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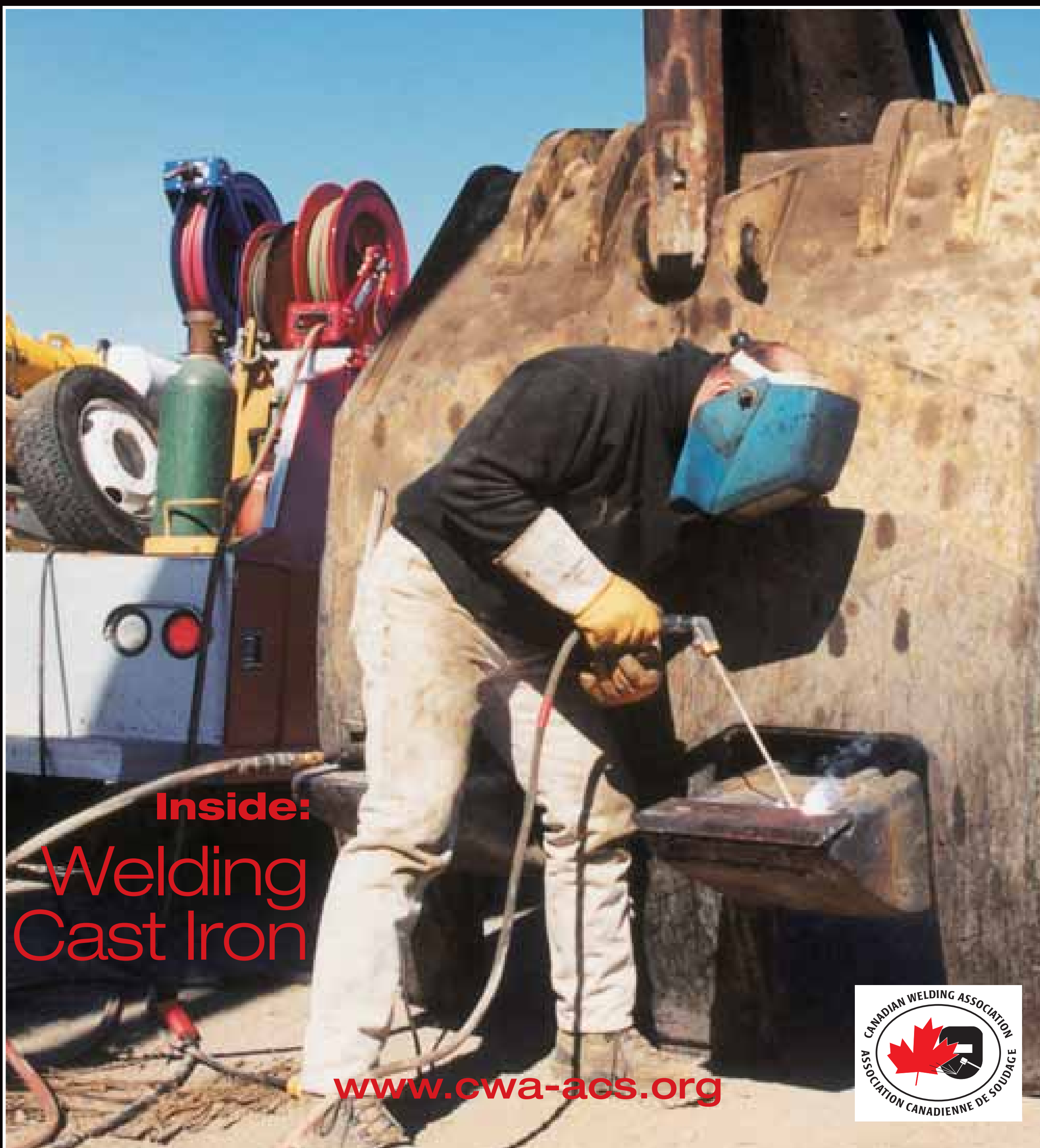

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# Welding Cast Iron: Straightforward (if the iron is known and understood)

**By Samuel D. Kiser, P.E., FAWS, and Michael Northey**

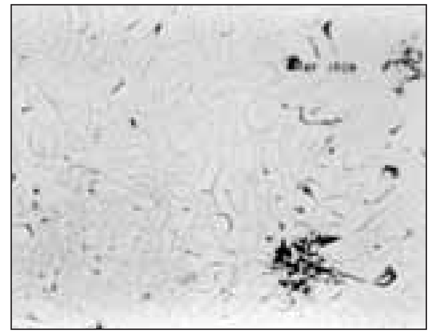

**Figure 1.** Microstructure of typical gray iron casting — note the flakes of graphite in edge-view

**Figure 2.** Repair welding of a 15,000# gray iron ingot mould with semi-automatic FCAW at 12#/hour

## Introduction

Cast iron is the name for a family of iron-based alloys that generally contains between two per cent and four per cent carbon, which is considerably above the solubility limit for steel alloys. As a result, cast iron contains either inclusions of pure carbon known as graphite, or hard phases that contain high levels of combined carbon. Cast iron is usually classified into families according to their graphite morphologies (or shapes of the graphite inclusions). Gray iron, for instance, is gray if it contains flakes of graphite that cause its fracture surface, when broken, to appear to be gray in colour. (Figure 1 is a typical microstructure of gray iron.) Ductile iron, or nodular iron, contains spheroids of graphite that are nodular-shaped and cause this iron to have better ductility than others due to the lack of internal notches that would be caused if the graphite were angular. (Figure 3 shows the microstructure of ferritic ductile iron.) Because ductile iron is treated during melting to cause the graphite to form as nodules in the molten state, these nodules are called "primary" graphite nodules. If a low-carbon, low-silicon cast iron is poured as carbidic, or "white iron," and then heat treated to precipitate and agglomerate carbon, the graphite is often referred to as "temper" carbon or graphite "rosettes," and the iron is called malleable iron. (See Figure 4 for microstructural details of malleable iron.) These three families are the major groups of cast iron.

## Alloying Elements

Cast irons usually contain silicon, in addition to iron and carbon, and often other intentional additions that impart various characteristics to the particular type of iron. Some elements added in very small amounts tend to stabilize various phases within the matrix or microstructure. Other elemental additions may impart performance characteristics, such as oxidation resistance or strength at elevated temperature. Unfortunately, cast irons also contain undesirable elements, such as phosphorus and sulfur. Each of these elements may have various effects on the microstructure and weldability of the cast iron.

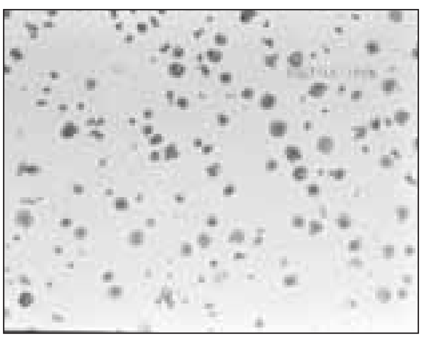

**Figure 3.** Microstructure of ferritic ductile iron — note the spheroids, or nodules, of graphite

## Matrix or Microstructure

The matrix, or general structure, of each iron is influenced by both the composition and the cooling rate from casting, heat-treating or welding. Under conditions of very slow cooling, equilibrium conditions favour the formation of graphite plus ferrite. At fast cooling rates, quench conditions are said to prevail, which result in hard phases composed of combined carbon, such as iron/carbide, and martensite.

## Grades Within Families

The classification of cast iron is often done by strength and ductility identification. Within the gray irons, grade 20 or 30 simply means the typical strength is 20,000 or 30,000 psi tensile strength. Because gray iron has little to no plastic ductility, one number is sufficient to define the gray-iron products. In the case of malleable irons, yield strength and percentage elongation are often used to define the class. For example, 35018 refers to 35,000 psi yield strength and 18 per cent elongation, and 45006 calls out a malleable iron with 45,000 psi yield strength with 6 per cent elongation. Ductile irons are defined by tensile and yield strengths, and elongation. For example, ferritize-annealed ductile iron is referred to as 60-40-18, and as-cast ductile is called 65-45-12, with the numbers defining minimum tensile and yield strengths and elongation, in that order.

## Weldability

The most weldable grades of cast iron are those that have a minimum of combined carbon and contain symmetrical inclusions of graphite. Ferritic ductile, or nodular iron, is produced by exposing as-cast ductile iron to a ferritize-anneal treatment or by casting a very-high-purity ductile iron. The ferritize anneal allows equilibrium cooling to take place and dissolves any carbides, martensite and pearlite. The use of high-purity ingredients can produce a largely ferritic matrix without further heat treatment. The result of both methods is a ferritic matrix much like that of AISI 1002 steel, but with spheroids of graphite scattered throughout the matrix. Also, the ferritize anneal provides very low residual stress levels in the casting. Both conditions are favourable for making successful welds. As the matrix of each cast iron contains more combined carbon in the forms of pearlite,

**Figure 4.** Microstructure of malleable iron — note the clusters, or rosettes, of graphite or “temper carbon”

**Figure 5.** GMAW-welded assembly of SIMO DI exhaust manifold in 409ss catalyst can that used NI-ROD Filler Metal 44HT (as used in the 2004 Cadillac XLR)

iron carbide and martensite, the ability to be welded without cracking decreases. As these phases make up increasing percentages of the matrix of each casting, higher preheats are often required, along with other crack-discouraging methods, such as peening.

## Welding Processes

A number of welding processes, including oxy-fuel welding (OFW), shielded metal-arc welding (SMAW), gas metal-arc welding (GMAW) and flux cored arc-welding (FCAW), have been used to successfully weld cast irons. The latter three types of welding typically use nickel, nickel/iron, or nickel/iron/manganese types of welding products. Usually, the higher-deposition-rate welding processes are the most appealing for higher productivity. Because these processes also have the most severe heating and cooling rates, they present the most challenging welding conditions. NI-ROD Flux Cored 55 at .093” diameter is often used at 350 amps and 29 volts, while NI-ROD Filler Metal 44HT is one of the newer types of solid wires used with the GMAW process at 300 amps and 28-30 volts and up to 40 in/min. travel speeds. Figure 2 shows a massive gray-iron ingot mould being repair welded with NI-ROD FC 55, while Figure 5 shows a modern silicon/molybdenum-containing ductile iron automotive exhaust manifold that has been automatically welded to a stainless steel catalyst can using NI-ROD Filler Metal 44HT. In Figures 2 and 5, products are welded successfully at very high heat inputs and at high deposition rates because high-quality welding products are used and because both parts being welded have predominantly ferritic matrices. The ingot mould has received numerous melts of alloys teemed at 2700°F to 2800°F and allowed to solidify and cool slowly over a period of days. While this service by the ingot mould is designed to produce alloy ingots, as a by-product, it also produces a totally ferritic matrix within the mould itself. Thus, when repair welding is required, the matrix is in the most weldable condition and is capable of having 20 to 30 pounds of weld metal deposited into it without cracking the base metal and without needing preheat or peening.

Silicon/molybdenum ductile iron is used for automotive exhaust manifolds for several reasons. It is very cost-effective, easily cast into the intricate shapes needed for runners, and is capable of maintaining usable strength to about 800°C. The silicon addition helps to stabilize the ferrite matrix at high temperatures and impart oxidation resistance and, together with molybdenum, provides stiffness and strength at the operating temperature. Also, the ferritic silicon/molybdenum ductile iron is usually produced with a minimum of 90 per cent ferrite, which provides excellent weldability, and NI-ROD Filler Metal 44HT provides overmatching strength and oxidation resistance, as well as the dissimilar capability of welding the simo-ductile iron to the 400 series stainless catalyst can.

**Chemical Composition (%) Table**

| | C | Mn | P | S | Si | Ni | Cr | Mo | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| **Base Materials** | | | | | | | | | | |
| **Gray Iron** | 3.25 | 0.58 | 0.017 | 0.062 | 1.75 | 0.22 | 0.08 | 0.34 | | Bal. |
| **Ductile Iron** | 3.63 | 0.28 | 0.027 | 0.005 | 2.23 | 0.05 | 0.04 | 0.01 | | Bal. |
| **Malleable Iron** | 2.38 | 0.59 | 0.031 | 0.031 | 1.54 | 0.04 | 0.05 | 0.01 | | Bal. |
| | | | | | | | | | | |
| **Weld Consumables** | | | | | | | | | | |
| **Nirod FC 55** | 1.0 | 4.2 | | | 0.6 | 50 | | | | Bal. |
| **Nirod 44 HT** | 0.3 | 11.0 | | | | 44 | 8.0 | | **Nb = 1.0 | Bal. |
| **Nirod** | 1.0 | 0.2 | 0.005 | 0.005 | 0.7 | 95 | - | - | 0.02 | 3.0 |
| **Nirod 55** | 1.2 | 0.3 | 0.005 | 0.005 | 0.7 | 53 | - | - | 0.1 | Bal. |
| **Nirod 44** | 1.5 | 11.0 | | | | 44 | | | | Bal. |

### Weld Metal and Heat-affected Zones

Because the cast irons have so much carbon, they are extremely hardenable. When welded using nickel-containing products, the weld metal typically remains austenitic at any cooling rate and, in spite of high carbon dilution into the weld, most of the NI-ROD weld deposits contain only austenite and graphite. However, the heat-affected zones (HAZ) present a different situation. We have discussed the benefits of welding on cast irons that have ferritic matrices; they typically do not form an abundance of hard phases in the HAZ when welded with a relatively fast travel speed. Time at temperature is minimized by the relatively fast travel speed, which doesn't allow enough time for carbon diffusion to take place from the graphite inclusions. Thus, continuous bands of martensite and iron carbides are avoided in these HAZs. On the other hand, those cast irons that contain pearlite in their matrices are much more susceptible to forming carbides and untempered martensite in their HAZs, unless preheat is used. For example, as-cast ductile iron is 65-45-12 and usually has acceptable welding characteristics without preheat. 65-45-12 usually has less than 50 per cent pearlite. However, 80-55-06 ductile iron has an increased amount of pearlite, which acts as a ready source of available carbon for the HAZ to draw from during cool down from welding. When welding 80-55-06 without preheat, a continuous layer of high-carbon untempered martensite with iron carbides is formed. This condition usually results in gross cracking in the HAZ and at the fusion line. Through the introduction of a minimum of 450°F (preferably 600°F) preheat, before welding, followed by slow cooling, the continuous layer of martensite can be avoided and crack-free welds can be produced when welding with the nickel-containing NI-ROD products. Steel products should never be used to weld cast irons, unless gross cracking of the welds can be tolerated. If steel products are used, the high carbon dilution into the steel weld metal produces a quenched high-carbon steel that is martensitic, very hard and very crack-sensitive.

### Summary

While many in the welding community consider cast-iron welding to be difficult, if the type of cast iron is known and understood, it can usually be welded efficiently and without cracking. The matrix must be identified with an accurate estimate of combined carbon, and the graphite-inclusion morphology must be known. Cast irons with totally ferritic matrices exhibit best weldability, and the ductile irons with spheroidal graphite inclusions enjoy best weldability. Ferritic Si/-Mo ductile iron is one of the newer grades of cast iron that provide excellent automatic weldability while requiring no preheat. Si/Mo ductile iron typifies recent accomplishments in cast-iron development that provide efficient, economical solutions to today's engineering challenges.

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