

ANSI/AWS D11.2-89 (R2006)
An American National Standard

Guide for Welding Iron Castings



American Welding Society



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ANSI/AWS D11.2-89 (R2006)
An American National Standard

Approved by the
American National Standards Institute
July 14, 1988

Guide for

Welding Iron Castings

Prepared by the
American Welding Society (AWS) D11 Committee on Welding Iron Castings

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors, March 3, 1988

Abstract

This standard presents briefly the history and metallurgy of cast iron and the welding processes applicable to it.

A newly developed weldability test is described in detail and instructions given for its application in specific cases.

Provision is made for qualification of welding procedures and welders when necessary; quality control practice is also included.



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Foreword

This foreword is not a part of ANSI/AWS D11.2-89 (R2006), *Guide for Welding Iron Castings*, but is included for informational purposes only.

This publication is a reaffirmation of the first edition published in 1989. The content of the standard is identical to the 1989 publication except that the safety and health facts sheets in Appendix F have been updated. Reaffirmation of this standard by the Committee on the Welding of Iron Castings indicates that this standard's content is still current with today's technology and practices.

This guide was prepared by the American Welding Society Committee on the Welding of Iron Castings as a service to the industry. Sufficient data have been gathered and organized to yield an authoritative source of sound technical practices for joining iron castings. The description of iron castings, together with factors to be considered in joining them, is presented here as clearly and concisely as possible. It is the Committee's hope that this guide will lead to better quality and performance.

These recommendations represent the best of current practice in the opinion of the Committee. At the present state of the art, all recommendations may not be applicable to all products and situations. Selection of pertinent requirements should be the result of rational decisions and not lack of knowledge on the part of those who are welding iron castings.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D11 Committee on Welding of Iron Castings, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Guide for Welding Iron Castings

1. Scope and History

1.1 Scope. The term *cast iron* encompasses a family of ferrous alloys with a variety of metallurgical, mechanical, and physical properties. The chemical composition and welding requirements of the metals vary within the family. This document discusses the relative weldability of various types of cast irons and the filler metals and processes used to weld them. It recommends the steps for qualification of welding procedures, welding operators and welders, and requirements for the quality of welds. The terms *welding procedure*, *welding operator*, and *welder*, are used as defined in the latest edition of ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

1.2 History

1.2.1 Types of Iron. Although iron has been used in various forms for over two thousand years, iron castings in the form used today evolved in Europe in the 15th and 16th centuries. The microstructure of medieval castings basically was gray iron with areas of white iron and nonmetallic inclusions. Refinements in foundry practices and melt control resulted in a more uniform structure.

Malleabilizing, a method of increasing the ductility of white cast iron by heat treatment, was first developed in the early 1700's. About a century later, black heart malleable iron was developed.

In the 1940's, ductile (spheroidal graphite) iron was developed. The ductility is improved by spheroidizing the graphite by the addition of magnesium, rare earth elements, or both.

The most recently developed form of cast iron is compacted graphite, a hybrid material with properties between gray and ductile irons.

1.2.2 Welding. Oxyfuel gas and arc welding of cast iron did not gain wide acceptance until early in the 20th century. The first filler metals were cast along with the iron castings so that the compositions were similar. Later, both ferrous and nonferrous (copper or nickel)

base electrodes and rods were developed and are still in use today.

New, more refined welding processes and procedures were developed to extend greatly the number of applications where welding is used. Shielded metal arc (SMAW), gas metal arc (GMAW), flux cored arc (FCAW) and submerged arc (SAW) welding currently are popular arc welding processes.

Gas tungsten arc (GTAW) and proprietary processes are used in a variety of applications.

2. Cast Iron — Its Metallurgy and Weldability

2.1 Metallurgy

2.1.1 General. Cast iron may be described as an alloy of iron, carbon and silicon. All commercially produced irons also contain manganese. They may be alloyed with nickel, chromium, copper, molybdenum, tin, antimony, vanadium, and other elements. The alloying elements may be present individually or in combination.

The carbon content is in excess of the quantity that can be retained in solid solution by austenite. Thus, during solidification, a portion of the carbon separates from the melt as either iron carbide (Fe_3C) or graphite. If the cooling rate is rapid, the carbon rich phase will be iron carbide. Elemental carbon (graphite) precipitates if the cooling rate is slow enough. The type of carbon constituent and its shape (if graphite), in part, determines the type and properties of cast iron. The phases present in the matrix also affect the properties; therefore, the entire microstructure of the casting must be considered when planning a suitable welding procedure.

2.1.2 Gray Iron. The most commonly used form of cast iron is gray iron. In this material, the excess carbon precipitates as flakes of graphite in a matrix of ferrite, pearlite, or a mixture of the two microconstituents (see Figure 1). The resultant product has moderate strength

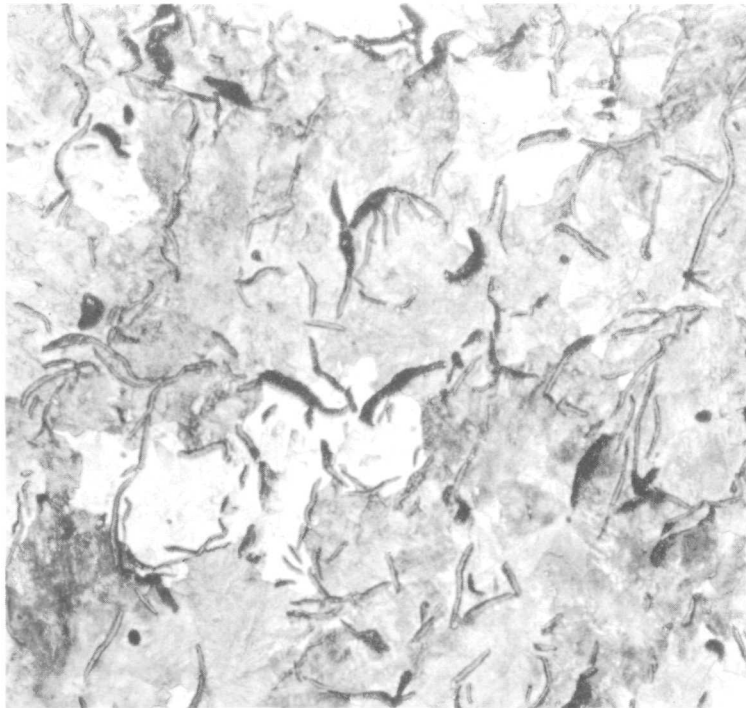


**Figure 1 — Gray Iron Microstructure Showing Random Flake Graphite Distribution in a Matrix of Ferrite and Pearlite
Magnification 100x. Nital etch**

excellent machinability and damping properties, but low ductility. The material is low in cost and easily cast, and thus, is used extensively. Gray iron typically contains 2 to 4 percent carbon, 1 to 3 percent silicon and up to 1 percent manganese, and has tensile strength up to 40 000 psi (276 MPa).

The microstructure and resulting properties of gray iron may be altered by the addition of any of the following elements: silicon (up to 6 percent), nickel (up to 36 percent), copper (1.5 to 7.5 percent), chromium (1 to 6 percent), molybdenum (up to 1 percent). Tensile strength of these alloyed grades may be as high as 80 000 psi (380 MPa). Microstructures may contain various intermetallic compounds such as chromium or molybdenum carbides, and the matrix may be austenitic in nature. Because of the complexity of these alloy systems, special welding procedures are often required. Not all grades of higher alloyed gray iron are weldable.

2.1.3 White Iron. If cooling is rapid (such as in a water or oil quench or at times in the heat affected zone of a weld), there is insufficient time for formation of graphite particles. The carbon remains in the metastable form of iron carbide (Fe_3C , also called cementite) (see Figure 2). This intermetallic compound is very brittle. Its abundance in the microstructure greatly reduces ductil-

ity and weldability, but increases hardness and abrasion resistance. As a result, the presence of cementite in applications subject to severe wear is often desirable. However, microstructures containing large amounts of cementite are quite prone to cracking and are essentially non-weldable. These irons contain typically 2.5 to 3.8 percent carbon, 0.2 to 2.8 percent silicon and, if designed for wear resistance, may contain up to 5.5 percent nickel, as much as 30 percent chromium, up to 6.5 percent molybdenum, and as much as 30 percent manganese. Tensile strengths range from 23 000 to 90 000 psi (160–620 MPa).

2.1.4 Malleable Iron. With heat treatment, white iron may be transformed to a ductile form of cast iron known as malleable iron. During long-time heat treatment, up to 60 hours, at high temperatures, up to 1600°F (871°C), the iron carbide dissociates, leaving a dispersion of graphite particles of approximately spherical shape. If the furnace atmosphere is oxidizing in nature, some of the carbon will be oxidized. This microstructure is called white heart malleable iron and is considered quite weldable (see Figure 3). When the atmosphere is reducing, the full amount of carbon is retained. This material, black heart malleable iron, is considered unweldable. Malleable iron typically contains 2.0 to 2.8 percent carbon and 1.0 to 1.7 percent silicon. Tensile

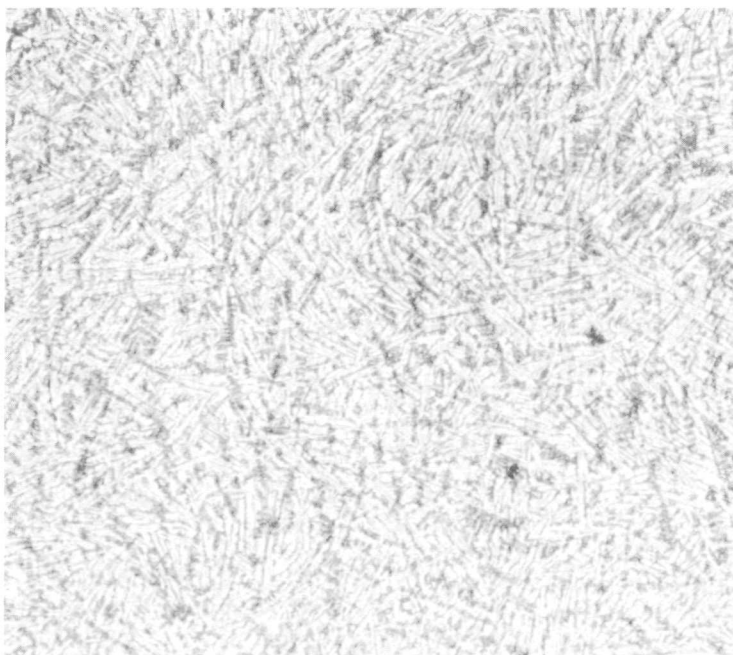


**Figure 2 — White Iron Microstructure Showing Nearly Complete Carbon Solution
in a Matrix of Cementite (Iron Carbide)
Magnification 100x. Nital etch**

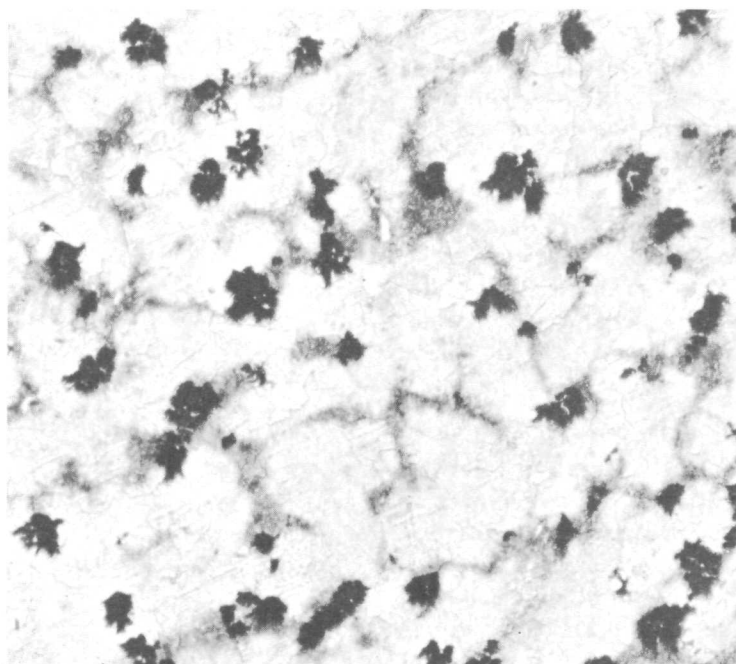


**Figure 3 — Malleable Iron Microstructure Showing Temper Carbon Nodule Distribution
in Ferrite and Pearlite
Magnification 100x. Nital etch**

strengths range from 45 000 to 90 000 psi (310–620 MPa), with tensile elongations ranging from 2 to 20 percent.

2.1.5 Ductile Iron. By controlled addition of nodularizers, such as magnesium or rare earths, the excess carbon in the cast iron melt will form spherical particles (see Figure 4). These materials possess the highest strength and ductility of the cast iron family. Thus, close control of welding practices is necessary to minimize reduction of these optimum properties. Ductile iron (also called spheroidal or nodular iron) typically contains 3 to 4 percent carbon, 1.8 to 2.8 percent silicon, and 0.7 percent manganese, maximum. Some manufacturers of ductile iron restrict manganese content to a maximum of 0.4 percent when impact properties are important. An increase of manganese in the heat affected zone during welding can result in segregation at base metal grain boundaries with a consequent reduction in impact resistance of the weld.

Tensile strength range is 60 000–120 000 psi (410–830 MPa).

As with gray irons, alloying additions are made to these types of iron to improve heat and corrosion resistance. These grades may contain 2 to 3 percent carbon, 1 to 6 percent silicon, 0.7 to 2.4 percent manganese, 18 to 36 percent nickel, and up to 5.5 percent chromium.

The matrix of the ductile iron may be varied by heat treatment, alloying, and casting practices. The common “as cast” product is 65-45-12 [65 000 psi (450 MPa) tensile strength, 45 000 psi (310 MPa) yield strength, and 12 percent elongation]. The matrix is ferrite with 10 to 20 percent pearlite. By annealing, the matrix becomes ferritic, producing 60-40-18 iron.

Several other higher strength grades are produced by alloying or heat treatment: 80-55-06, 100-70-03, and 120-90-02. In general, as the strength of the iron increases, the potential for welding problems also increases. Thus, the lower strength grades should be easily welded, while satisfactory welding of higher strength grades will be more difficult.

2.1.6 Compacted Graphite. The newest addition to the cast iron family is compacted graphite iron. The microstructure of this material may be described as intermediate between gray and ductile iron, giving it many of the features of both types (see Figure 5). Compacted graphite iron has better machinability and dampening characteristics than ductile iron and has improved ductility over gray iron. Since the material is new to the market at the time of this writing, little information is available regarding welding procedures.

2.1.7 Identification. Determination of the type of cast iron being welded is essential to producing sound

weldments with acceptable properties. A few suggestions are listed below:

- (1) Check the files for specifications, purchase orders and other paperwork which might list the type.
- (2) Contact the manufacturer of the iron.
- (3) Study a small piece under the microscope.
- (4) Run mechanical tests such as hardness, and determine chemical composition.

2.2 Difficulties in Welding Iron Castings. Because of the high carbon content and the various forms it can have in cast irons, as well as the wide range of microstructures and chemical composition, cast irons are among the most difficult metals to weld. The following paragraphs describe some of the sources of problems in welding cast irons and some recommended steps to alleviate them.

2.2.1 The Weld Metal. The weld metal consists of the base metal which is melted during welding, plus any filler metal. When molten cast iron is cooled rapidly (as is the case in an autogenous weld), the carbon is not rejected from the melt as graphite, but forms a hard, brittle iron carbide which is susceptible to cracking and is difficult to machine. The quantity of iron carbide formed can be reduced by the addition of alloying elements, by use of appropriate filler metal, or the use of a low-dilution welding technique. Post weld heat treatment may reduce or eliminate carbide in the weld metal.

2.2.2 Fusion Zone. There are three distinct regions in the fusion zone. The first is the weld metal, which is a mixture of melted base metal and filler metal. The second is base metal which melts but does not mix with the filler metal. The third is base metal which only partially melts. Carbide formation can be a problem in those regions where mixing with the filler metal does not take place.

2.2.3 Heat Affected Zone. The heat affected zone is that part of the base metal that reaches a temperature high enough to effect metallurgical changes, but not high enough to cause any melting. In this zone, the graphite is not altered sufficiently to cause carbide problems. The matrix however, is transformed to a hard, martensitic structure upon rapid cooling. Brittleness associated with the martensite can be reduced by slow cooling or a postweld heat treatment (PWHT).

2.2.4 Welding Stresses. Expansion and contraction associated with the welding process may cause distortion and residual stresses in any material. These stresses may cause cracking in iron castings with low ductility and in areas of reduced ductility such as the fusion zone. Residual stresses can be reduced by proper control of preheat, welding procedures, peening, and by PWHT.

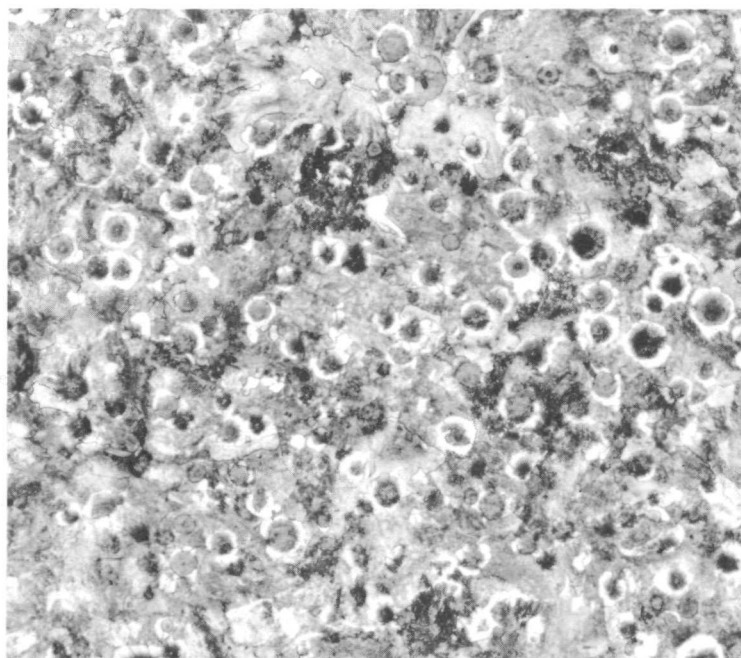


**Figure 4 — Ductile Iron Microstructure Showing Nodular Graphite Distribution
in a Matrix of Ferrite and Pearlite
Magnification 100x. Nital etch**

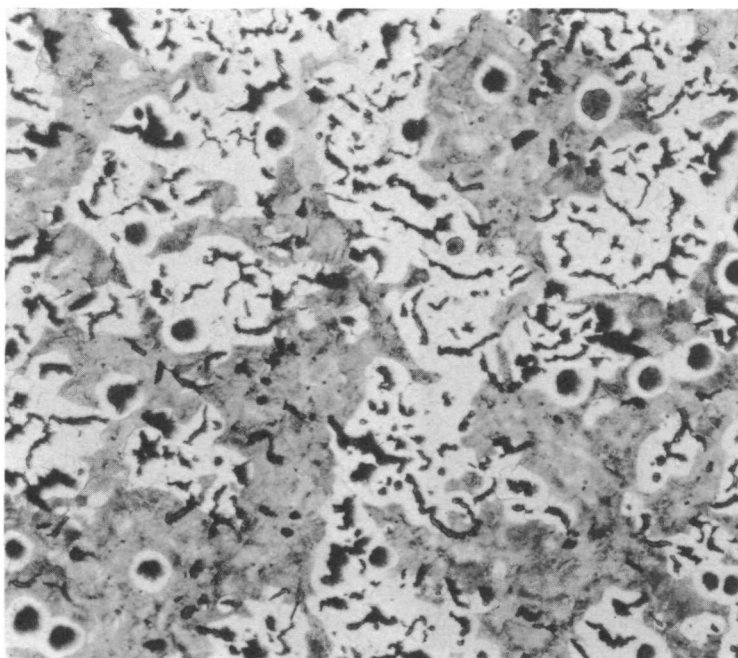


**Figure 5 — Compacted Graphite Microstructure Showing Mixture of Flake and
Nodular Graphite Distribution in a Matrix of Ferrite and Pearlite
Magnification 100x. Nital etch**

2.2.5 Porosity. Gases emitted during welding may cause porosity in the weld deposit. Such gases may result from volatile materials in the casting or from reactions between filler metals and atmospheres. The graphite in cast irons absorbs and retains lubricants and other liquids which permeate the entire section. When the material is welded, these liquids escape in a gaseous form and are trapped in the weld metal as porosity. Most porosity problems attributable to contaminants in the base metal can be avoided by proper preparation of the casting before welding (see 3.1).

2.3 AWS Weldability Test Program. Available literature on welding cast irons did not yield specific information on the weldability of cast iron base materials, especially on the relative weldability of the various types of cast irons. For this reason, the Committee on Welding Iron Castings undertook an investigation into the relative weldability of the various types of cast irons.

The committee considered the existing standard weldability tests such as Varestraint, Cruciform, Lehigh, and Houldcroft. It was found that these either required more base metal ductility than is found in some cast irons, used a filler metal, or were expensive and time consuming to prepare. It was decided, therefore, to develop a new test which would be practical, simple, repeatable, and did not require a filler metal.

2.3.1 Development of Weldability Test. Initial tests consisted of making an autogenous arc spot weld on the cast base metal with the gas tungsten arc welding process and attempting to evaluate the extent of cracking in the weld (see Figure 6). The tests were then refined to include travel of the torch and addition of preheating.

The test method finally developed consists of autogenous bead-on-casting welds made by a standard weld technique at various test temperatures to determine the minimum temperature (called *no-crack temperature*) at which there was no cracking in the test weld (see Figure 7). The test method is described in detail in Appendix A.

2.3.2 Weldability Test Results. When all the specimens had been welded and the no-crack temperature established for each, efforts were made to relate these results to some other variable that could be used to establish the no-crack temperature independent of this test. Variables evaluated were base metal type and strength as grouped by M number, weld and HAZ hardness, and chemical composition.

Table 1 compares the no-crack temperatures to the base metal type, actual strength, and M number from ANSI/AWS B2.1-84, *Standard for Welding Procedure and Performance Qualification*. Since there is no apparent correlation of any of these items to the no-crack temperature, strength and "M" number are not suitable for establishing the weldability of iron castings.



PREHEAT — 70°F



PREHEAT — 600°F

**Figure 6 — Grade 80-60-03 Ductile Iron GTAW Spot Weld Specimen (No Filler Metal).
Test Temperature as Indicated**

Table 2 compares the no-crack temperatures to the hardness of weld and HAZ of the test specimens welded at the no-crack test temperatures. The hardnesses were measured with Rockwell hardness testers on the A and B scales, and the values were converted to Brinell for comparison purposes. For all the base metals tested, there was considerable overlap of hardness data for the welds and heat affected zones, and no clear cut pattern or trend can be seen when the hardness values are compared. Based on this information, it was determined that hardness is not a suitable criterion for determining the weldability of iron castings.

Table 3 gives the chemical composition of the cast irons tested in this program, and Figure 8 is a plot of the calculated carbon equivalent versus the measured no-crack temperature. From this graph it can be seen that the chemical composition is directly related to the no-crack temperature and that the type of material (gray, malleable or ductile iron) has no apparent influence. The tolerance band has a temperature width of $\pm 60^{\circ}\text{F}$ (33°C), and a carbon equivalent width of ± 0.20 . A complete listing of all test results (hardness, mechanical properties, and weld tests) are given in Appendix A.

2.3.3 Carbon Equivalent Formula. In attempting to plot the no-crack temperature values against the carbon equivalent (CE), it was found that the conventional CE formula for steels was not applicable. A CE formula

especially for cast irons was found, and the results showed a definite correlation when plotted against the CE values calculated from this formula:

$$\text{CE \#1} = \text{C} + 0.31\text{Si} + 0.33\text{P} + 0.45\text{S} - 0.028\text{Mn}^*$$

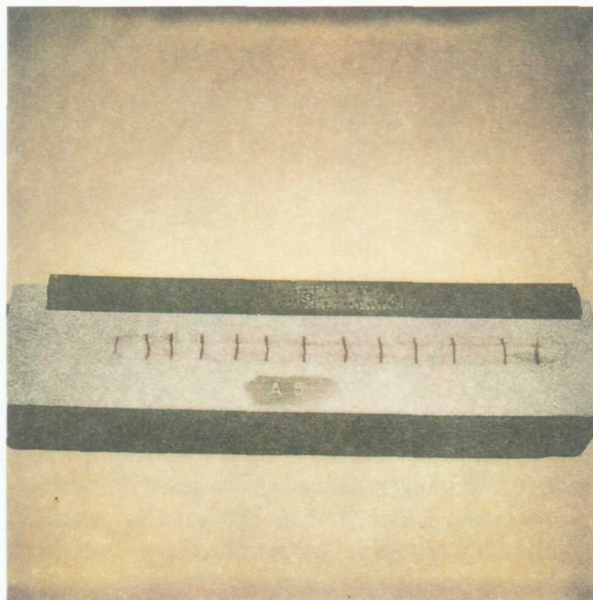
There was still considerable scatter, so the committee evaluated the chemical composition of the specimens further and found significant amounts of copper, nickel, chromium, and molybdenum were present. The formula was then modified to take these elements into account as follows:

$$\text{CE \#2} = \text{C} + 0.31\text{Si} + 0.33\text{P} + 0.45\text{S} - 0.028\text{Mn} + \text{Mo} + \text{Cr} - 0.02\text{Ni} - 0.01\text{Cu}$$

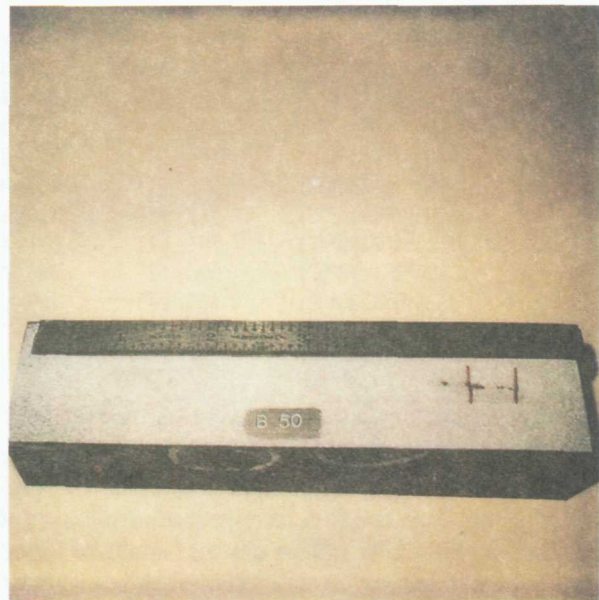
The results plotted in Figure 8 are based on CE #2, and are valid for castings with a total copper, nickel, chromium, and molybdenum content of 1.5 percent maximum. Weldability of higher alloy cast irons should be determined by testing by the user.

2.3.4 Discussion of Results. These tests were not conducted to determine a preheat temperature for specific base metals and should not be used for that purpose.

* *Ductile Iron, The State of the Art*. Chicago, IL: S.I., Karsay, Miller & Co. (1980) p 47.



PREHEAT — 70°F



PREHEAT — 600°F

**Figure 7 — Grade 80-60-03 Ductile Iron GTAW Weld Bead Specimen (No Filler Metal).
Test Temperature as Indicated**

Table 1
Comparison of No-Crack Temperature to Material
Type, Strength, and "M" Number

No-Crack Temperature	Material Type	Strength				"M" Number
		Tensile (psi)	(MPa)	Yield (psi)	(MPa)	
<70°F (20°C)	Malleable	48 000	(228)	31 000	(147)	2C
<70°F (20°C)	Malleable	78 000	(370)	50 000	(238)	2D
<70°F (20°C)	Malleable	95 000	(451)	59 000	(280)	2E
<70°F (20°C)	Malleable	106 000	(504)	66 000	(314)	2E
110°F (43°C)	Gray	45 000	(214)	—	—	2B
290°F (145°C)	Gray	52 000	(247)	—	—	2B
450°F (230°C)	Ductile	64 000	(304)	48 500	(230)	*
450°F (230°C)	Ductile	109 000	(518)	55 000	(261)	*
460°F (240°C)	Gray	46 000	(219)	—	—	2A
520°F (270°C)	Ductile	132 000	(627)	111 000	(527)	*
520°F (270°C)	Gray	36 000	(171)	—	—	2A
630°F (330°C)	Ductile	97 000	(461)	69 000	(328)	*

*Not classified in AWS B2.1-84.

Table 2
Comparison of No-Crack Temperature to
Weld and HAZ Hardness

No-Crack Temperature	Hardness (BHN)		Material (REF)		
	Weld	HAZ	Type	Strength ksi	(MPa)
<70°F (20°C)	534–561	152–212	Malleable	50	(238)
<70°F (20°C)	546–561	331–444	Malleable	70	(333)
110°F (43°C)	561–575	421–485	Gray	45	(214)
290°F (145°C)	564–587	432–519	Gray	50	(238)
450°F (230°C)	534–591	223–255	Ductile	65	(309)
450°F (230°C)	566–611	241–444	Ductile	80	(380)
460°F (240°C)	519–587	271–353	Gray	40	(190)
520°F (270°C)	591–611	321–444	Ductile	120	(570)
520°F (270°C)	546–587	286–326	Gray	34	(162)
630°F (330°C)	465–611	269–285	Ductile	100	(475)

Filler metal selection, weld heat input, and peening are some variables which can compensate for lack of pre-heat. The tests were run to determine if some measure of the relative weldability of iron castings could be found apart from conducting an elaborate test. It is suggested that the carbon equivalent is a good ranking process and is more realistic than the present "M" number classification system in ANSI/AWS B2.1-84, which recognizes only differences in casting types and mechanical properties.

It is therefore recommended that classification of iron castings for welding qualifications be based on a carbon equivalent value rather than the existing material-strength rating system of "M" numbers, especially when applying existing qualified procedures to cast iron base metals other than those used in the specific qualification tests.

This information can be used in two ways:

(1) When an existing qualified welding procedure is to be used on a new application, it should be successful if

Table 3
Chemical Composition

Specimen	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Mg	CE#1	CE#2
<u>Gray Iron</u>												
G1	3.25	0.58	0.017	0.062	1.75	0.22	0.08	0.34	0.09	—	3.811	4.226
G2	2.53	0.99	0.019	0.064	1.61	0.03	0.11	0.35	0.74	—	3.036	3.488
G3	2.62	1.00	0.022	0.066	1.66	0.03	0.11	0.02	0.04	—	3.144	3.273
G4	3.48	1.00	0.043	0.093	1.78	0.49	0.17	0.03	0.17	—	4.060	4.248
<u>Ductile Iron</u>												
D1	3.60	0.29	0.029	0.016	2.31	0.05	0.04	0.01	0.88	0.026	4.325	4.365
D2	3.67	0.29	0.028	0.006	2.20	0.06	0.04	0.20	1.32	0.022	4.356	4.582
D3	3.63	0.28	0.027	0.005	2.23	0.05	0.04	0.01	0.96	0.023	4.324	4.363
D4	3.51	0.43	0.030	0.014	2.37	0.88	0.10	0.03	0.10	0.025	4.248	4.359
<u>Malleable Iron</u>												
M1	2.42	0.73	0.015	0.030	1.54	0.04	0.05	0.01	0.10	—	2.896	2.954
M2	2.38	0.59	0.015	0.031	1.54	0.04	0.05	0.01	0.08	—	2.859	2.917
M3	2.21	0.94	0.027	0.050	1.51	0.05	0.03	0.01	—	—	2.684	2.723
M4	2.30	0.87	0.025	0.049	1.52	0.05	0.03	0.01	—	—	2.777	2.816

the carbon equivalent of the metal to be welded is lower than the carbon equivalent of the base metal used in the qualification test. The committee is recommending that welding procedures be limited to 1.1 times the CE of the base metal without requalification.

(2) When a new procedure needs to be qualified on a cast iron with a higher CE, a comparison of the CE's of the qualified base metal to the new base metal in conjunction with Figure 8 can assist in establishing a new preheat temperature for the new procedure.

2.3.5 Metallographic Examination. Figures 9 through 13 are representative photomicrographs of the weld, HAZ, and base metal of Grade 35 gray iron, Grade 50005 malleable iron, Grade 100-70-03 ductile iron, and Grade 120-90-02 ductile iron, tested in this program. The compacted graphite iron, Figure 13, is included for reference only, as it was received too late to be tested with the other iron castings.

The photographs show the nearly complete dissolution of the graphite flakes or nodules in the weld metal, the effect of heat (HAZ) on the matrix but not the graphite in the base materials.

Shallow cracks, shaped like a racetrack, occurred at the toe in the HAZ of all weld beads on gray iron specimens (see Figure 14). This is common even when filler metal is added. During liquid penetrant examination, the crack is first visible as a series of minute indications in very close proximity to each other, then the

liquid penetrant quickly spreads to give the appearance of a continuous crack. Figure 15 shows a cross section through one of these indications in the HAZ. It appears to be a microcrack connecting several graphite flakes, caused by the high residual stress imposed during cooling of the weld. Test temperatures in excess of 1100° F (593°C) did not eliminate these cracks. The cracks occur in the HAZ because this is the hardest area of the weldment, and it has the least ductility and the most notch sensitivity.

2.3.6 Weldability. Since the test developed for weldability of cast iron is unique to these base metals, the weldability of a specific iron casting is relative only to other iron castings. It may be determined by either of two methods:

(1) Establish the test temperature at which cracking will not occur when welded according to the established test method, and locate this temperature on the CE #2 versus Temperature graph. The lower this no-crack temperature, the more weldable the specific iron casting.

(2) Determine the carbon equivalent from the CE #2 formula (modified Karsay) and locate this value on the CE #2 versus Temperature graph. The lower this CE, the more weldable the specific iron casting.

2.3.7 Future Research. While the Committee has developed some basic data, subsequent evaluation of that data revealed that additional work needs to be performed in several areas.

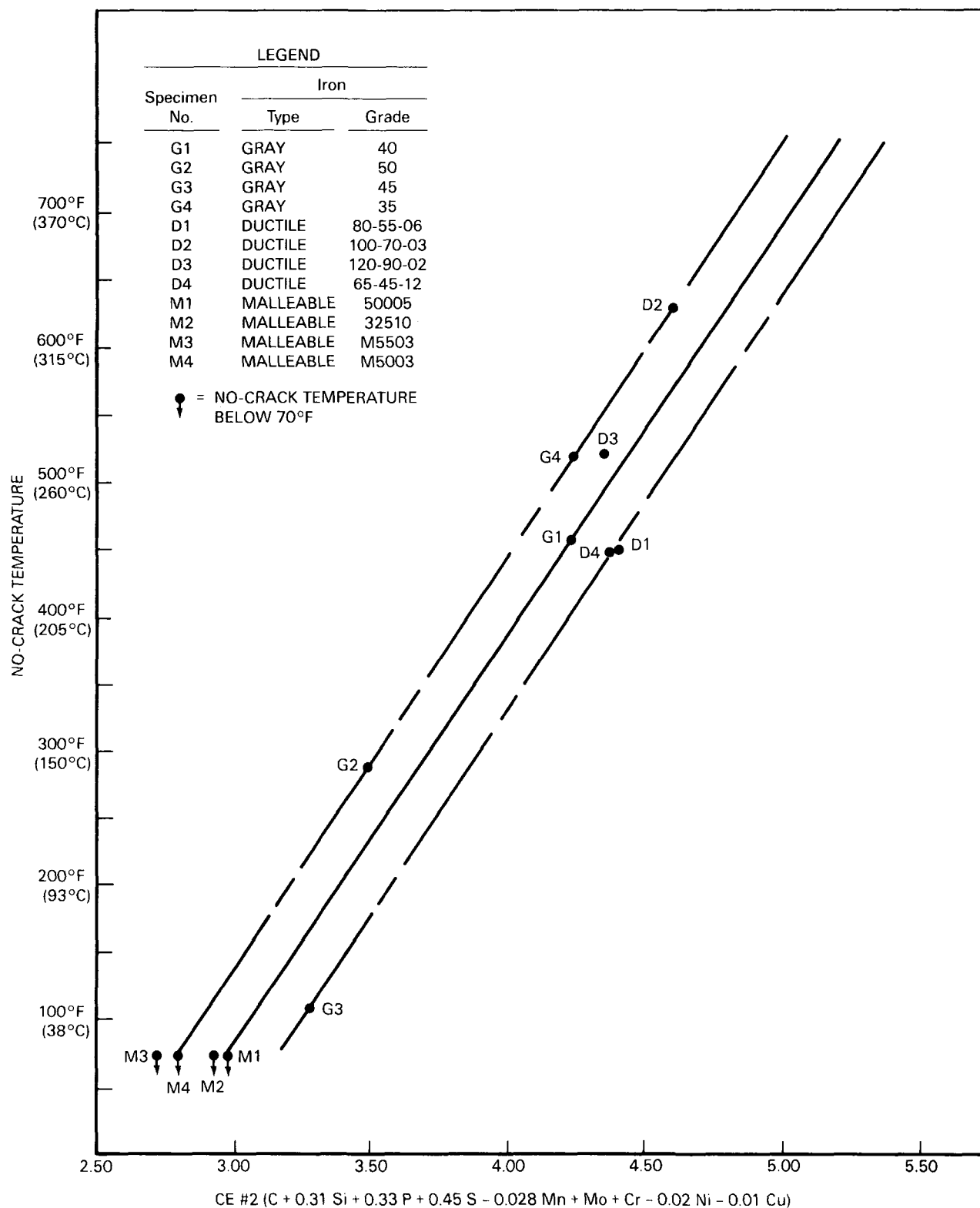


Figure 8— Relation of No-Crack Temperature to C.E. #2 for Several Grades of Iron Castings

First, the test data should be duplicated by others to verify the repeatability of the test, and thereby its reliability. Second, the validity of the Carbon Equivalent #2 Formula when applied to highly alloyed cast iron, needs to be established. Third, the maximum HAZ hardness of welds made according to the weldability test conditions with the base metal at room temperature should be compared to the no-crack temperatures of the cast irons, to see if there is any correlation.

2.4 Preweld Testing for Weldability. The AWS weldability test program established a correlation between the chemical composition of a cast iron and its tendency to crack when welded according to the standard test method described in 2.3 and Appendix A. These data should not be used to establish a preheat temperature for a particular casting to be welded. There are many other factors which also affect the ability to make a good weld on iron castings, such as filler metal, peening, and heat input. In addition, local contaminants such as phosphorous and sulfur in the skin of the casting, trapped sand, absorbed lubricants or other materials can be sources of poor weldability.

2.4.1 Effects of Contaminants. When heat is transmitted into the casting from a welding arc, the contaminants volatilize and become gaseous. The pressure from the escaping gases repel or force the molten weld metal away from the base metal, causing incomplete fusion and porosity at the base of the weld bead. These discontinuities greatly reduce the strength of the weld, frequently causing failures.

The surface of most iron castings often contain excessive concentrations of sulfur and phosphorus which should be removed by grinding prior to welding. Sand inclusions are also frequently present near the surface and into the casting itself. Due to the porous nature of cast iron, castings which have been in service for a period of time and have been exposed to grease, oil, chemicals, etc. will absorb these contaminants into the pores of the iron casting. It is important to preweld test for the presence of any of these contaminants prior to welding.

2.4.2 Preweld Testing for Contaminants. In the area where the welding will be done, with the electrode selected for the cast iron repair, weld a short stringer bead approximately two to three inches long, remove the

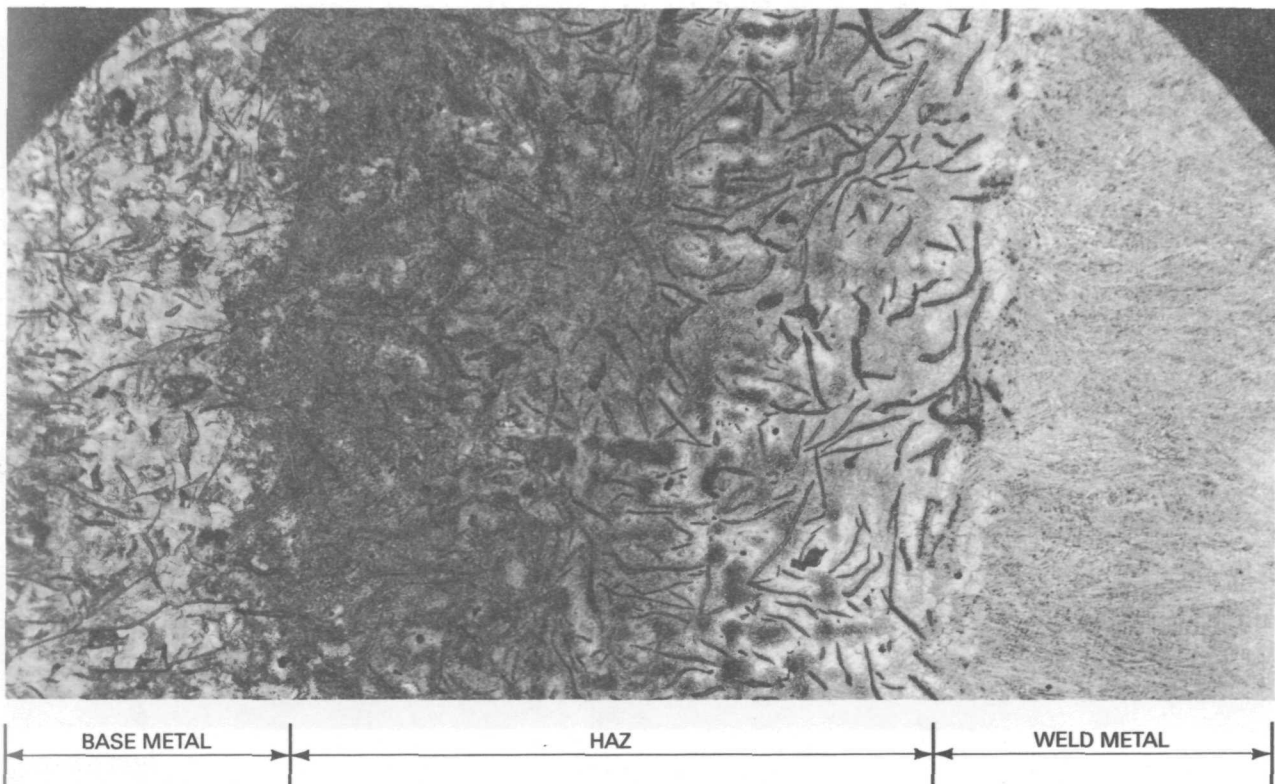


Figure 9 — Gray Iron ASTM A48, Grade 35, Typical Microstructure Showing As-quenched Weld Metal, Partially Hardened Heat Affected Zone, and Unaffected Base Metal (Note the Unaffected Graphite in HAZ and Base Metal) (50x Magnification)

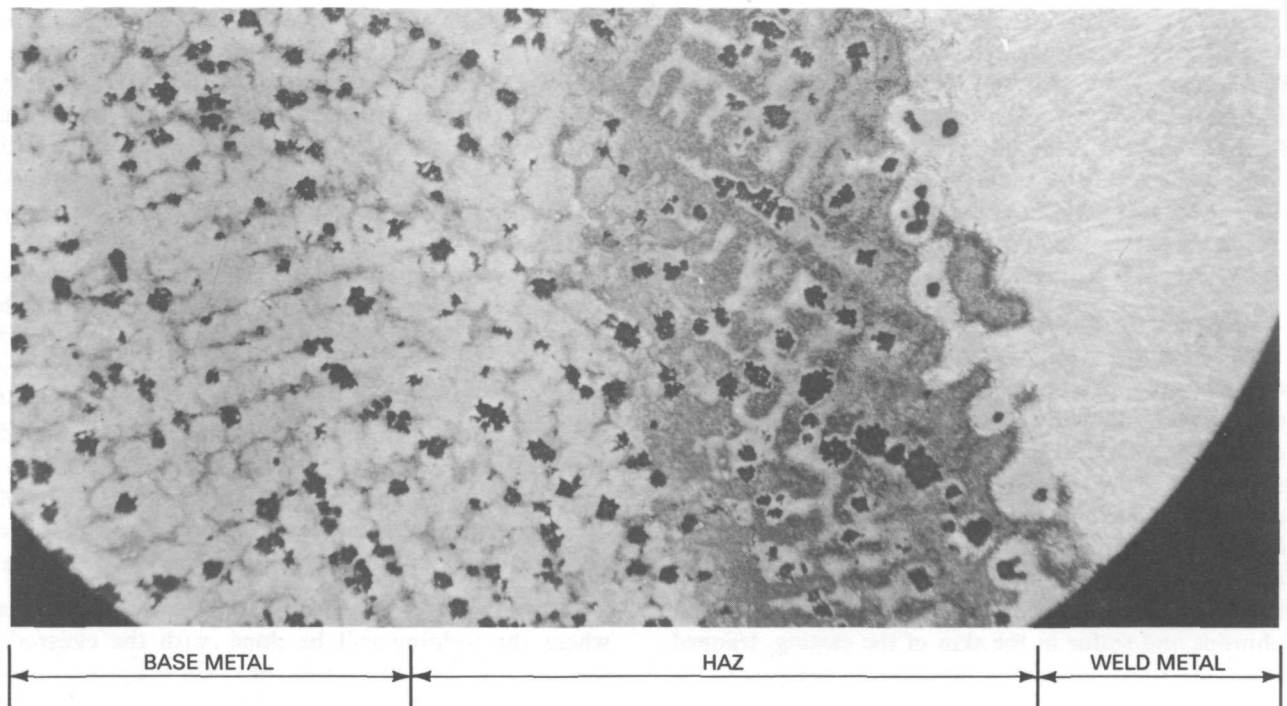


Figure 10 — Malleable Iron ASTM A220, Grade 50005, Typical Microstructure of Temper Carbon Nodules, in Coarse Dendritic Matrix (Note Isolated Graphite in Islands of Martensitic Matrix in HAZ) (50x Magnification)

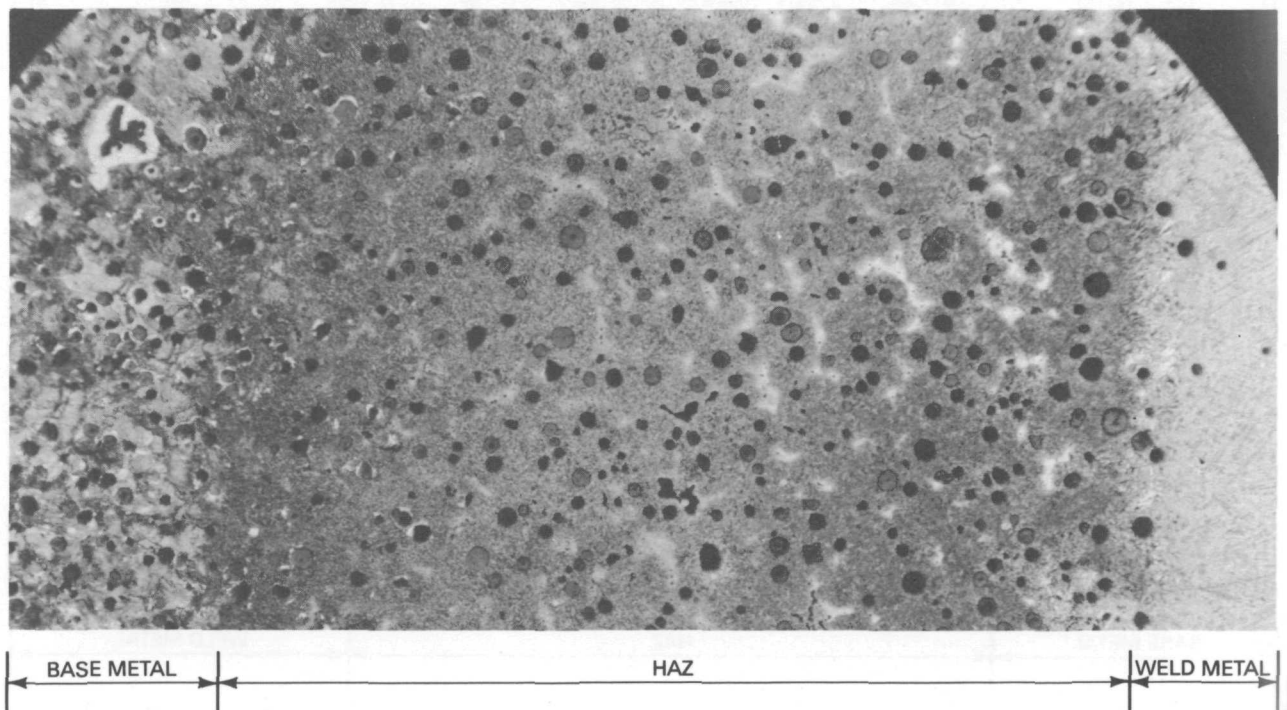


Figure 11 — Ductile Iron ASTM A536, Grade 100-70-03, Showing Nearly Uniform Nodular Graphite Distribution, Including Isolated Nodules in Weld Metal (50x Magnification)

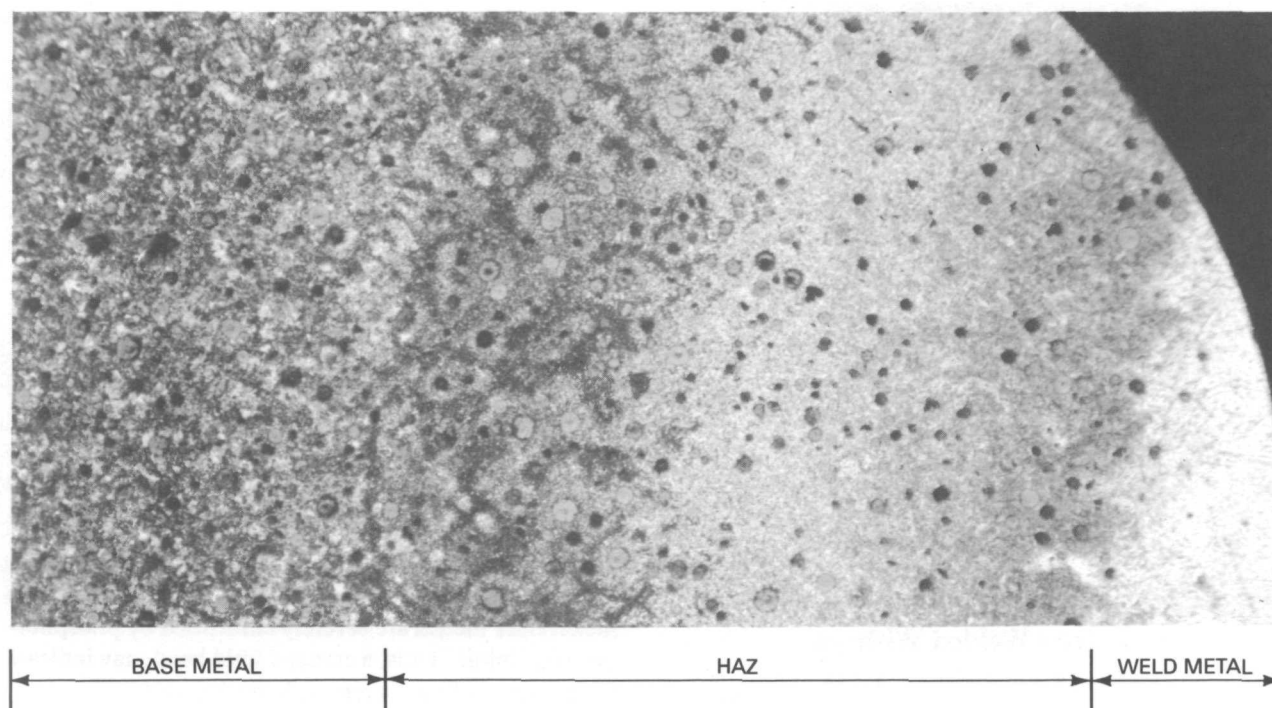


Figure 12 — Ductile Iron ASTM A536, Grade 120-90-02, Showing Uniform Nodular Graphite Distribution (50x Magnification)

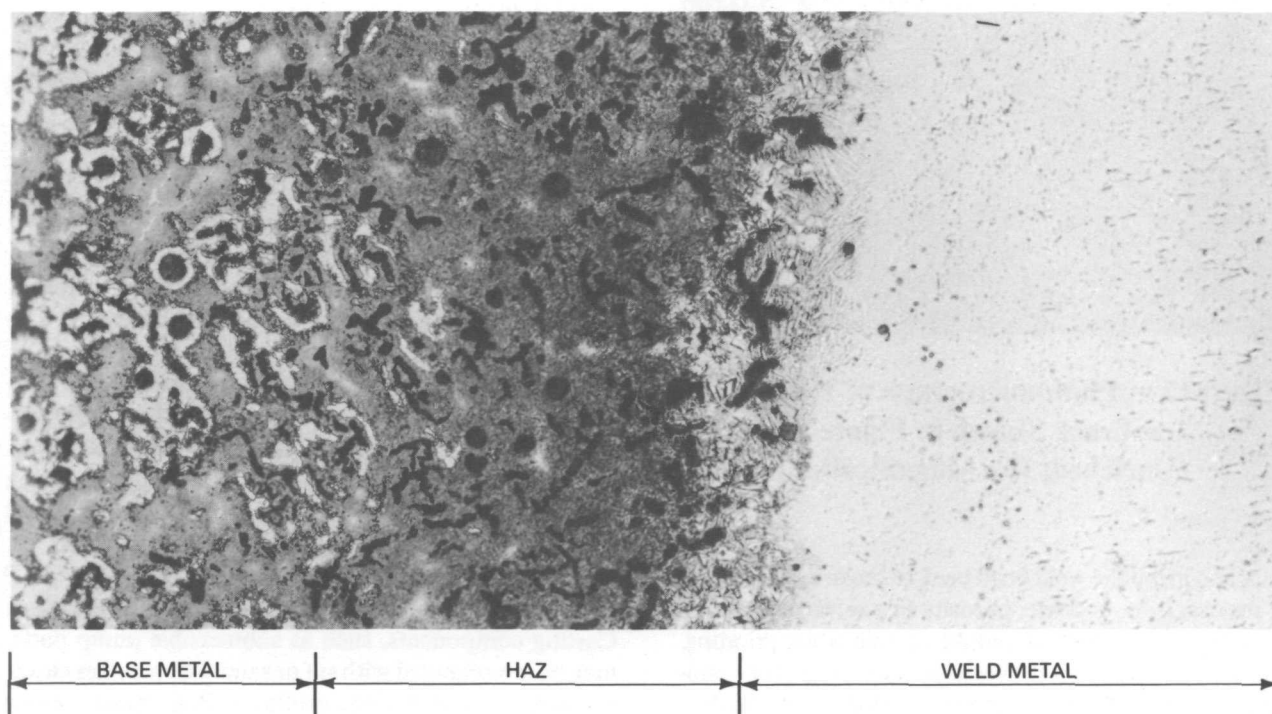


Figure 13 — Compacted Graphite Showing a Typical Microstructure of the Weld and HAZ (50x Magnification)

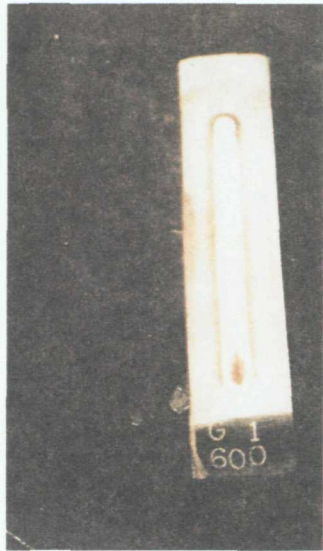


Figure 14 — Weld Toe Crack in Specimen of Gray Iron Welded Without Filler Metal Using GTAW



Figure 15 — Photomicrograph of HAZ Weld Toe Crack Shown in Figure 14 (Unetched, 15x Magnification)

slag, and grind the weld bead back to the original surface of the cast iron. A dense, porosity free surface where the weld bead was applied should remain after grinding. However, if porosity is in evidence, some form of contamination is present and must be removed before welding (see 3.1). Cast irons containing a great deal of contamination usually exhibit excessive porosity throughout the weld bead, and it is evident without grinding. However, where lesser amounts are present, the molten weld metal

will solidify before the gas formed can travel to the top of the weld bead. The resultant weld bead may appear sound, but excessive amounts of gas may be trapped, forming porosity and islands of incomplete fusion at the base of the weld bead. This can be detected only by grinding.

Caution: If the preweld test bead is applied without preheat, it should be in an area that does not require subsequent machining.

2.4.3 In situations where high phosphorous content, sand inclusions, severe oxidation, or extensive carburization exist, this test may also indicate to the experienced user the suitability of the filler metal selected or whether a fusion welding process is a viable choice. Danger signals are a collapsing base metal appearance resulting in excessive undercut, and lack of wetting during the test.

2.4.4 The test can also be used to select filler metal. For example, it is known that welds made with high nickel filler metals are severely embrittled by phosphorous or sulphur. Thus, a cracked weld bead may indicate the presence of too much of these elements.

3. General Considerations When Welding Iron Castings

The following items should be evaluated when welding cast iron, regardless of the type of iron being welded, or the process, equipment, electrode, or filler metal being used.

3.1 Base Metal Preparation. If a sound weld is to be produced, it must be made on a sound, clean, base metal. Thus, when a crack or linear defect is to be repaired, it should be completely removed before welding is begun. The same is true when repairing casting tears, porosity, shrinkage defects, inclusions, and other defects. The defect must be completely removed.

Casting skins, coatings, sand, rust, paint, oil, grease, moisture, dirt, and other materials may cause weld discontinuities unless removed prior to welding. Castings which have been exposed to high temperatures during service may be oxidized or carburized. Before repair, all affected metal in the weld area should be removed.

Baking at a temperature in the range 700–900°F (370–480°C) will remove most absorbed oil and grease. Casting components, such as submersible pump parts, may be impregnated with silt or sand which makes cleaning and subsequent welding difficult. Baking and preheat do not alleviate this situation.

One method of repair is to apply a weld bead and grind, repeating until the casting surface is smooth and free of defects.

Many excavation methods may lead to defect propagation unless precautions are taken. Often it is wise to “pin” the defect before beginning excavation. This is accomplished by first locating the ends of the defect by visual, magnetic particle, or liquid penetrant inspection. Holes are then drilled through the ends of the defect. The crack then terminates in a hole and cannot propagate. An alternate method to drilling is to weld a ductile bead across the end of the crack transverse to its direction, using a nickel or nickel-iron electrode. The excavation can then be completed and welded as required.

3.1.1 Thermal Cutting and Gouging

3.1.1.1 Air-Carbon Arc Process (AAC). The air carbon arc process may be used for cutting and gouging to prepare gray, ductile, or malleable irons for joining and repairs. It requires a power source, a source of compressed air, a torch, and an electrode. The power source should have 60 volts minimum open circuit voltage. Air carbon arc electrodes require higher voltages and currents than equivalent size shielded metal arc electrodes. The compressor should be capable of delivering air at 80 to 100 psi (560 to 700 kPa) at the torch to provide adequate pressure to remove the molten metal.

Either direct or alternating current may be used with cast irons. If the current is DCEP, it should be set near the maximum that the electrode is designed for. The arc length (distance between electrode and workpiece) should be minimal. However, the electrode should not be allowed to touch the workpiece. These steps are necessary to prevent formation of a refractory slag on the surface of the cast iron which interferes with the cutting action. Copper coated electrodes that are specifically designed for alternating current may also be used on DCEN. Recommended current ranges follow.

Electrode Size		DCEP	DCEN	AC
in.	mm	A	A	A
3/16	4.8	150–200	150–180	150–200
1/4	6.4	200–400	200–250	200–300
3/8	9.5	350–600	300–400	300–500
1/2	12.7	600–1000	400–500	400–600
5/8	15.9	800–1200	—	—
3/4	19.1	1200–1600	—	—

The push angle and travel speed control the depth of the cut. A steep push angle (approaching perpendicular to the workpiece) and a slow travel speed will produce a deeper groove than a flat push angle (approaching parallel to the workpiece) and a fast travel speed. Weaving will increase the width of the groove. As is the case with any process which results in temperature high enough to cause transformation in adjacent areas of the base metal, the AAC process will create a heat affected zone (HAZ)

with undesirable properties. To prevent wide heat affected zones, procedures should be chosen which minimize heat input. The HAZ may be removed by grinding or other mechanical methods before welding.

3.1.1.2 Shielded Metal Arc Cutting (SMAC). SMAC electrodes that do not require supplemental compressed air or a special torch can also be used to prepare gray, ductile or malleable irons for joining and repairs, and provide a clean, efficient method for the removal of unwanted or defective metal. Special exothermic flux coverings develop an instantaneous concentration of heat into a very small crater at the tip of the electrode. When placed in contact with the base metal, the high concentration of heat in the arc causes the base metal to melt very rapidly in an area the width of the electrode diameter. The combination of elements in the flux covering dissolve with the molten metal core, resulting in a tremendous forward thrust, forcing the melted base metal from the crater formed.

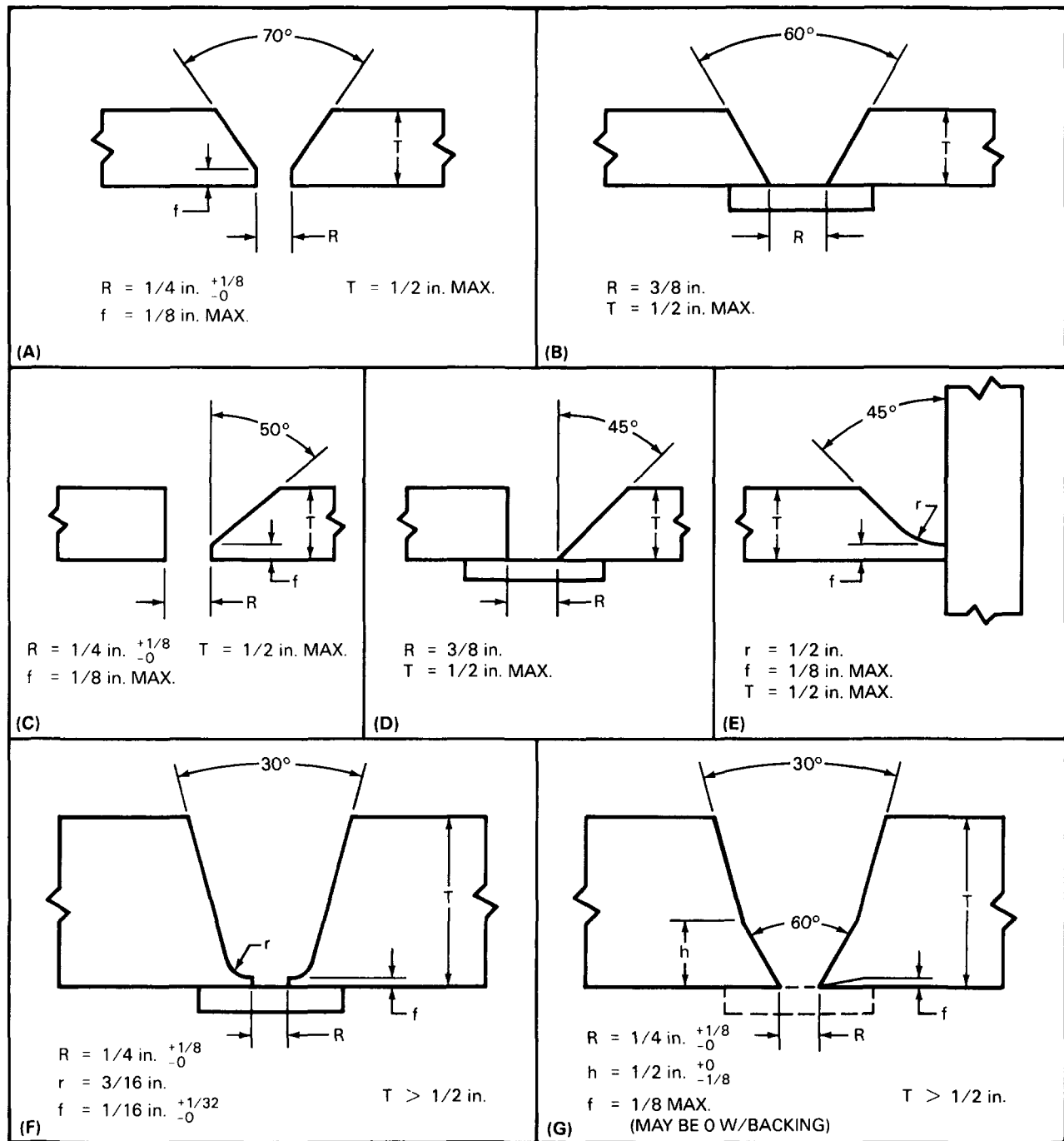
A standard electrode holder is used with ac or dc electrode negative and current settings near the maximum for the size being used. During cutting, the electrode covering will remain in contact with the base metal at the bottom of the groove. Otherwise, the same procedures previously outlined for the AAC process may be employed.

3.2 Joint Design. The design of the weld groove to be filled in an iron casting can greatly influence the properties of the weld and ultimately its performance in service. Base metal thickness and type, filler metal, and accessibility will influence the design of the groove.

3.2.1 Thin Base Metal. Welds in thin cast iron may be made with single-V or single-U grooves. For superficial repairs using steel filler metals, standard steel weld grooves are acceptable. With nickel base filler metals, groove angles should be increased to allow for manipulation of the sluggish weld pool. The root face must be reduced because the nickel base electrodes achieve less root penetration than steel electrodes [see Figure 16(A), (B), (C), (D), and (E)].

3.2.2 Thick Base Metal. For thicknesses greater than approximately 1/2 in. (12.7 mm), grooves that evenly distribute the stresses induced during welding should be used. Double welded joints are effective in such applications when both sides of the joint are accessible. For thicknesses up to 3/4 in. (19 mm), a double-V-groove or a double-bevel-groove should be used. For thicknesses over 3/4 in. a double-U-groove or double-J-groove should be considered.

When only one side of the section is accessible, a modified U-groove may be used. This allows access to the joint root and decreases the width of the weld face.



METRIC VALUES

in.	mm
1/32	0.8
1/16	1.6
1/8	3.2
3/16	4.8
1/4	6.4
3/8	9.5
1/2	12.7

Figure 16 — Suggested Complete Joint Penetration Single Grooves

thus decreasing both weld metal mass and shrinkage stresses induced [see Figures 16(F) and (G), and 17].

When welding thick base metal, buttering of the groove faces is often used. In this manner, the initial welding on the low ductility casting is done at a minimum stress level.

3.2.3 Braze Welding Joints. Joints for braze welding in cast iron are essentially the same as those used for arc welding. To allow for better flow, ease of access, and finishing, the edges of the joint may be rounded. This idea is shown schematically in Figure 18.

3.2.4 Joint Penetration Requirements. The degree of joint penetration required is dependent on the relative strength of the weld metal and base metal, the stresses in service, and the thickness of the workpiece being welded. The savings in welding time and filler metal achieved by making less than complete joint penetration welds must be carefully weighed against the service environment and the fitness for service of such a weld. If the use of a partial joint penetration weld is questionable, complete joint penetration should always be required.

Thick castings of gray iron are sometimes joined with less than complete joint penetration welds. Since most nickel base weld metals are considerably stronger than gray iron castings, partial joint penetration welds are often acceptable. For sections over 1/2 in. (12.7 mm) in thickness, welding only 2/3 of the thickness is usually adequate. For such applications, a double-U-groove is preferred.

Because of their considerably higher strength, ductile (nodular) iron castings require complete joint penetration welds. Even with CJP, 100 percent joint efficiency is not possible for the higher strength grades [greater than 80 ksi (550 MPa) tensile strength].

Welds in iron castings which will be exposed to fatigue loading should always be complete joint penetration welds. The unfused joint root can act as a crack, and propagate under fatigue.

Pipe welds should always have complete joint penetration. A joint with incomplete penetration can act as a crevice and induce accelerated corrosion.

3.2.5 Joint Alteration Techniques. The strength or fitness for service of weldments in iron castings can be improved by the incorporation of various welding techniques into standard procedures. Use of such procedures essentially incorporates some of the design features of mechanical fastening into welding procedures.

3.2.5.1 Groove Face Grooving. Grooving is accomplished by simply grinding or gouging weld bead size grooves on the groove faces of the weld groove (i.e., parallel to the direction of weld progression) as illustrated in Figure 19. The grooves are filled first by welding

with the chosen weld process and filler metal, then the joint is filled. In this manner, the weld interface is interrupted so that the path a crack might follow is not straight. To propagate, a crack must change direction so that the stress required is increased. Thus, the strength of the weld is higher, and fitness of the weld for service is improved.

3.2.5.2 Studding. The mechanical application of studs to the groove faces has been shown to increase the quality of the joint. Studs, depending on their design, are either driven or threaded into the groove faces (see Figure 20). The material of the stud is chosen so that it is compatible with the filler metal.

3.2.6 Joint Design Improvements. Methods for improving the design of joints in iron castings are shown in Figure 21. By applying these designs, the service of the resulting weldment should be improved.

In illustration (A), a complete joint penetration weld is compared with a partial joint penetration weld. The crevice created by incomplete penetration can act as a crack and propagate through the weld in conditions of fatigue.

Illustration (B) shows how improved casting design can locate welds away from changes in metal thickness where bending stresses will be concentrated. Thus, the weld is not in a highly stressed area.

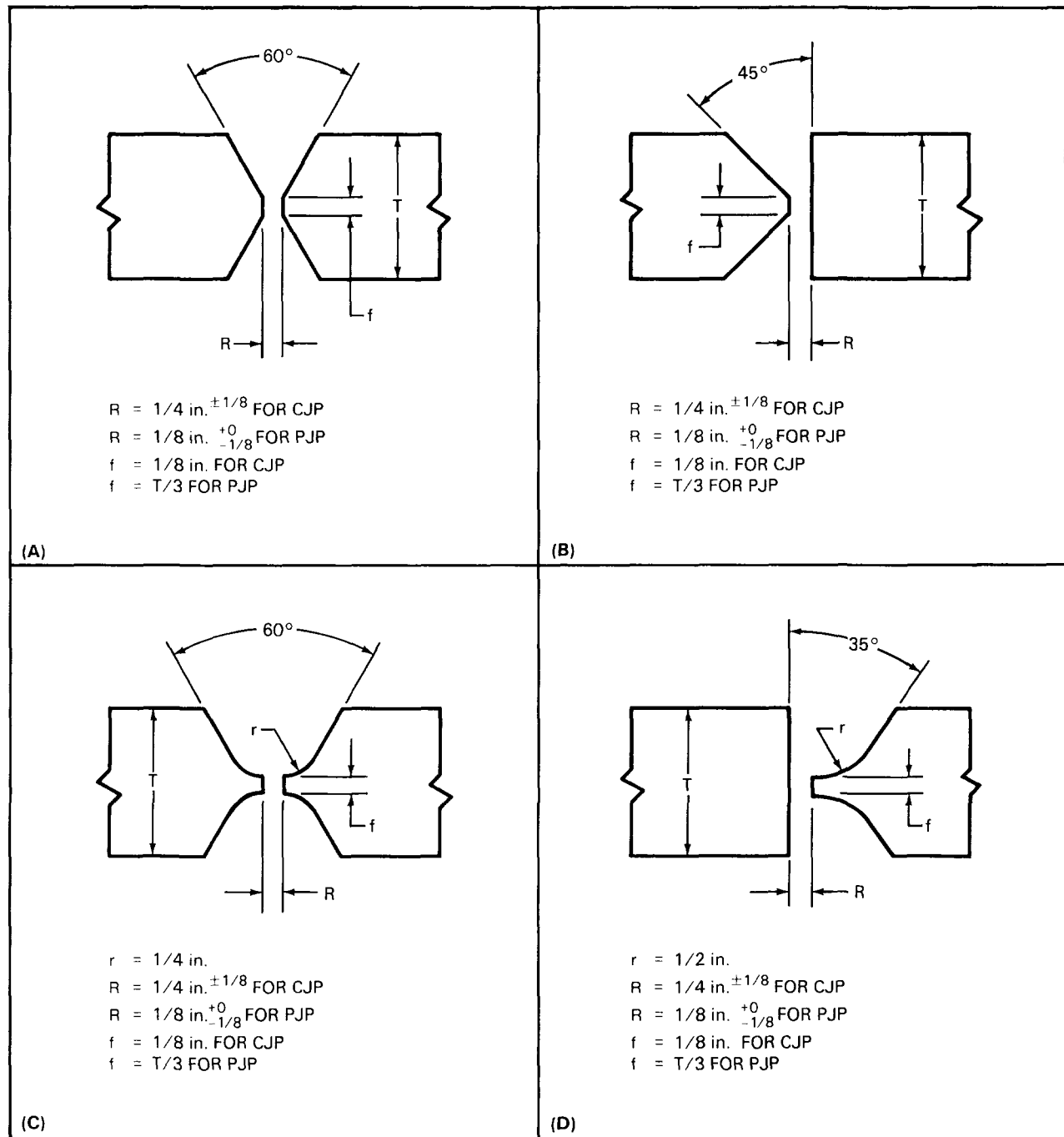
A fillet weld is added to the joint in the third frame, (C), to decrease flexing between the top and bottom joint member. Thus, the life of the joint under fatigue loading should be improved.

3.3 Heat Input. The size of the heat affected zone of a weld is dependent upon the heat input. Thus, the lower heat input processes are most applicable to the welding of iron castings. Welding currents should be maintained at the minimum consistent with complete fusion.

3.4 Preheat. Preheating castings before welding has the following advantages:

- (1) Improves fusion of weld metal to groove face to obtain complete fusion
- (2) Prevents cracking caused by temperature gradients and thermal stresses
- (3) Reduces residual stresses
- (4) Reduces distortion
- (5) Reduces hardness of heat affected zone
- (6) Reduces temperature gradients when welding thin to thick base metals
- (7) Reduces temperature gradients when welding dissimilar base metals

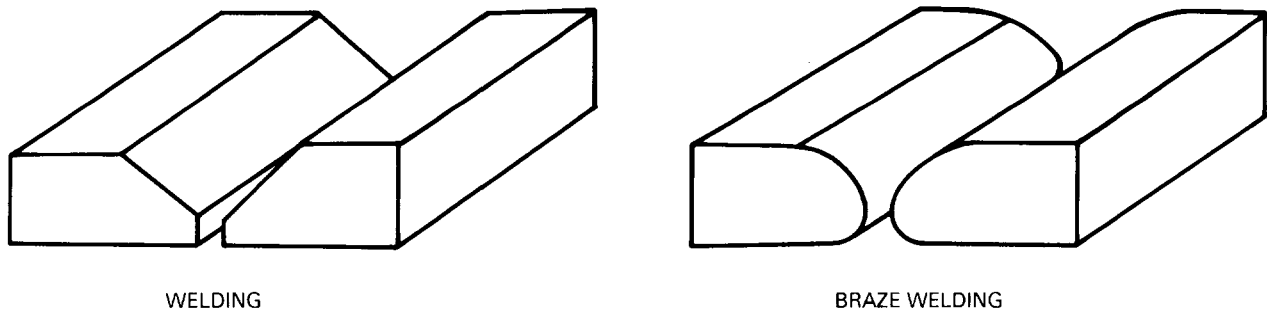
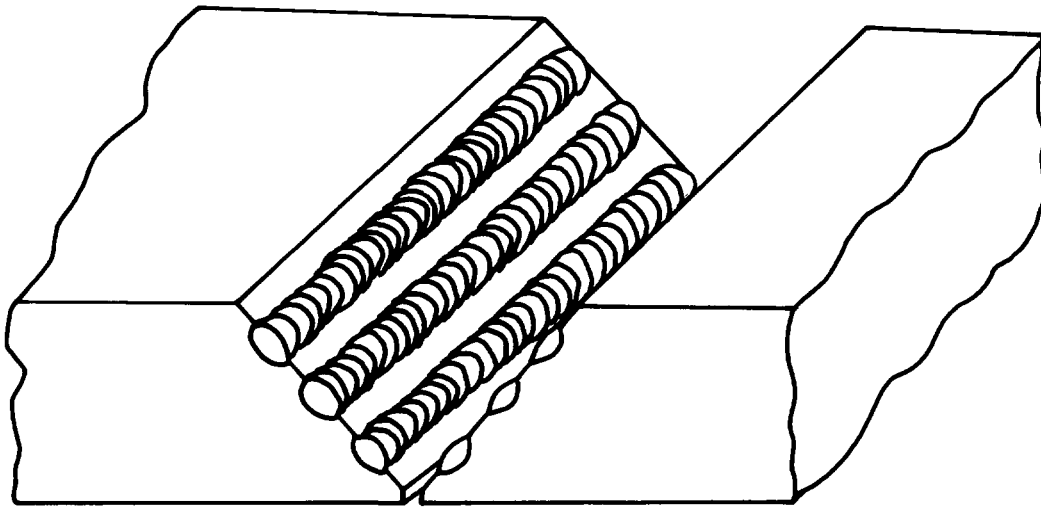
When, and how much to preheat are questions often asked. There are no simple answers, but general rules can assist in making this decision.



METRIC VALUES

in.	mm
1/32	0.8
1/16	1.6
1/8	3.2
3/16	4.8
1/4	6.4
3/8	9.5
1/2	12.7

**Figure 17 — Suggested Complete Joint Penetration (CJP)
and Partial Joint Penetration (PJP) Grooves**

**Figure 18 — Groove Designs****Figure 19 — Groove Face Grooving**

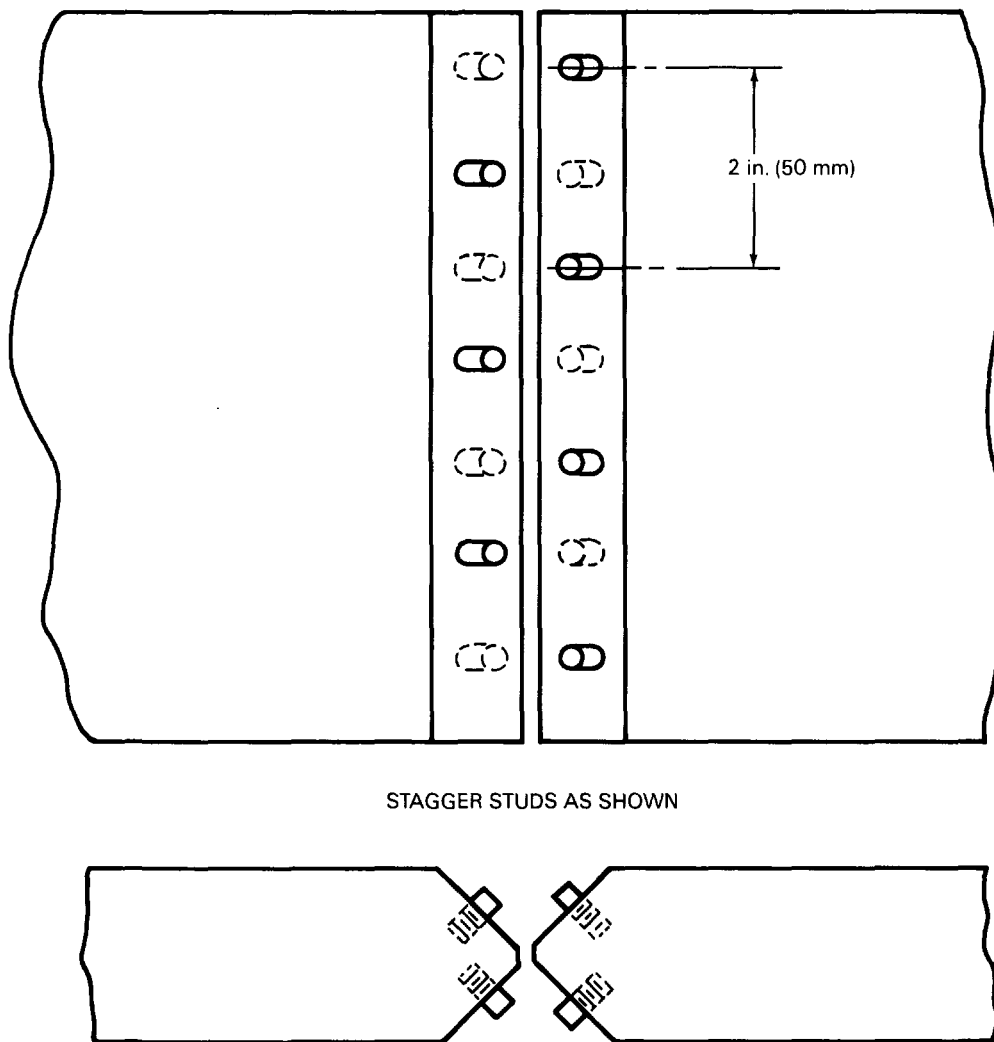
If the chemical composition of the cast iron is known, the carbon equivalent can be calculated and used as a guide to estimate preheating requirements. The higher the carbon equivalent, the higher the preheat temperature. If the type or grade of casting is known, but not the specific chemical composition, then the best estimates for preheat temperature are based on the strength and microstructure. Low strength cast irons usually require lower preheat temperature than high strength castings. Malleable or ductile types usually require lower preheat temperature than gray or white cast irons, and ferritic microstructures usually require lower preheat temperature than pearlitic, martensitic or highly alloyed types.

The shape of the casting influences the preheat temperature. A complex casting will usually need a higher preheat temperature to control distortion or residual stresses. When welding thin to thick base metal,

it may be desirable to preheat the thicker member. This decreases its heat sink capacity, which reduces thermal stresses caused by temperature gradients.

Preheat is applied to control the microstructure of the weld area. By preheating to relatively high temperatures, 600–1000°F (320–540°C), the cooling rate can be slowed to the point that formation of martensite is minimized. Slow cooling in this manner also assists in decreasing residual stresses. By decreasing these stresses and the hard phases referred to above, machinability of the welded casting is improved.

If preheating is to accomplish its intended purpose, certain rules must be followed in its application, otherwise, the heat may be ineffective or even detrimental. Preheat should be applied so that the weld is in compression on cooling. While the weld metal is contracting due to cooling, the base metal around it is also contracting. A



STAGGER STUDS AS SHOWN

Figure 20 — Studding to Increase Strength at the Weld Interface

good example of this is shown in Figure 22. Preheating in the areas indicated in Figure 22(B) will expand the metal, as shown in Figure 22(C). Thus, the weld groove opens. After welding, Figure 22(D), the weld will be compressed as the ends cool and the metal shrinks.

When preheating castings of a complex shape, it may be necessary to apply heat to the entire casting to avoid inducing high stresses due to thermal gradients. The area to be welded may be brought to an even higher temperature if necessary. A complete structural analysis of the casting will determine how preheat can be applied most effectively.

3.5 Electrode Manipulation. Welds can be made in any position by using either a stringer or weave technique.

Dilution can be minimized by utilizing stringer beads in the flat position and holding the electrode almost vertical with the arc directed into the weld pool. The weave should not be more than three times the diameter of the electrode. When welding in grooves, a weaving technique may be used to improve the fusion to the groove faces. A skip technique may be used to minimize distortion in extensive repair welds, extra long welds, or thick base metal.

Arc length should be as short as practical to assure good bead shape. Flux should be removed from each crater before making a restrike and completely removed from each pass before starting subsequent passes. Removal is done readily by light hammer blows with the corner of a cold chisel or slag hammer followed by wire brushing.

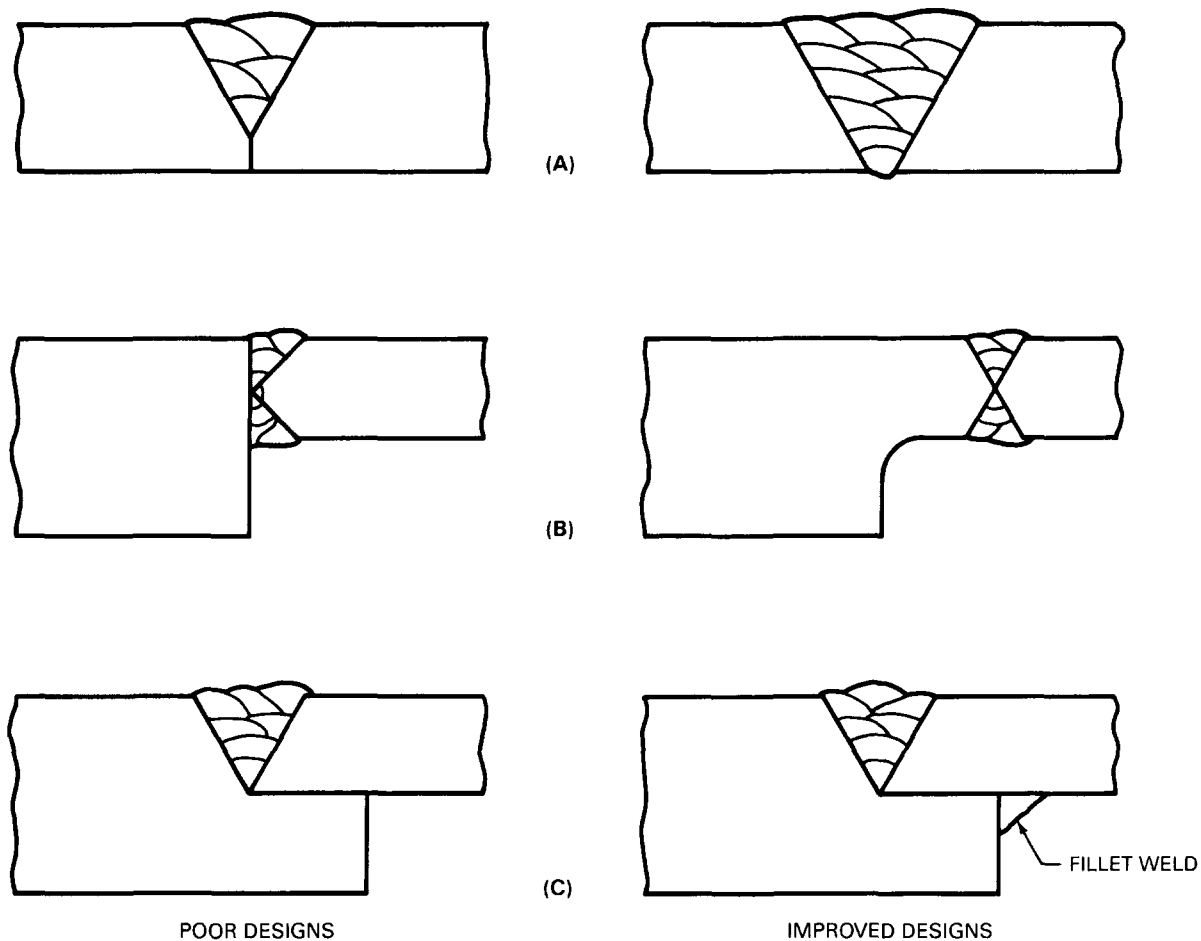


Figure 21 — Joint Design Improvements

3.6 Peening. Peening can be used to control distortion or to reduce cracking by altering the stress distribution in the weldment. If peening is to be done, it should be by many moderate blows perpendicular to the weld surface rather than by a few heavy blows, peening each bead as deposited. A 1/2 to 3/4 in. (13 to 19 mm) diameter rounded peening tool or a ballpeen hammer is suitable. During any peening operation, the weld metal should be maintained at, or near, red heat, but never allowed to cool below 1000°F (538°C).

A typical peening procedure is the use of a reciprocating air hammer operating at 90 psi (600 kPa) (to approximate many moderate blows) on a weld of up to 3 in. (76 mm) in length. The peening tool tip should be no wider than the weld bead and with a tip radius of half the tip width. Recommended peening travel speed is 30–40 in. (750–1000 mm) per minute.

Peening, properly done, can be quite effective in reduction of distortion. For example, a single-V-groove

weld, unpeened and unrestrained, causes considerable distortion. The same weld, properly peened, can be completed with virtually no distortion.

3.7 Cooling. The final stress level of a welded casting is affected by its rate of cooling. If the casting is cooled rapidly, residual stresses remain in the casting. If the residual stress is high enough, cracking may occur. Slowing the cooling rate can alleviate this problem. This can be accomplished by the following:

- (1) Burying the casting in sand or vermiculite
- (2) Postheating the welded casting with a torch
- (3) Transferring the welded units to a furnace
- (4) Covering the casting with an insulating blanket

3.8 Postweld Heat Treatment (PWHT). After welding, heat treatment may be necessary to accomplish the following:

- (1) Improve the ductility of the HAZ of the weld.
- (2) Improve the machineability of the weld and HAZ.

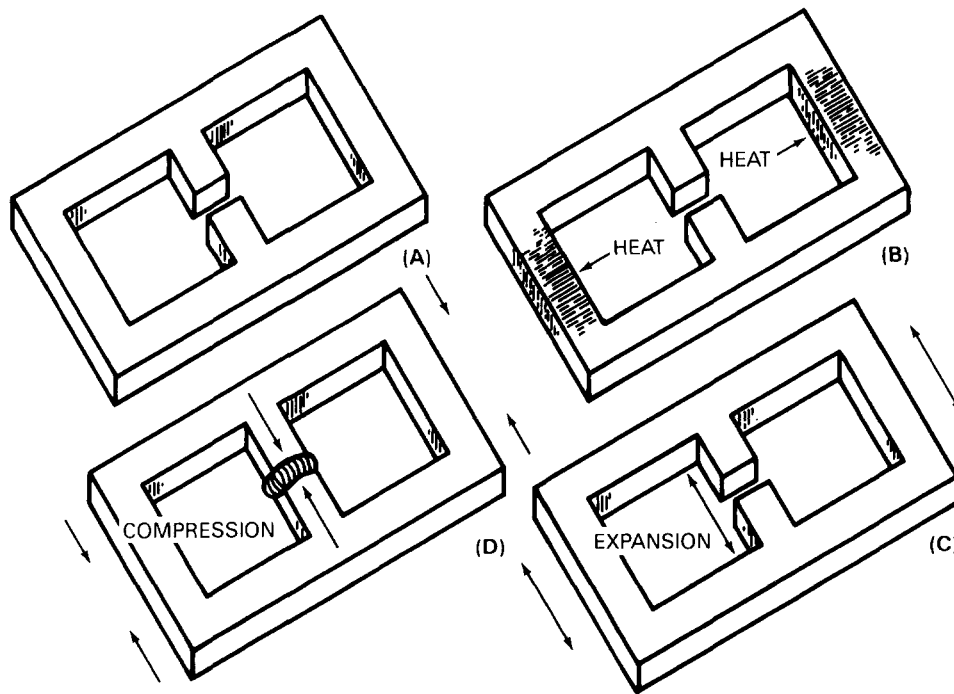


Figure 22 — Fundamentals Involved in Preheating Castings for Welding

- (3) Decompose the cementite formed during welding.
- (4) Transform martensite to a less brittle phase.
- (5) Relieve residual stresses.

The selection of the final PWHT depends in large part on the condition of the casting, the effect on finish machined surfaces, possible distortion, and prior heat treatment. Unfinished castings still at the foundry can generally be heat treated after weld repairs. New, finish machined castings may be given a stress relief PWHT, with actual temperature dependent on the composition and prior heat treatment.

Castings taken out of service may be given a complete or local stress relief, or no PWHT whatever. Thermal cycles, if used, are described in 3.8.1 and 3.8.2. The selection is based on the individual case, taking into consideration economics, weldability, critical nature of the part, and location of the repair.

To avoid thermal stress cracking due to temperature variations in the casting, the postweld heating and cooling rate should not exceed 100°F (55°C) per hour when heat treating large or complex castings. Unusual cases may require even slower rates.

3.8.1 Gray Iron. If a minimal stress relief (30 percent) or only a partial reduction of hardness is necessary, heating the casting to 900°F (480°C) and cooling in still air should produce suitable results. A temperature of

1100°F (590°C) will reduce the residual stress to about one-half and further reduce the hardness. Again, cooling in still air is satisfactory. For maximum softening, heat to 1650°F (900°C) and furnace cool.

3.8.2 Ductile Iron. Because of this material's comparatively high ductility, it is often desirable to heat treat castings after welding to restore the ductility of the weld area. For best results, the casting should be either heat treated immediately after welding or cooled slowly after welding.

If only moderate improvement of ductility is necessary, heating to 900°F (482°C) and slow cooling in still air is sufficient. The treatment will stress-relieve the weldment, as well as reduce the hardness of the heat affected zone.

If greater ductility is required, the following annealing cycle may be used:

- (1) Heat the part to 1650°F (900°C) at a rate not to exceed 100°F (55°C) per hour.
- (2) Hold at 1650°F (900°C) for one hour per inch of maximum thickness.
- (3) Furnace cool to 500°F (260°C) at a rate not to exceed 100°F (55°C) per hour.
- (4) Cool to room temperature in still air.

This high temperature annealing cycle dissolves iron carbides and transforms the martensite and bainite to

austenite. The slow cooling allows the formation of ferrite, pearlite, and the precipitation of the carbon as graphite, while avoiding the reformation of the harder constituents, martensite and bainite.

If maximum ductility is required, the following ferritizing annealing cycle may be used:

- (1) Heat the part to 1500–1700°F (840–900°C) at a rate not to exceed 100°F (55°C) per hour.
- (2) Hold at temperature for one hour per inch (25 mm) of maximum thickness.
- (3) Furnace cool to 1250°F (675°C) at a rate not to exceed 100°F (55°C) per hour.
- (4) Hold at temperature for 5 to 6 hours.
- (5) Furnace cool to 500°F (260°C) at a rate not to exceed 100°F (55°C) per hour.
- (6) Cool to room temperature in still air.

This treatment, in addition to transforming the hard constituents as in the preceding treatment, will allow time for the formation of a ferrite matrix.

4. Gas Processes

4.1 Oxyfuel Welding (OFW)

4.1.1 Process Description. OFW includes any welding process that uses oxygen and a fuel gas as a heating medium. The process involves the melting of the base metal and a filler metal by means of the flame produced at the tip of a welding torch. Fuel gas and oxygen are mixed in the proper proportions in a mixing chamber which may be part of the welding tip assembly. Molten metal from the groove faces and filler metal intermix in the weld pool and, upon cooling, coalesce to form a continuous piece.

An advantage of this welding process is the control a welder can exercise over the rate of heat input, the temperature of the weld zone, and the oxidizing or reducing potential of the welding atmosphere. Weld bead size and shape and viscosity of the weld pool are also controlled in the welding process because the filler metal is added independent of the welding flame. OFW is ideally suited to the welding of thin sections, tubes, and small diameter pipe, and also for repair welding. Except for repair welding, the process is not economical for thick base metal.

The equipment is low in cost, usually portable, and versatile enough to be used for a variety of related operations, such as bending, straightening, preheating, post-heating, surfacing, braze welding, and torch brazing. With relatively simple changes in equipment, manual and mechanized oxygen cutting can be performed.

Commercial fuel gases all require oxygen to support combustion. To be suitable for welding, a fuel gas, when burned with oxygen, must have the following:

- (1) High flame temperature
- (2) High rate of flame propagation (combustion velocity)
- (3) Adequate heat content
- (4) Minimum chemical reaction of the flame with base and filler metals

Among the commercially available fuel gases, acetylene most closely meets all these requirements. Other fuel gases, such as stabilized methylacetylene-propadiene, propylene, propane, natural gas, and proprietary gases based on these have sufficiently high flame temperatures but exhibit low flame propagation rates. These other gas flames are excessively oxidizing at oxygen-to-fuel gas ratios high enough to produce usable heat transfer rates. For this reason, acetylene is preferred for welding cast irons.

Oxyacetylene welding (OAW) with cast iron filler rod has been used widely for the weld repair of minor defects in gray cast iron and less frequently for ductile iron castings. The characteristic slow heating rate of the process causes a wide heat affected zone, but prevents formation of hard martensite. Oxyacetylene welding procedures reported in the literature commonly recommend the following filler metals and procedural guidelines to avoid cracking and produce sound welds. Use of proper welding techniques is an important factor in producing a weld metal that closely matches the strength and machinability of the gray iron base metal.

4.1.2 Filler Metals and Fluxes. Many different compositions of filler metals are used for welding cast iron. Some of those most used and their best application are described below.

4.1.2.1 Gray Iron Welding Rods. Gray iron welding rods normally are cast with higher silicon and carbon content than the casting itself to compensate for losses during welding. The resultant weld metal has a graphitic structure, is machineable, and maintains a good color match. Chemical composition requirements for the two gray iron welding rods covered by ANSI/AWS A5.15-82, *Specification for Welding Rods and Covered Electrodes for Cast Iron* (Class RCI and RCI-A) are given in Table 4. RCI filler metal is used to join Class 20 through 35 gray irons. RCI-A filler metal, with higher levels of nickel and molybdenum, is intended to weld Class 35 through 45 gray irons.

Proprietary filler metals also are available for welding gray irons. Although compositions are not generally stated, these filler metals must be designed to furnish weld metal of adequate strength containing a minimum of iron carbide. To achieve the foregoing, alloying elements which promote solid solution strengthening are combined with a graphitizing agent. Nickel, manganese,

Table 4
Chemical Composition Requirements of Filler Metals, Percent

AWS Classification	C	Mn	Si	P	S	Fe	Ni ^{3a}	Mo	Mg	Ce
Cast Iron Filler Metals^{3b}										
RCI	3.2–3.5	0.60–0.75	2.7–3.0	0.50–0.75	0.10	remainder	trace	trace	—	—
RCI-A	3.2–3.5	0.50–0.70	2.0–2.5	0.20–0.40	0.10	remainder	1.2–1.6	0.25–0.45	—	—
RCI-B	3.2–4.0	0.10–0.40	3.2–3.8	0.05	0.015	remainder	0.50	—	0.04–0.10	0.20

Notes:

1. Analysis shall be made for the elements for which specific values are shown in this table.
2. Single values shown are maximum percentages.
3. Excerpted from ANSI/AWS A5.15-82.
 - (a) Nickel plus incidental cobalt.
 - (b) Chemical composition requirements for the Cast Iron Filler Metals are based on the as-manufactured composition of the bare welding rod.

molybdenum, and silicon are the most common additions. Silicon plays a dual role as a hardener and a graphitizing agent. Aluminum, in conjunction with calcium, can be substituted for silicon.

Phosphorus improves fluidity of molten iron. There is an upper limit to its usefulness, however, because the end product is a hard, brittle, iron/iron phosphide eutectic which is no more desirable than the iron/iron carbide eutectic which it resembles. Chromium, molybdenum, nickel, and copper are alloying elements frequently added to gray iron melts; therefore, their presence in a filler metal would be expected. If these elements are added to filler metal, the quantities must be carefully regulated. Chromium promotes iron carbide formation which can embrittle the weld metal. Copper will be present as a film along grain boundaries if its solubility in the matrix is exceeded. This film can cause hot cracking.

4.1.2.2 Ductile Iron Welding Rods. Ductile iron welding rods are different from gray iron rods because they contain additions of nodularizing elements such as magnesium (Mg) and cerium (Ce). Such filler metal is classified in ANSI/AWS A5.15-82 as RCI-B, as shown in Table 4. Bare welding rods containing other nodularizers or alloying elements are available, but are not yet classified by AWS. Welding rods, capable of producing nodular graphite weld metal, often are made by individual foundries from small quantities of production iron with Mg or Ce additions. These types are capable of producing weld metal with a nodular graphite structure, provided the Mg or Ce addition from the rod is sufficient to compensate for oxidation losses incurred during welding. Such losses vary depending on the welder's technique, and may be on the order of 50 to 80 percent.

Cerium-containing welding rod may be preferred to minimize porosity problems. Magnesium-containing rods develop a scum during welding unless adequate flux is employed. This scum is hard to remove and results in contaminated, low-strength welds. It is absolutely necessary that the filler metal be thoroughly mixed with the weld pool during welding. Proper welding must be followed closely to consistently produce high quality ductile iron weldments. Strength of the weld will depend greatly on the soundness of the weld metal. According to the test program reported in AWS D11.1-65, the tensile strength of some welds made in ferritic ductile iron test blocks with ductile iron welding rods containing cerium, was as high as 73 000 psi (500 MPa).

The overall average tensile strength was about 56 000 psi (390 MPa), mainly due to the variability in the soundness of the welds. Even though the strength of the weld metal may closely match that of the minimum base metal requirements, the ductility of the oxyfuel gas weld repair will be considerably lower when compared to the ductile iron base metal, even after a postweld annealing heat treatment. Test results presented in AWS D11.1-65 had an average tensile elongation of only 3 percent compared to a base metal elongation of 19 to 20 percent.

4.1.2.3 Malleable Iron. The cast iron welding rods listed in Table 4 have been used for welding malleable iron. However, the effect of oxyacetylene gas welding on malleable iron is to create a wide heat affected zone of brittle white iron. Thus, the base metal ductility is lost, and the weld is prone to cracking. Rather than repair weld the finished casting, some foundries make the repair on the rough casting while it is still in the white iron condition, before the malleabilizing heat treatment.

White iron welding rods cast by the foundry are used. Repair procedures suitable for gray iron are followed.

4.1.2.4 Flux. Fluxes are used for oxyacetylene welding of cast iron to protect the molten metal from oxidation, increase the fluidity of the iron silicate slag that forms, and dissolve oxides and other impurities. Proprietary fluxes are available. Fluxes for oxyacetylene welding gray iron typically contain borax (sodium borate) or boric acid, soda ash (sodium carbonate), plus some iron oxide powder. Fluxes used for the oxyacetylene welding of ductile iron are similar to those for gray iron, except they may be formulated to produce a slag with a lower melting point. Some proprietary ductile iron fluxes also may contain inoculant powders to promote the formation of spheroidal graphite.

4.1.3 Welding Procedure Guidelines

4.1.3.1 Preparation for Repair Welding. Preparation and careful cleaning of the repair excavation is necessary to obtain sound welds and to minimize the oxyacetylene welding time.

The defect must be completely removed. Base metal must be free of all foreign material. The casting skin should be removed at least 1 in. (25 mm) from the edges of the weld groove.

The groove excavation must be prepared wider than that used for shielded metal arc welding to allow room for unrestricted manipulation of the welding rod and torch. Groove angles of 90 to 120 degrees commonly are employed, the former for double groove welds and the latter for single groove welds.

4.1.3.2 Preheat and Interpass Temperature. A preheat temperature of 1000–1200°F (540–640°C), a dull red color, is recommended for the oxyacetylene welding of cast irons. This allows repairs to be made rapidly and results in a slow cooling rate, thus preventing formation of martensite in the base metal heat affected zone. Ideally, the entire casting should be preheated uniformly in a furnace to reduce danger of cracking from thermal stresses. Gray iron, which has low strength and nil ductility, is especially susceptible to cracking due to thermal stresses induced by localized preheating of the repair area. Localized preheating carefully done with a torch can be used successfully on small castings.

Once the proper preheat temperature is reached, the repair weld should be made quickly before the adjacent base metal can cool. Ideally, a weld repair should be made in less than five minutes without allowing the casting to cool below 600–800°F (320–470°C). If the welding takes so long that the casting cools below this temperature, the casting should be reheated to the original preheat temperature range. An insulating blanket material placed over the casting, exposing only the repair

area, reduces heat loss, especially when the surrounding air is cold or drafts are present.

The repair area should not be heated above 1250°F (680°C). At higher temperatures, phase transformations take place with accompanying volume changes which may introduce increased stress levels. Excessive preheat temperatures further increase the danger of distortion and a possible reduction in tensile strength due to the high interpass temperatures and extended welding times.

Temperature-indicating crayons are recommended to monitor the temperature of the repair area during preheating and welding when preheating is used. If a permanent furnace is not available, a preheat table or temporary furnace can be used to heat the casting before, during, and after welding. A preheat table is relatively inexpensive compared to the cost of a permanent furnace. It can be made from sheet steel with a fire brick top and gas burners underneath. The castings will be heated more uniformly, kept hot during welding, and can be covered up on the table after welding to slow their cooling rate.

4.1.3.3 Welding Technique. General details of the techniques considered good practice for the oxyacetylene repair welding of cast iron are as follows:

(1) The size of the welding torch and tips employed should be the same as would be used for welding similar thicknesses of mild steel.

(2) A neutral flame or very slightly reducing (carburizing) flame should be employed. An oxidizing flame must be avoided to prevent oxidation loss of the silicon, the resultant formation of brittle white iron (iron carbide), and porosity in the weld metal.

(3) After preheating, flux is sprinkled on the groove faces, and the flame directed to the bottom of the groove to begin welding. The cone of the flame should be kept approximately 1/8 to 1/4 in. (3.2 to 6.4 mm) from the base metal surface. Contact of the cone with the surface may cause oxidation of silicon and carbon and formation of hard spots.

(4) The weld pool is formed in the same manner as for steel welding. When the bottom of the groove has melted, the torch flame is moved from side to side to melt down both groove faces and the welding rod added, gradually forming the weld pool. The fluxed welding rod should be placed into the pool for melting. Melting the rod over the pool drop by drop by direct contact of the flame should be avoided.

(5) Flux is added at intervals during welding by heating the tip of the welding rod in the outer portion of the flame and dipping the heated tip into the flux. The appearance of white spots or gas bubbles in the weld pool is a sign that impurities are present and additional flux is required.

(6) A “puddling” or stirring action with the welding rod is used to help oxide and slag impurities float to the surface of the weld pool, and to obtain good fusion with the groove faces. Excessive stirring must be avoided, however, to minimize oxidation. Impurities on the top of the weld pool can be skimmed from the weld with the welding rod, and removed from the rod by lightly tapping it against the work table.

(7) The filler metal can be deposited using a block sequence (see Figure 23), where separate sections, each about 1 in. (25 mm) long, are welded before intervening lengths are welded. Care must be taken to obtain complete fusion between block sections, as well as to the groove faces. Excess molten metal that runs ahead of the block being welded must be remelted before welding over it. Some welders prefer a cascade sequence where the weld is made in successive thin layers as in arc welding (see Figure 23).

4.1.3.4 Postweld Heat Treatment. The completed weld must be cooled carefully. Sudden chilling of the casting must be avoided as the fast cooling rate may produce hard brittle phases in the weld repair area. As a minimum requirement, the casting should be insulated from the surrounding air or drafts and cooled slowly. As an additional precaution, the entire completed repair can be heated to above 1000°F (540°C) followed by slow cooling.

It is recommended that large castings with complex shapes, or those requiring stability during machining, be given a postweld stress-relief heat treatment immediately after welding without allowing the casting to cool. Stress relief treatment consists of holding the casting at 1000–1200°F (540–650°C) for one hour per inch of thickness, followed by slow cooling. The stress relief will relieve residual stresses imposed by welding and stabilize dimensions for machining.

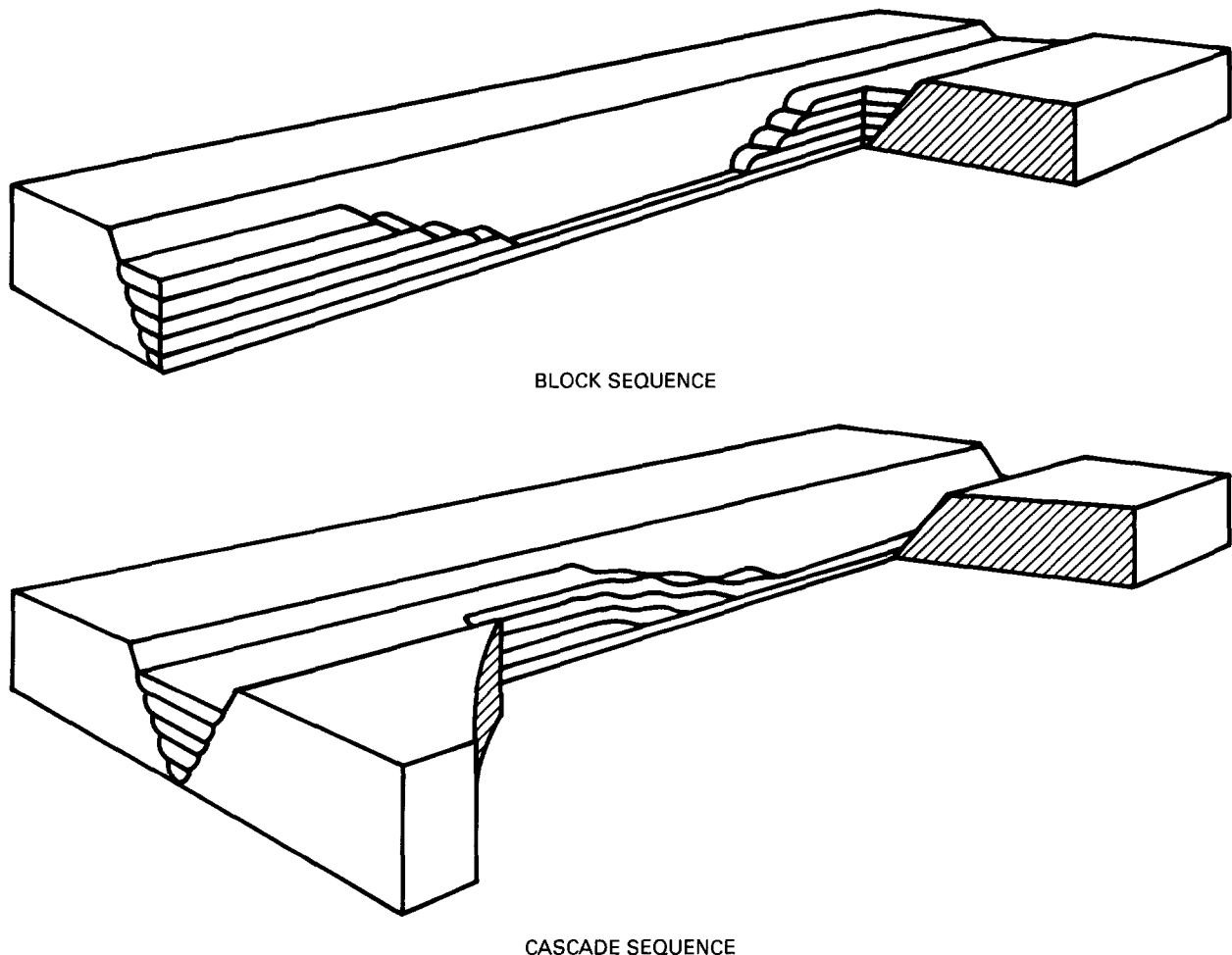


Figure 23 — Block and Cascade Welding Sequences

4.2 Flame Spraying (FLSP) of Gray Iron. The use of flame spraying for the repair of minor defects in gray iron castings originated in the glass industry, specifically for the repair of worn areas, defects, and broken corners on gray iron glass molds. Over the last 25 years, it has proven to be the most successful process available for glass mold repair for the following reasons:

(1) The precision control of the deposited powder surfacing metal requires a minimum of finishing time. Spray deposits as thin as .004–.005 in. (.1016–.1270 mm) can be applied uniformly to a complex contour.

(2) High strength bonds are obtained with varying hardness values.

(3) The deposits are easily hand-filed or machined back to the original finished contours of the casting.

As a result of the many years of proven success on gray iron glass molds, it has now become an accepted practice for the repair of minor defects uncovered in gray iron castings during finish machining operations.

4.2.1 The Process. The flame spraying process employs a special oxyacetylene torch designed to store and inject powder particles into the gas stream ahead of the flame. The powder particles then pass through the flame and become semimolten before striking the workpiece.

4.2.2 Surfacing Metals (Powder Alloys)

4.2.2.1 Atomization. The powder alloys used for cast iron repairs are manufactured by an atomization process. This process incorporates a special nozzle located at the top of a tank into which the molten alloy is poured. As the molten metal is released from the nozzle, high pressure jets of inert gas or water cause the molten metal to explode into fine particles and settle at the bottom of the tank.

4.2.2.3 Blending. After the atomization process, the finished powder then is blended to become an aggregate of various sized particles. Following is a typical distribution of particle size.

Mesh Size	Percentage
+100	0
–100 +140	5–15
–140 +325	Balance
–325	35–50

The importance of maintaining the correct mesh size distribution relates to both efficient flow of the powder through the torch and thermal spraying deposition efficiency. The balance of mesh sizes greater than 325 promotes uniform flow of powder through the torch. The smaller mesh sizes melt quickly and enhance bonding to the base metal. An improper blend of powder mesh sizes will cause torch clogging, poor bonds, and decrease deposition efficiency.

4.2.2.4 Grades. A family of powder alloys providing machineable spray deposits for gray iron repairs has been developed around the standard AMS 4779 nickel-base brazing alloy with the following chemical composition:

Aerospace Materials Specification 4779*

C	B	Si	Fe	Ni
0.6 max	1.0–2.2	4.0–5.0	1.5 max	Remainder

Variations in performance and hardness are produced by selectively altering the percentage of each element, by the addition of chromium, or both. Hardness values range from 85 HRB through 40 HRC. Performance can vary from a very liquid, thin flowing alloy for surfacing to a sluggish alloy for buildup work.

4.2.3 Preparation. The area to be flame sprayed must be completely clean and free of all foreign materials. All oxides on the casting surface must be removed by grinding, machining, or filing. Sandblasting is not recommended. Minute particles of silica can become imbedded in the casting surface and inhibit bonding of the surfacing metal.

4.2.4 Fusing Technique. The area to be flame sprayed is first preheated with the oxyacetylene flame to a temperature of 500–600°F (260–320°C). The preheated area is then sprayed completely with a thin layer 0.004–0.007 in. (0.10–0.18 mm) thick. The powders are self-fluxing and this initial spraying eliminates the formation of oxides during the fusion cycle.

Using the oxyacetylene flame only, starting at one end, edge, or corner of the spray deposit, the deposit and base metal are heated simultaneously to a temperature of 1850–2100°F (1010–1150°C). This procedure is continued until all of the spray deposit has been completely fused to the substrate.

After the original deposit has been applied, additional surfacing metal can be deposited to the desired depth using this spray-and-fuse technique.

4.3 Braze Welding

4.3.1 Process Definition. Braze welding is a welding process variation in which a filler metal having a liquidus above 840°F (450°C) and below the solidus of the base metal is used. Unlike brazing, in braze welding the filler metal is not distributed in the joint by capillary action.

4.3.2 Process Essentials. Braze welding was originally developed for the repair of cracked or broken cast iron parts. Unlike arc welding, braze welding requires heating, but not melting of the base metal. The lower

*Specification may be obtained from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

temperature reduces the tendency to form brittle cementite, and also the tendency to form cracks.

To obtain a strong, metallic bond between the filler metal and the unmelted base metal, the molten filler metal must wet the hot base metal.

The base metal is heated to the required temperature with an oxyfuel gas torch.

With torch braze welding, flux is generally required to clean and protect both the base metal and weld metal. Filler metal is fed to the progressively heated groove faces in one or more passes until the groove is completely filled. Stringent control of joint fit up is not critical because the filler metal is deposited in grooves and spaces. Joint design is similar to that required for oxyfuel gas or arc welding. Typical groove and joint designs are presented in Figures 16 through 21.

4.3.3 Advantages. Braze welding exhibits the following advantages when compared to the fusion welding processes:

- (1) Less heat is required permitting higher travel rates and lower fuel consumption. Distortion and susceptibility to cracking are decreased.
- (2) The weld metal is relatively soft and ductile, providing excellent machinability and low residual stresses.
- (3) Joints can be produced with adequate strength for many applications.
- (4) Equipment is simple and easy to use.
- (5) Cast iron grades which are brittle and sensitive to thermal shock, can be braze welded without extensive preheating.

4.3.4 Disadvantages. Conversely, there are specific disadvantages to be recognized in braze welded joints:

- (1) Joint strength is limited to that of the braze weld metal or the braze weld interface.
- (2) Permissible service performance temperatures are lower than those of fusion welds because of the lower melting temperature of the filler metal. With copper alloy filler metal, the service temperature is limited to 500° F (260° C) or lower.
- (3) Braze welded joints may be susceptible to differential chemical attack caused by galvanic corrosion.
- (4) Braze welding metals will not match the color of the base metal.
- (5) Nonwetted areas are harder to detect than fusion weld defects.

4.3.5 Equipment. Braze welding uses an oxyfuel gas welding torch and associated equipment. In some applications, an oxyfuel gas preheating torch may be required. Clamping and fixturing equipment may also be needed to hold and align the part. The manufacturer and distributor of this equipment should be consulted.

4.3.6 Base Metals. Braze welding can be used to join cast iron to itself or dissimilar metals such as steel and stainless steels, if suitable filler metals are selected.

Retention of ductility in the braze weld joint can be improved, in many cases, by buttering one or both groove faces. The surfacing can be the same as the filler metal, or it can be another surfacing metal chosen to act as a buffer between two incompatible base metals.

4.3.7 Filler Metals. The most commonly used filler metal is a brass containing 60 percent copper and 40 percent zinc. Small additions of tin, iron, manganese, silicon and nickel may be added to improve flow characteristics, lower the melting temperature, decrease volatilization of zinc, scavenge oxygen, and increase strength and hardness. The chemical composition and properties of several filler metal rods are listed in Tables 5A and B. The minimum tensile strengths of these alloys vary between 40 000 and 70 000 psi (276 and 483 MPa). However, the strengths of these alloys will decrease rapidly at service temperatures above 500° F (260° C).

4.3.8 Fluxes for braze welding are proprietary compounds developed for use with specific combinations of base metals and filler metals. These compounds are designed for use at higher temperatures and must remain active for longer periods than fluxes used for brazing. The following types are in general use for braze welding cast iron:

- (1) A basic flux of alkali fluoride and borax mixtures which cleans the base metal and weld metal, assists in wetting of the base metal, and is active over the full melting range of the filler metal used for malleable iron.
- (2) A modified flux which performs the same functions as the basic flux and also suppresses the formation of zinc oxide fumes may be used.
- (3) A flux that is formulated specifically for braze welding of cast iron contains iron oxide or manganese dioxide that combines with the free carbon on the cast iron surface to promote wetting.

Fluxes may be applied by one or a combination of the following four methods:

- (a) The heated filler metal rod may be dipped into the flux and transferred to the joint during braze welding.
- (b) The flux may be brushed into the joint.
- (c) The filler metal rod may be precoated with flux.
- (d) The flux may be introduced through the oxy-fuel gas flame.

4.3.9 Metallurgical Considerations. The metallic bond between the filler metal and the base metal is the same as with brazing. The clean base metal is heated to a temperature that is sufficient to permit the wetting of its surface by the molten filler metal and the development of

Table 5A
Chemical Composition
Rods and Electrodes for Braze Welding Iron Castings

AWS Specifi- cation	AWS Specifi- cation	Cu	Zn	Sn	Fe	Ni	Mn	Al	Si	Pb	P	Total Other
A5.27	RBCuZn-A	57.0 – 61.0	Bal.	0.25 – 1.00	—	—	—	0.01	0.04 – 0.15	0.05	—	0.50
A5.27	RBCuZn-B	56.0 – 60.0	Bal.	0.80 – 1.10	0.25 – 1.2	0.20 – 0.80	0.01 – 0.50	0.01	0.04 – 0.15	0.05	—	0.50
A5.27	RBCuZn-C	56.0 – 60.0	Bal.	0.80 – 1.10	0.25 – 1.2	—	0.01 – 0.50	0.01	0.04 – 0.15	0.05	—	0.50
A5.27	RBCuZn-D	46.0 – 50.0	Bal.	—	—	9.0 – 11.0	—	0.01	0.04 – 0.25	0.05	0.25	0.50

Table 5B
Properties and Applications of Braze Welding Filler Metal

AWS Classification	Room Temperature Tensile Properties Minimum		Liquidus Temperatures		Applications
	Ksi	MPa	°F	°C	
RBCuZn-A	40	275	1650	900	A low fuming bronze used on copper sheet, mild tube steel, deep drawing steel and cast iron (OFW).
RBCuZn-B	50	344	1630	890	Higher strength, used to surface, or braze weld copper, steel, cast iron or wrought iron (OFW).
RBCuZn-C	50	344	1630	890	Better color match with mild steel, cast iron, and wrought iron (OFW).
RBCuZn-D	60	413	1715	935	Nickel silver bronze filler metal providing best strength and color match with cast iron and wrought iron (OFW).

a metallic bond. Since the presence of dirt, oil, grease, oxide film, carbon, and other contaminants will inhibit wetting, cleanliness is important to obtain the wetting necessary for braze welding.

Wetting accomplishes metallic bonding between the braze weld filler metal and the base metal in a narrow zone at the braze weld interface. For some filler metal/base metal combinations, the filler metal may slightly penetrate the grain boundaries of the base metal, affecting strength, corrosion properties, and cracking behavior.

4.3.10 Braze Welding Techniques

4.3.10.1 Fixturing. Fixturing is generally required to hold parts in their proper location and alignment for braze welding. In repairing cracks and other defects in cast iron parts, fixturing may not be necessary, unless the part has separated.

4.3.10.2 Joint Designs and Preparation. Joint designs are similar to those used for fusion welding. Fit is

not as critical as the tolerances required for brazing. The braze welding filler metal is deposited in the grooves where the molten filler metal wets the base metal. For thicknesses over 3/32 in. (2 mm), single- and double-V grooves are prepared with a groove angle between 90 and 120 degrees to provide large weld interface areas between the base metal and the weld metal. Square grooves may be used for a thickness of 3/32 in. (2 mm) or less. In large casting repairs, studs may be inserted into the groove surfaces to increase the groove strength of the repair (Figure 20).

The groove faces and adjacent surfaces of the base metal must be cleaned to remove all oxide, dirt, grease, oil and other foreign material that will inhibit wetting. When braze welding cast iron, the groove faces must also be free of graphite smears caused by prior machining. These graphite smears which have an adverse affect on wetting, can be removed by quickly heating the cast iron to a dull red color with a slightly oxidizing flame and then wire brushing after it cools.

If the casting has been heavily soaked with oil, it must be heated to 700–900°F (370–480°C), to burn off the oil. The surfaces are then wire brushed to remove any residue.

Malleable iron, because of its lower total carbon content and its round graphite nodules, can be readily cleaned by abrasive blasting. Ductile iron, also with round nodules, is more difficult to braze weld because of its higher total carbon content. The graphite flakes in gray cast iron make it the most difficult to braze weld and it requires special surface preparation such as caustic cleaning or decarburization with a slightly oxidizing oxyfuel gas flame.

In production braze welding of cast iron components, the groove faces are usually cleaned by immersion in an electrolytic molten salt bath. This is the most effective method for removing the free graphite present on machined or broken surfaces.

4.3.10.3 Preheating. Preheating depends on the type of cast iron and the size of the part. It may be required to prevent cracking by reducing thermal gradients in large cast iron parts.

Preheating may be local or general, depending upon the size of the part and its thermal conductivity. Preheat temperatures range from 800–900°F (425–480°C) for cast iron. After braze welding is completed, cast iron parts should be covered with heat resistant blankets or vermiculite for slow cooling to room temperature. This will minimize the development of thermally induced stresses in the casting.

4.3.10.4 Flame Adjustment. Braze welding is generally performed with an oxyfuel gas torch. For braze welding of cast irons, a slightly oxidizing flame is required. This is attained by increasing the oxygen/fuel gas ratio until the feather disappears and the cone becomes slightly necked. This type of flame removes the smeared graphite from the cast iron surface, but then is not needed once the surface has been cleaned and wetted.

4.3.10.5 Braze Welding Technique. The joint to be braze welded must be properly aligned and fixtured. Braze welding flux is applied to the preheated filler metal rod (unless flux coated) and also is spread on groove faces of thick joints. Next, the base metal is heated with the flame until the filler metal melts, wets the base metal, and flows onto the groove faces. The groove is filled with one or more passes using techniques similar to oxyfuel gas welding. Note that the cone of an oxyfuel gas flame should not be directed on copper-zinc alloy filler metals nor on iron base metal. Braze welding requires a more diffused heat pattern than welding. The techniques used with arc torches are similar to those described for oxyfuel gas braze welding, except that flux is not generally used.

4.3.10.6 Scope of Process. A wide variety of workpieces can be braze welded with the use of typical weld joint designs. Groove, fillet, and edge welds can be used to join simple and complex assemblies. An effort should be made to avoid sharp corners that are easily overheated and may become points of stress concentrations. Edges should be rounded as shown in Figure 18. To obtain good joint strength, the weld groove should provide adequate groove face area so that the joint will not fail along the weld interfaces.

4.3.10.7 Quality. Braze weld quality will depend on operator skill and technique, and on the care and control exercised during the preparation of the base metal. The strength and soundness of the joint will depend on the filler metal used, cleanliness of the base metal, proper flame adjustment, proper heat input control, and the adequacy of fluxing during braze welding to ensure complete wetting of the base metal. With correct procedures, braze welded joints frequently will be produced that are as strong as the adjacent base metal.

5. Arc Welding Processes

5.1 General. Arc welding may be manual, semi-automatic, or fully automatic. The most widely used processes are shielded metal arc (SMAW), gas metal arc (GMAW), flux cored arc (FCAW), gas tungsten arc (GTAW), and submerged arc (SAW). These processes are described in detail in Volume 2, Seventh Edition, of the *AWS Welding Handbook*.

No single process is the most efficient and economical for every application. Consideration must be given to the specific requirements of the application, the equipment, and personnel available, when choosing a welding process.

5.2 Shielded Metal Arc Welding (SMAW)

5.2.1 Definitions and General Description. Shielded Metal Arc Welding (SMAW) is an arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the workpiece. Shielding is obtained from decomposition of the electrode covering. Pressure is not used, and filler metal is supplied by melting the electrode.

5.2.2 Principles of Operation. Shielded metal arc welding is the most widely used of the various arc welding processes. It employs the heat of the arc to melt the base metal and the tip of a consumable covered electrode. The electrode and the workpiece are part of an electrical circuit known as the welding circuit, as shown in Figure 24. This circuit begins with the electric power source and includes the welding leads, an electrode

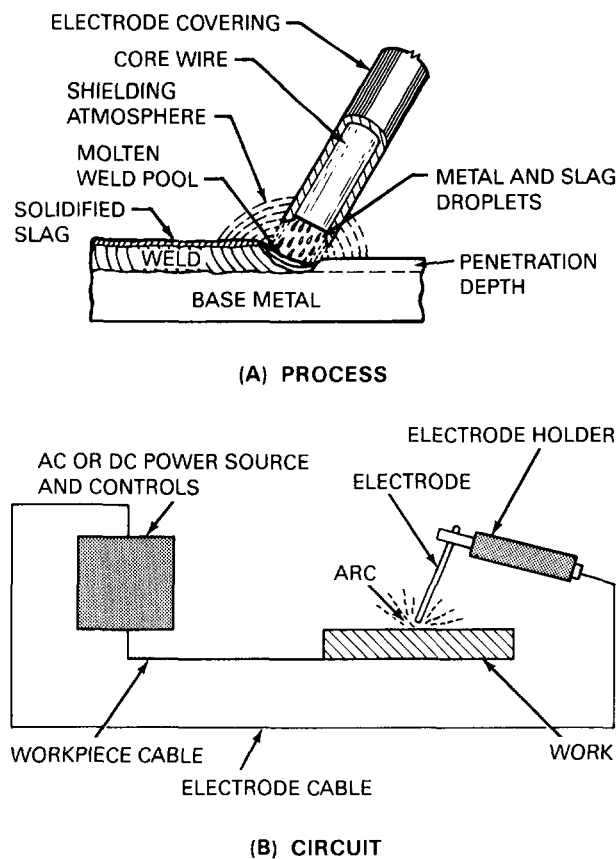


Figure 24—Elements of a Typical Welding Circuit for Shielded Metal Arc Welding

holder, the workpiece, and an arc welding electrode. One of the two leads from the power source is attached to the workpiece. The other is attached to the electrode holder.

Welding commences when an electric arc is struck between the tip of the electrode and the workpiece. The intense heat of the arc melts the tip of the electrode and the surface of the workpiece beneath the arc. Globules of molten metal rapidly form on the tip of the electrode, then transfer through the arc stream into the weld pool.¹ In this manner, filler metal is deposited as the electrode is progressively consumed. The arc is moved over the work holding an appropriate arc length and travel speed, melting a portion of the base metal and adding filler metal as the arc progresses.

Since the arc is one of the hottest of the commercial sources of heat [temperatures above 9000°F (5000°C) have been measured at its center], melting takes place almost instantaneously, as the arc contacts the metal. If welds are made in either the flat or the horizontal posi-

tion, metal transfer is induced by the force of gravity, gas expansion, electric and electromagnetic forces, and surface tension. For welds in other positions, gravity works against the other forces.

The process requires sufficient heat input to melt both the electrode and a proper amount of base metal. It also requires an appropriate arc length between the tip of the electrode and the base metal or the weld pool.

5.2.3 Welding Equipment. The size and types of electrodes for shielded metal arc welding define the equipment. Any power source capable of supplying the necessary range, type, and polarity of current, and having a suitable open circuit voltage, may be used. The current may be either alternating or direct, but the power source must be able to control the level of current within a reasonable range in order to respond to the requirements of the welding process itself. The user should follow the electrode manufacturer's recommendations for type of current and polarity.

5.2.4 Filler Metals for Shielded Metal Arc Welding. The versatility and ease of operation make SMAW an excellent choice for most cast iron welding. Economic

1. Metal transfer across the welding arc is described in AWS *Welding Handbook*, Chapter 2, Physics of Welding, Vol. 1, 8th Ed., pp. 50–54.

considerations and weld requirements will determine the appropriate electrode for each application.

5.2.4.1 Cast Iron Electrodes. Cast iron rods are covered with fluxes to improve arc stability, reduce porosity, and add alloying elements. The covering normally is applied by dipping rather than extrusion, due to the irregular surface of the cast iron rods. Such electrodes are classified in ANSI/AWS A5.15-82 as ECI (see Table 6). They are of low comparative cost and produce a weld of similar chemical composition, mechanical properties, microstructure and matching color. As with the bare cast iron rods, appropriate procedures must be closely followed to assure weld quality.

5.2.4.2 Steel Electrodes. ESt (Steel) Classification (see Table 6). This covered all-position electrode with carbon steel core wire is designed specifically for the welding of cast iron. It has a low melting-point covering and differs from the ordinary mild steel electrodes included in ANSI/AWS A5.1-81, *Specification for Covered Carbon Steel Arc Welding Electrodes*. Welds made with this electrode are not readily machineable.

Since it is virtually impossible to prevent the formation of a hard weld metal with low ductility using this type of electrode, its use is largely confined to the repair

of small pits and cracks, with some application in the repair of castings that require no machining. Since the shrinkage of steel is greater than that of cast iron, high tensile stresses develop as the weld metal cools. Stress may be severe enough to cause cracking.

For most repair jobs, the groove preparation is the same as described previously. However, the formation of a hard weld metal of low ductility and the possibility of cracking make it generally advisable in welding any sizable casting to employ studs which key the weld to the unaffected base metal below the weld interface, as shown in Figure 20.

Preheating is employed only when necessary to prevent excessive stresses in other parts of the casting. ESt electrodes generally are used at low current to minimize dilution and consequent weld metal and base metal cracking. Recommended welding currents are 60 to 95 A for 3/32 in. (2.4 mm), 80 to 110 A for 1/8 in. (3.2 mm), and 110 to 150 A for 5/32 in. (4.0 mm) diameter electrodes using DCEP (electrode positive) or AC. The beads should be short and widely separated, to distribute the heat, and each bead should be peened lightly.

The slag volume is low but very alkaline; therefore, slag should be removed completely if the weld area is to be painted.

Table 6
Chemical Composition of Filler Metals, Percent^{2,3c}

AWS Classification	C	Mn	Si	P	S	Fe	Ni ^{3a}	Cu ^{3b}	Al	Total Other Elements
Nickel Base Electrodes										
ENi-CI	2.0	1.0	4.0	—	0.03	8.0	85 min	2.5	1.0	1.0
ENi-CI-A	2.0	1.0	4.0	—	0.03	8.0	85 min	2.5	1.0–3.0	1.0
ENi-Fe-CI	2.0	1.0	4.0	—	0.03	remainder	45–60	2.5	1.0	1.0
ENiFe-CI-A	2.0	1.0	4.0	—	0.03	remainder	45–60	2.5	1.0–3.0	1.0
ENiCu-A	0.35–0.55	2.3	0.75	—	0.025	3.0–6.0	50–60	35–45	—	1.0
ENiCu-B	0.35–0.55	2.3	0.75	—	0.025	3.0–6.0	60–70	25–35	—	1.0
Mild Steel Electrodes										
ESt	0.15	0.30–0.60	0.03	0.04	0.04	remainder	—	—	—	—

Notes:

1. Analysis shall be made for the elements for which specific values are shown in this Table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for "Total Other Elements" in the last column of this Table.

2. Single values shown are maximum percentages except where otherwise specified.

3. Excerpted from A5.15-82.

a. Nickel plus incidental cobalt.

b. Copper plus incidental silver.

c. Chemical composition requirements for the Electrodes are based on weld metal analysis.



Documents

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The hardness of the ESt weld metal depends to a great extent upon the amount of dilution, which can be controlled within reasonable limits during welding. Small single beads have high dilution and may have a hardness as high as 500 BHN. Moderately heavy beads, when the dilution is reduced by directing the arc on the weld pool, and later beads of multiple-pass welds, have lower hardness.

Low Hydrogen Electrodes. The low-hydrogen electrodes classified in ANSI/AWS A5.1-87 as E7015, E7016, E7018, E7028, and E7048 are sometimes used for welding cast iron. These electrodes are low in cost, readily available, and offer excellent operability. Color match of the weld metal and base metal is good. When these welding electrodes are used on cast iron, the resulting weld metal will contain 0.8 to 1.5 percent carbon. The weld metal, therefore, will be high carbon steel exhibiting high hardenability. Rapid cooling rate of a weld frequently produces weld metal with a hard, crack sensitive, martensitic microstructure. This condition may be minimized by preheat and slow cooling, or postweld annealing. These electrodes are used most often for cosmetic repair in nonstructural areas and where machining is not necessary and cracking is not a major concern.

5.2.4.3 Stainless Steel Electrodes. Stainless steel electrodes are not recommended for welding cast iron because: (1) precipitation of chromium carbides in grain boundaries results in a crack-prone, brittle microstructure, (2) heat affected zone cracking due to differences in tensile strength between the weld and base metal, and (3) the difference in coefficient of expansion of the dissimilar metals can result in tensile stresses of such magnitude that welds may crack.

5.2.4.4 Nickel Base Electrodes. Electrodes which contain substantial amounts of nickel are used successfully to weld iron castings. Unlike iron, nickel does not form stable carbides and, in the solid state, has a low solubility for carbon. As the weld metal solidifies and cools, carbon is rejected from solution as graphite. This reaction increases the volume of the weld metal, thus reducing shrinkage stresses and lessening the likelihood of weld metal and heat affected zone cracking. Compositions of nickel-base electrodes commonly used to weld iron castings are shown in Table 6.

ENi-CI Electrodes. Electrodes classified by ANSI/AWS A5.15-82 as ENi-CI produce a high nickel weld metal. Thus, even when highly diluted by the cast iron base metal, the weld remains soft and machineable. For this reason, the ENi-CI electrodes are used for surfacing or highly diluted welds which must be machined. Electrodes depositing filler metal that contains more than one percent of aluminum are classified as ENiCI-A.

ENiFe-CI Electrodes. ANSI/AWS A5.15 ENiFe-CI and ENiFe-CI-A electrodes deposit filler metal of approximately equal amounts of nickel and iron. This composition differs from that of the ENi-CI and ENiCI-A electrodes in three important ways.

Welds made with nickel-iron alloy are stronger and more ductile than welds made with essentially pure nickel. Typical mechanical properties are presented in Table 7. The strength of the nickel-iron electrode makes it suitable for welding ductile irons and the high-strength gray irons. The electrode is also used for dissimilar joints such as cast iron containing chromium to carbon steel, stainless steel, and nickel-base alloys. Some chromium containing alloys may require buttering with ANSI/AWS A5.11-83, *Specification for Nickel and Nickel Alloy Covered Welding Electrodes*, ENi-1 electrodes before making the weld. This is to avoid chromium-carbide formation.

Phosphorous is known to cause cracking in high nickel weld metal. The presence of iron in the weld metal increases the tolerance to phosphorous. Thus, these electrodes have been used with some success for welding the higher phosphorous gray cast irons.

The coefficient of expansion of nickel-iron alloys is minimum at a chemical composition of about 30 percent nickel and 70 percent iron. When the ENiFe-CI or ENiFe-CI-A electrodes are deposited on cast iron, composition of the resulting weld metal approximates this 30-70 iron-nickel composition. This low expansion allows these electrodes to be used for welding thicker base metal than is possible with ENi-CI or ENiCI-A electrodes.

When highly diluted, as in a single pass weld, hardness of the nickel-iron weld metal is considerably higher than that of ENi-CI or ENiCI-A electrodes. Thus, if weld machineability is a critical factor, ENi-CI or ENiCI-A electrodes are preferred. In multipass welds, each bead is tempered by the heat of subsequent passes, thus improving machinability. Typical values of weld metal hardness are presented in Table 8.

Nickel-Iron-Manganese Electrodes. The addition of manganese to the nickel-iron alloy commonly used to weld iron castings improves fusion with the base metal, strength, ductility and resistance to cracking. An electrode depositing about 12 percent manganese, 44 percent nickel, and the balance iron is commercially available. The strength of the weld metal is sufficient for joining nodular irons up to the 80-55-06 grades. It is also applicable to surfacing or buildup when improved wear resistance is required.

Since the electrode is patented and proprietary, it is not included in an AWS specification. The supplier should be directly consulted for usage information and welding parameters.