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Supplement 7

Welding of High Alloy Castings

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Welding of high alloy steel castings

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1. Introduction

Iron-base and nickel-base high alloys - by definition those containing eight percent or more of another element - are widely used for construction of industrial process equipment that must resist the deteriorating effect of a corrosive of high temperature environment. Both wrought and cast forms of such alloys may be welded during the manufacture of finished components so the weldability of the alloys often is a matter of concern to the user. The same welding processes are applied to wrought and cast products and, in general, similar techniques and practices are employed. Differences between wrought and cast alloys in chemical composition and microstructure, however, influence the welding characteristics of each form and must be given consideration. In addition, the high alloys differ markedly from carbon and low alloy steels in physical properties such as electrical resistance, thermal expansion and thermal conductivity. It is essential, therefore, to employ procedures allowing for all these factors when welding high alloy castings.

1.1 All the casting alloys have equal or better weldability than the corresponding wrought alloys, but there are variations from grade to grade in the ease with which satisfactory welds are obtained. The low-carbon, austenitic grades usually are considered easier to weld than high-carbon austenitic or straight-chromium ferritic or martensitic types. Nevertheless, each of the standard alloy compositions can be welded successfully in the foundry. Using information derived from the extensive research of Alloy Casting Institute and Steel Founders' Society of America, the foundryman often is able to tailor the composition balance especially to provide the optimum weldability. Accordingly, castings are readily welded into fabricated structures and welding is considered a regular part of the foundry production process.

1.2 Welding is used a procedure for upgrading casting quality during the course of manufacture through improvement of surface conditions, or by elimination of shrinkage voids. It is also used for producing large or complex assemblies where the size of the completed structure precludes production as a one-piece castings, or where total quality will be improved by dividing the structure into simpler components which can later be welded int an integral assembly.

1.3 Welds properly made do not impair high alloy castings with respect to their corrosion resistance or their mechanical properties from sub-zero to elevated temperatures.

Proven welding techniques that are procedurally correct and metallurgically sound involve consideration of the following factors:

a. Characteristics of the alloy type
b. Choice of filler material
c. Preparation of the weld cavity or joint
d. The weld process to be used
e. Preweld and postweld heat treatment
f. Methods of demonstrating weld quality

All of these topics will be covered in subsequent sections of this discussion or in the accompanying welding procedure descriptions.

2. Properties of the alloy types

At the outset it is necessary to review the microstructures and the physical and mechanical properties of the different high alloy types because the effects of exposure to welding temperatures vary among the alloy grades. The microstructures that are developed during welding influence the physical and mechanical properties of the alloys, and they, in turn, influence the soundness of the welds. Four classes of high alloy castings will be discussed: a) Iron-Chromium, b) Iron-Chromium-Nickel, c) Iron-Nickel-Chromium, and d) Nickel-base. The cast alloys are also classified according to their end use as “corrosion resistant” or “heat resistant” and there are important differences in the alloy compositions used in each group. In the corrosion resistant category by far the greatest tonnage of castings is produced in the iron-chromium-nickel class, with iron-chromium types in second place; whereas in the heat resistant group the iron-nickel-chromium alloy types rank almost equally with the iron-chromium-nickel class. The heat resistant alloys are generally higher in alloy content than the corrosion resistant types and in nearly all cases are substantially higher in carbon content. These differences make it desirable to consider the corrosion and heat groups separately.

2.1 Corrosion resistant grades

Electrical resistivity of the corrosion resistant alloys is five to ten times higher than carbon steel. Welding current requirements therefore, are lower than for carbon steel and attention should be given to the amperage and voltage recommendations of the filler metal manufacturer. Excessive heat input should be avoided because the low thermal conductivities of the high alloys (about 50 percent less than steel) combined with the generally higher thermal expansion coefficients (about 50 percent greater than steel) tend to create steep temperature gradients and high thermal stresses in the weld zone.

2.1.1 Iron-chromium alloy types are martensitic or ferritic in microstructure depending on the chromium and carbon content in the composition. They are sub-divided, therefore, into “hardenable” and “non-hardenable” groups.

2.1.1.1 The CA15 and CA40 (11.5 - 14 Cr) hardenable alloys transform to austenite in the weld and in the heat affected zone of the base metal. Transformation of the austenite to hard, brittle martensite is essentially completed at about 300°F (149°C) on cooling from welding temperature and will promote weld cracking - the higher the carbon content the greater the cracking tendency. For this reason castings are preheated to about 500°F (260°C) and maintained above the martensite transformation temperature during welding. As soon as possible after welding, and without cooling below 300°F (149°C), castings are heated to 1100 - 1450°F (593 - 788°C) and cooled to temper any martensite that has formed and to restore the ductility and impact strength of the metal. Stray arc strikes can cause hard spots and should be avoided. These alloys have coefficients of thermal expansion similar to carbon steel but are sometimes welded using austenitic, iron-chromium-nickel filler metal which has a coefficient about 50 percent greater. In addition to the differences in ductility and hardness, the difference in expansion characteristics of the base and weld metals should be considered before using such filler metal, particularly if the welded structure will be subjected to heating and cooling in service.

2.1.1.2 The CB30 (18 - 22 Cr) and CC50 (26 - 30 Cr) non-hardenable alloys are subject to rapid grain growth during welding which reduces their ductility and promotes cracking. Furthermore, although the alloys are essentially ferritic, it is possible for some austenite to form and subsequently transform to martensite. Preheating to above 400°F (204°C) sometimes as high as 1300°F (704°C) usually is necessary, therefore to obtain satisfactory welds. Postweld heat treatment is required to reduce brittleness in the weld zone. The CB30 alloy customarily is heated to 1450°F (788°C) and the CC50 alloy to 1650°F (899°C) or higher then air cooled. Rapid cooling through the range 1100 - 750°F (593 - 399°C) is advisable to avoid embrittlement. If conditions of service permit the welded area to have mechanical properties different from the remainder of the casting, an austenitic filler metal can be used to improve the ductility of the weld deposit. This does not change the need for pre- and pot-weld heat treatments, however, because the dilution of the base metal with nickel increases the probability of martensite formation. Consideration also must be given to difficulties that might arise from the difference in thermal expansion coefficients of the weld and base metals.

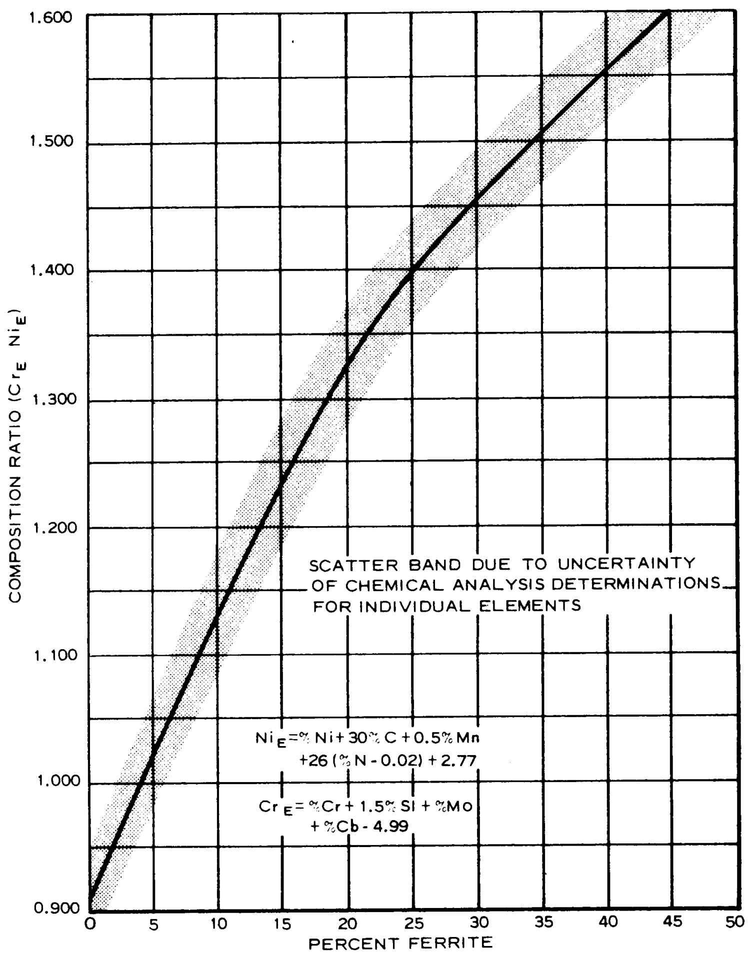
2.1.2 Iron-chromium-nickel alloys with additions of copper (CB7Cu) or copper and molybdenum (CD4MCu) are high-strength, two-phase austenite-martensite or austenite-ferrite structures.

At elevated temperatures the CB7Cu grade is transformed to austenite most of which forms martensite on cooling below 300°F (149°C). This is a relatively soft martensite, however because of the low carbon content. Copper, retained in the martensite as a super-saturated solution, precipitates sub-microscopically if the alloy is reheated to the range 900-1100°F (482-593°C) and subsequently increases the strength and hardness of the casting. In either the annealed or hardened condition castings can be welded without preheat, although it sometimes desirable to preheat tp 500°F (260°C) when welding heavy sections. Sections which require multi-pass welds are handled better in the annealed condition than after aging since the prolonged heat of welding will introduce non-uniform hardening characteristics to the weld zone. Thus, such castings require a solution heat treatment in the temperature range 1850 -1950°F (1010 -

1066°C) followed by rapid cooling before being hardened by reheating to the precipitation temperature. Only the low temperature aging treatment is needed to harden the weld zone on single pass welds.

The CD4MCu alloy has very low carbon content, but the two-phase, austenite-ferrite microstructure is strengthened by the copper and molybdenum contents. Properties of the alloy are influenced critically by the chemical composition balance so it is essential that the filler metal used in welding this grade create a weld deposit closely matching the base metal. Castings are welded in the solution annealed condition and preheat is not required. To restore the ductility and maximum corrosion resistance to the weld zone, castings require a postweld solution heat treatment at 2050°F (1121°C) or higher, slow cooling to 1900°F (1038°C) to allow transformation of some ferrite to austenite, followed by rapid cooling to room temperature.

2.1.3 Iron-chromium-nickel alloy types CE30, CF3, CF8, CF20, CF8C, CF3M, CF8M, CG8M, CH20 and CK20 are all austenitic in microstructure. Depending on the balance in the chemical composition among the austenite-promoting elements (nickel, carbon, manganese and nitrogen) and the ferrite-promoting elements (chromium, silicon, molybdenum, and columbium), the structure may vary from wholly austenite to austenite plus ferrite in the range 0 to 40 percent. In this respect the casting alloys differ from the corresponding wrought stainless steels which normally are balanced to be wholly austenitic since partially ferritic alloys have inferior rolling qualitites. The corrosion resistance of the alloys is greatest when the carbon is completely dissolved and this accomplished by heating them to 1900°F (1038°C) or higher, followed by rapid cooling through the range 1600 to 800°F 871 tp 427°C). If the alloys cool slowly through the "sensitizing" temperature range, there is a danger that the carbon will combine with some of the chromium and precipitate as chromium carbide. Since a high chromium content is essential to maximum corrosion resistance, any area that has been depleted of chromium by the precipitation of chromium carbide will be subject to increased corrosive attack. This is so-called "weld-decay" in which severe corrosion is experienced in the heat affected zone adjacent to a weld.



Relation of ferrite content and composition ratio for alloys in the range of 16 to 26 percent chromium, 6 to 14 percent nickel, 0 to 4 percent molybdenum, 0 to 1 percent columbium, up to 0.30 percent carbon, 0.15 percent nitrogen, 2.00 percent manganese, and 2.00 percent silicon.

When wholly austenitic microstructures such as usually found in wrought alloys are exposed to sensitizing temperatures they suffer from intergranular corrosion because the chromium carbides precipitate along the grain boundaries and thus form a continuous network along which corrosion can proceed. Due to the presence of some ferrite in castings, on the other hand, the carbides precipitate in the discontinuous ferrite pools so that intergranular attack is less likely to occur. Nevertheless, to restore maximum corrosion resistance to the weld zone, the carbides must be redissolved by a high temperature heat treatment and a rapid quench. The extra-low carbon content of alloys CF3 and CF3M can be welded without postweld heat treatment because very little chromium carbide can be formed. Chromium depletion is avoided in the CF8C alloy type by the intentional addition of columbium carbides instead of chromium carbides.

The presence of ferrite in the microstructure of the austenitic alloys is also helpful in avoiding cracking or microfissuring of welds. Consequently, the CE30, CF3, CF8, CF16F, CF3M, CF8M, CF8C and CG8M grades, which normally contain over 5 percent ferrite, are less susceptible to cracking than the wholly austenitic types CH20 and CK20. Because as previously noted, wrought stainless steels of the AISI 300 series are generally balanced to have wholly austenitic structures, they are prone to cracking when welded so the filler compositions used are usually balanced to a partially ferritic weld deposit and thereby take advantage of the improved resistance to microfissuring provided by this structure. Since may of the casting alloys are themselves partially ferritic, these grades can be welded more readily than the wrought types without the use of filler metal, as in the case of the inert gas tungsten welding process often used for fusion of root passes or elimination of small surface discontinuities.

Upper limits on the ferrite contents of castings and weld deposits are frequently set when heavy sections are to be welded or where the service temperature may exceed 800°F (427°C). High chromium alloys held for appreciable times at elevated temperatures may transform partially to the sigma phase with resultant decrease in high temperature strength and room temperature ductility. This transformation can take place after long exposure of alloys that are initially wholly austenitic, but may occur quite rapidly in partially ferritic alloys. Embrittlement and possible cracking of high ferrite content weld deposits may result form the slow cooling of heavy sections so that nominal ferrite contents are usually limited to maximum amounts depending on experience with specific casting configurations. Small amounts of sigma that may form in a ferrite-containing weld of a heavy section will be eliminated, however, through retransformation to ferrite by a postweld solution heat treatment.

Although there are several methods for estimating the amount of ferrite present in an austenitic alloy, the one most often used is based on the fact that ferrite is ferro-magnetic whereas austenite is not. Instruments for measuring the magnetic attraction of a weld deposit or casting have assumed to be capable of determining the true percentage of ferrite present. Recent investigations have shown, however, that no method is yet available for the accurate determination of absolute ferrite content. Accordingly, a method has bee approved by the Advisory Subcommittee of the Welding Research Council for calibrating magnetic measuring instruments to read in "Ferrite Numbers". (See Item 20 in the Bibliography.) *It should be recognized that considerable variation of indicated ferrite content will occur over the surface of a casting or weld zone, and due allowance should be made for this in any specification.* For example, a spread of ferrite number from 4 to 16 should not be unexpected when the nominal value is 10.

2.1.4 The iron-nickel-chromium and nickel-base alloys CN7M, CW12M, CY40, N12M, M-35, and CZ100 are "austenitic" in microstructure and do not undergo change in phase when cooling from welding temperature. They are subject to carbide precipitation, however, and have lowered ductility in the 1200 to 1800°F (649 to 928°C) temperature range. Cracking of the weld zone may occur for this reason if there is substantial restraint, and in such cases preheat is sometimes helpful as indicted on the individual alloy procedure sheets. Another cause of cracking in high alloys is embrittlement from contamination of the weld by lead, sulfur, phosphorous and other elements such as arsenic and antimony. Producers o castings exert great care to ensure low levels of these contaminants in the alloys, and similar care must be exercised in keeping weld areas and the heat affected zones clean. Anything that might contribute one or more of the detrimental elements-marking crayon, paint, oil and even some degreasing compounds can be such sources - should be removed by a final washing with alcohol, acetone of hot water before starting to weld. Removal of all traces of molding sand by grinding the surface in the weld area is desirable for type —35 and sometimes for other alloys.

Castings are usually welded in the solution annealed condition and are given a postweld heat treatment to restore corrosion resistance and relieve stresses.

2.2 Heat resistant grades

These have physical properties similar to the corrosion resistant grades so that some of the same considerations apply with regard to electrical characteristics and thermally imposed stresses. The generally higher carbon contents of the heat resistant alloys makes them stronger at elevated temperatures than the corrosion resistant types and the extensive carbide networks in the microstructures result in relatively low room temperature ductility.

2.2.1 Iron-chromium alloy type HA is a hardenable, pearlitic-martensitic alloy that has good oxidation resistance at temperatures up to about 1200^{o}F (649^{o}C). Its behavior in welding is similar to that described for the CA alloys in Section 2.1.1.1.

Type HC has the same microstructure and welding characteristics as the CC50 alloy discussed in Section 2.1.1.2. It is especially difficult to weld castings that have been in elevated temperature service because of embrittlement.

2.2.2 Iron-chromium-nickel alloy types HD and HE have two-phase austenite-ferrite microstructures containing chromium carbides. They have substantially better ductility as-cast than the iron-chromium HC type but will become embrittled upon long exposure to temperatures around 1500^{o}F (816^{o}C) through formation of the sigma phase. Ductility of the alloys can be restored by heating them to the range 1800 - 2000^{o}F (982 - 1093^{o}C) and cooling rapidly to below 1200^{o}F (649^{o}C). It is unnecessary to preheat castings for welding and postweld heat treatment is required only for relief of welding stresses in complicated sections.

The HF, HH, HI, HK and HL grades, as normally made, have a microstructure of carbides in a wholly austenitic matrix. The HH and HI alloys are borderline and unless balanced to be wholly austenitic will contain some ferrite. Ferrite-free compositions are preferred for high temperature strength and less susceptibility to sigma formation. Because increase in carbon content tends to decrease the microfissuring of wholly austenitic welds, the alloys with carbon at the higher end of the composition range are somewhat easier to weld than those on the low side. Furthermore, welding filler metal matching the carbon content of the cast alloys is available and is preferred to the low-carbon, partially ferritic type used for welding corrosion resistant alloys since it provides high temperature strength comparable to the base metal.

2.2.3 Iron-nickel-chromium alloys in which the nickel content exceeds the chromium are grades HN, HT, HU, HW and HX. They are wholly austenitic in microstructure and contain substantial amounts of carbides but do not form sigma phase under any conditions. The ratio of silicon to carbon is important to the weldability of these alloys - especially the HT and HU grades. Depending on the actual silicon and carbon contents, a ratio in the general neighborhood of 2:1 is considered to give the best balance between weld soundness and ductility. With sufficiently high carbon, the weld is sound at any silicon level but ductility decreases as carbon content increases. Ductility falls off sharply at high silicon-low carbon ratios and welds are badly fissured. Welding electrodes and filler metal that create weld deposits having silicon and carbon ion the ranges 0.75 to 1.50 percent and 0.40 to 0.55 percent, respectively, are available and are preferred for successful welds. Preheat is not required for welding these alloys in general, but complex shapes and heavy sections of the HN, HT and HU grades have improved weldability if preheated to around 400^{o}F (204^{o}C). Contamination of the weld by lead, sulfur or phosphorous is also very detrimental to these alloys and the same precautions regarding cleaning of the weld zone should be observed as described for the high nickel corrosion resistant grades in Section 2.1.4.

2.3 Welding dissimilar metals

Welds between different high alloys or between a high alloy and low alloy or carbon steel, can be made successfully with most of the heat and corrosion resistant grades. When such welds are attempted, the effects of dilution of the filler metal in the weld deposit must be given attention. The microstructure in the weld zone between a wholly austenitic and ferritic alloy, for example, will be different from either of the base materials and will have properties determined by the chemical composition balance of the diluted metal. Prediction of the structure to be expected can be obtained form the Schaeffler diagram. (See items 3 and 12 in the Bibliography.) Filler metals of higher alloy content than the high alloy base metal. are often used when welding high alloys to carbon steel. The use of carbon or low alloy steel filler metal on high alloys must be avoided since brittle, crack-prone welds will result. In order to prevent martensite formation in the weld zone under conditions of restraint, the low alloy should first be "buttered" with a layer of high alloy weld metal which should subsequently be shaped to provide the weld groove. The high alloy piece than can be welded to this prepared groove by using the normal filler metal.

3. Welding as a casting production and utilization process

Few processes are more important to the production and utilization of high alloy castings than welding. Although it may be obvious why welding is an important means for incorporating castings into composite structures (pipe lines, for example, where mechanical connections are undesirable), it may seem a misnomer to call welding a foundry "production process". Welding frequently is looked on as just a repair technique whereby defective castings are salvaged. It is implied, therefore, that improved foundry practices would result in production of defect-free castings and obviate the need for weld repair. Such a viewpoint overlooks the fact that the use of welding in casting production is dictated largely by specification requirements of the user and by the casting design.

3.1 Surface irregularities on castings are inherent in varying degree in the available molding processes. The foundry often can offer a choice of manufacturing methods and, where relative freedom from surface irregularities is desired, the purchaser's selection may then be based on economic considerations. If warranted by a large quantity of pieces and savings in cost to the purchaser on subsequent manufacturing processes in *his* operation, a casting technique requiring the most costly pattern equipment may be selected with the result that little or no welding on the surface of the castings will be involved. On the other hand, if the least costly molding method is chosen, then welding becomes a production tool for the "cosmetic" improvement of surface quality by elimination of excessive irregularities or for the structural rebuilding of surface discontinuities. Where surfaces are machined, machining is the production tool for the improvement of the surface finish, yet it is seldom, if ever, considered a "salvage" or "repair" operation. On occasion, both welding and machining may be required if rough machining discloses shallow sub-surface voids.

3.2 The relative versatility of the casting process among the various methods for producing desired shapes, leads many designers into the belief that any configuration, no mater how complex, should be castable with all sections completely free of internal voids or inclusions. Such is not the case, however, so that if the casting design makes it impossible to feed every portion of the mold effectively, unacceptable shrinkage must be corrected by the deposition of weld metal to fill the voids.

3.2.1 Preparation fo welding involves removal of metal inward from the surface of the as-cast section to eliminate the internal shrinkage or non-metallic inclusion. The cavity is then inspected to determine that all "unsound" metal has been removed before the section is rebuilt with layers of weld beads. This inspection may be visual or it may be specified to be done by radiographic or dye penetrant examination. What constitutes removal of porosity or inclusions to "sound" base metal is subject to interpretation and should be a matter of agreement between the purchaser and the foundry. Visual determination that unsound metal has been removed is usually considered sufficient to allow welding to proceed. If dye penetrant or radiographic examination is required the same criteria of acceptability are often applied to the prepared cavity as those applying (or which would apply, if specified) to the casting a s a whole.

3.2.2 Where design considerations prevent the proper feeding of casting sections, an otherwise uneconomical or impractical configuration may become feasible by welding together several less complex components. When the structure is assembled from two or more smaller and simpler castings, production of the individual parts can be arranged for optimum soundness, and higher over-all quality achieved than possible with a one-piece casting. It is obviously more economical to weld sound cast sections to one another in a preplanned fashion than to search for an internal void by non-destructive inspection, to remove good as-cast metal in order to get to the flaw, and then rebuild the section with weld metal. The usefulness of cast-weld construction, however, is not confined to exceptionally large or complex castings. Economies also can be obtained, for example, where a part is too big to be machine-molded in one piece but which can be divided into two machine-molded castings and then reunited by welding. For large structures that require machining in only one area, it is sometimes advantageous to cast and machine that portion separately and afterward to weld the two parts together.

3.3 Quality of welds in most of the high alloy types is not affected by the size of the sections or the cavity dimensions. Thus the distinction between so-called "minor" and "major" welds has no real significance and is often over-emphasized in purchase specifications. The strength of properly made welds is equivalent to that of the base metal (if the filler metal used creates a weld deposit of the same alloy composition) so that arbitrary limitations on the amount of welding permitted on castings, or time-delaying inspection and approval requirements prior to welding, are both costly and frequently unnecessary.

4 Welding processes in general use for high alloy castings

Cast high alloys can be welded by electric arc, electroslag, and oxyacetylene processes. The great majority of welds are made by arc-welding techniques and of these the shielded metal-arc process is the most popular. All the processes provide protection of the metal from the atmosphere during welding which is essential to ensure quality of the weld. The type of weld to be made and the characteristics of the alloy being welded, however, are influential in the choice of welding process to be employed.

4.1 detailed descriptions of the equipment used in each process, suggested joint designs, and discussions of each welding technique, are contained in equipment manufacturers' literature and in several of the references listed in the appended bibliography. The appropriate chapters in Volume 6 "Welding and Brazing" of the *Metals Handbook*, Eight Edition, published by the American Society of Metals, are especially informative. The following comments, therefore, are confined to the application of the processes to high alloy castings.

4.1.1 Shielded metal-arc process

Used for repair and fabrication welding on both corrosion and heat resistant alloy types, this process is adaptable to many of the situations encountered in casting manufacture or assembly. Electrodes are available in small or large quantities for all alloy compositions. It is a manual process that lends itself to wide variation in size and configuration of welds and to conditions of shop or filed welding. The slag developed during welding is a drawback, however, since it may result in weld inclusions and must be cleaned carefully from each bead before deposition of the next one. Although in carbon steel weld slags on one bead may sometimes be "floated out" through the next pass, this cannot be relied on in high alloys. Considerable skill is required of the operator in control of the arc and weld metal. Electrode coatings must be guarded against pick up of moisture in order to minimize pinholing.

4.1.2 Gas metal-arc process

Known frequently as “MIG” welding but currently designated as “GMAW” by the American Welding Society, this process is used mainly for fabrication welding where advantage can be taken of the high speed and relatively long periods of welding made possible by the continuous feeding of filler metal in the form of uncoated wire. Shielding of the weld by an inert gas practically eliminates development of slag, but slag can be formed by reactions within the molten pool so that cleaning of each weld pass is advisable. In addition to fabrication welding, the process is used for repair welding of some alloy types as noted on the individual welding procedure sheets. The need for protection of the shielding gas from drafts and reduced portability of the equipment make this process less attractive tan shielded metal-arc welding or gas tungsten-arc welding fo casting repair.

4.1.3 Gas tungsten-arc process

Like the gas metal-arc process described earlier, gas tungsten-arc (TIG or GTAW) uses an inert gas to protect the weld zone from the atmosphere but heat for fusion is provided by an arc between the casting and a non-consumable tungsten electrode. Thus welds can be made merely by fusion of the base metal without the addition of filler metal, or filler metal, if needed, may be added as bare wire. High heating rates and low heat inputs are characteristic of the tungsten arc which is especially desirable in welding in welding corrosion resistant alloys, particularly where postweld heat treatment is inconvenient. For this reason many superficial welds are made by this process. Gas tungsten-arc welding is also used for the root pass of fabrication welds because of the excellent visibility of the weld pool to the operator and the high quality of welds obtained. Subsequent passes often are laid down by other processes where large welds are involved. The process suffers from the same disadvantage as the gas metal-arc in that the weld zone must be protected from drafts that might dilute the shielding gas and cause inferior weld quality.

4.1.4 Electroslag welding

This process is used almost exclusively for the production of fabrication welds joining very large and heavy-walled castings where considerable quantities of metal are required in the joint. Filler metal is added through an electrically conductive molten slag which melts the surface of the base metal, and the entire weld pool is retained by water-cooled copper shoes bridging the joint on each side of the pieces being welded. This requires extensive auxiliary equipment for positioning the castings and for automatically feeding the filler metal to the weld. The process is used for high alloys, but because of its limited application, no welding procedure sheets are being issued.

4.1.5 Oxyacetylene welding

Welding using the flame of a torch burning a mixture of oxygen and acetylene gases to heat the work and simultaneously protect the weld pool from the air can be done on high alloy castings. As in the GTAW process, filler metal is added to the weld in the form of bare wire. The process is never advisable for use with the corrosion resistant alloys because of the pick up of carbon from the flame which reduces the corrosion resistance of the weld. This is not a serious factor with high-chromium, heat resistant alloy types, but oxyacetylene welding has no advantage over electric are welding which has almost completely superseded it commercially.

4.2 Individual alloy welding procedures

The following pages covering individual alloy types provide specific welding procedure information for may of the standard grades of corrosion resistant and heat resistant casting alloys.

Some general comments are in order regarding the production of good welds on high alloy castings and their acceptability. Proper training of welders is essential. Safety precautions should be observed. These are covered by American National Standard Z 49.1, “Safety in Welding and Cutting”. For many types of construction, compliance must be established with the Boiler and Pressure Vessel Code and the American National Standard Code for Pressure Piping both of which are published by the American Society of Mechanical Engineers. The qualification of welders and welding procedures necessary to meet the requirements of these codes are set forth in Section IX of the ASME Boiler and Pressure Vessel Code.

Care must be taken to keep the coatings on coated electrodes free from moisture. Once the container in which such electrodes are received is opened, the coating may absorb water from the atmospheric humidity and a porous weld deposit may result. Several hours exposure to high humidity can raise the coating moisture to a detrimental level. For this reason, unused electrodes should be stored at 200°F (93°C) or higher. Electrodes from freshly opened packages are considered best for critical welds.

The coatings on electrodes (for direct current welding) can be either the lime of titania type. A large, hot arc pool is characteristic of the lime coatings and the slag freezes quickly. Titania coatings which can be used for either AC or DC welding are distinguished by small arc puddles and a thin, low viscosity slag. Although welds made with titania-coated electrodes have generally smoother surfaces than those made with the lime-coated types, and slag that is easier to remove, lime coatings give better weld pool protection and are more frequently used for welding cast high alloys.

The need for cleanliness for the surfaces of prepared cavities or joints cannot be over emphasized. Cleaning of the entire weld zone before, during and after welding is essential to successful welding of high alloy castings. Contamination of the weld itself or the adjacent base metal can seriously affect the performance of the casting in service.

The requirements for postweld heat treatment as set forth in Section 12 of the individual alloy welding procedures should be given careful attention. A weld zone that is mechanically sound may be unfit for its intended service if it has not been restored to a microstructure having adequate corrosion resistance.

Bibliography

For additional information on the subjects covered in the foregoing review, the reader will find details in the following references:

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18. K.A. Ebert, "Influencing the Weldability of Austenitic Chromium Nickel Steels by Means of Their Ferrite Contents", *Schweissen und Schneiden*, 20, No.2, 1968 [Ferrite is location of precipitated phosphorus, silicon, carbon, etc. in preference to austenite grain boundaries and thus reduces crack sensitivity of weld]

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Procedure followed by experienced producers of high alloy castings in welding of type CA6NM alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CA6NM (11.5-14 Cr, 3.5-4.5 Ni, .40-1.0 Mo) static and centrifugal castings.
2	**Filler Metal** AWS E410 Ni Mo-15 — Lime coated electrode is preferred for DC welding. (This rod should not be used for AC.) AWS E410 Ni Mo-16 — Titania coated electrode is preferred for AC welding and may be used for DC. This type rod is useful for welding positions other than vertical-down.
3	**Position** Whenever possible, all welding is done in the "flat" position. A ±15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the castings as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly. Alcohol and acetone are solvents frequently used for cleaning.
6	**Preheat Temperature** CA6NM can normally be welded at room temperature (70°F) (21°C). For large welds in heavy or highly stressed sections, castings may be preheated in the range of 212 to 300°F (100 to 150°C), and the interpass temperature may be maintained at 500 to 600°F (260 to 315°C) as a guideline. Welding of castings in the heat treated condition is preferred to welding as-cast metal.
7	**Section Size** Section size normally is considered unimportant in welding this alloy. If section thickness is under ½ inch, it may be desirable to limit electrode size to 1/8 inch maximum. For section thicknesses over three inches, preheating may be employed.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.

9 **Welding Techniques**

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to two to three times the electrode wire diameter, or twice the gas cup orifice diameter. All slag is removed between passes with a hammer and a stainless wire brush, or a needle gun. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, one 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 **Electrical Characteristics**

Welding normally is done using DC reverse polarity. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings; it is good practice to use small diameter electrodes and low heat to prevent distortion.

12 **Post-Weld Heat Treatment**

Welds normally are heated to the range 1100-1150°F (593-620°C) and then air cooled. In cases where a special hardness requirement must be attained, the welded casting is given a full reheat treatment followed by tempering.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, liquid penetrant, magnetic particle, radiography, ultrasonic, or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of types CA15 and CA40 alloys as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CA15 (11.5-14 Cr, 0.15 max. C) static and centrifugal castings.
2	**Filler Metal** AWS E410-15 — Lime coated electrode is preferred for DC welding. (This rod should not be used for AC.) AWS E410-16 — Titania coated electrode is preferred for AC welding and may be used for DC. This type rod is useful for welding positions other than vertical-down.
3	**Position** Whenever possible, all welding is done in the "flat" position. A ±15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly. Alcohol and acetone are solvents frequently used for cleaning.
6	**Preheat Temperature** Heat this alloy to the range 300-600°F (149-315°C) and maintain the metal above 300°F (149°C) during the welding operation. Welds sometimes are made successfully without preheat, especially if the carbon content of the alloy is less than 0.10 percent. In general, preheat is preferred. Heating in the range 600-1100°F (315-593°C) is avoided because it will result in a loss of ductility and impact strength. Welding of castings in the annealed condition is preferred to welding of as-cast metal.
7	**Section Size** Section size usually is considered unimportant in welding this alloy. If section thickness is under ½ inch, it may be desirable to limit electrode size to 1/8 inch maximum. For section thicknesses over three inches, preheat temperature should be at the high end of the range.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° are sometimes used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.

9 **Welding Technique**

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to two to three times the electrode wire diameter. All slag is removed between passes with a hammer and a wire brush, or a needle gun using stainless steel needles. No peening is done unless the welds are large and/or the cavity or weld groove is deep. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld (6 and 7).

10 **Electrical Characteristics**

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc sometimes can be caused by initial hand recoil and may result in weld spatter or porosity.

11 **Technique for Welding Machined Castings**

This process can be used for welding machined castings by keeping heat to a minimum through use of small electrodes, and by cooling to room temperature between passes. Type AWS E309-15 or AWS E310-15 electrodes sometimes are used.

12 **Post-Weld Heat Treatment**

Welds usually are heated to the range 1100-1450°F (593-788°C), and then either air or furnace cooled depending on the specification of mechanical properties for the casting. In some cases where welds are large or located in critical areas of the casting, they are given a full re-heat treatment of heating to 1800°F (982°C) minimum, followed by air cooling and tempering at the specified temperature. Minor, superficial welds sometimes are not post-heat treated when the presence of hard spots resulting from untempered martensite in the weld deposits can be tolerated.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, magnetic particle, radiography, pressure, or ultrasonic.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of types CA15 and CA40 alloys as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CA15 (11.5-14 Cr, 0.15 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ER410 - Bare wire is used in this process.
3	**Position** All welding is done in the "flat" position. A ±15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly. Alcohol and acetone are solvents frequently used for cleaning.
6	**Preheat Temperature** Heat this alloy to the range 300-600°F (149-315°C) and maintain the metal above 300°F (149°C) during the welding operation. Welds sometimes are made successfully without preheat, especially if the carbon content of the alloy is less than 0.10 percent. In general, preheat is preferred. Heating in the range 600-1100°F (315-593°C) is avoided because it will result in a loss of ductility and impact strength. Welding of castings in the annealed condition is preferred to welding of as-cast metal.
7	**Section Size** Section size usually is considered unimportant in welding this alloy. For section thicknesses over two inches, preheat should be above 400°F (204°C).
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result*

in defective welds. Either stringer or weave bead placement is used. Weaving, if any, is limited to about the diameter of the gas nozzle. No peening is done. It is customary to remove any defects in the weld by grinding before laying down the next bead. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld (6 and 7).

10 Electrical Characteristics

Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 0.094 inch. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually argon plus two percent (2%) oxygen at a flow rate of 30 to 50 cfh. An alternate mixture of 75 percent argon plus 25 percent carbon dioxide at a flow rate of 20 cfh also is used.

11 Technique for Welding Machined Castings

This process is seldom used to weld machined castings; when it is, AWS ER309 or AWS ER310 type electrode wire is used.

12 Post-Weld Heat Treatment

Welds usually are heated to the range 1100-1450°F (593-788°C), and then either air or furnace cooled depending on the specification of mechanical properties for the casting. In some cases where welds are large or located in critical areas of the casting, they are given a full re-heat treatment of heating to 1800°F (982°C) minimum, followed by air cooling and tempering at the specified temperature. Minor, superficial welds sometimes are not post-heat treated when the presence of hard spots resulting from untempered martensite in the weld deposits can be tolerated.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, magnetic particle, radiography, pressure, or ultrasonic.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of types CA15 and CA40 alloys as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CA15 (11.5-14 Cr, 0.15 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ER410 - Bare wire is used to weld this alloy.
3	**Position** Whenever possible, all welding is done in the "flat" position. A ±15° angle of the groove with the horizontal plane normally is considered flat. Successful welds can be made by this process, however, in all positions.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by grinding. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly. Alcohol and acetone are solvents frequently used for cleaning.
6	**Preheat Temperature** Heat this alloy to the range 300-600°F (149-315°C) and maintain the metal above 300°F (149°C) during the welding operation. Welds sometimes are made successfully without preheat, especially if the carbon content of the alloy is less than 0.10 percent. In general, preheat is preferred. Heating in the range 600-1100°F (315-593°C) is avoided because it will result in a loss of ductility and impact strength. Welding of castings in the annealed condition is preferred to welding of as-cast metal.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is not restricted in extent. Peening may be done between successive passes on deep welds. If parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be

performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld (6).

10 Electrical Characteristics

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used normally are followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; it is good practice, however, to use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

Welds usually are heated to the range 1100-1450°F (593-788°C), and then either air or furnace cooled depending on the specification of mechanical properties for the casting. In some cases where welds are large or located in critical areas of the casting, they are given a full re-heat treatment of heating to 1800°F (982°C) minimum, followed by air cooling and then tempering at the specified temperature. Minor, superficial welds often are not post-heat treated.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, magnetic particle, radiography, pressure, or ultrasonic.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CB7Cu alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy types CB7Cu-1 (15.5-17.0 Cr, 3.6-4.6 Ni, 2.5-3.2 Cu, 0.07 max. C) and CB7Cu-2 (14.0-15.5 Cr, 4.5-5.5 Ni, 2.5-3.2 Cu, 0.07 max. C) static and centrifugal castings.
2	**Filler Metal** AWS E630-15 — Lime coated electrode is preferred for DC welding. This rod should not be used for AC. AWS E630-16 — Titania coated electrode is used for AC welding and may be used for DC.
3	**Position** All welding is done in the "flat" position. A ±15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly. Alcohol and acetone are solvents frequently used for cleaning.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 500°F (260°C).
7	**Section Size** Section size usually is considered unimportant in welding this alloy. Thick sections may require preheat (6) for satisfactory welds.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result*

in defective welds. Either stringer or weave bead placement is used. Weaving, if any, is limited to two and one-half times the electrode diameter. Fully hardened castings are frequently preheated (6) and welded with low heat and small rods. No peening is done. All slag is removed with a stainless steel wire brush or slagging hammer, or needle gun using stainless steel needles. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld (6 and 7).

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 1/4 inch may be used with the amperage and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; it is good practice, however, to use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, it is desirable to quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary since the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

Both annealed and aged type CB7Cu castings can be restored to specified hardness by low temperature postweld hardening treatment in the range 900-1100°F (482-593°C). But to restore hardenability properties to multiple-pass welds on heavy sections, they are heated to the range 1850-1950°F (1010-1066°C), held until uniformly at temperature, rapidly cooled by quenching in water, oil or air, and followed by the desired aging treatment. Single-pass welds usually do not require postweld solution heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CB7Cu alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy types CB7Cu-1 (15.5-17.0 Cr, 3.6-4.6 Ni, 2.5-3.2 Cu, 0.07 max. C) and CB7Cu-2 (14.0-15.5 Cr, 4.5-5.5 Ni, 2.5-3.2 Cu, 0.07 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ER630 Bare wire is used.
3	**Position** All welding is done in the "flat" position. A ±15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1.).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly. Alcohol and acetone are solvents frequently used for cleaning.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 500°F (260°C).
7	**Section Size** Section size usually is considered unimportant in welding this alloy. Thick sections may require preheat (6) for satisfactory welds.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to two and one-half times the wire diameter. No peening is done. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch

backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld (6 and 7).

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/64 to 3/32 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc sometimes can be caused by initial hand recoil and may result in weld spatter or porosity. Shielding gas is usually argon plus two percent (2%) oxygen at a flow rate of 30 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary since the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

Both annealed and aged type CB7Cu castings can be restored to specified hardness by low temperature postweld hardening treatment in the range 900-1100°F (482-593°C). But to restore hardenability properties to multiple-pass welds on heavy sections, they are heated to the range 1850-1950°F (1010-1066°C), held until uniformly at temperature, rapidly cooled by quenching in water, oil or air, and followed by the desired aging treatment. Single pass welds usually do not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CB7Cu alloy as reported in a survey of SFSA members

Section	Subject/Procedure

1 Base Metal
Alloy types CB7Cu-1 (15.5-17.0 Cr, 3.6-4.6 Ni, 2.5-3.2 Cu, 0.07 max. C) and CB7Cu-2 (14.0-15.5 Cr, 4.5-5.5 Ni, 2.5-3.2 Cu, 0.07 max. C) static and centrifugal castings.

2 Filler Metal
AWS ER630 — Bare wire is used. For repair of small surface irregularities, welds are sometimes made without the use of any filler metal.

3 Position
All welding is done in the "flat" position. A ±15° angle of the groove with the horizontal plane normally is considered flat.

4 Base Metal Preparation for Repair
Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).

5 Base Metal Preparation for Fabrication
Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly. Alcohol and acetone are solvents frequently used for cleaning.

6 Preheat Temperature
Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 500°F (260°C).

7 Section Size
Section size usually is considered unimportant in welding this alloy. Thick sections may require preheat (6) for satisfactory welds.

8 Cavity Dimensions
This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.

9 Welding Technique
Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used, but very little weaving is done. No peening is done. Because no slag is formed during the welding

operation, interpass cleaning is not necessary. If parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld (6 and 7).

10 Electrical Characteristics

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 15 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary since the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

Both annealed and aged type CB7Cu castings can be restored to specified hardness by low temperature postweld hardening treatment in the range 900-1100°F (482-593°C). But to restore hardenability properties to multiple-pass welds on heavy sections, they are heated to the range 1850-1950°F (1010-1066°C), held until uniformly at temperature, rapidly cooled by quenching in water, oil or air, and followed by the desired aging treatment. Single pass welds usually do not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CD4MCu alloy as reported in a survey of SFSA members

Section — Subject/Procedure

1 **Base Metal**
Alloy type CD4MCu (24.5-26.5 Cr, 4.75-6 Ni, 1.75-2.25 Mo, 2.75-3.25 Cu, 0.04 max. C) static and centrifugal castings.

2 **Filler Metal**
Lime coated electrodes that will deposit weld metal of the CD4MCu composition are available and are used. The weld deposit should approximate the base metal because the properties of this alloy are influenced critically by the chemical composition, however, some minor variation in composition may be necessary to obtain the desired microstructure.

3 **Position**
All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.

4 **Base Metal Preparation for Repair**
Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).

5 **Base Metal Preparation for Fabrication**
Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.

6 **Preheat Temperature**
No preheat is required for type CD4MCu alloy.

7 **Section Size**
Section size usually is considered unimportant in welding this alloy.

8 **Cavity Dimensions**
Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.

9 **Welding Technique**
Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to two to three times the electrode wire diameter. No peening is done. All slag is removed between passes with a hammer and/or a stainless steel wire brush. If a defect

penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. This alloy cannot be welded satisfactorily to other metals.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CD4MCu castings, they are heated to 2050°F (1121°C) minimum, held until uniformly at temperature, furnace cooled to 1900°F (1038°C), and then rapidly cooled by quenching in water, oil or air.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CD4MCu alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CD4MCu (24.5-26.5 Cr, 4.75-6 Ni, 1.75-2.25 Mo, 2.75-3.25 Cu, 0.04 max. C) static and centrifugal castings.
2	**Filler Metal** Small defects and root passes are sometimes welded by fusion of the base metal only, without the addition of any filler metal. When filler metal is used, it is frequently cast rod of the CD4MCu composition. The weld deposit should approximate the base metal because the properties of this alloy are influenced critically by the chemical composition, however, some minor variation in composition may be necessary to obtain the desired microstructure.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects usually are removed before attempting any repair. Defect removal is accomplished by grinding. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** This process is not being used for fabrications of type CD4MCu castings.
6	**Preheat Temperature** No preheat is required for type CD4MCu alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. This alloy cannot be welded satisfactorily to other metals.
10	**Electrical Characteristics** Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may

be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CD4MCu castings, they are heated to 2050°F (1121°C) minimum, held until uniformly at temperature, furnace cooled to 1900°F (1038°C), and then rapidly cooled by quenching in water, oil or air.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CF8 alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type — CF8 (18-21 Cr, 8-11 Ni, 0.08 max. C) static and centrifugal castings. Also types — CF3 (17-21 Cr, 8-12 Ni, 0.03 max. C) and CF16F (18-21 Cr, 9-12 Ni, 1.5 max. Mo, 0.20-0.35 Se, 0.16 max. C).
2	**Filler Metal** AWS E308-15 — Lime-coated electrode is preferred for DC welding. (This rod should not be used for AC.) Used for types CF8 and CF16F. AWS E308L-15 — Lime-coated electrode is preferred for DC welding. (This rod should not be used for AC.) Used for type CF3. AWS E308-16 — Titania-coated electrode is used for AC welding and may be used for DC.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type CF8 alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy. When sections are under ½ inch in thickness, use an electrode no larger than 1/8 inch.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result*

in defective welds. Either stringer or weave bead placement is used. Weaving, if any, is limited to two to four times the electrode wire diameter. No peening is done. All slag should be removed between passes with a hammer and/or a stainless steel wire brush, or a needle gun using stainless steel needles. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 1/4 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CF8 castings, they are heated to 1900°F (1038°C) (2000°F [1093°C] for CF16F and CF20) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment. Type CF3 castings may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CF8 alloy as reported in a survey of SFSA members

Section Subject/Procedure

1 **Base Metal**

Alloy type CF8 (18-21 Cr, 8-11 Ni, 0.08 max. C) static and centrifugal castings.
Also types CF3 (17-21 Cr, 8-12 Ni, 0.03 max. C) and
CF16F (18-21 Cr, 9-12 Ni, 1.5 max. Mo, 0.20-0.35 Se, 0.16 max. C).

2 **Filler Metal**

AWS ER308L Bare wire is used for CF3.
AWS ER308 Bare wire is used for CF8 and CF16F.

3 **Position**

All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.

4 **Base Metal Preparation for Repair**

Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.1.2).

5 **Base Metal Preparation for Fabrication**

Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.

6 **Preheat Temperature**

No preheat is required for type CF8 alloy.

7 **Section Size**

Section size usually is considered unimportant in welding this alloy.

8 **Cavity Dimensions**

Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.

9 **Welding Technique**

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to about ½ inch, or not in excess of the diameter of the gas nozzle. No peening is done. Beads are cleaned between passes with a stainless steel wire brush. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 0.094 inch. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually argon plus two percent (2%) oxygen at a flow rate of 30 to 50 cfh. An alternate mixture of 75 percent argon plus 25 percent carbon dioxide at a flow rate of 20 cfh is also used, but may affect the corrosion resistance of the weld adversely on multipass welds.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CF8 castings, they are heated to 1900°F (1038°C) (2000°F [1093°C] for CF16F and CF20) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment. Type CF3 castings may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).
2. Use the proper filler metal (2).
3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CF8 alloy as reported in a survey of SFSA members

Section Subject/Procedure

1 **Base Metal**

Alloy type	CF8 (18-21 Cr, 8-11 Ni, 0.08 max. C) static and centrifugal castings.
Also types	CF3 (17-21 Cr, 8-12 Ni, 0.03 max. C) and CF16F (18-21 Cr, 9-12 Ni, 1.5 max. Mo, 0.20-0.35 Se, 0.16 max. C).

2 **Filler Metal**

AWS ER308L	Bare wire is used for CF3. Small defects and root passes are sometimes welded by fusion of the base metal only, without the addition of any filler metal.
AWS ER308	Bare wire is used for CF8.

3 **Position**

All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.

4 **Base Metal Preparation for Repair**

Minor, superficial defects are occasionally welded without any preparation other than sandblasting. Defects usually are removed, however, before attempting repair. Removal normally is accomplished by grinding. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.

5 **Base Metal Preparation for Fabrication**

This process is seldom used for fabrication of composite castings. It is more frequently used for combining wrought and cast components. Parts to be joined are ground or machined to provide a groove when placed together. Good practice is to machine dry with no lubricant and to clean the parts thoroughly before assembly. A good fit of the mating parts is essential for production of good welds.

6 **Preheat Temperature**

No preheat is required for type CF8 alloy.

7 **Section Size**

Section size usually is considered unimportant in welding this alloy. When section thickness is under 1/4 inch, use a copper back-up strip for through welds.

8 **Cavity Dimensions**

This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.

9 **Welding Technique**

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited; very little weaving is done in this process. No peening is done and, because no slag is formed during the welding operation, interpass cleaning usually is unnecessary. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CF8 castings, they are heated to 1900°F (1038°C) (2000°F [1093°C] for CF16F and CF20) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment. Type CF3 castings may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CF8M alloy as reported in a survey of SFSA members

Section	Subject/Procedure	
1	**Base Metal**	
	Alloy type	CF8M (18-21 Cr, 9-12 Ni, 2-3 Mo, 0.08 max. C) static and centrifugal castings.
	Also types	CF3M (17-21 Cr, 9-13 Ni, 2-3 Mo, 0.03 max. C) and CG8M (18-21 Cr, 9-13 Ni, 3-4 Mo, 0.08 max. C).
2	**Filler Metal**	
	AWS E308 Mo-15 AWS E316-15 AWS E317-15 *	Lime-coated electrode is preferred for DC welding. (This rod should not be used for AC.)
	AWS E316L-15 AWS E308 MoL-15	Used for welding type CF-3M alloy.
	AWS E308 Mo-16 AWS E316-16 AWS E317-16 *	Titania-coated electrode is used for AC welding and may be used for DC.

3 Position

All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.

4 Base Metal Preparation for Repair

Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).

* For welding type CG8M castings.

5 Base Metal Preparation for Fabrication

Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.

6 Preheat Temperature

No preheat is required for type CF8M alloy.

7 Section Size

Section size usually is considered unimportant in welding this alloy.

8 Cavity Dimensions

Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.

9 Welding Technique

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to two to three times the electrode wire diameter. All slag is removed between passes with a hammer and/or a stainless steel wire brush, or a needle gun using stainless steel needles. No peening is done on most welds, but occasionally light peening of the bead edges may prove beneficial. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 1/4 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, it is desirable to quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CF8M castings, they are heated to 1900°F (1038°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment. Type CF3M castings may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CF8M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type: CF8M (18-21 Cr, 9-12 Ni, 2-3 Mo, 0.08 max. C) static and centrifugal castings. Also types: CF3M (17-21 Cr, 9-13 Ni, 2-3 Mo, 0.03 max. C) and CG8M (18-21 Cr, 9-13 Ni, 3-4 Mo, 0.08 max. C).
2	**Filler Metal** AWS ER308 MoL, AWS ER316L — Bare wire is used for CF3M. AWS ER316, AWS ER308 Mo — Bare wire is used for CF8M. AWS ER317 — Bare wire is used for type CG8M.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type CF8M alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or

weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to about ½ inch, or not in excess of the diameter of the gas nozzle. No peening is done. Beads are cleaned between passes with a stainless steel wire brush. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 0.063 inch. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually argon plus two percent (2%) oxygen at a flow rate of 30 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; it is good practice, however, to use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CF8M castings, they are heated to 1900°F (1038°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment. Type CF3M castings may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CF8M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type: CF8M (18-21 Cr, 9-12 Ni, 2-3 Mo, 0.08 max. C) static and centrifugal castings. Also types: CF3M (17-21 Cr, 9-13 Ni, 2-3 Mo, 0.03 max. C) and CG8M (18-21 Cr, 9-13 Ni, 3-4 Mo, 0.08 max. C).
2	**Filler Metal** AWS ER308 MoL, AWS ER316L — Bare wire is used for CF3M. AWS ER316, AWS ER308 Mo — Bare wire is used for CF8M. AWS ER317 — Bare wire is used for type CG8M. Small defects and root passes are sometimes welded by fusion of the base metal only, without the addition of any filler metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Minor, superficial defects are occasionally welded without any preparation other than sandblasting. Defects usually are removed, however, before attempting repair. Removal normally is accomplished by grinding. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** This process is seldom used for fabrication of composite castings. It is sometimes used for the root pass with subsequent passes laid down by some other process. More frequently, it is used for combining wrought and cast components. Parts to be joined are ground or machined to provide a groove when placed together. A good fit of the mating parts is essential for production of good welds. Good practice is to machine dry with no lubricant and to clean the parts thoroughly before assembly.
6	**Preheat Temperature** No preheat is required for type CF8M alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.

9 **Welding Technique**

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited; very little weaving is done in this process. Interpass cleaning usually is not required because no slag is formed unless coated electrodes (even with the coating removed) have been used as filler metal. Any cleaning should be done with a stainless steel wire brush. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 **Electrical Characteristics**

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, it is desirable to quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 **Post-Weld Heat Treatment**

To restore maximum corrosion resistance to welded type CF8M castings, they are heated to 1900°F (1038°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment. Type CF3M castings may not require postweld heat treatment.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CK20 alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CK20 (23-27 Cr, 19-22 Ni, 0.20 max. C) static and centrifugal castings.
2	**Filler Metal** AWS E310-15 — Lime-coated electrode is preferred for DC welding. (This rod should not be used for AC.) AWS E310-16 — Titania-coated electrode is used for AC welding and may be used for DC.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type CK20 alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to two to three times the electrode wire diameter. All slag is removed between passes with a hammer and/or a stainless steel wire brush, or a needle gun using stainless steel needles. No peening is done on most welds, but light peening of each pass is sometimes helpful in producing sound welds. If a defect penetrates through the casting,

or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CK20 castings, they are heated to 2000°F (1093°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CK20 alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CK20 (23-27 Cr, 19-22 Ni, 0.20 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ER310 Bare wire is preferred in this process. Small defects and root passes are sometimes welded by fusion of the base metal only, without the addition of any filler metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Minor, superficial defects are occasionally welded without any preparation other than sandblasting. Defects usually are removed, however, before attempting repair. Removal normally is accomplished by grinding. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** This process is seldom used for fabrication of composite castings. It is sometimes used for the root pass with subsequent passes laid down by some other process. More frequently, it is used for combining wrought and cast components. Parts to be joined are ground or machined to provide a groove when placed together. A good fit of the mating parts is essential for production of good welds. Good practice is to machine dry with no lubricant and to clean the parts thoroughly before assembly.
6	**Preheat Temperature** No preheat is required for type CK20 alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Stringer bead placement is used. Beads are cleaned between passes with a stainless steel wire brush if required because of slag formation. No peening is done. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all

directions.

10 **Electrical Characteristics**

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 **Post-Weld Heat Treatment**

To restore maximum corrosion resistance to welded type CK20 castings, they are heated to 2000°F (1093°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CN7M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CN7M (19-22 Cr, 27.5-30.5 Ni, 2-3 Mo, 3-4 Cu, 0.07 max. C) static and centrifugal castings.
2	**Filler Metal** AWS E320-15 — Lime-coated electrode is preferred for DC welding. (This rod should not be used for AC.) AWS E320-16 — Titania-coated electrode is used for AC welding and may be used for DC.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally, this alloy is not preheated; however, if the extent of the weld is substantial, the alloy may be preheated to 400-600°F (204-315°C).
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to four times the electrode wire diameter. Interpass temperature is kept as low as possible. All slag is removed with chisel, hammer, and/or stainless steel wire brush.

Beads are lightly peened at edges first, then at center. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. If preheating is done, tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage on the low side of the range suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CN7M castings, they are heated to 2050°F (1121°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CN7M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CN7M (19-22 Cr, 27.5-30.5 Ni, 2-3 Mo, 3-4 Cu, 0.07 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ER-320 Bare wire is used in this process.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** This process is not being used for repair welding of castings.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally, this alloy is not preheated; however, if the extent of the weld is substantial, the alloy may be preheated to 400-600°F (204-315°C).
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Good fitting, well prepared joints are essential, but dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Special attention is paid to directing the arc into the side walls and root of the joint. No peening is done. Beads are cleaned between passes with a stainless steel wire brush.
10	**Electrical Characteristics** Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 0.094 inch. For root passes, the smaller size wires are used. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually argon plus two percent (2%) oxygen at a flow rate of 30 to 50 cfh.
11	**Technique for Welding Machined Castings** This process is not being used to weld machined castings.

12 **Post-Weld Heat**

TreatmentTo restore maximum corrosion resistance to welded type CN7M castings, they are heated to 2050°F (1121°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that surfaces to be welded are thoroughly cleaned (5 and 9).
2. Use the proper filler metal (2).
3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CN7M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CN7M (19-22 Cr, 27.5-30.5 Ni, 2-3 Mo, 3-4 Cu, 0.07 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ER320 Bare wire is used in this process. Small defects and root passes sometimes are welded by fusion of the base metal only, without the addition of any filler metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, sandblast, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** This process is not being used for fabrication of castings.
6	**Preheat Temperature** No preheat is required for type CN7M alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited. Beads are cleaned with a stainless steel wire brush. No peening is done.
10	**Electrical Characteristics** Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 **Post-Weld Heat Treatment**

To restore maximum corrosion resistance to welded type CN7M castings, they are heated to 2050°F (1121°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require postweld heat treatment.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CW12M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CW12M (15.5-20 Cr, 16-20 Mo, 7.5 max. Fe, 5.25 max. W, 2.5 max. Co, 0.12 max. C, balance Ni) static and centrifugal castings.
2	**Filler Metal** AWS ENiCrMo-4-15 Lime coated electrode is used. AWS ENiCrMo-5-15
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. It is considered good practice to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally, this alloy is not preheated; however, if the extent of the weld is substantial, the alloy may be preheated to 400-600°F (204-315°C).
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to two and one-half times the electrode wire diameter. All slag is removed between passes with a hammer and/or stainless steel wire brush. Light peening of the first pass is sometimes helpful in producing a sound weld. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is

formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends to a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; it is good practice, however, to use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, it is desirable to quench the weld zone with a wet cloth between each pass. For small welds on heavy sections this may not be necessary since the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type CW12M castings, they are heated to 2150^{o}F (1177^{o}C) minimum, held for two hours or until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require post weld heat treatment

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

In order to produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CW12M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CW12M (15.5-20 Cr, 16-20 Mo, 7.5 max. Fe, 5.25 max. W, 2.5 max. Co, 0.12 max. C, balance Ni) static and centrifugal castings.
2	**Filler Metal** AWS ENiCrMo-4 Bare wire is used. AWS EniCrMo-5 AWS EniCrMo-7 Small defects and root passes are sometimes welded by fusion of the base metal only, without the addition of any filler metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** This process is not being used for the fabrication of castings.
6	**Preheat Temperature** No preheat is required for type CW12M alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** The process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Beads are cleaned with hammer and/or stainless steel wire brush if any slag is present. No peening is done.

10 **Electrical Characteristics**

Welding normally is done using DC reverse polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a “scratch start” to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Amperage and voltage suggested by the electrode manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings; it is good practice, however, to use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, it is desirable to quench the weld zone with a wet cloth between each pass. For small welds on heavy sections this may not be necessary since the heavy mass will tend to cool the weld zone rapidly.

12 **Post-Weld Heat Treatment**

To restore maximum corrosion resistance to welded type CW12M castings, they are heated to 2150°F (1177°C) minimum, held for two hours or until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds which have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service may not require post weld heat treatment

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 **Summary**

In order to produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CY40 alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CY40 (14-17 Cr, 11 max. Fe, balance Ni, 0.40 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ENiCrFe-1 Coated electrodes of the types listed are used for DC welding.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally, this alloy is not preheated; however, if the extent of the weld is substantial, the alloy may be preheated to 400-600°F (204-315°C).
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to two and one-half times the electrode wire diameter. All slag is removed between passes with a hammer and/or stainless steel wire brush. No peening is done. If the casting will be exposed to high temperature in service, remove all traces of slag from the finished weld area. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after

welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

Welded type CY40 castings are heated to 1900°F (1038°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CY40 alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CY40 (14-17 Cr, 11 max. Fe, balance Ni, 0.40 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ERNiCrFe-5 Bare wire is used. Small defects and root passes sometimes are welded by fusion of the base metal only, without the addition of any filler metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by sandblasting and grinding, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** This process is not being used for fabrication of castings.
6	**Preheat Temperature** No preheat is required for type CY40 alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Beads are cleaned with hammer and/or stainless steel wire brush if any slag is present. No peening is done.
10	**Electrical Characteristics** Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

Welded type CY40 castings are heated to 1900°F (1038°C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds may not require postweld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type CZ100 alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type CZ100 (95 min. Ni, 3 max. Fe, 1.00 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ENi-1 A coated electrode with 0.10 max. carbon.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type CZ100 alloy. For complicated castings where high stresses may be developed in welding, preheat of 200-300°F (93-149°C) sometimes is desirable.
7	**Section Size** Section size usually is considered unimportant in welding this alloy. If sections are under ½ inch in thickness, however, use small electrodes and keep the heat low.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 80° should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. When breaking the arc, it should be shortened and the rate of travel increased to avoid crater oxidation. All slag is removed between passes and from the completed weld with a hammer and/or stainless steel wire brush, or a needle gun using stainless steel needles. Light peening of the first pass is helpful, but no peening is done on later passes. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of

3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 1/8 or 5/32 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

No postweld heat treatment is given to welded type CZ100 alloy.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type N-12M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type N-12M (26-33 Mo, 6 max. Fe, balance Ni, 0.12 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ENiMo-1-15 Lime coated electrode is used.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly. Cleanliness is especially important in welding this alloy. Minimum weld restraint is arranged.
6	**Preheat Temperature** Normally this alloy is not preheated: however, if section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 800-1000°F (427-538°C).
7	**Section Size** Section size usually is considered unimportant in welding this alloy (6).
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. Stringer beads usually are preferred. All slag is removed between passes with a hammer and/or stainless steel wire brush. Light peening of the first pass is sometimes helpful in producing a sound weld. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it

extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 1/8 to 5/32 inch may be used with the amperage and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; it is good practice however, to use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, it is desirable to quench the weld zone with a wet cloth between each pass. For small welds on heavy sections this may not be necessary since the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

To restore maximum corrosion resistance to welded type N-12M castings, they are heated to 2100ºF (1149ºC) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type N-12M alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type N-12M (26-33Mo, 6 max. Fe, balance Ni, 0.12 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ERNiMo-1 Bare wire is used. AWS ERNiMo-7 Small defects and root passes sometimes are welded by fusion of the base metal only, without the addition of any filler metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** This process is not being used for fabrication of castings.
6	**Preheat Temperature** No preheat is required for type N-12M alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Stringer bead placement is used. No peening is done. Any slag or oxide present is removed by chipping or brushing with a stainless steel wire brush.
10	**Electrical Characteristics** Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Amperages and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings; however, it is good practice, however, to use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, it is desirable to quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 **Post-Weld Heat Treatment**

To restore maximum corrosion resistance to welded type N-12M castings, they are heated to 2100^{o}F (1149^{o}C) minimum, held until uniformly at temperature, and then rapidly cooled by quenching in water, oil or air. Small welds that have been made to improve the appearance of casting surfaces that will not be subjected to corrosive attack in service, may not require postweld heat treatment.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type M-35 alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type M-35 (26-33 Cu, 3.5 max. Fe, balance Ni, 0.35 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ENiCu-7 Electrode is preferred for welding this alloy.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type M-35 alloy. For complicated castings where high stresses may be developed in welding, preheat of 200-300°F (93-149°C) is sometimes desirable.
7	**Section Size** Section size usually is considered unimportant in welding this alloy. For sections under ½ inch in thickness, small electrodes and low current are used to keep temperature as low as possible.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. Stringer beads are preferred. All slag is removed between passes with a hammer and/or stainless steel wire brush. No peening is done. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in

order to minimize the possibility of initiating a crack at the tack weld.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

No postweld heat treatment is used for type M-35 castings.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

4. Grind surface area around the groove or cavity to be welded to remove silica from molding sand to prevent surface cracking around weld-base metal interface.

Procedure followed by experienced producers of high alloy castings in welding of type M-35 alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type M-35 (26-33 Cu, 3.5 max. Fe, balance Ni, 0.35 max. C) static and centrifugal castings.
2	**Filler Metal** AWS ERNiCu-1 Bare wire is used. AWS ERNiCu-7 Small defects and root passes sometimes are welded by fusion of the base metal only, without the addition of any filler metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, grinding, or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** This process is not being used for fabrication of castings.
6	**Preheat Temperature** No preheat is required for type M-35 alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** This process is used mainly for surface welds, hence very little metal excavation is necessary and dimensions are not critical.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Agitation of the molten puddle is avoided, and the puddle plus the hot end of filler metal wire is kept within the shielding gas at all times. Care is taken to prevent air contamination of the shielding gas from drafts.
10	**Electrical Characteristics** Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications

for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 1/8 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. If the welded area will be subject to corrosion, quench the weld zone with a wet cloth between each pass. For small welds on heavy sections, this may not be necessary because the heavy mass will tend to cool the weld zone rapidly.

12 Post-Weld Heat Treatment

No postweld heat treatment is used for type M-35 castings.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography, or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4), and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

4. Grind surface area around the groove or cavity to be welded to remove silica from molding sand to prevent surface cracking around weld-base metal interface.

Procedure followed by experienced producers of high alloy castings in welding of type HC alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HC (26-30Cr, 4max. Ni, 0.50max.C) static and centrifugal castings. NOTE: This alloy is considered extremely difficult to weld because of low ductility and tendency toward cleavage type fractures. Several re-welds may be required.
2	**Filler Metal** AWS E446-15 Lime coated electrodes are preferred for welding type HC castings. AWS E310-15, AWS E312-15, AWS E329-15 — Lime coated electrodes are also used where improved ductility of the weld is required.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. It is considered good practice to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Preheat temperatures from 400-600°F (204-313°C) are used in welding this alloy.
7	**Section Size** Section size usually is considered important in welding this alloy. If section thickness is 1/4 inch or less, preheat is sometimes omitted but on heavier sections preheat is required. Although successful welds are made with low preheat temperatures, it may be necessary to go to the high end of the range to obtain good welds. When the depth of a defect exceeds 15 percent of the wall thickness, attempts to repair by welding are often considered to be useless.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root. (Refer to Secs. 6 and 7)

9 **Welding Technique**

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. Staggered stringer beads are used on heavy sections. All slag is removed between passes with a hammer and/or wire brush. Generally, peening is not done but a light peen after each pass is sometimes helpful. If parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 **Electrical Characteristics**

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 1/8 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 **Technique for Welding Machined Castings**

No special technique (see Sec. 9) is necessary for welding machined castings; it is good practice, however, to use small rods and low heat to avoid distortion.

12 **Post-Weld Heat Treatment**

Welds are usually heated to the range 1550-1900°F (843-1038°C) and then cooled rapidly.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HC alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HC (26-30Cr, 4max. Ni, 0.50max.C) centrifugal castings. NOTE: This alloy is considered extremely difficult to weld because of low ductility and tendency toward cleavage type fractures.
2	**Filler Metal** This process is used mainly for root passes which are welded by fusion of the base metal without the addition of any filler metal. Subsequent passes are laid down by the shield metal-arc process (SMAW).
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. It is considered good practice to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Preheat temperatures from 400-600°F (204-313°C) are used in welding this alloy.
7	**Section Size** Section size usually is considered important in welding this alloy. (See procedure for shielded metal-arc welding of type HC alloy.)
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* If parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the

tack weld.

10 Electrical Characteristics

Welding normally is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 15 to 25 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings.

12 Post-Weld Heat Treatment

Welds are usually heated to the range 1550-1900°F (843-1038°C) and then cooled rapidly.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

In order to produce welds that will satisfy the user's requirements, it is customary to take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HF alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HF (19-23Cr, 9-12Ni, 0.20-0.40C) static and centrifugal castings.
2	**Filler Metal** AWS E308-15 / AWS E310-15 (0.30C) / AWS E330-15 — Lime coated electrodes are used for DC welding of this alloy. (These rods should not be used for AC) AWS E308-16 / AWS E309-16 — Titania coated electrodes are preferred for AC welding and may be used for DC.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation. (See Introduction, welding (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) is often used before welding of aged castings.
7	**Section Size** Section size usually is considered important in welding this alloy. Heavy sections may require preheat or postheat. (6 and 12)
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.

9 Welding Technique

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. Sometimes stringer beads are used exclusively, or are used for root passes with weave beads use for later passes. No peening is done. All slag is removed between passes and from finished weld with hammer, grinder and/or wire brush. Residual slag is very corrosive to the alloy at high temperature. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 1/8 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

In general no post-weld heat treatment is given to type HF alloy, but when section size exceeds one inch castings may be stress relieved at 1600°F (871°C) after welding.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HF alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HF (19-23Cr, 9-12Ni, 0.20-0.40C) static and centrifugal castings.
2	**Filler Metal** AWS ER310 (0.30C) Bare wire is used.
3	**Position** This process is being used mainly for fabrication of tubes positioned horizontally on rolls.
4	**Base Metal Preparation for Repair** This process is not being used for repair welding of castings.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) is often used before welding of aged castings.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Stringer beads are used on the root pass, then weave beads on subsequent filler passes. Beads are cleaned between passes by wire brushing. No peening is done.
10	**Electrical Characteristics** Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 0.062 inch. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually argon plus 2-5 percent oxygen at a flow rate of 30 to 50 cfh.
11	**Technique for Welding Machined Castings** This process is not being used to weld machined castings.

12 Post-Weld Heat Treatment

Welded castings may be stress relieved by heat to 1600°F (871°C) and held for one hour.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HF alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HF (19-23Cr, 9-12Ni, 0.20-0.40C) static and centrifugal castings.
2	**Filler Metal** This process is used mainly for root passes which are welded by fusion of the base metal without the addition of any filler metal. Subsequent passes are laid down by the shield metal-arc process (SMAW).
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. It is considered good practice to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type HF alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 **Electrical Characteristics**

Welding normally is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings.

12 **Post-Weld Heat Treatment**

Usually no postweld heat treatment is required.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HH alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HH (24-28CR, 11-14Ni, 0.20-0.50C) static and centrifugal castings. Also types HE (26-30Cr, 8-11Ni, 0.20-0.50C) and HI (26-30Cr, 14-19Ni, 0.20-0.50C)
2	**Filler Metal** AWS E309-15HC Lime coated, high carbon electrode is preferred for DC welding. (Should not be used for AC) AWS E309-16HC Titania coated, high carbon electrode is used for AC welding and may be used for DC. AWS E312-15 or AWS E310-15HC are used for welding alloy types HE and HI.
3	**Position** All welding usually is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat (8).
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. It is considered good practice to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) followed by furnace or air cooling is often used before welding of aged castings.
7	**Section Size** Section size usually is considered important in welding this alloy. When sections are under ½ inch in thickness, good practice is to use an electrode no larger than 1/8 inch diameter.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root. For large defects, a vertical uphill welding position is sometimes used.

9 **Welding Technique**

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. All slag is removed between passes and from finished weld with a hammer and/or stainless steel wire brush. Residual slag is very corrosive to the alloy at high temperature. No peening is done. Any undercuts or rough spots in beads are faired in by grinding before next pass. Interpass temperatures are held to 300°F (149°C). If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 **Electrical Characteristics**

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 1/4 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings; it is good practice, however, to use small rods and low heat to avoid distortion.

12 **Post-Weld Heat Treatment**

Welded castings of alloy types HH, HE and HI usually are not given any post-weld heat treatment. In some cases where welds are large or located in critical areas of geometrically complicated castings, they are given a heat treatment of 3-4 hours at 1900-2050°F (1038-1121°C) and either furnace cooled or air cooled.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HH alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HH (24-28CR, 11-14Ni, 0.20-0.50C) static and centrifugal castings. Also types HE (26-30Cr, 8-11Ni, 0.20-0.50C) and HI (26-30Cr, 14-19Ni, 0.20-0.50C)
2	**Filler Metal** AWS ER309 Bare wire is used with composition modified to match carbon content of the HH alloy. AWS ER310 Bare wire is used for types HE and HI.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) followed by air or furnace cooling is often used before welding of aged castings.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° are sometimes used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to the diameter of the gas nozzle. Maximum bead thickness is held to 1/8 inch. All oxides are cleaned from beads by hammer and/or wire brush. No peening is done. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16

inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 0.094 inch. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually argon plus two percent (2%) oxygen at a flow rate of 30 to 50 cfh. An alternate mixture of 75 percent argon plus 25 percent carbon dioxide at a flow rate of 20 cfh is also used but may affect that corrosion resistance of the weld adversely on multipass welds.

11 Technique for Welding Machined Castings

This process is not being used to weld machined castings.

12 Post-Weld Heat Treatment

Welded castings of alloy types HH, HE and HI usually are not given any post-weld heat treatment. In some cases where welds are large or located in critical areas of geometrically complicated castings, they are given a heat treatment of 3-4 hours at 1900-2050°F (1038-1121°C) and either air cooled or furnace cooled.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HH alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HH (24-28CR, 11-14Ni, 0.20-0.50C) static and centrifugal castings. Also types HE (26-30Cr, 8-11Ni, 0.20-0.50C) and HI (26-30Cr, 14-19Ni, 0.20-0.50C)
2	**Filler Metal** This process is used mainly for root passes which are welded by fusion of the base metal without the addition of any filler metal. Subsequent passes are laid down by the shield metal-arc process. (See procedure for that process.)
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. It is considered good practice to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type HH alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 **Electrical Characteristics**

Welding normally is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings.

12 **Post-Weld Heat Treatment**

Usually no postweld heat treatment is required.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HK alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HK (24-28CR, 18-22Ni, 0.20-0.60C) static and centrifugal castings. Also types HL (28-32Cr, 18-22Ni, 0.20-0.60C),HN (19-23Cr, 23-27Ni, 0.20-0.50C) and HP
2	**Filler Metal** AWS E310-15HC Lime coated, high carbon electrode is preferred for DC welding. (Should not be used for AC) AWS E310-16HC Titania coated, high carbon electrode is used for AC welding and may be used for DC. AWS E330-15HC Lime coated electrode is used for welding alloy type HN. The carbon content of the electrode used is matched to that of the base metal as closely as possible. HP
3	**Position** All welding usually is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat (8).
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. It is considered good practice to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) followed by furnace or air cooling is often used before welding of aged castings.
7	**Section Size** Section size usually is considered important in welding this alloy. Changes in welding technique sometimes are made when section thickness exceeds one inch (8 and 9).
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to

90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root. For large defects, castings may be preheated (6) and a vertical uphill welding position is sometimes used.

9 Welding Technique

Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. On heavy sections, the sides of the cavity or groove are "buttered" with stringer beads before the central portion of the weld is completed. Very little peening is done. All slag is removed between passes and from finished weld with a hammer and/or stainless steel wire brush. Residual slag is very corrosive to the alloy at high temperature. Any undercuts or rough spots in beads are faired in by grinding before next pass. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 1/8 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

Welded castings of alloy types HK usually are not given any post-weld heat treatment. For large welds and heavy sections it is sometimes desirable to give a stress relief treatment of one hour at 1600°F (871°C) minimum and either air cool or furnace cool.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HK alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HK (24-28CR, 18-22Ni, 0.20-0.60C) static and centrifugal castings. Also types HL (28-32Cr, 18-22Ni, 0.20-0.60C), HN (19-23Cr, 23-27Ni, 0.20-0.50C), and HP
2	**Filler Metal** AWS ER310HC Bare wire with carbon content matched to that of the base metal as closely as possible. AWS ER330HC Bare wire is used for welding type HN. HP
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** This process is not being used for repair of casting defects.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) followed by air or furnace cooling is often used before welding of aged castings.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to filler passes after stringer bead root pass. Beads are carefully cleaned between passes with a stainless steel wire brush. No peening is done.
10	**Electrical Characteristics**

Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 0.062 inch. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually argon plus two percent (2%) oxygen at a flow rate of 30 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings.

12 Post-Weld Heat Treatment

Welded castings of type HK alloy usually are not given any post-weld heat treatment. For large welds and heavy sections it is sometimes desirable to give a stress relief treatment of one hour at 1600°F (871°C) minimum.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HK alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HK (24-28CR, 18-22Ni, 0.20-0.60C) static and centrifugal castings. Also types HL (28-32Cr, 18-22Ni, 0.20-0.60C), HN (19-23Cr, 23-27Ni, 0.20-0.50C), and HP
2	**Filler Metal** AWS ER310HC Bare wire is used for filler passes on multipass welds. Root passes are usually made by fusion of the base metal without the addition of any filler metal. Subsequent passes are laid down by this or by the shielded metal-arc process (SMAW). Carbon content of wire is matched to that of the base metal. AWS ER330HC Bare wire is used for welding type HN. HP
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation(3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type HK alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or

weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to 3/8 inch. No peening is done. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire size is 1/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use low heat to avoid distortion.

12 Post-Weld Heat Treatment

Usually no postweld heat treatment is required.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HT alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HT (15-19CR, 33-37Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** AWS E330-15 Lime coated electrodes is modified to deposit weld metal with carbon content approximately matching the composition of the base metal are preferred.
3	**Position** Whenever possible, all welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat. (8)
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) followed by furnace cooling is often used before welding of aged castings.
7	**Section Size** Section size usually is considered important in welding this alloy. When sections are under ½ inch in thickness, good practice is to use an electrode no larger than 1/8 inch diameter. For sections thicker than 3/4 inch, preheat may be helpful (6).
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root. For large defects, a vertical uphill welding position is sometimes used.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is

limited to three times the electrode wire diameter. Sides of the cavities are sometimes "buttered" to minimize dilution of weld deposit by base metal. Any undercuts or rough spots in beads are faired in by grinding before next pass. No peening is done. All slag is removed between passes and from finished weld with a hammer and/or stainless steel wire brush. Residual slag is very corrosive to the alloy at high temperature. Interpass temperatures are held to 300°F (149°C). Inspection of weld quality during course of work is desirable (13). If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 1/4 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. Weld beads are peened to counteract contraction.

12 Post-Weld Heat Treatment

Welded castings of alloy types HT usually are not given any post-weld heat treatment. In some cases where welds are large or located in critical areas of geometrically complicated castings, they are heat treated for 3-4 hours at 1900-2100°F (1038-1149°C) and furnace cooled.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HT alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HT (15-19CR, 33-37Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** AWS ER330 Bare wire with composition modified to deposit weld metal approximately matching the carbon content of the base metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** This process is not being used for repair of casting defects.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) is often used before welding of aged castings.
7	**Section Size** Section size usually is considered unimportant in welding this alloy. In welding sections over ½ inch thick the type of weld bead is changed (9).
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to sections thicker than ½ inch. Parts to be welded are carefully tacked to maintain good fit and matching of groove lands.
10	**Electrical Characteristics** Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 1/16 inch. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually 100 percent argon at a flow rate of 30 to 35 cfh.

11 Technique for Welding Machined Castings

This process is not being used for welding of machined castings.

12 Post-Weld Heat Treatment

Welded castings of type HT alloy usually are not given any post-weld heat treatment. In some cases where welds are large or located in critical areas of geometrically complicated castings, they are heat treated for 3-4 hours at 1900-2100°F (1038-1149°C) and furnace cooled.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HT alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HT (15-19CR, 33-37Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** This process is used mainly for root passes which are welded by fusion of the base metal without the addition of any filler metal. Subsequent passes are laid down by the shielded metal-arc process (SMAW).
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type HT alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 **Electrical Characteristics**

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings.

12 **Post-Weld Heat Treatment**

Usually no postweld heat treatment is required.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HU alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HU (17-21CR, 37-41Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** AWS E330-15 Lime coated electrodes modified to deposit weld metal with carbon content approximately matching the composition of the base metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat (8).
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) is often used before welding.
7	**Section Size** Section size usually is considered important in welding this alloy. When sections are under ½ inch in thickness, good practice is to use an electrode no larger than 1/8 inch diameter. For sections thicker than 3/4 inch, preheat may be helpful (6).
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root. For large defects, a vertical uphill welding position is sometimes used.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. Sides of the cavities are sometimes "buttered" to

minimize dilution of weld deposit by base metal. Any undercuts or rough spots in beads are faired in by grinding before next pass. No peening is done. All slag is removed between passes and from finished weld with a hammer, stainless steel wire brush, or needle gun using stainless steel needles. Residual slag may be corrosive to the alloy at high temperature. Interpass temperatures are held to 300°F (149°C). Inspection of weld quality during course of work is desirable (13). If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions. Tack welding should be performed *after* the casting has been preheated in order to minimize the possibility of initiating a crack at the tack weld.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 3/32 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion. Weld beads are peened to counteract contraction.

12 Post-Weld Heat Treatment

Welded castings of alloy types HU usually are not given any post-weld heat treatment. In some cases where welds are large or located in critical areas of geometrically complicated castings, they are heat treated for 3-4 hours at 1900-2050°F (1038-1121°C) and furnace cooled.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HU alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HU (17-21CR, 37-41Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** AWS ER330 Bare wire with composition modified to deposit weld material approximately matching the carbon content of the base metal.
3	**Position** All welding is done in the "flat" position. A ±15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** This process is not being used for repair of casting defects.
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) followed by furnace cooling is often used before welding.
7	**Section Size** Section size usually is considered unimportant in welding this alloy. In welding sections over ½ inch thick the type of weld bead is changed (9).
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to sections thicker than ½ inch. Parts to be welded are carefully tacked to maintain good fit and matching of groove lands.
10	**Electrical Characteristics** Welding is done using DC reverse polarity. Wire diameter range is from 0.035 to 0.063 inch. Currents and voltages suggested by the manufacturer's specifications for the wire size used are normally followed. Shielding gas is usually argon plus two percent (2%) oxygen at a flow rate of 30 to 50 cfh.

11 **Technique for Welding Machined Castings**

This process is not being used for welding of machined castings.

12 **Post-Weld Heat Treatment**

Welded castings of type HU alloy usually are not given any post-weld heat treatment. In some cases where welds are large or located in critical areas of geometrically complicated castings, they are heat treated for 3-4 hours at 1900-2050°F (1038-1121°C) and furnace cooled.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HU alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HU (17-21CR, 37-41Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** This process is used mainly for root passes which are welded by fusion of the base metal without the addition of any filler metal. Subsequent passes are laid down by the shielded metal-arc or gas metal-arc processes. (See procedure for those processes.) When gas tungsten-arc process is used for entire weld AWS ER330(high carbon), bare wire is used for filler metal.
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type HU alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all

directions.

10 Electrical Characteristics

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Where filler metal is used, wire sizes range from 1/16 to 3/16 inch. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings.

12 Post-Weld Heat Treatment

Welded castings of type HU alloy usually are not given any post-weld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HW alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HW (10-14CR, 58-62Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** AWS ENiCr-1 and AWS EniCrFe-1 Lime coated electrodes are preferred. AWS E330-15 Lime coated electrode is also used.
3	**Position** Welding is usually done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat. Successful welds can be made in all positions.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) followed by furnace cooling is often used before welding.
7	**Section Size** Section size usually is considered important in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. All slag is removed between passes and from finished weld with a hammer and/or stainless steel wire brush. Light peening of each pass before laying down next pass is sometimes helpful. If a defect penetrates through the casting,

or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 1/8 to 1/4 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

Welded castings of alloy types HW usually are not given any post-weld heat treatment. In some cases where welds are large or located in critical areas of the casting, they are given a stress relief treatment of heating to 1750°F (955°C) for two hours**.**

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HX alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HX (15-19CR, 64-68Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** AWS ENiCrFe-1 Lime coated electrode is preferred. AWS e330-15HC Lime coated electrode is also used.
3	**Position** Welding usually is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** Normally this alloy is not preheated; however, if the section size is over 3/4 inch in thickness, and the extent of the weld substantial, the alloy may be preheated to 200-400°F (93-204°C). Prior solution annealing at 1800-2100°F (982-1149°C) followed by furnace cooling is often used before welding of aged castings.
7	**Section Size** Section size usually is considered important in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* Either stringer or weave bead placement is used. Weaving, if any, is limited to three times the electrode wire diameter. All slag is removed between passes and from finished weld with a hammer and/or stainless steel wire brush. Residual slag may be corrosive to the alloy at high temperature. Interpass temperatures held to 200°F (93°C)

maximum is sometimes helpful. Light peening of each pass before laying down next pass is sometimes desirable. If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 Electrical Characteristics

Welding normally is done using DC reverse polarity. Successful welds can be made, however, using AC. Electrode sizes from 1/8 to 3/16 inch may be used with the current and voltage suggested by the electrode manufacturer's specifications for the particular size rod. Due to the high electrical resistance of stainless steel, the burn-off rate of the electrode is much higher than for carbon steel. Arc length should be maintained as short as possible. A short arc length is very important when starting a weld pass since a long arc can sometimes be caused by initial hand recoil and may result in weld spatter or porosity.

11 Technique for Welding Machined Castings

No special technique (9) is necessary for welding machined castings; however, use small rods and low heat to avoid distortion.

12 Post-Weld Heat Treatment

Welded castings of alloy types HX usually are not given any post-weld heat treatment.

13 Non-Destructive Tests

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 Summary

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.

Procedure followed by experienced producers of high alloy castings in welding of type HX alloy as reported in a survey of SFSA members

Section	Subject/Procedure
1	**Base Metal** Alloy type HX (15-19CR, 64-68Ni, 0.35-0.75C) static and centrifugal castings.
2	**Filler Metal** This process is used mainly for root passes which are welded by fusion of the base metal without the addition of any filler metal. Subsequent passes are laid down by the shielded metal-arc process (SMAW).
3	**Position** All welding is done in the "flat" position. A ± 15° angle of the groove with the horizontal plane normally is considered flat.
4	**Base Metal Preparation for Repair** Defects are removed before attempting any repair. Defect removal is accomplished by arc-air, chipping, gouging, grinding or machining, or by some combination of these operations. Defect removal to sound base metal is assured by the use of one or more of the following inspection processes: Visual, dye penetrant, or radiography. Where dye penetrant or radiographic inspection of a prepared cavity discloses shrinkage of a severity not in excess of that specified for the casting as a whole, acceptable practice is to weld such areas without further preparation (3.2.1).
5	**Base Metal Preparation for Fabrication** Parts to be fabricated by welding are shaped to provide a groove when placed together. The mating areas are either cast to shape and then ground, or ground or machined so that a good fit of the welding groove can be obtained. Good practice is to machine dry with no lubricant. Components are thoroughly cleaned before assembly.
6	**Preheat Temperature** No preheat is required for type HX alloy.
7	**Section Size** Section size usually is considered unimportant in welding this alloy.
8	**Cavity Dimensions** Cavity dimensions are not critical. A minimum included angle of 30° (included angles up to 90° sometimes are used) should be maintained between the sides of the cavity, and a root radius of 3/16 to 1/4 inch should be provided to allow full access to the root.
9	**Welding Technique** Surfaces to be welded should be dry and cleaned to remove any residue from cavity or weld groove preparation or other previous operations. *Lack of attention to this may result in defective welds.* If a defect penetrates through the casting, or if parts to be fabricated fit together poorly, a 3/16 inch backing plate is formed to the inside contour of the casting and tack welded in place. The backing plate, which should be removed after welding, is generally of such a size that it extends a minimum of 3/16 inch beyond the edge of the cavity in all directions.

10 **Electrical Characteristics**

Welding is done using DC straight polarity. A non-consumable electrode made of thoriated tungsten (EWTh-2) is used. A high frequency method of starting the arc is preferred over a "scratch start" to avoid tungsten contamination of the weld. The arc should not be struck on a carbon block. Currents and voltages suggested by the manufacturer's specifications for the electrode size used are normally followed. Either helium or argon may be used for the inert shielding gas, but argon is preferred with a flow of 20 to 50 cfh.

11 **Technique for Welding Machined Castings**

No special technique (9) is necessary for welding machined castings.

12 **Post-Weld Heat Treatment**

Welded castings of type HX alloy usually are not given any post-weld heat treatment.

13 **Non-Destructive Tests**

Welds are tested for quality by one or more of the following methods of inspection: Visual, dye penetrant, radiography or pressure.

14 **Summary**

To produce welds that will satisfy the user's requirements, take the following precautions:

1. Make sure that all defects have been removed to sound base metal (4) and that surfaces to be welded are thoroughly cleaned (5 and 9).

2. Use the proper filler metal (2).

3. Use a welding technique (9) which will produce welds free of porosity, undercutting or lack of penetration.