utility vaults, and pipelines. They can also include even the unventilated corner of a room. Death and serious injury have resulted from welding operations in confined spaces due to fire, explosions, asphyxiation, and exposure to hazardous air contaminants.

**C9.1** Verify that personnel designated by the responsible management person have taken the following actions before you approve entrance to a confined space. *Note: consult the list of references for detailed information on implementation.*

**C9.1.1** Open all covers and secure them from closing.

**C9.1.2** Test the atmosphere of the confined space to assure that the following apply:

(1) The oxygen content is suitable for breathing.

(2) The atmosphere is not combustible or reactive.

(3) The atmosphere is not toxic.

*Note: Special equipment and training is required to perform this testing.*

**C9.1.3** Isolate lines by capping or double valving and venting, if feasible. Make sure the vent is free of any obstruction and the valves do not leak.

**C9.1.4** Lock out all systems not required during welding, cutting, or heating.

**C9.1.5** Provide means for readily turning off power, gas, and other supplies from outside the confined space.

**C9.2** Verify that personnel designated by the responsible management person have begun the following actions to protect the occupants of a confined space and consulted the list of references for detailed information on implementation.

**C9.2.1** Ventilate and continually monitor the space to assure safe conditions.

(1) Make safe or remove any hazardous materials or materials which may become hazardous when heated or exposed to an arc.

(2) Continuously ventilate the space to assure that fumes and gases do not exceed safe exposure limits. These limits may be found in C9.2.4(2). Use NIOSH/OSHA approved breathing apparatus when proper ventilation cannot be provided or when the material being welded or heated has such toxicity as to require this type of apparatus ether by code, instruction or good practice.

**C9.2.2** Keep nonessential equipment to a minimum. Do not permit required equipment to impede exit or rescue efforts. Locate as much of the required equipment as possible outside the confined space.

**C9.2.3** Do not occupy a confined space unless someone, properly equipped and trained for rescue, is outside the confined space and in continuous communication with the occupants.

**C9.2.4** Provide means for turning off power, gases, and fuel from inside the confined space, if feasible, especially if outside turn-off means is not provided, feasible, or certain.

Refer to the following sources for more detailed information on confined welding space work:

(1) American National Standards Institute. Z117.1-77, *Safety requirements for working in tanks and other confined spaces.* New York, New York: American National Standards Institute, Standard, 1977.

(2) De Reamer, R. *Modern safety and health technology.* New York, New York: John Wiley & Sons.

(3) National Institute of Occupational Safety and Health. NIOSH Publication No. 80-106, *Criteria for a recommended standard —working in confined spaces*. Cincinnati, Ohio: Department of Health and Human Services.

(4) Occupational Safety and Health Administration. *Code of federal regulations*, Title 29 Labor, Chapter XVII, Part 1910, OSHA. General Industry Standards. Washington, D.C. Superintendent of Documents, U.S. Government Printing Office.

## C10. General Guidelines on Safety and Health

Use of the welding processes and consumables are safe provided proper procedures are followed and precautions taken. If these procedures and precautions are followed, welding, cutting, and allied processes can be done safely with minimal health risk.

> **FUMES AND GASES** can be dangerous to your health. Keep your head out of the fume plume.
> Use enough ventilation, exhaust at the work, or both, to keep fumes and gases from your breathing zone and the general area.
> **ARC RAYS** can injure the eyes.
> **INFRARED (HEAT) RADIATION** can cause burns.
> **ULTRAVIOLET RADIATION** can cause skin injury similar to sunburn.
> **ELECTRIC SHOCK** can kill.
> Do not touch live electrical parts.
> Read and understand the manufacturers' instructions and your employer's safety practices.

Before using the processes and consumables, acquaint yourself and those for whom you are responsible with the proper procedure and precautions. The primary source for these is contained in ANSI Z49.1, available from the American Welding Society.

## C11. Contact Lens Wear

Since 1967, the American Welding Society has received reports concerning welders who have claimed to have had contact lenses fused to their eyes, either by the heat of the arc or by microwave radiation. None of these reports have been substantiated and safety bulletins issued by the Occupational Safety and Health Administration (OSHA), the Food and Drug Administration (FDA), and the National Safety Council (NSC) have all refuted that such incidents could possibly have occurred.

The American Optometric Association (AOA) has stated that improvements in lens materials, and in design, fitting, and care procedures, have eliminated many of the problems formerly associated with contact lenses. The Association noted that contact lenses do not make the eye more susceptible to injury nor will they make matters worse if an eye injury accidentally happens.

The following guidelines, issued by the Contact Lens Ophthalmologists Association (CLAO) and endorsed by AWS, should be used where contact lenses are worn in welding situations:

**C11.1** Contact lenses should be worn in industrial environments, in combination with appropriate industrial safety eyewear, except where there is likelihood of injury from intense heat, massive chemical splash, highly particulate atmosphere, or where specific federal regulations prohibit such use.

**C11.2** Employees wearing contact lenses must be identified and known to their immediate supervisors, and to the plant safety and medical personnel.

**C11.3** First aid personnel should be trained in the proper removal of contact lenses.

**C11.4** Employees whose central, and peripheral, vision can be increased by the wearing of contact lenses, as contrasted to spectacle lenses, should be encouraged to wear contact lenses in industry. Examples of such employees are those who have had a cataract removed from one or both eyes, those with irregular astigmatism from corneal scars, or keratoconus, and those who are extremely nearsighted.

**C11.5** Employees should keep a spare pair of contacts prescription spectacles in their possession on the job to avoid an inability to function if they should damage or lose a contact lens while working.

**C11.6** Safety and medical personnel should not discriminate against an employee who can achieve visual rehabilitation by contact lenses, either in job placement or on return to a job category.

**C11.7** Safety and medical personnel should determine on an individual basis the wearing of spectacle or contact lenses in jobs which require unique visual performance. The Occupational Safety and Health Administration and the National Institute for Occupational Safety and Health recommendations must be considered. Information references include the following:

(1) Occupational Safety and Health Administration. "OSHA, eye experts dispel contact lens rumors." OSHA News Release. Washington, D.C.: U.S. Department of Labor Office of Information, August 9, 1983.

(2) U. S. Food and Drug Administration. "Phony contact lens scare." FDA Talk Paper. Rockville, MD: U.S. Food and Drug Administration, May 16, 1983.

(3) National Safety Council. "Let's end the contact lens tumor." *National Safety News*. Chicago, IL: National Safety Council, June 1983.

(4) American Optometric Association. "It's safe to wear contacts in school shops and labs." AOA News Release. St. Louis, MO: American Optometric Association, November 1984.

(5) Contact Lens Association of Ophthalmologists. CLAO Position Paper, New Orleans, Louisiana: Contact Lens Association of Ophthalmologists.

# Appendix D

# Mill Plate Tests and Inspection Procedures

(This Appendix is not a part of ANSI/AWS D3.5-93, *Guide for Steel Hull Welding*, but is included for information purposes only.)

## D1. ASTM Specifications

This section lists some of the related ASTM specifications for the following:

(1) Chemistry
(2) Mechanical properties
(3) Surface and internal soundness
(4) Dimensional Tolerances

Where appropriate, a brief explanation and related ASTM tables are also presented.

**D1.1 Chemistry Standards.** The following ASTM methods are used to determine the chemistry and metallurgical grain size of steel plates:

**Spec** Chemistry and Grain Size

**E415** Ladle and product chemistry: "Heat Chemistry" is determined by analyzing a ladle sample; "Product Chemistry" is determined by analyzing a sample of the rolled product and is available at extra cost.

**E112** Grain size determination (McQuaid Ehn Test). A specimen cut from the rolled product is used to categorize austenitic grain size when required.

The grade chemistry specifications are given as minimums, ranges, or maximums. The specification will also specify the grain size, if applicable.

**D1.2 Mechanical Property Standards.** The following ASTM methods are used to determine mechanical properties of steel plate:

**Tension Coupon Test**

**A 370** Standard Methods and Definitions for Mechanical Testing of Steel Products. (Sections 5 through 13 describe the test coupons.)

**E8** Standard Methods of Tension Testing of Metallic Materials. (Discusses the test procedure and specimens.)

**Bend Test**

**A370** Standard Methods and Definitions for Mechanical Testing of Steel Products. (Section 14 discusses the bend test.)

**E290** Standard Method for Semi-Guided Bend Test for Ductility of Metallic Materials. (Describes the bend test specimen and test.)

**Impact Toughness Testing**

**A370** Standard Methods and Definitions for Mechanical Testing of Steel Products. (Sections 19 through 23 discuss Charpy Impact Testing.)

**A673** Standard Specification for Sampling Procedure for Impact Testing of Structural Steel. (Discusses sampling procedures.)

**E23** *Standard Methods for Notched Bar Impact Testing of Metallic Materials.* (Discusses the test equipment and specimens for Charpy and Izod Impact Testing.)

**E208** *Standard Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels.* (Discusses the test, equipment, procedure, specimens, and data interpretation of this test.)

**E399** *Standard Test Method for Plain-Strain Fracture Toughness of Metallic Materials.* Fracture toughness testing is not within the routine capability of the plate mills.

**E436** *Drop-Weight Tear Tests of Ferritic Steels.* (Discusses a test procedure to rank steels used for pipe.)

**E604** *Dynamic Tear (DT) Energy of Metallic Materials,* 5/8 in. (16 mm) by Drop Weight or Pendulum Test.

The dynamic tear test is used to measure the resistance of plates to rapid progressive fracture (see Figure D1). The bright "cleavage" fracture is shown in broken sample faces in clear distinction to the dull appearing shear areas. The test is used in some specifications as an alternative test to low temperature Charpy-V-notch testing. For example in MIL-S-16216J, dynamic tear test values of 450 ft/lb at –40°F are acceptable for HY-80 in lieu of 35 ft/lb CVN at –120°F and 60 ft/lb CVN at 0°F.

**Through Thickness Testing**

**A770** Standard Specification for Through-Thickness Tension Testing of Steel Plates for Special Applications. (Discusses the test, procedure and samples to measure a plate's resistance to lamellar tearing.)

**Hardness Testing**

**A370** Standard Methods and Definitions for Mechanical Testing of Steel Products. (Sections 5 through 13 describe the test coupons.)

**E10** Standard Test Method for Brinell Hardness of Metallic Materials. (Discusses Brinell hardness testing, procedures, and specimens.)

**E18** Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials. (Discusses Rockwell hardness.)

**E92** Standard Test Method for Vickers Hardness of Metallic Materials. (Discusses Vickers hardness.)

**E110** Standard Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers. (Discusses portable Brinell, Rockwell and Vickers Testers.)

**E384** Standard Test Method for Microhardness of Materials. (Discusses microhardness of materials using Knoop and Vickers indenters.)

*Note: The conversion between the various Hardness Testing Systems can be found in Table 2A, B, C, D of ASTM A370.*

## D2. Application of Standards

The tests listed below are (1) mandatory on some grades, and the cost is included in the grade cost, (2) listed as optional on some grades, and are done at an extra cost, and (3) available upon request by the customer, and are done at an extra cost. It is important to note that when a mechanical property (such as yield strength) is given as a minimum there is no maximum value for that property. If a property is given as a range, the test value must fall in that range.

**D2.1 Tension Coupon Test ASTM A370, E8.** The Tension Coupon Test of plates 3/16 to 3/4 in. (4.76 to 19 mm) thick will be a flat 8 in. (203 mm) gage length coupon. For plates over 3/4 in., coupon type will be at the producer's option.

Unless otherwise specified, all plates over 24 in. (609 mm) wide will have the tensile coupons made with the rolling direction of the plate *transverse* to the load axis of the tensile coupon. See Figure D2 for coupon orientation. All plates under 24 in. wide will have the rolling and test direction parallel.

If the stress-strain diagram is characterized by a sharp knee or discontinuity, the *yield point* is the stress corresponding to the top of the knee [Figure D2(A)]. Yield point may also be defined as stress at .005 in./in. unit strain. The term *yield point* is used by ASTM for structural steels with yield strengths of 80 ksi and lower.

*Yield strength* is the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to unit strain. The deviation may be expressed as percent offset [Method 1, Figure D3(B)] or total extension under load (Method 2, Figure D3B).

Tensile strength is the maximum load measured divided by the original cross-sectional area of the coupon.

The tensile coupon test provides the total elongation of a specimen (in percent) at failure. These data are obtained by marking the 8 or 2 in. (203 or 51 mm) gage length on the specimen before testing. After the coupon is loaded to failure, it is removed from the test machine, and the broken ends are matched together. The distance between gage marks is remeasured, and the total elongation is calculated.

The conversion between the elongations of 8 and 2 in. (203 and 51 mm) gage length specimens can be found in Paragraph S29 of ASTM A370.

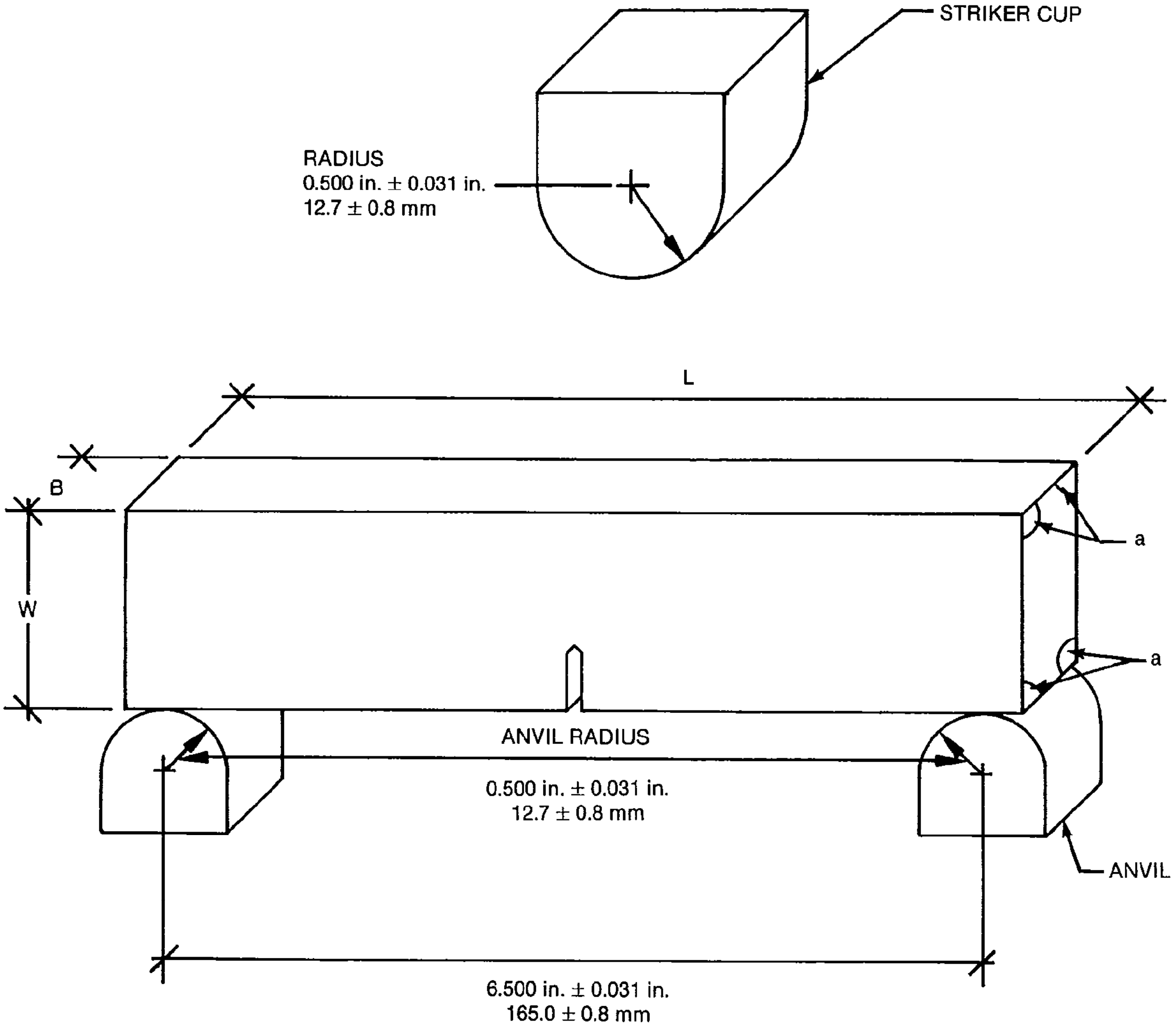
Each plate specification stipulates the *minimum* amount of elongation which must be met. Also, elongation requirements are generally reduced for structural plates over 24 in. (609 mm) wide which are tested in the transverse direction.

ASTM Specifications A6 and A20 permit reduction in the amount of elongation as a function of the test coupon thickness. This recognizes that plate thinner than 0.3125 in. and thicker than 3.50 in. with similar chemistry to a plate between these ranges, will have reduced elongation.

See Figure D4 for a plot of the formula stated in ASTM A6 and A20.

The sampling procedure for the number of tensile coupons for a rolling of steel into plate varies between ASTM A6, and ASTM A20.

ASTM A6 requires at least two tests be made from each "heat," as specified in ASTM A6, paragraph 11.4.




DIMENSIONS AND TOLERANCE FOR SPECIMEN BLANK

| PARAMETER | UNITS | DIMENSION | TOLERANCE |
|---|---|---|---|
| LENGTH, L | IN. | 7.125 | ±0.125 |
| | mm | 181 | ±3 |
| WIDTH, W | IN. | 1.60 | ±0.10 |
| | mm | 41 | ±2 |
| THICKNESS, B | IN. | 0.625 | ±0.035 |
| | mm | 16 | ±1 |
| ANGULARITY, a | DEG. | 90 | ±1 |

**Figure D-1—Dynamic Tear Test Specimen, Anvil Supports and Striker**

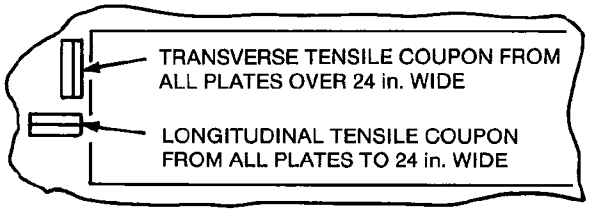



**Figure D-2—Tensile Coupon Sampling**

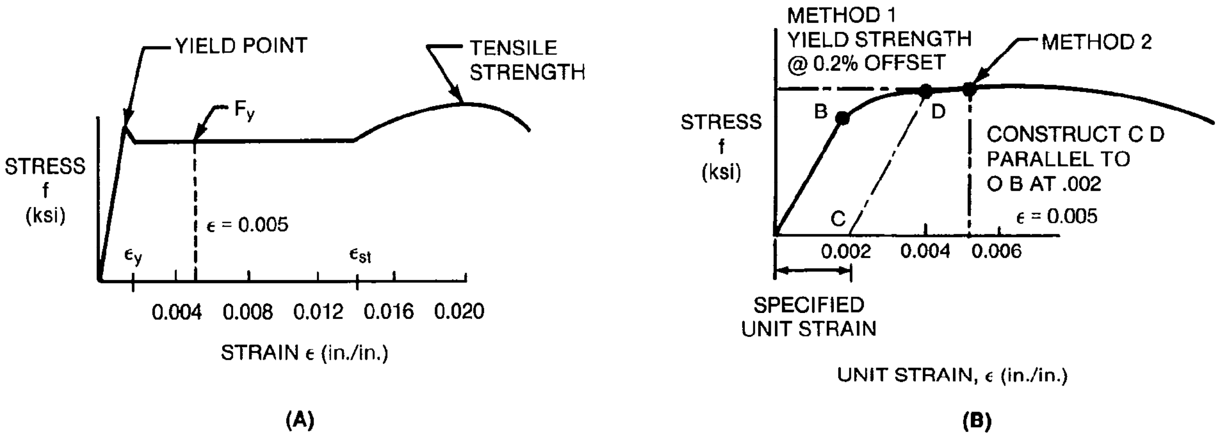



**Figure D-3—Yield Stress Defined**

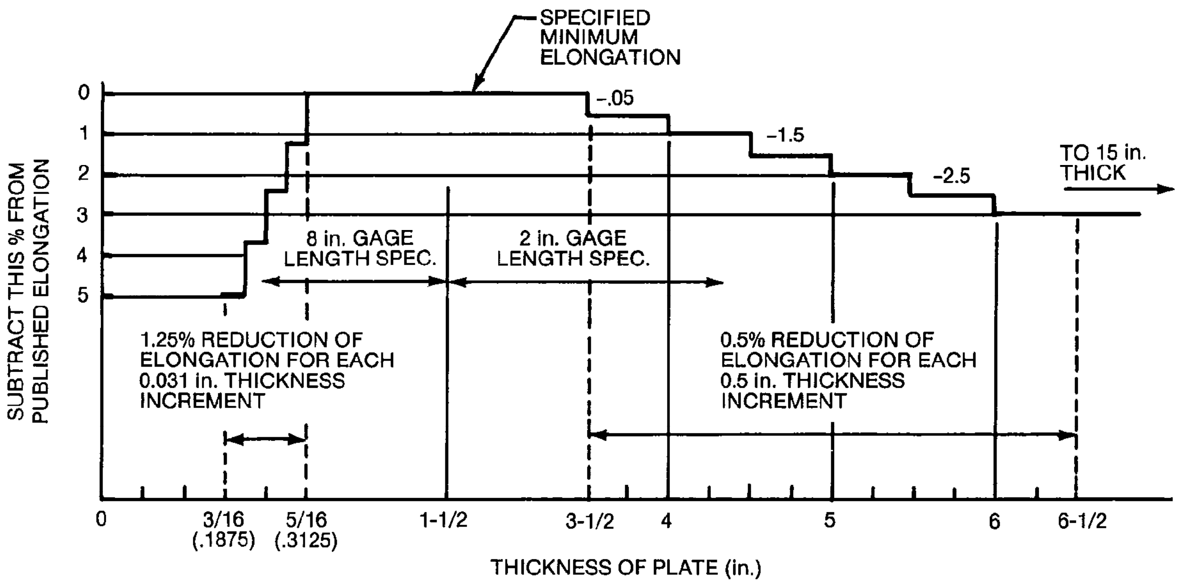



**Figure D-4—Allowable Reduction in Tensile Coupon Elongation if Coupon Thickness is Less Than 5/16 Inch or More Than 3-1/2 Inch**

ASTM A20 requires a greater sampling of tensile coupons. Paragraph 11.1 specifies at least one tension test for each "plate-as-rolled."

The customer may specify greater frequency of sampling at extra cost.

**D2.2 Plate Bend Tests ASTM A370, ASTM E290.** The Plate Bend Test (A370, A290) is a "supplemental" requirement for every ASTM grade and is an option that can be ordered by the customer. The test is performed on a specimen whose longitudinal edges have been *milled.* The bend radii successfully obtained in this test may be less than normally obtained in a routine fabrication procedure. The individual "grade" sheets in this manual list the optional bend radii specified by ASTM. The bend test was removed as a mandatory requirement of ASTM structural steel specifications and was installed as an optional Supplementary Requirement in 1975. This change was based on a long standing history of absence of failures in the performance of the bend test to the specified radii and an acknowledgement by the cognizant ASTM committee that performance of the test did not enhance the material.

**D2.3 Notched Bar Impact Testing of Metallic Materials (Charpy and Izod Impact Testing) ASTM E23, ASTM A370.** This is the most popular means of measuring the impact toughness of steel plate. It is part of some specifications, and often ordered by customers as an additional requirement. Charpy V-notch specimens are used for plate steels.

Charpy coupons are held as simple beams in an anvil and struck by a free swinging pendulum as specified by ASTM E23. The pendulum breaks the coupon. The energy consumed is noted and the test result is reported in ft-lb. This test may be conducted at various temperatures as required by the specification or customer. The coupon orientation is shown in Figure D5. Plate and structural mills can routinely test coupons down to –75°F (–60°C).

Longitudinal test coupons will absorb more energy than transverse coupons.

The test coupon sizes very with the plate thickness, as shown below:

| Coupon Size | Plate Thicknesses | Coupon Cross Section |
|---|---|---|
| Full | Over 0.436" | 10 x 10 mm |
| 3/4 | 0.312" to 0.436" | 10 x 7.5 mm |
| 2/3 | 0.290" to 0.311" | 10 x 6.7 mm |
| 1/2 | 0.250" to 0.289" | 10 x 5 mm |
| 1/3 | less than 0.249" | 10 x 3.3 mm |

Impacts are generally specified in terms of the full-size specimen. The correlation of the full size to the subsize specimens is shown above. (Some specifications require different subsizes than those shown above.)

**D2.4 Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels. ASTM E208.** The object of this test is to determine the maximum temperature at which a precracked plate specimen will break when struck by a free-falling weight (see Figure D6).

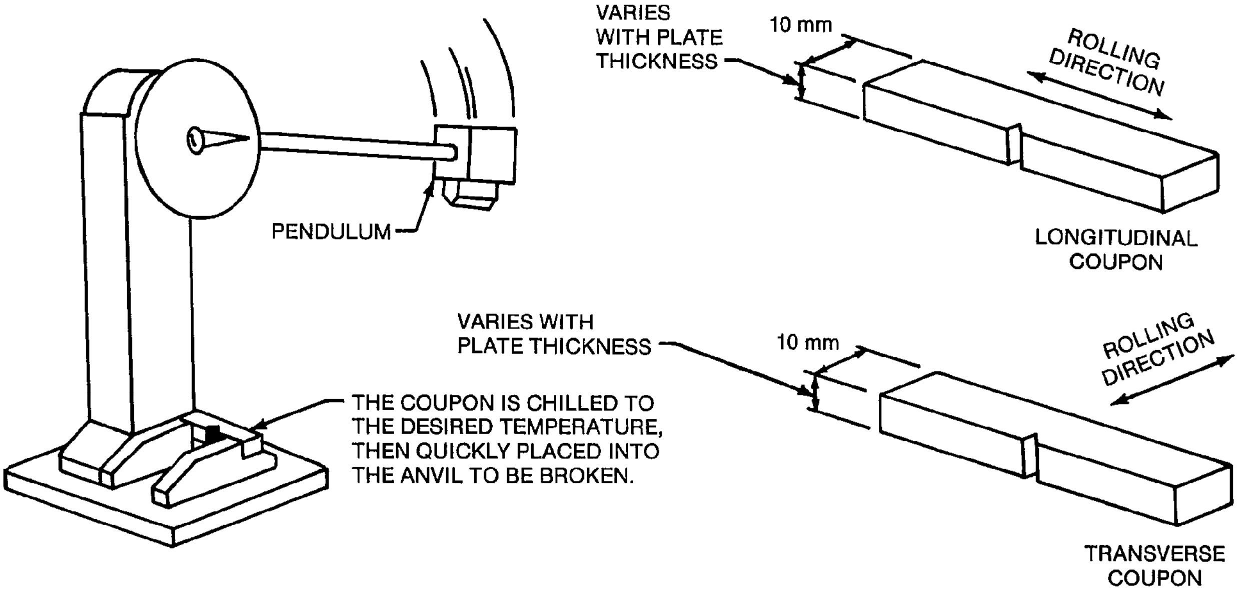
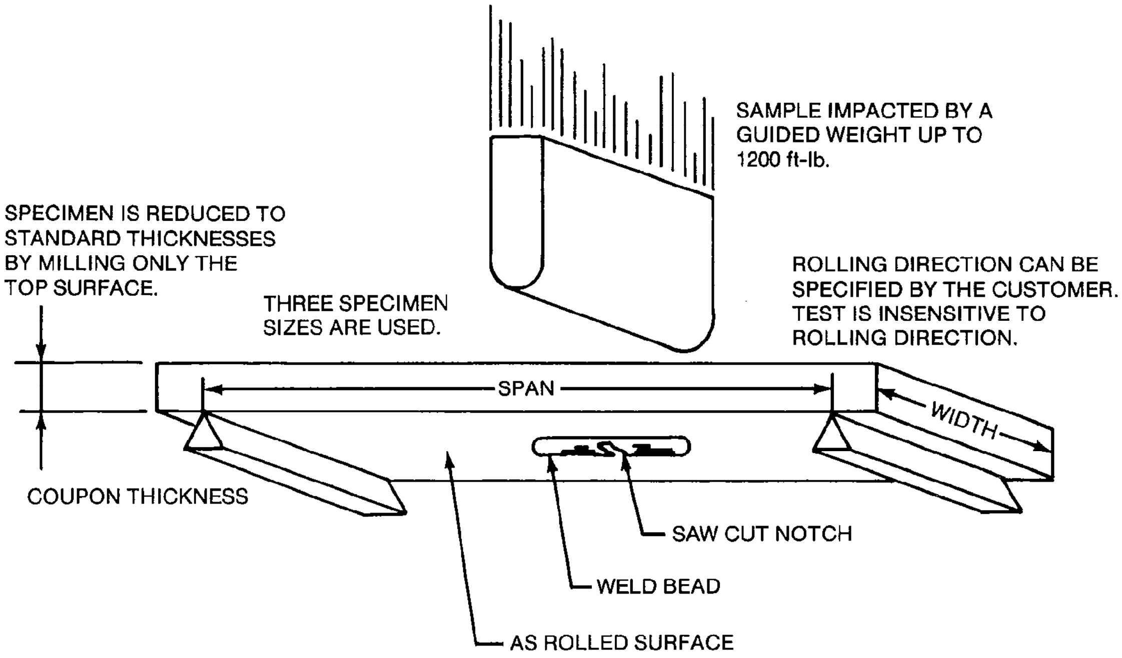



**Figure D-5—Charpy Coupon Testing**




DROP-WEIGHT TEST COUPON SIZES

| TYPE OF SPECIMEN | COUPON t (in.) | COUPON WIDTH (in.) | COUPON SPAN (in). |
|---|---|---|---|
| P1 | 1 | 3-1/2 | 14 |
| P2 | 3/4 | 2 | 5 |
| P3 | 5/8 | 2 | 5 |

**Figure D-6—Drop-Weight Test Setup to Determine Nil-Ductility (ASTM E208)**

Specimens are tested as a function of temperature. The maximum temperature at which a specimen breaks in the test is defined as the nil ductility transition temperature (NDT).

**D2.5 Drop-Weight Tear Tests of Ferritic Steels. ASTM E436.** The object of this test is to determine the appearance of the propagating fractures in plain carbon and low alloy steels with yield strengths less than 120 000 psi. Details are shown in Figure D7. The specification limits testing to plates 1/8 to 3/4 in. (3.17 + 019 mm) in thickness. Testing is conducted as a function of temperature.

This test can be readily conducted with the Drop-Weight test equipment used for the ASTM E208 tests. The falling weight must provide enough energy to break the specimen.

Broken faces are examined for appearance of the fracture surface. Cleavage or brittle failure is indicated when a bright and crystalline appearance is noted. Sheared area is gray in color. The test is reported as the percentage of shear area of the fracture surface at the specified temperature.

**D2.6 Through-Thickness Tension Testing of Steel Plates for Special Application, ASTM A770.** This test is used to measure a sample of a plate's resistance to lamellar tearing. This test indicates the effect of nonmetallic inclusions on the reduction of area of a tensile coupon.

The mill's metallurgical test laboratories make either the type 1, 2, 3, or E, F test coupons, as shown in Figure D8.

The Type 1, 2, 3 specimens are made by cutting 1 in. (25 mm x 25 mm) x 1 in. section through the thickness of the plate. One-inch round bars are welded to the surfaces of the rectangular piece and then machined to the required type designation. An alternative method used to make tensile coupons from plates over 2 in. thick is by machining an E or F test coupon from a saw cut blank from the

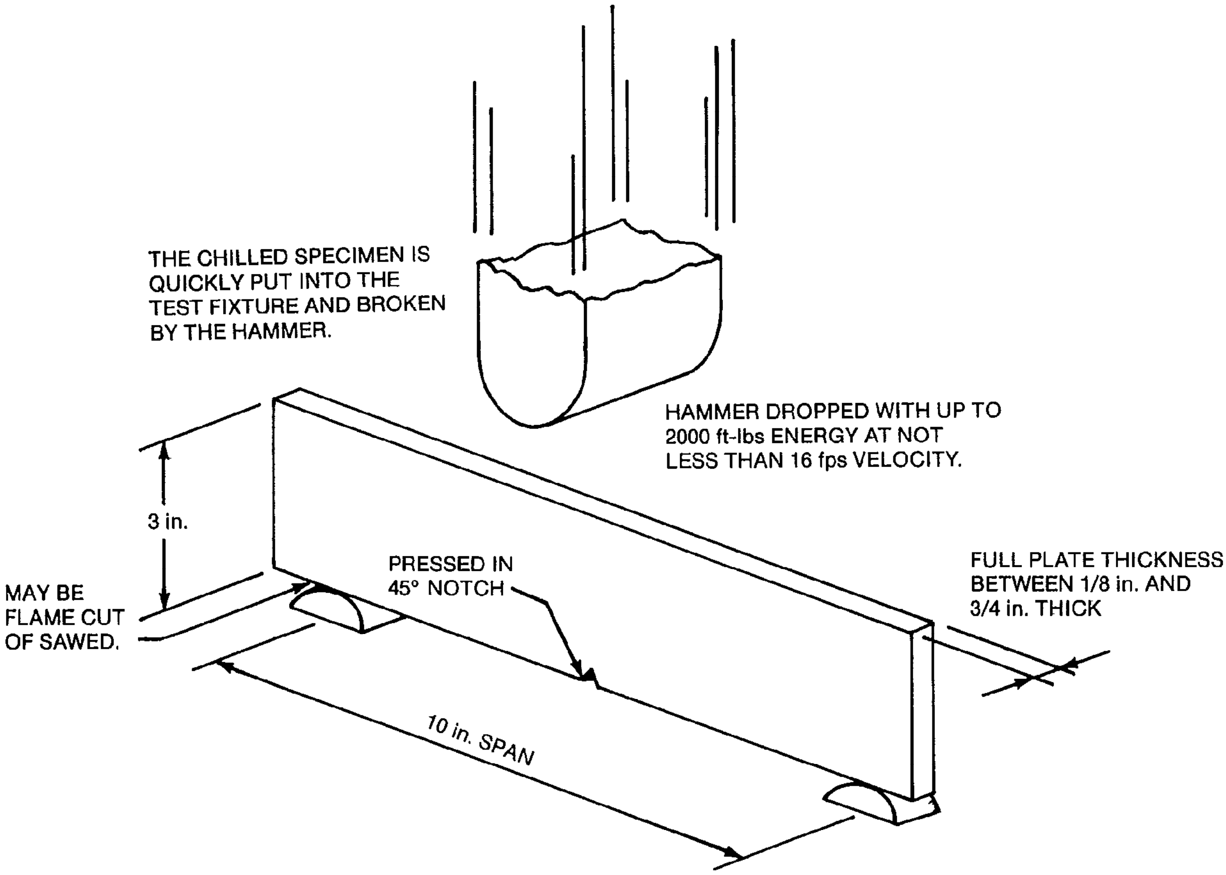



**Figure D-7—Drop Weight Tear Test (ASTM E436)**

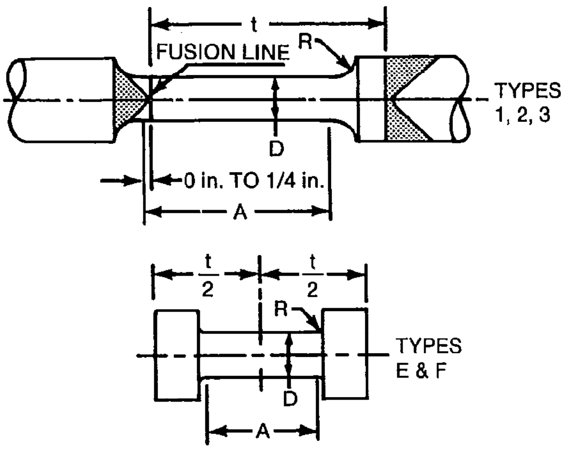



**Figure D-8—ASTM A770 Through Thickness Tensile Coupons**

plate in test. The data recorded from the test are the reduction in area after failure. For A770 acceptance, the failed section must have a reduction in cross-sectional area of at least 20%.

**D2.7 Hardness Test.** Mill metallurgical laboratories are equipped to make Brinell and Rockwell hardness tests on laboratory specimens, and Brinell test on plates using portable equipment.

**D2.8 Hardness Tests ASTM A370, E10, E18, E92, and E384.** Some hardness tests such as E10 and E18 may be used to estimate the tensile strength of steel plates. The ability of a steel plate to resist wear in an abrasive environment is often correlated to its hardness.

Grades of steel have a listed hardness rating. This offered to give the engineer *typical* hardness data for consideration, such as wear resistance, machinability, etc.

## D3. Plate Inspection

The inspection of a plate begins immediately after the plate has been rolled and consists of the following examinations:

(1) Surface condition
(2) Internal soundness (when required)
(3) Thickness verification
(4) Width and length verification
(5) Camber
(6) Flatness
(7) Waviness

The degree of precision practicable in the production of plates is limited by the essential character of rolling mill equipment, and unavoidable contingencies in rolling mill operations. It is necessary to make allowance for deviations from theoretical exactness.

The customary tolerances used in the steel industry in the United States are found in ASTM Specifications A6 and A20. Specification A6 is the general specification for structural steel plates and A20 is the general specification for pressure vessel plates.

Since ASTM A6 is a very popular standard, it will be discussed in more detail. The tolerances for plates with respect to thickness, width and length, camber, flatness, and waviness are the same for ASTM A6 and A20.

**D3.1 Surface Conditioning.** The plate as-rolled surfaces are inspected immediately after the plate has been rolled. Surface imperfections are marked using the inspection criteria specified.

Structural quality plate grades (ASTM A6) are conditioned as described below:

Imperfections that do not affect the utility of the plates are not considered defects. Some plates are conditioned by plate mills for the removal of surface imperfections or depressions on either surface by grinding, provided the ground area is well flared and grinding does not reduce the thickness of the as-rolled plate:

(1) Below the minimum thickness specified for plates ordered to thickness.

(2) More than 7% of the nominal thickness for plates ordered to weight per square foot, but in no case more than 1/8 in. (3.17 mm).

When not prohibited by the plate specification, plates may have surface imperfections removed and weld metal deposited in accordance with the following:

The surface area removed for repair from each side of the plate surface is not to exceed 2% of its plan area. After removal of any imperfections preparatory to welding, the thickness of the plate must not be reduced by more than 30% of the nominal thickness of the plate.

When welding is performed, the welds must be sound and the weld metal thoroughly fused on all surfaces and edges without undercutting or overlap. The weld metal shall project at least 1/16 in. (1.59 mm) above the rolled surface and the projecting metal shall be removed by grinding to make it flush with the rolled surface.

Pressure vessel quality plate grades (ASTM A20) surface conditioning requirements are more stringent than ASTM A6. Refer to these specifications for more detail.

Request for special surface requirements or conditioning restrictions may be satisfied by mutual agreement and may be subject to extra cost.

**D3.2 Internal Soundness.** It is possible to have gross internal discontinuities in a plate resulting from pipe, ruptures, or nonmetallics. These anomalies are isolated layers inside a plate with sound steel surrounding them.

An ultrasonic inspection procedure has been developed to locate and map internal discontinuities. This inspection procedure is described in ASTM A435 and ASTM A578. Refer to these specifications for more detail.

Ultrasonic examination of plates is a supplemental test listed in ASTM A6 and ASTM A20.

The principle of both standards is the same:

(1) A beam of sound about 3/4 in. (19 mm) in diameter is transmitted into the rolled surface of the plate.

(2) An echo from the opposite surface is established as a spike on a cathode-ray tube display.

(3) The source of the ultrasound is moved on the plate surface in a prescribed search pattern.

(4) A discontinuity is seen as a reduction in the size of the spike of the surface echo and an intermediate spike which represents a surface of discontinuity inside the plate.

**ASTM A435**

A435 rejects a plate when a total loss of signal from the opposite surface cannot be contained in a circle whose diameter is 3 in. (76.2 mm) or one-half the plate thickness whichever is greater, as shown in Figure D9. If the plate is acceptable, it is stamped or stenciled UT 435.

**ASTM A578 — Level 2**

The acceptance standards for ASTM A578 Level 2 and ASTM A435 are similar, except that A578 Level 2 requires a record to be made and forwarded to the customer showing a plan of all the discontinuities over a specified size.

**ASTM A578 — Level 1**

The acceptance standards for Level 1 are more stringent than Level 2. The same record has to be made and forwarded to the customer as in Level 1. The acceptance criteria for Level 1 and 2 are shown in Figure D10.

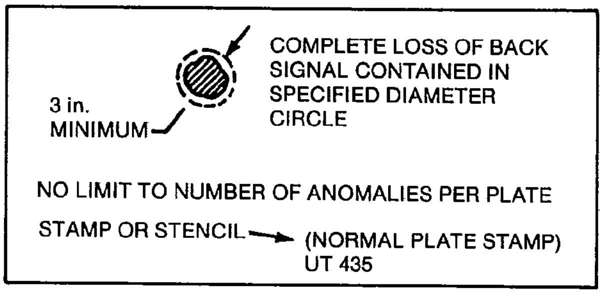
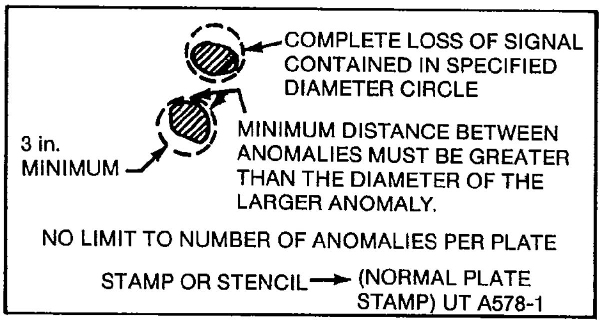



**Figure D-9—UT A435 Minimum Acceptance Criteria and Marking Requirement**

**A578 LEVEL 1**
**MINIMUM ACCEPTANCE CRITERIA,**
**AND MARKING REQUIRED**




**A578 LEVEL 2**
**MINIMUM ACCEPTANCE CRITERIA,**
**AND MARKING REQUIRED**

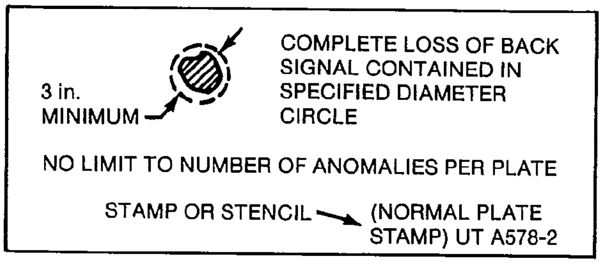



**Figure D-10—A578 Minimum Acceptance Criteria and Marking Requirement**

# D3.5 Guide for Steel Hull Welding
## Alpha-Numerical Document Title Reference — by Source

| | |
|---|---|
| **ANSI** | **American National Standards Institute** |
| Z41 | Safety — Toe Footwear |
| Z49.1 | Safety in Welding and Cutting |
| Z87.1 | Practice for Occupational and Educational Eye and Face Protection |
| Z136.1 | Safe Use of Lasers |
| Z244.1 | Safety Requirements for the Lockout/Tagout of Energy Sources |
| **ASTM** | **American Society for Testing and Materials** |
| A6 | Specification for General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use. |
| A20 | Specification for General Requirements for Steel Plates for Pressure Vessels |
| A27 | Specification for Steel Castings, Carbon, for General Application |
| A36 | Specification for Structural Steel |
| A370 | Test Methods and Definitions for Mechanical Testing of Steel Products |
| A435 | Specification for Straight-Beam Ultrasonic Examination of Steel Plates for Pressure Vessels |
| A537 | Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel |
| A578 | Specification for Straight-Beam Ultrasonic Examination |
| A668 | Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use |
| A673 | Specification for Sampling Procedure for Impact Testing of Structural Steel |
| A710 | Specification for Low-Carbon Age-Hardening Nickel-Copper Chromium — Molybdenum-Columbium and Nickel-Copper Columbium Alloy Steels |
| A736 | Specification for Pressure Vessel Plates, Low-Carbon Age-Hardening Nickel-Copper-Chromium-Molybdenum-Columbium Alloy Steel |
| A770 | Specification for Through-Thickness Tension Testing of Steel Plates for Special Applications |
| **ASTM** | **American Society for Testing and Materials** |
| E8 | Test Methods of Tension Testing of Metallic Materials |
| E10 | Test Method for Brinell Hardness of Metallic Materials |
| E18 | Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Material |
| E23 | Methods for Notched Bar Impact Testing of Metallic Materials |
| E92 | Test Method for Vickers Hardness of Metallic Materials |
| E112 | Methods for Determining Average Grain Size |
| E208 | Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels |
| E290 | Test Method for Semi-Guided Bend Test for Ductility of Metallic Materials |
| E384 | Test Method for Microhardness of Materials |

E399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials

E415 Method for Optical Emission Vacuum Spectrometric Analysis of Carbon and Low-Alloy Steel

E436 Method for Drop-Weight Tear Tests of Ferritic Steels

E604 Test Method for Dynamic Tear Testing of Metallic Materials

**AWS American Welding Society**

A2.4 Standard Symbols for Welding, Brazing, and Nondestructive Examination

A3.0 Standard Welding Terms and Definitions

A5.18 Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding

A5.20 Specification for Carbon Steel Electrodes for Flux Cored Arc Welding

A5.25 Specifications for Consumables Used for Electroslag Welding of Carbon and High Strength Low Alloy Steels

A5.26 Specification for Consumables Used for Electrogas Welding of Carbon and High Strength Low Alloy Steels

A5.28 Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding

A5.29 Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding

## AWS Marine Welding Document List

| Code | Document |
| --- | --- |
| D3.5 | Guide for Steel Hull Welding |
| D3.6 | Specification for Underwater Welding |
| D3.7 | Guide for Aluminum Hull Welding |

## Additional Documents of Fundamental Subject Matter

| | |
| --- | --- |
| A1.1 | Metric Practice Guide for the Welding Industry |
| A2.4 | Standard Symbols for Welding, Brazing and Non-destructive Examination |
| A3.0 | Standard Welding Terms and Definitions |

For ordering information, contact the Order Department, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135. Phone: 1-800-334-9353