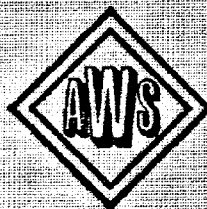


Welding of Cast Iron

A Selection of Papers



AMERICAN WELDING SOCIETY

Welding of Cast Iron

A Selection of Papers

Welding of Cast Iron

**A collection of outstanding
articles from periodicals
and reference literature**

**Prepared by the AWS Committee on
Welding of Iron Castings**

AMERICAN WELDING SOCIETY
550 N.W. LeJeune Road, P.O. Box 351040
Miami, Florida 33135

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Preface

The welding of cast iron is a subject of concern to many people both in and out of the welding community. The level of confidence in obtaining dependable welds is low, particularly among those who do not have ready access to reliable information on this subject. In reality, the picture is not as dark as it may seem.

In 1965, the American Welding Society, through its D11 Committee on Welding Iron Castings, published a comprehensive study entitled "A Test Program on Welding Iron Castings". Additionally, hundreds of articles and reports have appeared in technical publications in most of the industrialized nations of the world. To this body of knowledge must be added the data contributed by many foundries and filler metal manufacturers whose research programs have developed many new applications and materials.

The AWS D11 Committee, which includes members from AWS, ASM, ASME, the Ductile Iron Society, the Iron Casting Society, and the Centre Technique des Industries de la Fonderie (France), addressed the task of reviewing nearly four hundred articles from all sources. Forty-three articles were chosen for reproduction in this reference book. The aim was to cover all types of iron castings and all commonly used welding processes. The criteria for selection were (1) completeness of information, (2) accuracy and agreement with currently accepted practice, and (3) sound background of historical fact.

The book includes a Subject Index which is cross-referenced so that pertinent information may be found under several headings.

Additional articles and reports have been listed in a Bibliography to assist the reader who wishes to delve further into a subject.

Because cast iron is nonhomogeneous and has high carbon content, welds on iron castings will not yield good results ~~as~~ consistently as welds on mild steel. A shop may occasionally encounter an unweldable casting. Also, a weld in an iron casting will seldom, if ever, have properties equal to those of the base metal. Nevertheless, there are many applications where useful welds can be made in iron casting when information presented here is used in conjunction with sound engineering judgement.

The Committee welcomes suggestions, comments, and constructive criticism pertaining to this publication. Please address correspondence to Secretary, D11 Committee on Welding Iron Castings, American Welding Society, P.O. Box 351040, Miami, FL 33135.

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WELDING GRAY IRON WITH MILD STEEL ELECTRODES

By R. L. KUMAR
Indian Institute of Technology
Kharagpur, India



Microstructure at the weld area shows that fusion is complete at the junction of steel (top) and gray iron.

For a listing of available free literature on welding, turn to page 133.

not in this book

IN BRIEF: Gray iron can be welded most economically by arc welding with mild steel electrodes so long as certain precautions are taken before, during, and after welding. Some key precautions are proper joint preparation, choice of electrode, preheating, and post heating. The author explains what to do and why.

■ **WELDING** can be a valuable tool for the gray iron foundry, not only for repairing surface defects on castings, but also for welding together two or more castings. And with welding, castings can be incorporated in assemblies including rolled, forged, or other cold-worked materials.

Under these conditions, the metallic arc welding process is the most satisfactory and economical, particularly when mild steel electrodes are used. For one thing, they are the least expensive of the available electrodes for welding gray iron. For another, the mild steel weld metal has a high solidification rate. This fact makes possible arc welding in any position, which is not possible with other welding methods because of the high fluidity of gray iron.

Success in welding gray iron with mild steel electrodes, however, requires an understanding of the process.

Metallurgical Aspects—Properties of the final component depend to a large extent on the composi-

tion and structure of the metal at the interface between the different work pieces joined together; so metallographic techniques are important in studying the structures of the gray iron, the weld metal deposited from the electrode, and the heat-affected zone at the interface. Proper understanding of the changes in volume that take place near the interface during welding also are essential.

During welding, the highly localized heat input results in steep temperature gradients between the weld metal and the cold gray iron. They produce high expansion and contraction stresses in the restricted space. Because steel shrinks more than gray iron, precautions must be taken to prevent formation of shrinkage cracks, and lack of pressure tightness can result.

Both the graphitic or free carbon and the combined carbon in gray iron go into solution in the molten metal. Simultaneously, the mild steel weld metal absorbs carbon from the molten iron, and some of the remaining carbon and silicon is burned out by the high heat at the weld zone.

Then the molten metal is cooled rapidly by the surrounding mass of cold gray iron. The rapidly cooled gray iron first solidifies as a mixture of austenite and cementite. When it cools below 750 C (about 1,380 F) the austenite changes to pearlite. At room temperature, the alloy consists of a mixture of pearlite and cementite because most of

Source: Foundry, January 1968

the free carbon is retained in combined form. This metal, which is brittle, unmachinable white iron, is formed in the parent metal next to the interface.

On the other side of the interface, the mild steel changes to martensite under similar heating and cooling conditions. Away from the interface, the weld metal is high carbon steel. Both of those constituents impair the machinability of the weld joint.

Thus the interface area is a complex structure that includes free graphite, martensite, pearlite, and some ferrite. It presents problems if machining is needed, and it can be the source of poor strength.

The hard white iron in the weld zone is weaker than the gray iron behind it on one side of the interface, as well as the high carbon steel on the other side, and the steel weld metal behind that. When a welded joint fails in tension, it fails in the white iron area.

Usually, on gray iron castings, the welds are not required to be machined. Then, welding with the mild steel electrodes without further treatment is quite satisfactory, particularly if the strength requirements are not high and the structure of the weld metal is not important.

Recommendations — As we've mentioned, definite precautions must be taken when the common coated mild steel electrodes are used because they otherwise tend

to produce cracks in the weld or at the interface.

To minimize the development of stresses, the gray iron should be heated to the bare minimum. Also, because mild steel gives easy fusion with minimum penetration, a small-gage electrode with the lowest current setting that gives sufficient penetration should be used. Although steel rods less than $\frac{1}{8}$ in. in diam can be used, a $\frac{1}{8}$ -in. rod usually is employed with a setting of 70 to 90 amp.

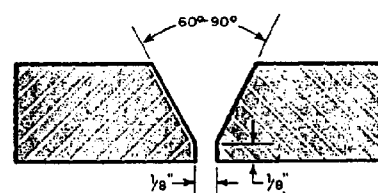
Suitable fluxes are provided as coatings on the electrodes. A typical coating contains 40 to 60% graphite, 1% barium chloride, and remainder silicon carbide.

For welding gray iron, alternating current is smoother in operation at low current values, and it produces a less penetrating arc. Reverse-polarity direct current also can be used.

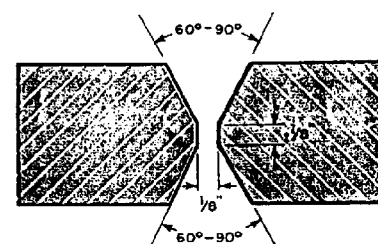
Grooves required for welding may be prepared by chipping, grinding, or cutting with a gas torch.

A single V-groove is used for metal sections up to $1\frac{1}{2}$ in. thick, and a double V is made for those greater than $1\frac{1}{2}$ in. thick. The V-grooves should have an included angle of 60 to 90°.

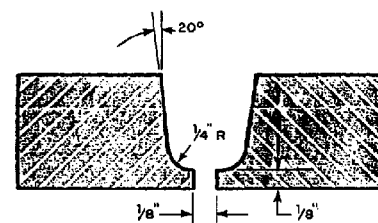
For heavy castings, a U-shaped groove with the walls of the U sloping by about 20° can be provided. This groove is intermediate between the single and the double V-groove, and welding is done from one side only.



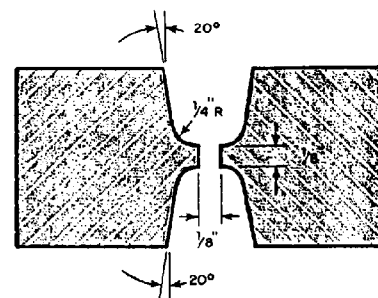
SINGLE V GROOVE



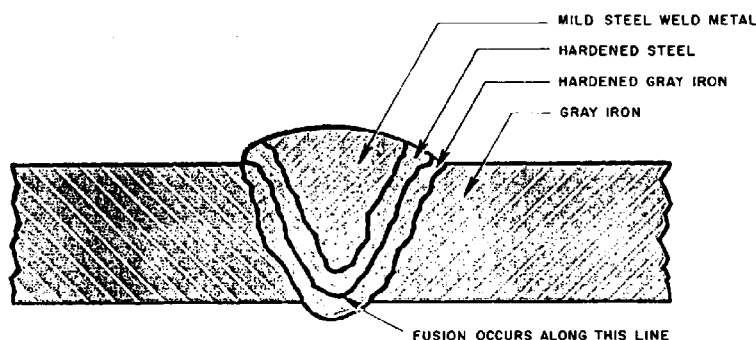
DOUBLE V GROOVE



SINGLE U GROOVE



DOUBLE U GROOVE



Cross-section represents the heat-affected zone when gray iron has been welded with mild steel electrodes.

The grooves that should be used in joining two pieces of cast iron depend on the section thicknesses involved.

On small castings, the V-groove is made with a grinding wheel. For those castings having sections greater than 1 in. thick, a cutting torch should be used. A pneumatic chipping hammer also can be used to rough out the grooves, which then are finished by grinding. The disadvantage with chipping is that it may cover up certain defects in the castings that are critical.

Since steel contracts more than

gray iron during cooling, the former tries to pull away from the latter. This effect is more pronounced when long weld beads are deposited. As the first step in overcoming this difficulty, the beads are deposited in a curved path instead of a straight line. In addition, the beads are placed in short lengths widely separated from each other so that each bead can cool for 3 to 5 min to minimize the heat

absorbed by the work at one time. As a final step, peening the hot beads helps to produce good joints.

Heat Treatment—In case machining of the weld is essential, the main problem is to obtain softer welds. Often adequate strength in the weld joint also is desirable. The best method available under such circumstances is to preheat the work to an optimum temperature of 300 C (570 F) with a maximum of 600 C (1,110 F).

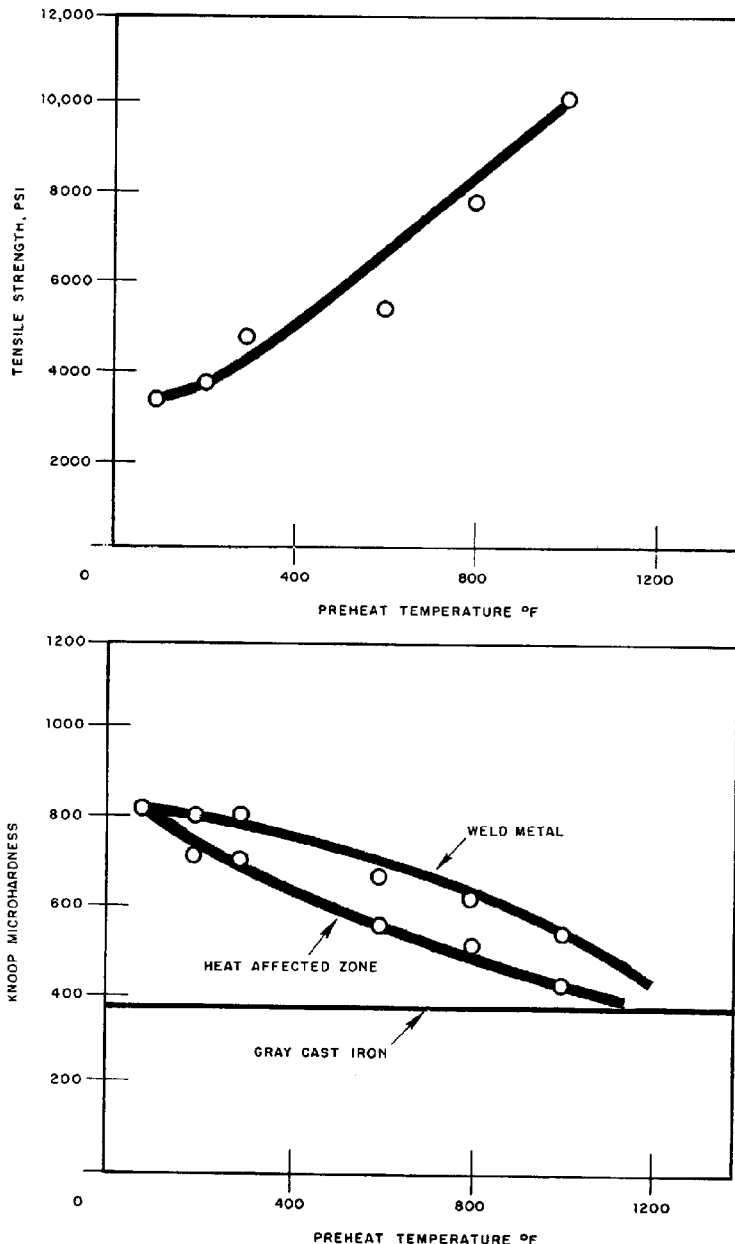
Preheating reduces the cooling rate and hence prevents hardening and cracking in the weld zone. Those conditions are inevitable if the cooling rate is greater than 600 F per min. Preheating is recommended when the components to be welded are such that the expansion caused by the heat of welding results in excessive stresses in other parts of the casting.

Preheating cannot be used, however, when minimum heat is to be applied to avoid distortion of the parts being welded.

Preheating offers other problems than distortion. Even after an annealing treatment, an unmachinable area of high carbon steel remains in the weld zone, and high preheat temperatures — say above 450 C (840 F)—are likely to weaken the gray iron. Owing to the low total input, supplementary heating very often is required to maintain the preheating temperature.

The machinability of welded gray iron can be increased by a post welding heat treatment up to 650 C (1,200 F). That treatment specifically reduces the hardness of the heat-affected zone. A further reduction of hardness can be accomplished by applying a full anneal treatment that decomposes the unstable cementite to graphite and ferrite. Unfortunately, it also weakens the gray iron.

In both the above methods, local heating of the joints or total heating of welded assemblies is done at temperatures of 540 to 650 C (1,000 to 1,200 F). The castings are covered with materials like asbestos or sand that are designed to promote slow cooling.



Plots relate preheat temperature and weld area microhardness.

Weldability of Gray Iron Using Fluxless Gray Iron Electrodes for SMAW

Welds having original base metal hardness and graphite content are attained by decreasing weld cooling rate and increasing the carbon equivalent of the weld admixture

BY J. H. DEVLETIAN

ABSTRACT. The weldability of class 40 gray iron using fluxless gray iron electrodes was investigated. Single and multiple-pass welds were deposited by the SMAW process with preheating temperatures up to 830C (1550 F). The cooling rate for each weld was recorded. Evaluation of weldability included microhardness studies, metallurgical analysis and crack susceptibility of the weld and heat-affected zone (HAZ).

The weldability of gray iron was significantly affected by the cooling rate and carbon equivalent of the weld admixture. Decreasing cooling rate and/or increasing carbon equivalent substantially lowered weld hardness due to the increased amounts of graphite and ferrite forming in the weld. Peak HAZ hardness of the gray iron base metal was also found to decrease with decreasing weld cooling rate.

Cracking tendencies in the weld and HAZ were eliminated by maintaining the cooling rate below 10 C/s or 1.8 F/s (or above 300 C or 572 F preheat). Crack-free welds having original base metal hardness and graphite content were readily attained by reducing the cooling rate (through preheating) to a

level that was dependent upon the carbon equivalent of the weld admixture.

Introduction

The utilization of inexpensive gray iron electrodes to weld or repair-weld large gray iron castings by the shielded-metal arc welding (SMAW) process has been largely ignored in favor of the more costly nickel-base electrodes—namely ENi-CI and ENiFe-CI. Despite the increased cost and the consumption of the strategic element nickel, many foundries have been reluctant to use gray iron electrodes for fear of producing cracked white iron weld metal with a martensitic heat-affected zone (HAZ).

The gray iron literature is replete with research concerning the factors affecting the degree of graphitization of gray iron castings and its associated mechanical properties. It is well-

known that high quality gray iron castings can be obtained by:

1. Slow cooling rates during eutectic and eutectoid transformations.
2. Carbon equivalent (C.E.) of near-eutectic composition.¹
3. Use of graphitizing inoculants.^{2,3}
4. Low superheating temperatures.^{4,5}

Under these conditions the resulting microstructure will contain the desired graphite flakes in a matrix of ferrite and/or pearlite.

The welding of gray cast iron with gray iron electrodes, however, is particularly difficult because the effective use of inoculants and low superheating temperatures are not practical in the SMAW process. Successful welding of gray iron would require a sufficiently slow weld cooling rate and a near-eutectic C.E. in the weld admixture to insure a high graphitizing potential; otherwise, a white iron weld is inevitable. Recently, Hogaboom⁶ reported that fluxless cast iron electrodes could be used to repair-weld large gray iron castings provided that adequate preheating, high welding currents and controlled cooling proce-

Source: *Welding Journal*, 57(7), July 1978

Table 1—Chemical Composition of Gray Iron Electrode and Base Metal, %

	C	Si	P	Mn	S	C.E. ^(a)
Base metal	2.87	1.80	0.10	0.81	0.067	3.4
Electrode	3.84	2.92	0.35	0.75	0.020	4.5

^(a)C.E. = %C + .3 (%Si + %P)**Table 2—Chemical Compositions of Weld Admixtures Deposited on Gray Iron, %**

	C	Si	P	Mn	S	C.E.
Single pass weld	3.00	2.30	0.20	0.69	0.040	3.8
Multiple pass weld (Analysis on final pass)	3.35	2.66	0.29	0.70	0.015	4.2

dures were utilized.

The purpose of the study reported here was to further refine the existing work on the weldability of gray iron using fluxless gray iron electrodes and the SMAW process. Specifically, this paper quantitatively relates the microhardness, degree of graphitization, microstructure and crack susceptibility of the weld admixture as a function of measured values of weld cooling rate and C.E.

Procedure

Materials

ASTM class 40 gray cast iron in the as-cast condition was used exclusively in this investigation. Ingots approximately 20 × 20 × 70 cm (7½ × 7½ × 27½ in.) were machined into 10 × 10 × 2 cm (3½ × 3½ × ¾ in.) test plates for subsequent welding. A 90 deg single V-groove was also machined into half of the test plates. In order to duplicate the repair-welding procedures used in commercial practice, the surfaces to be welded were cleaned by using a hand operated grinder.

Filler metals used to weld gray iron were 5 × 5 mm (0.2 × 0.2 in.) square class 20 gray iron and 3.2 mm (¼ in.)

diameter ENi-CI electrodes. Compositions of all materials are given in Table 1.

Welding

Single pass, bead-on-plate welds were deposited on the flat test plates using the manual SMAW process. Multiple-pass welds were deposited on the test plates containing the 90 deg single V-groove. The interpass temperature was either the specified preheating temperature or room temperature when no preheating was used.

All SMA welds made with fluxless gray iron electrodes were deposited at a constant arc energy input of 2700 J/mm, using a welding current of 450 A and a travel speed of approximately 2.5 mm/s (5.9 ipm). The ENi-CI electrodes used 160 A and approximately 6 mm/s travel speed.

Control of Weld Cooling Rate

A weld cooling curve was obtained for each weld specimen by plunging a 0.38 mm (0.015 in.) diameter W-3%Re/W-25%Re thermocouple directly into the molten weld pool. Cooling curves

were recorded on a continuous chart recorder and the weld cooling rate for each weld was taken at 704 C (1300 F). Weld cooling rates ranging from 0.19 to 160 C/s (0.35 to 288 F/s) were investigated.

Slow weld cooling rates were obtained by preheating the workpiece on a heavy-duty electric hot plate. Accurate preheating temperatures were assured by welding a chromelalumel thermocouple onto each test plate. As soon as the thermocouple registered the desired preheating temperature in the test plate, a variac attached to the hot plate was adjusted to stabilize this temperature. After stabilization, the power to the hot plate was shut off and welding commenced immediately.

The fastest weld cooling rates were obtained by partially immersing the 20 mm (¾ in.) thick test plates in a shallow pool of water about 5 mm (0.2 in.) deep and then welding. The water which was maintained at 25 C (77 F) acted as an efficient heat sink during welding.

Metallography

All metallography of weld and HAZ structures were performed on transverse-to-weld sections taken within 1 cm (0.04 in.) of the embedded thermocouple for an accurate correlation between weld cooling rate and microstructure. Sections were polished and then etched in 4% picral.

Carbon Equivalent

To study the effects of C.E. on weld properties, two values of C.E. (namely, 3.8% and 4.2%) were compared throughout this investigation.

The value of 3.8% was obtained by welding class 40 gray iron having a C.E. of 3.5% with a class 20 gray iron electrode with a C.E. of 4.6%. The resulting weld metal admixture possessed the C.E. of 3.8%—Table 2.

Similarly, the 4.2% C.E. value was obtained for the multiple-pass welds where the final pass of the resulting weld admixture contained a C.E. of 4.2%—Table 2.

Microhardness

Diamond pyramid microhardness tests were conducted on transverse-to-weld sections using a 300 gram (0.66

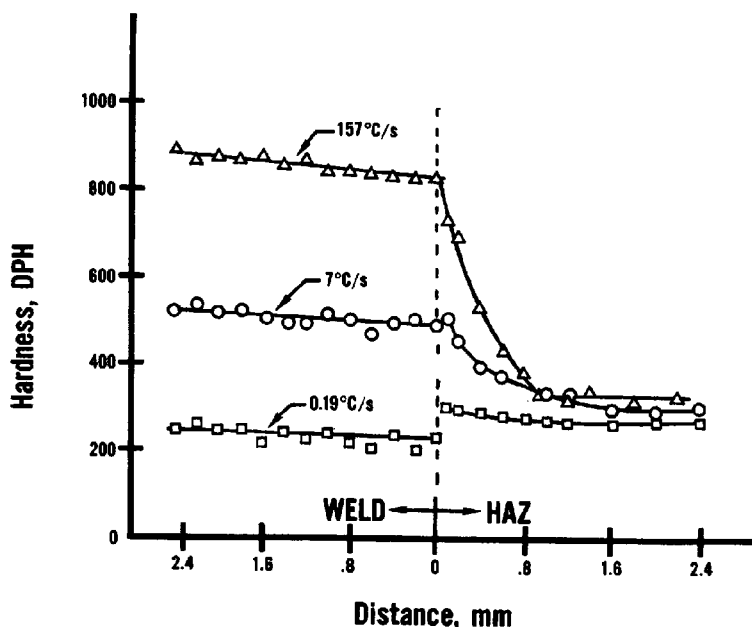


Fig. 1—Microhardness scan over the weld and HAZ for fast, intermediate and slow weld cooling rates. Weld admixture contains 3.8% C.E. Base metal is class 40 gray iron

lb) weight acting on the indenter. The average hardness of each polished and etched weld was obtained by taking at least ten equally spaced indentations (at 0.2 mm (0.08 in.) intervals) vertically and at least 10 readings horizontally within the weld fusion zone. Similarly, the average value of the peak HAZ hardness was obtained by taking at least six indentations along the HAZ side of the weld-base metal interface. Care was taken not to indent any of the large graphite flakes in the HAZ.

The diamond pyramid microhardness test was chosen because of its ability to provide the microhardness values of any part of the weld/HAZ microstructure. This test was used to obtain the hardness of the matrix and not that of large graphite flakes. Thus, the diamond pyramid hardness values tend to be slightly higher than similar Brinell or Rockwell test results when large graphite flakes are present in the microstructure.⁷

Weld Cracking

Weld cracking was reported after visual and dye-penetrant examinations

were performed on the single-pass and multiple-pass welds.

Results

The weldability of gray cast iron using gray iron filler metal and the SMAW process was evaluated by hardness tests and metallographic analysis. Results of this work are presented in Figs. 1-8.

Hardness

The hardness profile across the weld and HAZ of a single-pass (C.E. = 3.8%) weld was found to be dependent upon weld cooling rate. Typical microhardness scans for welds having fast, intermediate, and slow cooling rates are shown in Fig. 1. The fast cooling weld resulted in the highest overall hardness values in the weld and HAZ, while the slow cooling weld resulted in lowest hardness.

Average weld metal hardness values for both the 3.8% and 4.2% C.E. welds were found to decrease with decreasing weld cooling rate as shown in Fig. 2a. The hardness values for the 4.2%

C.E. welds were consistently lower than those for the 3.8% C.E. welds. For example, at a weld cooling rate of 3 C/s (5.4 F/s), the average hardness values for the 3.8% and 4.2% C.E. welds were 420 and 265 DPH, respectively.

Weld metal hardness values were comparable with those of the gray iron base metal only when the weld cooling rates for the 3.8% and 4.2% C.E. welds were reduced to approximately 0.7 and 5.3 C/s (1.3 and 9.5 F/s), respectively. By contrast, all welds deposited with the ENi-CI electrodes (for reference only) were much softer than the gray iron base metal regardless of weld cooling rate.

The peak HAZ hardness of the gray iron workpiece was also affected by weld cooling rate. In Fig. 2b, peak HAZ hardness decreased significantly with decreasing weld cooling rate.

Metallographic Analysis

Graphite Formation. In this study, both the amount and size of the graphite flakes which resulted during eutectic solidification were found to increase substantially with decreasing values of weld cooling rate and

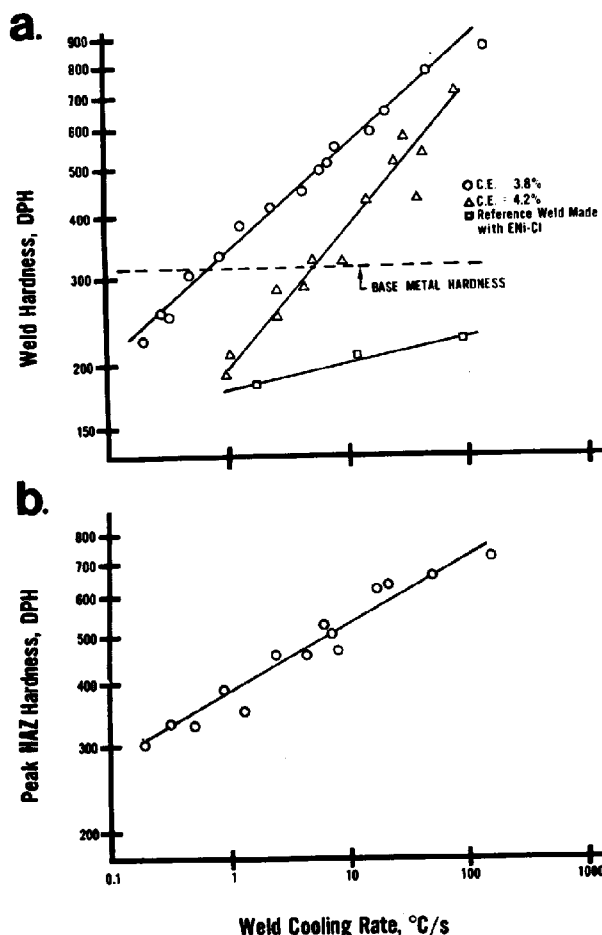


Fig. 2—The effect of weld cooling rate on: a—average weld metal hardness for admixture compositions of 3.8% and 4.2% C.E.; b—peak HAZ hardness of gray iron

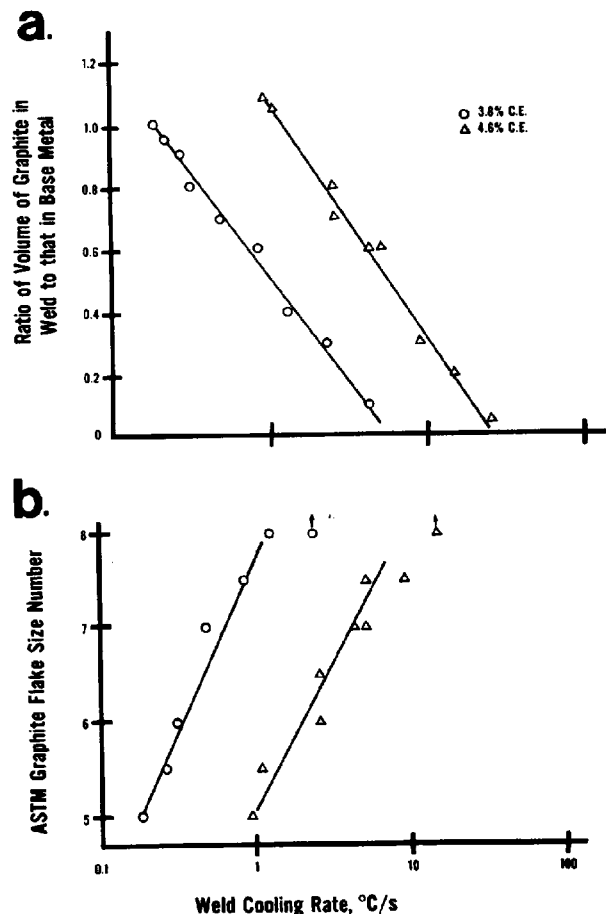


Fig. 3—The effect of weld cooling rate on: a amount and b size of graphite flakes forming in 3.8% and 4.2% C.E. weld metal

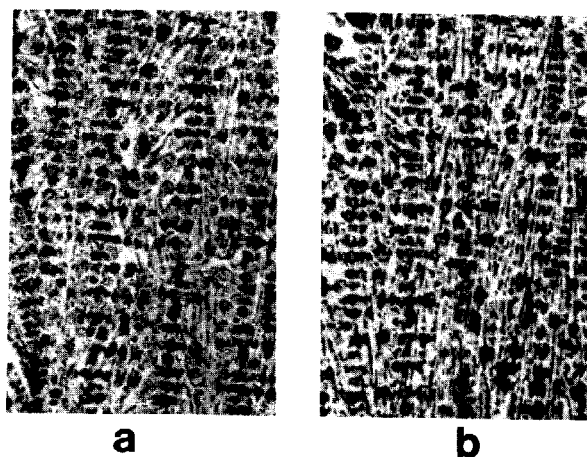


Fig. 4—Rapidly cooled welds deposited on gray iron having been preheated to 200 C (392 F). Weld in **a** has a 3.8% C.E. and 22 C/s (39.6 F/s) cooling rate while the weld in **b** has a 4.2% C.E. and a 26 C/s (46.8 F/s) cooling rate. Picral etchant; $\times 400$ (reduced 50% on reproduction)

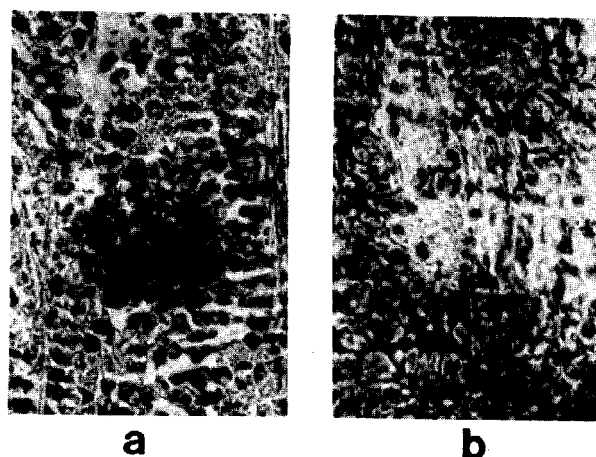


Fig. 5—Welds having an intermediate cooling rate were preheated to 400 C (752 F). Weld in **a** has a 3.8% C.E. and 4.2 C/s (7.6 F/s) cooling rate while the weld in **b** has a 4.2% C.E. and 5.2 C/s (9.4 F/s) cooling rate. Picral etchant; $\times 400$ (reduced 50% on reproduction)

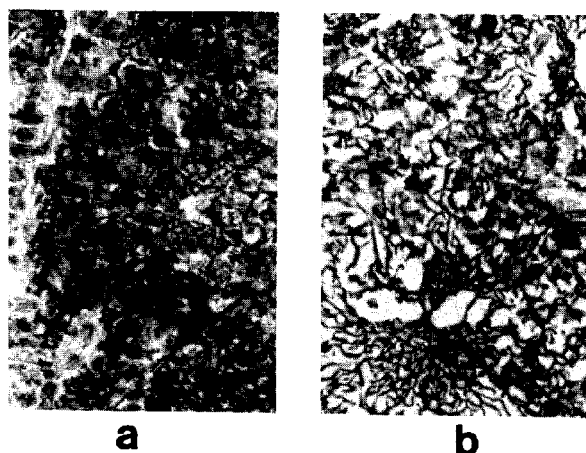


Fig. 6—Slowly cooled welds deposited on gray iron having been preheated to 590 C (1094 F). Weld in **a** has a 3.8% C.E. and 0.89 C/s (1.6 F/s) cooling rate while the weld in **b** has a 4.2% C.E. and 0.95 C/s (1.7 F/s) cooling rate. Picral etchant; $\times 400$ (reduced 50% on reproduction)

increasing C.E.—Fig. 3. The amount and size of graphite flakes observed in the 4.2% C.E. welds were consistently greater than those observed in the 3.8% C.E. welds. Generally, the form of graphite flakes observed in all welds were predominantly the interdendritic ASTM types D and E.⁸ No graphite was observed in 3.8% C.E. and 4.2% C.E. welds for weld cooling rates greater than approximately 6 and 30 C/s (11 and 54 F/s), respectively.

The weld microstructures in Figs. 4–7 illustrate the effect of weld cooling rate and C.E. on the formation of graphite. The fast cooling welds in Fig. 4 are clearly white iron. In Fig. 5, intermediate cooling conditions resulted in a mottled iron structure with the 4.2% C.E. weld containing significantly more graphite than the 3.8% C.E. weld. The microstructure of the slowly cooled welds in Fig. 6 shows that the 4.2% C.E. weld was fully gray iron while that of the 3.8% C.E. weld was still mottled iron. It was not until the weld cooling rate was reduced to

0.32 C/s that a fully gray iron structure developed in the 3.8% C.E. weld as shown in Fig. 7.

Solid State Transformations. Once the eutectic structure had solidified, the subsequent eutectoid transformation proceeded very much like that of a high carbon steel. For the fast cooling welds, both the primary dendrites of austenite and the austenite in ledeburite transformed to a bainitic structure—Fig. 4.

With decreasing cooling rate, this bainitic structure was replaced by fine pearlite—Fig. 5. At very slow cooling rates, the solid state transformation of austenite resulted in pearlite and ferrite as shown in Figs. 6 and 7.

Cracking in Welds

Severe transverse cracks resulted in both the 3.8% and 4.2% C.E. welds when the cooling rate was excessive, while no cracking occurred for the slowly cooled welds. In this investigation, cracking tendencies in the weld

and HAZ were eliminated by reducing the weld cooling rate below approximately 10 and 36 C/s (18 and 65 F/s) for the 3.8% and 4.2% C.E. welds, respectively.

Preheating Temperature vs. Weld Cooling Rate

Following the preheating procedures outlined in this study, the preheating temperature was found to be a consistently workable control over weld cooling rate. With welding parameters fixed for all welds, increasing the preheating temperature decreased the weld cooling rate as shown in Fig. 8.

Discussion

The two most significant variables affecting the weldability of ASTM class 40 gray iron using class 20 gray iron electrodes were found to be the cooling rate and the C.E. of the weld metal. These two factors had a pronounced effect on the weld hardness, formation

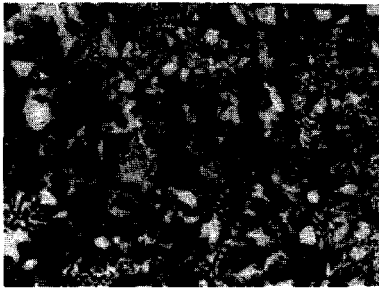


Fig. 7—Very slowly cooled weld deposited on gray iron having been preheated to 760 C (1400 F). This weld has a 3.8% C.E. and 0.32 C/s (0.58 F/s) cooling rate. Picral etchant; $\times 400$ (reduced 50% on reproduction)

of the Fe-graphite eutectic, eutectoid transformation and weld cracking.

Hardness and Carbon Equivalent

In this investigation, the hardness of cast iron weld metal of a given C.E. was found to depend directly upon the weld cooling rate—Fig. 2. This behavior is in agreement with the cast iron literature^{1,7,9,10} in that:

1. The higher temperature eutectic reaction of austenite + graphite dominates during solidification of slowly cooled (i.e., with minor undercooling) castings.

2. The lower temperature eutectic reaction of austenite + carbide dominates for fast cooling rates (i.e., with large undercooling) resulting in white iron.

In this investigation, the occurrence of gray, mottled or white iron in the weld admixture of a given C.E. depended essentially upon weld cooling rate.

The C.E. of the weld admixture also had a significant effect upon weld hardness. Since increasing the silicon and carbon contents intensifies the graphitization potential of the weld metal, the 3.8% C.E. welds developed significantly higher hardness and less graphite than the 4.2% C.E. welds.

Microstructure

Since the formation of eutectic graphite depends upon nucleation and growth kinetics,¹⁰ the amount and size of the flakes are controlled by the solidification time and the graphitization potential of the weld admixture. In welding of gray iron, the amount and size of the graphite flakes in the weld admixture increased with decreasing weld cooling rate and increasing C.E.

Because graphite-nucleating inoculations and low superheating temperatures are not practical for welding and, therefore, not used in this study, the morphology of the eutectic graphite

forming in cast iron weld metal is predominantly the interdendritic ASTM types D and E (see Figs. 5 and 6a). It is only at extremely slow weld cooling rates that some non-interdendritic types of graphite are observed as in Figs. 6b and 7.

Furthermore, the eutectoid transformation also contributed to the resulting hardness of the weld metal. The slower the weld cooling rate and the greater the C.E., the more potent are both the solid state graphitizing and ferritizing effects. For example, at the slow cooling rates indicated in Figs. 6 and 7, solid state graphitization has permitted the formation of some ferrite during the eutectoid transformation. This is why the ferritic areas are usually located adjacent to graphite flakes.

Increased C.E. substantially augments the graphitizing and ferritizing potentials of the weld metal as can be seen by comparing Figs. 6a and 6b where the ferrite content of the 4.2% C.E. weld is far greater than that of the 3.8% C.E. weld.

Preheating Welds

The preheating temperature required to obtain a soft gray iron weld and HAZ depends upon several factors:

1. C.E. of the weld admixture.
2. Section size and configuration of workpiece.
3. Arc-energy input.

A high C.E. significantly increases the graphitizing and ferritizing potentials of the weld. Thus, increasing the weld C.E. would allow a lower preheating temperature (or faster weld cooling rate) to produce a specified weld hardness value. For example, to obtain a weld hardness of 325 DPH (see Figs. 2a and 8), the 3.8% C.E. weld

requires a preheating temperature of 600 C or 1112 F (or a cooling rate of 0.88 C/s, i.e., 1.6 F/s) while the 4.2% C.E. weld needs to be preheated to only 360 C or 680 F (or 6.3 C/s i.e., 11.3 F/s). This would represent a substantial cost and energy savings.

In this study, the size and shape of the workpiece and the arc-energy input were held constant. Under these restricted conditions, the relationship between the preheating temperature and the resulting weld cooling rate is shown in Fig. 8. However, if the section size were reduced or the arc-energy input were increased, the curve in Fig. 8 would shift to the left—i.e., lower preheating temperatures to obtain a given value of weld cooling rate. In fact, Hogaboom⁸ reported that SMA repair welds made on gray iron could be deposited with such high values of arc-energy input that no preheating at all was required.

The results of this study show that, metallurgically, there is no upper limit for preheating gray iron. The higher the preheating temperature, the greater the degree of graphitization and ferritization which produces softer weld and HAZ structures. However, an upper limit may be required only when excessive softening can not be tolerated.

Conclusions

The effects of SMA welding of ASTM class 40 gray cast iron using gray iron electrodes were evaluated by microhardness and metallographic analysis. Based on this study, the following conclusions were reached:

1. Weld metal and peak HAZ hardness decreases significantly with decreasing weld cooling rate.

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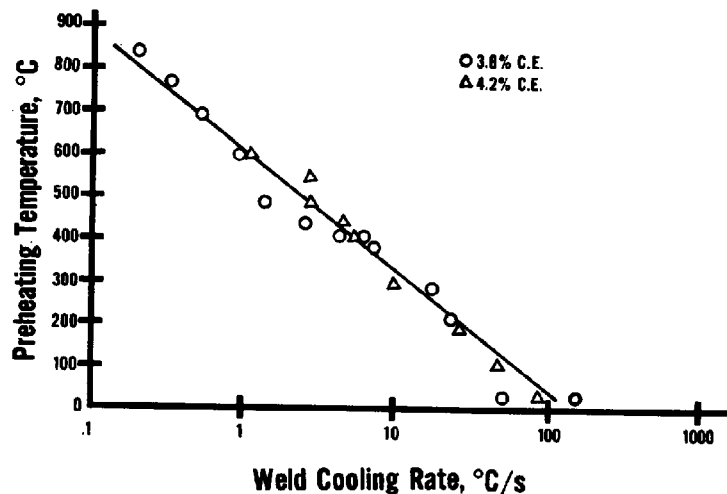


Fig. 8—The effect of preheating temperature on the cooling rate of single-pass gray iron welds where the arc-energy input, specimen size and geometry were held constant

2. Increasing the C.E. of the weld admixture decreases weld hardness and reduces the need and cost for preheating. E.g., the 4.2% C.E. welds develop original base metal hardness and graphite content with a weld cooling rate of 5.3 C/s or 9.5 F/s (or 390 C or 734 F preheat); but decreasing the C.E. to 3.8% requires a substantially slower cooling rate of 0.7 C/s or 1.3 F/s (or 640 C or 1184 F preheat) to attain similar results.

3. The eutectic graphite content of the weld admixture increases with decreasing cooling rate and/or increasing carbon equivalent, but its morphology is primarily the interdendritic ASTM types D and E. No graphite occurs in the 3.8% and 4.2% C.E. welds when the weld cooling rates exceed 6 and 30 C/s (10.8 and 54 F/s), respectively.

4. Weld cracking due to the forma-

tion of brittle white iron is highly probable when the weld cooling rate exceeds about 10 C/s or 18 F/s (or less than 300 C or 572 F preheating).

References

1. Schneidewind, R., and McElwee, R. G., "Composition and Properties of Gray Iron, Parts I and II," *Transactions of American Foundrymen's Society*, 58, 1950, pp. 312 to 332.
2. Lownie, Jr., H. W., "Theories of Gray Cast Iron Inoculation," *Transactions of American Foundrymen's Society*, 54, 1946, pp. 837 to 844.
3. Eash, J. T., and Bayonne, N. J., "Effect of Ladle Inoculation on the Solidification of Gray Cast Iron," *Transactions of American Foundrymen's Society*, 49, 1941, pp. 831 to 849.
4. Schneble, Jr., A. W. and Chipman, J., "Factors Involved in Superheating Gray Cast Iron and Their Effects on Its Structure and Properties," *Transactions of American Foundrymen's Society*, 52, 1944, pp. 113 to 158.
5. Schneidewind, R., and D'Amico, D. A., "The Influence of Undercooling on the Graphite Pattern in Gray Cast Iron," *Transactions of American Foundrymen's Society*, 47, 1939, pp. 831 to 849.
6. Hogaboom, A. G., "Welding Gray Cast Iron," *Welding Journal*, 56 (2), Feb. 1977, pp. 17 to 21.
7. Walton, C. F., "Gray and Ductile Iron Castings Handbook", Iron Founders' Society, Inc., Cleveland, 1971, pp. 187 to 238.
8. ASTM Specification A-247-67, "Standard Method for Evaluating the Microstructure of Graphite in Iron Castings."
9. Geist, K. R., and Hambley, W. A., "A Practical Method of Selecting the Correct Type of Cast Iron, Part 2," *Iron Age*, 158, Oct. 17, 1946, pp. 64 to 70, and Oct. 24, 1946, pp. 58 to 64.
10. Hughes, I. C. H., "A Review of Solidification of Cast Irons with Flake Graphite Structures," *The Solidification of Metals*, Iron and Steel Institute, London, 1967, pp. 184 to 191.

WELDING OF GRAY CAST IRON

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The welding of cast iron is usually considered to be rather undependable, erratic and a sort of hit-or-miss deal. This is partly because of an apparent widespread lack of understanding of the various factors associated with the welding of cast iron—also partly because of inconvenience in welding cast iron in the more dependable ways, partly because of a scarcity of suitably skilled welders versed in the more dependable methods and partly because of a scarcity or complete absence of published information concerning the fundamentals of cast iron welding and more dependable methods.

The intent of this paper is to provide at least a little insight into some of the major interrelating factors and outline a little known but very fast, economical and high quality way to make certain types of major repairs.

The Problem

Cast iron—or at least the gray variety—is a rather crude, impure alloy of mainly iron, carbon and silicon. Its formation during solidification and cooling is such that much of the carbon separates out of solution as free graphite in flake form in a matrix of rather impure, high silicon, medium to high carbon steel. The metallurgical structures typical of gray cast iron in both the unetched and etched conditions are shown in Figs. 1 and 2.

The graphite flakes act like tiny cracks within the matrix metal to promote fracture without appreciable yielding. At the same time, the high carbon, silicon and impurity content of the matrix material tends to limit its ductility and ability to deform without fracture. Combined, the two factors of crack-like discontinuities

"Hot Arc" welding in progress on a gray cast iron casting



Source: *Welding Journal*, 56(2), February 1977

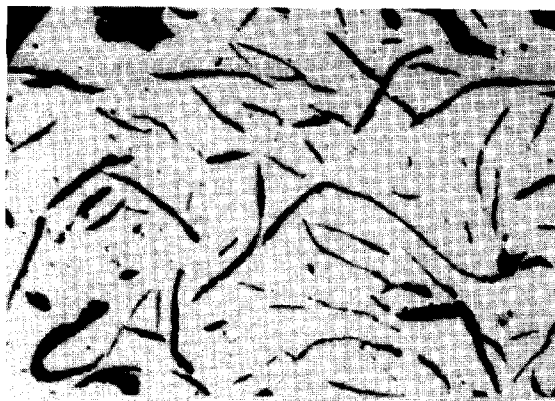


Fig. 1—Typical unetched structure of gray cast iron showing graphite flakes. $\times 100$



Fig. 2—Etched structure of gray cast iron—mixture of ferrite pearlite and graphite flakes. Nital etch, $\times 100$

and limited ductility of the matrix material result in the no ductility characteristics of gray cast iron.

Graphite is black, and the many flakes exposed on fracture surfaces give gray cast iron its characteristic gray appearance.

Hardening Characteristic

Alloys of iron and carbon, especially when accompanied by other alloying elements such as manganese, silicon, chromium, nickel, etc., are quite readily hardened by rapid cooling from high temperature. Files, knife blades, springs, the gears and axles in automobiles and many other things are hardened and strengthened in that way. However, they are usually given a second, lower temperature treatment to partly soften and toughen the parts.

The area immediately adjacent to a weld pass is heated to the melting point and cools very rapidly to or nearly to adjacent metal temperature by conduction of heat into the surrounding metal. If that temperature is fairly low—say below about 500 F (260 C)—and the material is high in carbon such as gray cast iron, extreme hardening is almost certain, irrespective of the kind of filler metal used. About the only way to prevent the hardening is to heat the surrounding material to a high enough temperature to slow down the cooling rate sufficiently to prevent hardening. In other words, preheat it. The temperature usually needed to prevent severe hardening of the heat-affected zones adjacent to arc weld passes on cast iron is about 600 F (316 C) or a bit higher.

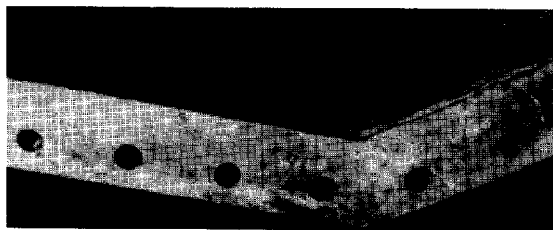


Fig. 3—Finish machined "Hot Arc" welds



Fig. 4—Preheating of gray iron casting for "Hot Arc" welding

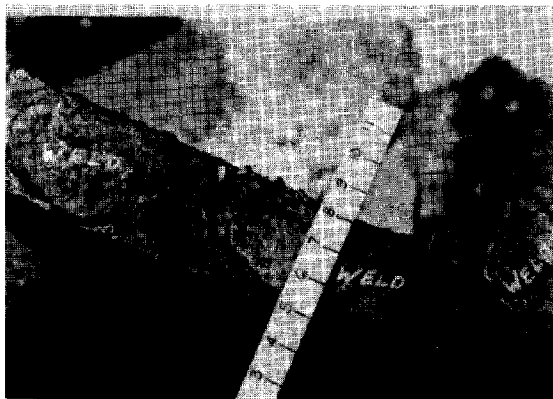


Fig. 5—"Hot Arc" weld—showing surface finish before machining

Stress Build-Up

Stresses are another important factor. Most materials expand on heating and shrink on cooling. Cast iron is no exception. On heating, the heat-affected zones adjacent to weld passes expand, soften, upset, and shrink on cooling. So also does the deposited weld metal shrink on cooling.

Shrinkage or attempted movement of anything attached to something else that is not similarly moving will set up stress—twisting a child's ear or trying to take off in a car while tied to a tree are examples of a non-metallurgical sort. For weld passes, the stress magnitude will depend on temperature difference, shrinkage characteristics of the materials involved, span over which the shrinkage difference takes place and the elastic, plastic and strength characteristics of the materials involved.

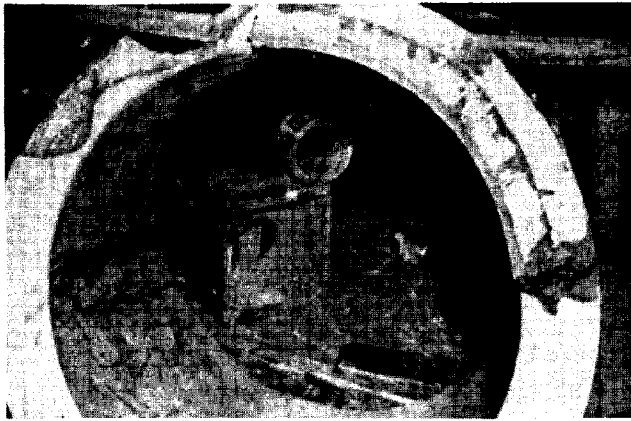


Fig. 6—Example of excavation and area damming for "Hot Arc" welding (see Fig. 7)

About the only way to prevent stress build-up is to lessen the degree of temperature and shrinkage difference or develop easy yielding, putty-like conditions in the adjoining metals. Heating the base metal to a sufficiently high temperature—say, around 1500 F (816 C) or higher—will accomplish the latter. Heating to somewhat lower temperature—say, around 1000 F (538 C)—will lessen stress build-up sufficiently for most, if not all, practical purposes. Furthermore, heating cast iron to much over 1000 F for any extended period of time will cause considerable weakening of the base metal. All of these factors—hardening, stress and possible weakening—need to be taken into account in welding cast iron.

Basically, then, the problem boils down to near zero ductility of the base metal, tendency to harden along low preheat weld passes, stress build-up from shrinkage of passes and almost certainty of at least some cracking adjacent to welds unless sufficient preheat is used to eliminate both hardening and high stress build up. This being the case, it is in order to consider process characteristics, application problems and popular opinion concerning the welding of cast iron.

Processes for Casting Repair

Nowadays, when a gray iron casting needs repair, first thought usually turns to the possibilities of repair with nickel or nickel alloy electrodes and little or no preheat. This, of course, involves rapid heating and cooling of heat-affected zones, the hardening thereof, differential shrinkage, high stresses and a likelihood or certainty of at least some cracking in or along the welds. Consequently,

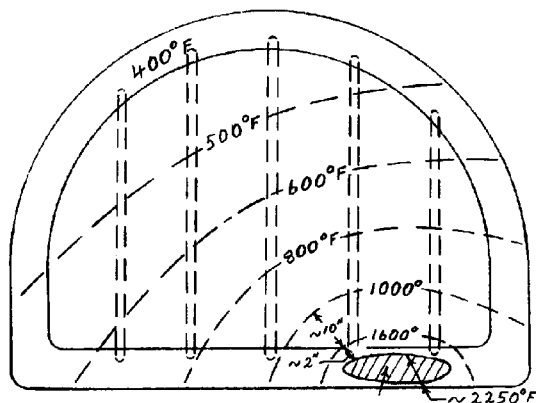


Fig. 8—Typical temperature gradient pattern for "Hot Arc" welding large cast iron parts

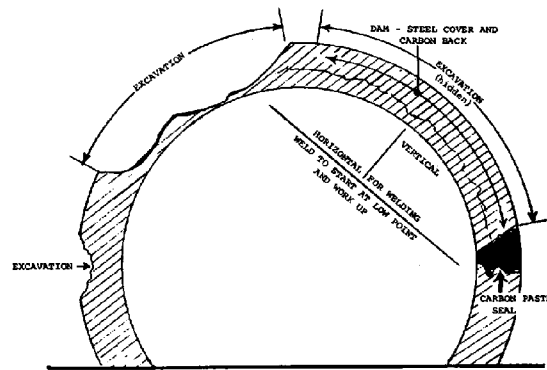


Fig. 7—Schematic representation of Fig. 6 showing excavation areas and an example of damming

there is little or no possibility of producing welds in this way with over about 60 to 75% of the strength of the base metal and often much less.

If the foregoing strength and consistency are not considered adequate for the application involved, next thought would probably turn to the possibilities for gas welding with preheat, or brazing. The gas process is capable of producing welds of quite high strength and more consistently than is generally possible by arc welding with nickel alloy electrodes. However, gas welding suffers from marked inconvenience, due to the heat associated with welding on preheated parts with a big gas flame. Furthermore, the process is relatively slow and this extends the time workmen are exposed to the disagreeable heat from the gas torch and preheated base metal. Because of these factors, there are now very few men who are experienced or knowledgeable in the art of gas welding or willing to stand the heat involved in gas welding large gray iron castings. The result is usually to make the process unattractive or inapplicable, although capable of producing quite good welds.

As for brazing, this is a very good process for some repairs and is easier to apply than gas welding with cast iron rod. Bond strength may, however, be somewhat variable. Also, for high stress and cyclic load applications, the yield and fatigue strength of the brass filler metals (so-called bronzes) may also be too low.

Another method for repair of gray iron parts (but one that does not involve heat or welding) is a proprietary mechanical cross-link method called "Metalock." It is basically similar to stitching a seam with needle and thread; the process involves drilling and the insertion of tie-bars across the fracture surfaces. For some applications, to avoid dismantling, delay or distortion problems in welding, this may be a quite favorable method of repair.

If none of the foregoing methods are considered adequate or applicable for one reason or another, what other possibility (or possibilities) exist? Although relatively unknown, there is another method for welding gray iron. It is far faster than nickel electrode or gas welding and is capable of producing higher strength welds than any of the foregoing repair methods. It may be termed "Hot Arc" welding with cast iron electrodes. By this method, welds can readily be made very rapidly with the full strength of the base metal; also, the welds are both machinable and gray iron in character. Figure 3 shows the type of weld obtainable. Details of the process follow.

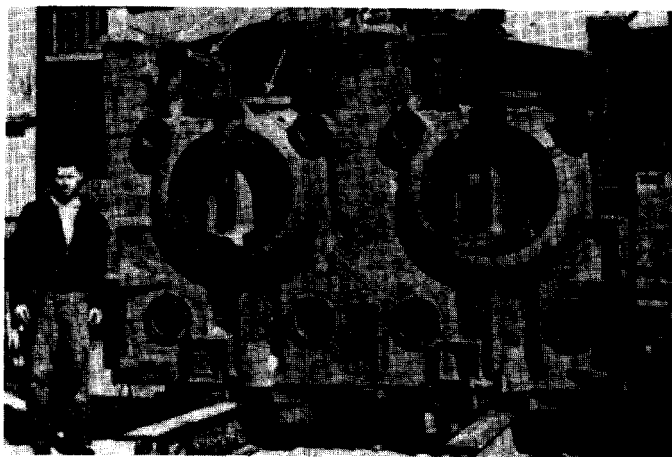


Fig. 9—Gray iron casting which had rather large shrink and sand inclusion areas repaired by "Hot Arc" welding. Arrows indicate weld regions

"Hot Arc" Process

Process Characteristics

Basically, the "Hot Arc" process is similar to gas welding except that cast iron weld metal is deposited by the metal arc process. Preheat is essential, the same as for gas welding—say, around 900 to 1100 F (482 to 593 C). The welding is then done by the arc process using cast iron rod for the electrode. The latter may be ordinary gas welding rod such as is available at any welding supply house or special rod made with a little higher carbon and silicon contents to compensate for burn-out during welding. Rods may also be coated with graphite or flux, if so desired, but coatings are not essential.

For best results, the welding, itself, should be done with rather large electrodes at high amperage and with a big, fluid puddle, rather than with quick solidifying "beads" such as are most common in welding most other materials. Typical is use of 1/4 in. diameter cast iron rod with around 400 to 450 A, or larger rod with up to 600 A.

So applied, deposit rates will run from around 10 to 30 pounds per hour (4.5 to 13.6 kg/h) and may be further increased by feeding electrically neutral filler metal (i.e., cold rod) from the side, by placing broken pieces of rod along run paths, or by feeding in cast iron chips.

The type of weld obtainable by this process and machinability thereof are shown in Fig. 3. Figure 4 and the lead photograph show preheating and welding of a gray iron casting. Figure 5 shows a finished weld before machining, the same weld as shown in Fig. 3 after machining.

Area Damming

Due to the high amperage used and extreme fluidity of superheated cast iron, the hot arc process cannot be used in other than the flat position and even for that must be surrounded and supported by some sort of solid material. The root of through joints and edges of weld areas are best supported or dammed and blocked off with carbon or graphite plates and carbon paste to seal any irregularities. The carbon plates and paste may, in turn, be held in place with braces or straps tack welded with nickel alloy electrodes. However accomplished, a complete edge seal under and around hot arc welds is absolutely essential to avoid molten metal run-out.

An example of area damming is shown in Figs. 6 and 7. The casting shown here was dammed on the face and back sides of the flange and welded from the edge. The sloping surfaces presented something of a problem (but not too much).

Metal run-out from the ends can be prevented in several ways. One is to tack weld steel dams in place (see steel cover in Fig. 7). A second is to have someone hold a steel bar or carbon strip in place to chill and hold the end metal of each layer in place. A third is to deposit a low amperage "bead" across the ends of each layer before depositing the hot fill part. Any of these methods will result in a rather rough and irregular surface that can readily be melted and washed off after finishing the fill part.

Control of Undercut

The finish of "Hot Arc" welds is crucial to the success of the process. There is a tendency for rather deep undercut around the edges of such welds and a tendency for the weld edges to become white iron and glass-hard unless the finish is properly handled.

The undercut tendency is due to the graphite flakes in gray iron and their not dissolving abruptly as the adjacent matrix metal melts under the intense heat of the arc. Thus, they tend to remain for a bit and for the intervening matrix metal to melt and draw away from the "dry," unfused graphite surfaced edges, due to surface tension in the molten material.

This situation can be handled in several ways. One is to leave the undercut and fill it with nickel alloy electrodes after completion and cooling of welds. A better method is to finish the edges by gas welding, which process applies heat at a slower rate and allows time for the graphite flakes to dissolve in the molten weld metal and for the edges to smooth out without undercut.

In most cases, other than with very coarse graphite, the undercut can also be eliminated by either carbon arc or gas tungsten arc welding the edges, as both processes permit slower melting and continued application of heat in a given region. If suitably experienced men are available, however, the gas process is generally preferable for edge finishing.

Controlled Cooling

Weld edge hardness is a function of cooling rate during the first three or four minutes after the deposition of passes or completion of welds. If weld edges cool from molten or near white heat to a dull, dark red or black heat within a minute or so, the edges are apt to become white iron and very hard. On the other hand, if, at the finish of welds, the cooling rate of the weld and especially the edges is controlled by application of gas torch heat so as to remain quite red, say around 1600 to 1700 F (871 to 927 C) for a period of about 2½ to 3 minutes and the cooling rate of the weld region is then controlled by torch heat so that the weld region does not cool to a black heat—say, 1100 F (593 C)—in less than another 3 to 4 minutes, the weld and heat-affected zones will be soft, gray and readily machinable.

The latter two details of undercut fill and controlled cooling of weld areas are vitally important to the success and machinability of "hot arc" cast iron welds.

Preheat

Comment about overall preheat and cooling after welding is pertinent and follows. In many cases, overall preheat to the aforementioned 1000 F (538 C) temperature range is not essential. It was not needed for the part shown in the lead photograph, largely because of no internal cross-members. Were the part more complex, containing cross-members, more even or overall preheat would be essential. In many cases, a tapered preheat may be used, with full preheat in the weld vicinity, about half that at midpoint across the part and little or none on the



Fig. 10—Unetched "Hot Arc" weld and fusion zone structure. $\times 100$

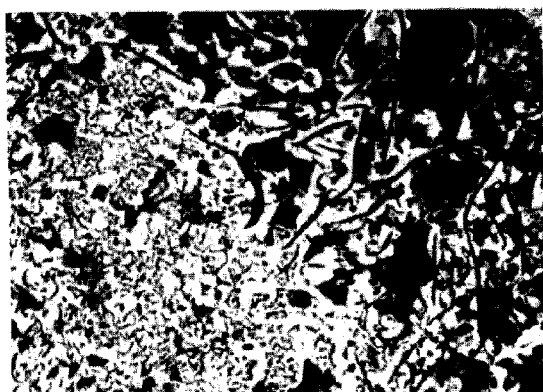


Fig. 11—Etched "Hot Arc" weld, fusion line and heat-affected zone structure. Weld is at left; base metal is at right. Nital etch, $\times 100$

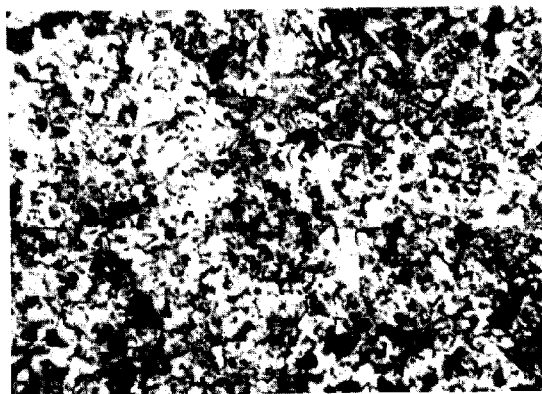


Fig. 12—Typical etched structure of "Hot Arc" weld deposits. Nital etch, $\times 100$

opposite side. The same principle but carried to a lesser degree is usually adequate for most gray iron weld repairs—say, with a full 1000 F (538 C) in the general weld area—perhaps half that on the opposite side and gradually tapered heat in between.

Preheat temperatures alone without illustration of gradients may be somewhat misleading. Cast iron melts at around 2200 to 2300 F (1204 to 1260 C) which is a rather light red or cream colored heat. In welding, the

fusion line must of course reach that temperature and there must be some sort of temperature gradient leading away therefrom. For soft, gray deposits, the gradient should not be too great.

Typical gradients for good deposit conditions are illustrated on Fig. 8. Although overall preheat may be either uniform and in the 900–1000 F (482–538 C) temperature range or tapered, immediately adjacent to weld areas, the base metal should be torch heated to a good red heat for the start of "Hot Arc" weld deposition—say, to about 1500 F (816 C)—with the drop to black heat of about 1000 F (538 C) spread over a distance of from about 8 to 12 in. as indicated by Fig. 8.

For maximum certainty of avoiding cracking or deleterious stress build-up, a full overall preheat followed by a furnace stress relief heat treatment at around 1000 F (538 C) is undoubtedly best. The large casting shown in Fig. 9 was handled in that way. It had over 200 lb of weld metal deposited in it in around 3½ hours one day, which illustrates the speed of the process. The casting was then returned to the furnace for a full overall 950–1000 F (510–538 C) stress relief. When machined, there was no indication or evidence of repair, which illustrates the quality of properly made "Hot Arc" cast iron repairs.

Discussion

The "Hot Arc" process for welding cast iron is not new. It was briefly outlined in the 1938 edition of the AWS Welding Handbook. It has also been referenced in Russian and other foreign literature. However, these references have been mainly in connection with electrode coatings to promote graphitization or produce gray iron deposits from electrodes with steel cores, details and references for which I no longer have.

Covered electrodes for this general type of cast iron welding were also available for many years in this country from the Chicago Hardware Foundry Company which, however, no longer makes the electrodes. The guidelines for welding with the Chicago Hardware Foundry Co. covered electrodes were, however, somewhat different from "Hot Arc" procedure. Lower amperage, smaller electrodes and lower preheat were generally recommended, along with more conventional quick solidifying bead deposition. From trial and what I have seen, such bead deposition frequently results in some sort of weld deposit trouble—either from slag entrapment, hard areas in welds, porosity, cracking or other factors. Conversely, high amperage, big puddle, hot weld region welding and controlled cooling procedures with "Hot Arc" have given consistently satisfactory results. So deposited, welds which are completely free of cracks and of full base metal strength can readily be made.

The metallurgical structures typical of "Hot Arc" weld deposits and heat-affected zones in gray cast iron are shown in Figs. 10–12. Tensile strength of such joints made with ordinary bare cast iron gas welding rods such as are available from any local welding supply house typically run from about 30000 to 35000 psi (241.3 MPa), and higher strengths should be readily attainable with appropriate alloying.

Conclusion

It is to be emphasized that the "Hot Arc" process is not intended for miscellaneous, odd-shaped or small part welding. It can only be used in the flat position with complete edge and root seal. For appropriate work, however, it offers an outstandingly fast method for making top quality, full base metal strength repairs in gray iron castings.

GRAY CAST IRON WELDING

CALLS FOR APPROPRIATE PREHEATING MEASURES
BEFORE PROCEEDING TO EFFECT REPAIRS WITH EITHER
OXYACETYLENE OR ARC WELDING



*Author Klimek using oxyacetylene torch and rod to make
welding repair in gray iron casting.*

BY J. KLIMEK AND A. V. MORRISON

Source: *Welding Journal*, 56(3), March 1977

The Iron Casting Society—located in Cleveland, Ohio—has provided data indicating that, in 1975, 10,622,000 tons of gray iron casting were produced. The production of ductile iron castings reached 1,825,000 tons, while 730,000 tons of malleable iron castings were produced. Data for white iron and alloy iron castings were not available.

We can reasonably assume that 0.1% of the gray iron castings produced either in 1975 or in previous years will fracture or wear in critical areas and can be salvaged by welding. On this basis, the task of weld repairing—its magnitude—and the economic advantage of reclaiming 10,662 tons of gray iron castings becomes apparent.

Cast Irons—Types and Properties

Generically, the term “cast iron” encompasses a broad variety of engineering materials, all of which have unique properties for specific applications. A brief description of cast irons—their types, physical properties and engineering applications—is pertinent to an understanding of the welding techniques used in their successful repair. In this respect, cast irons are differentiated by their color when fractured into two broad classes—gray and white. Also, they are further differentiated by microstructure, physical properties and alloy composition into many other grades. In turn, the physical properties of cast irons are established during the melting cycle by control of composition. If the iron is not an alloy iron, control is primarily related to the percentages of carbon and silicon in the alloy:

Gray Iron

The fracture surface of gray iron is gray in color due to the presence of free graphite. The alloy contains varying amounts of carbon, silicon, manganese, phosphorus, sulfur, and residuals and may be alloyed with other

elements in small amounts such as nickel, molybdenum and chromium to enhance specific properties such as machinability, tensile strength, heat resistance, etc.

In addition to color of fracture, gray irons are further differentiated by specified tensile strength, deflection and brinell hardness, there being essentially no practical yield strength, elongation or reduction of area.

The rate of cooling between heavy and light sections and other factors in the mold can, for practical purposes, affect the physical properties of a gray iron casting. All of these variables must be controlled by the foundry to produce a satisfactory product.

White Iron

The fracture surface of white iron is white in color due to the absence of free graphite, all of the carbon being combined with iron or other carbide forming elements. The basic elements in white iron are the same as in gray iron. The difference is that white iron contains appreciably less carbon and silicon, and if alloyed the amount of alloying elements added is much more than in gray iron to promote maximum hardness and erosion resistance.

White irons may be white throughout the fracture or white on the outer area and gray on the inner area depending on chemistry, section size and cooling rate. The white irons are generally considered to be **nonweldable** due to high hardness, high residual stress, low deflection plus engineering applications and economics that dictate replacement rather than repair.

Malleable Iron

Malleable iron is a low carbon, low-silicon cast iron. It has definite physical properties of tensile and yield strength and elongation due to either a ferritic or pearlitic matrix with free carbon in the temper form. The temper form of carbon has the appearance of an irregular shaped mass; this gives the malleable iron properties closer to nodular carbon iron than to flake carbon iron. The microstructure and temper carbon form are developed by heat treatment.

Malleable iron is **not normally welded** although it can be brazed or silver soldered.

J. KLIMEK is Owner and Welder, Weldize Corporation, Brooklyn, N. Y., and A. V. MORRISON is Chief Equipment Inspector, Chevron Oil Company, Perth Amboy, N. J. (Editor's Note: At age 75, Mr. Klimek is still welding and has 50 years of gray iron welding experience.)



Fig. 1—Preheating a gray iron casting with charcoal before proceeding with welding repair

Alloy Cast Iron

The term "alloy cast iron" can be construed to include a great variety of cast irons, from ductile cast iron to austenitic cast irons, including alloyed gray and white cast irons. The most unique of these is ductile cast iron which is made by inoculating gray cast iron with magnesium. The addition of magnesium causes the normal gray cast iron flake graphite to assume a nodular or spherical shape. Composition control and heat treatment result in a cast iron having the essential physical properties of a low carbon steel. The nodular structure is **not retained** if these irons are **welded**.

Other alloy cast irons encompass a range of alloy content from less than 1% to over 20% of alloying elements such as tellurium, phosphorus, nickel, chromium, molybdenum and silicon, each of which implants unique properties of hardness, heat resistance, corrosion resistance, and impact strength, etc., for specific engineering applications. Some alloy irons can be welded but normally are not.

Welding Repair of Gray Iron Castings

"Burning In"

If welding can be construed as being "the application of sufficient heat to a base metal to cause it to melt and form an alloy with an applied liquid metal or itself", then the first gray iron welding repair method would probably be the foundry method of "burning in" a defective casting.

"Burning in" is done by building a containment around the defective area and then slowly but continuously pouring molten metal into and overflowing the

containment until, by judgement and experience, fusion with the base metal is achieved.

This type of weld repair is a foundry method applicable to relatively large expensive raw castings with small defects. It is not applicable to field or shop repair of finished and engineering applied castings.

Arc and Oxyacetylene Welding—Comparisons

Gray iron castings may be repaired in the field or shop by means of arc or oxyacetylene welding. However, either type of welding without proper preheat involves the strong possibility of cracking due to the concentration of heat resulting in severe thermal gradients and stress concentrations during the heating and cooling cycles. In addition, some section of the fusion or heat-affected zone matrix will transform to martensite which is an embrittled phase, thus compounding both current and future woes.

Of the two methods of welding without specific preheat, arc welding is more prone to cracking and martensite formation than is oxyacetylene. In addition, arc welding does not give a color match due to core wire, an iron-nickel alloy, being a different composition than gray iron, an iron, carbon, silicon alloy. This may or may not be of importance depending on application. The same is true of brazing with copper base alloys.

With either oxyacetylene or arc welding, preparation of a defect area by mechanical means—grinding, chipping, machining—is a prerequisite to success. Moreover, with arc welding, skip welding, peening and cooling to ambient temperature before applying the second pass, etc., are recommended to help avoid the undesirable effects of cracking and martensite formation due to the

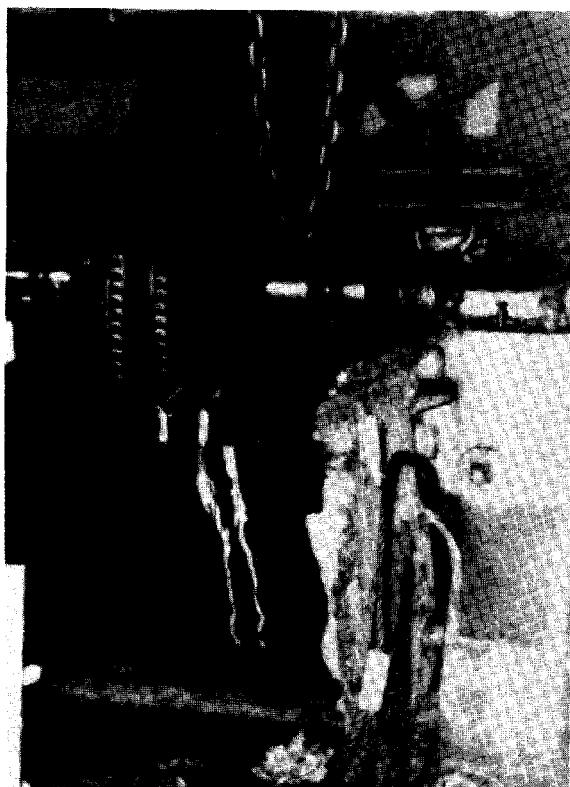


Fig. 2—Cracked "Elliott" 600# steam turbine



Fig. 3—Cracked "Elliott" 600# steam turbine prepared for welding repair and preheating

heat generated by the arc. An oxyacetylene flame is considerably colder than an arc, and its heat is not as concentrated. The result is that a welder must apply considerable preheat before he can commence actual welding, a result being that cracking and martensite formation may be minimal.

Preheat Procedures

Some Basic Considerations

Preheating a gray iron casting sounds simple but actually requires forethought, equipment, time, patience and—very often—experience. Forethought is required to look at the defective casting and form a mental or written plan of job progress. Included in the plan are items such as casting alloy composition, overall dimensions of the casting, wall thicknesses of both the area to be welded and other areas, and grinding out the defect. Other items to be considered are rate of heating, positioning of casting for desired sequence of welding (which may involve several moves of a hot casting or cycles of heating-cooling-heating), electrode and torch sizes and types, fitting, thickness and type of insert material, etc.

The minimum preheat temperature to successfully weld gray iron castings is 700 F (371 C); 800 F (427 C) is preferred and up to 1100–1200 F (593–649 C) will not hurt and may actually aid in acetylene welding because some casting thicknesses are tremendous heat sinks, and proper fusion as well as impurity and gas bubble flotation require that the welder be able to maintain a pool of fluid metal.



Fig. 4—Welded "Elliott" 600# steam turbine

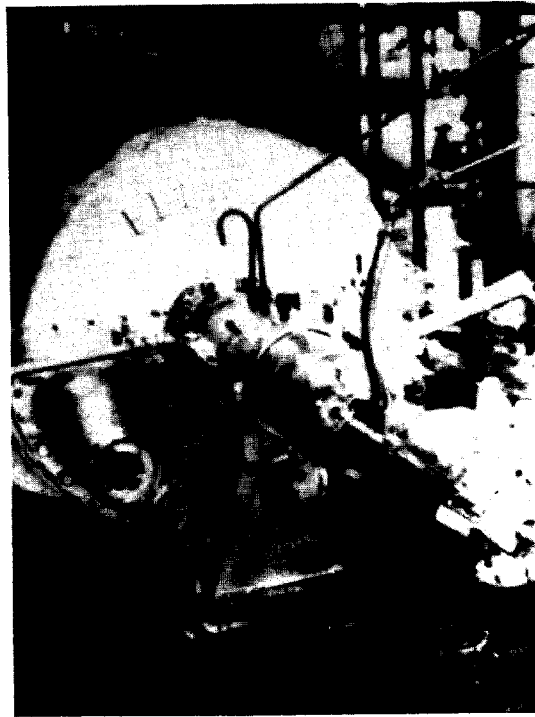


Fig. 5—"Elliott" 600# steam turbine back in service—only minor machining was required after welding repair

Equipment

Preheat equipment varies from the simple and cheap to the elaborate and expensive. All preheating should be done in a refractory oven. The oven can be constructed of loose bricks to accommodate one-of-a-kind type jobs, or it can be a permanent oven to accommodate multiple, similar jobs such as cylinder heads.

The use of a refractory oven is crucial to success when weld repairing complex castings. This is because it permits controlled rates of heating and cooling to avoid thermal stresses and retains residual heat during the actual welding operation.

Depending on the job, other equipment would include welding supplies, cranes, machine tools and miscellaneous handtools.

Fuels

The fuel for preheating may be gas, charcoal briquettes or wood charcoal. If the fuel is gas, it must be diffused through a bed of refractory briquettes to permit slow, even heating. With all but the most simple uniform-wall thickness castings, a direct gas flame will result in high thermal stresses and potential cracking.

Many old time practitioners of the art of acetylene welding gray iron castings (including coauthor Joe Klimek) firmly believe that the best fuel for miscellaneous small to medium sized castings is wood charcoal. However, a more modern concept well established in the pressure vessel, piping, chemical plant and petroleum refining industries which has not been applied to gray iron welding is to use electricity for fuel, especially when preheating large castings.

The development of reliable, accurate thermocouples and resistance heating blankets applicable to almost any

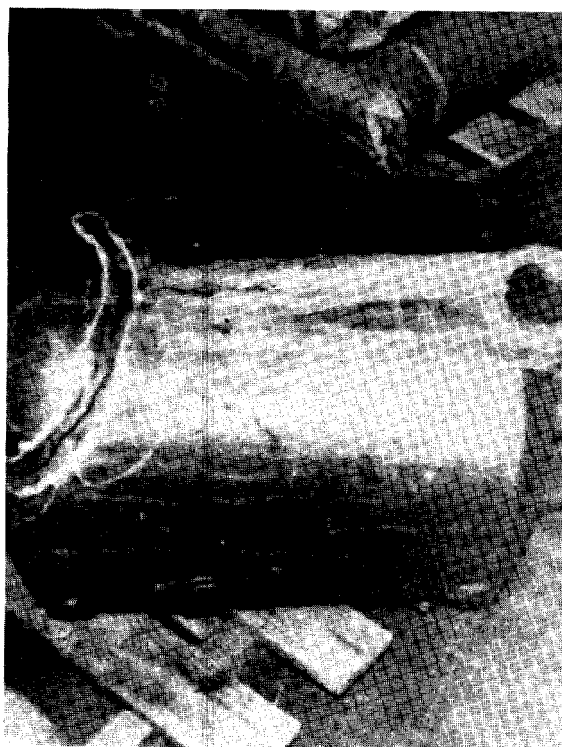


Fig. 6—Cracked “knock out pot”

shape, together with programmed multi-point time-temperature controllers and lightweight insulation, must be noted. Together, these are more feasible, safer and more desirable than an open flame for preheating prior to effecting weld repairs in gray iron castings.

Final Considerations

Preheating is time-consuming and is thus an anathema to much modern industrial production thinking. A multi-wall complex casting of varying wall thicknesses may take two to four hours to preheat slowly to welding temperature. To go much faster is to invite trouble from thermal stresses. It is common practice to preheat on the night shift and weld on the day shift.

If a casting is properly preheated, then either oxyacetylene or arc welding, or brazing, will make a useable joint depending on application. If the preheating is not correct, none of the welding methods will be totally satisfactory.

The choice of welding method is dictated by job variables, i.e.:

1. Is color match important? If “yes,” use oxyacetylene welding and gray iron rod. If “no,” use either oxyacetylene or arc welding with nickel alloy rod.
2. Is out of downhand welding required? If “yes,” use arc welding, although oxyacetylene welding with gray iron rod can be used very well vertically.
3. Are increased strength and ductility required at a high stress crack location? If so, use arc welding and nickel alloy rod.
4. Speed of welding—this is important on any job for cost control. However, actual welding time is generally self-administrative, because the nature of gray iron welding is such that once you start to weld you must

finish. Other factors such as preparation, preheating, finishing and overhead are cost controlling. However, it is to be noted that, with an oxyacetylene torch with a big tip and two 3/16 or 1/4 in. (4.76 or 6.35mm) rods welded together to make one, it is possible to deposit filler metal very fast.

5. Are pressure tightness and uniform thermal expansion important such as on cylinder heads or steam turbine or pump cases? If “yes,” the choice is oxyacetylene welding with gray cast iron rod. This is because the finished welded casting must be as uniform as possible.

Differences in chemical composition as related to elements that impart fluidity to molten weld metal (i.e., carbon, silicon, manganese and nickel) make the difference between “good” iron and “dry” iron, and strongly influence the ease of fusion. Contrary to a popular welder’s belief, the previous service of the casting does not “burn” these elements out of the metal unless it is a high temperature application such as the surface of a steel ingot mold.

The normal difference in composition between the skin of a casting and the interior also may present difficulties in tying in the surface pass. However, the main difficulty is that some castings have included gas pockets, sand, gas producing inclusions, etc., which result in pressure test rejections unless carefully removed during the actual welding operation. In this respect, oxyacetylene is superior to arc welding because the welder has a chance to work out the defects. The oxyacetylene welding is thus enhanced by the skills of an experienced welder of high integrity and devotion to the art such that its superiority cannot be surpassed as a repair method for gray cast iron.



Fig. 7—Welded “knock out pot.” No leaks were detected after welding repairs were made

The metal arc welding of cast iron for maintenance and repair welding

by Clive Cookson, M.Weld.I.

The author argues that the development of low heat input weld metal compositions and welding techniques have made metal arc welding a viable proposition for cast iron repair work.

The metal arc welding of cast iron is still widely considered as a dubious method for joining and overlaying. It is true that many difficulties do exist, but with the development of specialised low heat input weld metal chemistries and welding techniques, these difficulties have been largely overcome, with the result that repairs over a wide field can be carried out confidently.

In this paper, the selection of suitable weld metal compositions is considered, and the paramount welding and metallurgical problems discussed, together with possible solutions. Finally, a selection of difficult but successful weld repairs is presented.

Heat input

The heat from the welding arc results in the formation of a liquid pool consisting of a weld/base metal mixture which brings a narrow band of base metal to an austenitic condition causing rapid solution of the graphite flakes or nodules.

This austenitic region becomes enriched in carbon, and the rapid quench effect from the base metal mass, as the arc is traversed, transforms the carbon-rich austenite to martensitic structures with eutectic carbides at the interface where carbon-rich microscopic pools have formed.

This interfacial carbide band can be continuous or discontinuous. The heat treatment necessary to transform this heat affected zone (HAZ) and so alter the structure is generally impractical on large components, and also on smaller components which have been extensively machined, due to scaling and distortion problems.

The depth of the HAZ is relative to the heat input and the welding technique used. It has been shown that where electrodes are used which exhibit a soft arc-brazing characteristic, minimal hardening occurs due to a reduction of hard transformation products.¹ This is illustrated in Fig. 1 with a macrograph of two weld deposits made under identical welding parameters. The low dilution value can be seen on the left, which has produced minimal hard microconstituents in the photomicrograph beneath. There is evidence of only slight, discontinuous carbide at the interface. In Fig. 1, right, high dilution has occurred with mass martensitic and carbide structures shown in the relevant micrograph.

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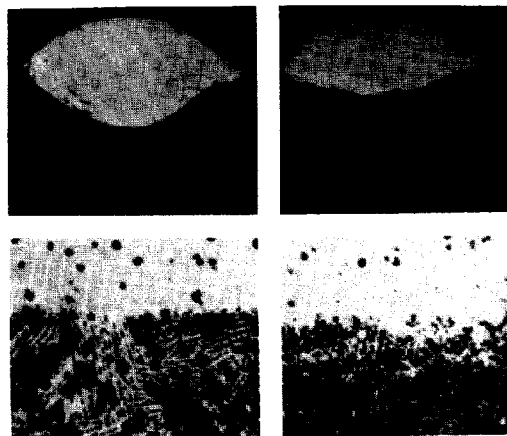
The depth of hardening of a particular cast iron, which governs the width of the HAZ, depends to some extent on the structure of the cast iron before welding. The presence of pearlite, especially in SG irons, can influence the depth of the HAZ, the controlling factors being solution of carbide and diffusion rates of carbon. The actual hardness of the HAZ, however, does not differ very much with different irons.

Choice of electrode chemistry

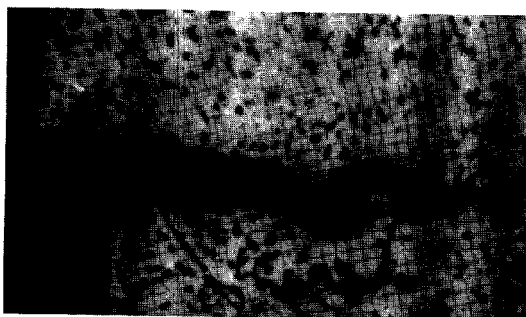
Research work is being carried out by the author's company on improvements to metal arc electrodes for the welding of cast iron. It is generally established that the 60/40 nickel iron type of electrode offers the highest crack-resistivity, but remarkable results have been obtained with various flux coatings extruded on identical filler wires. Flux densities, remelt and flotation characteristics are also pertinent factors in the homogeneity of the weld metal.

Figure 2 shows the effect of a slag inclusion and the incipient hot cracks emanating from this. Microscopic inclusions of this nature can lower the tensile strength to around 93 N/mm², as shown by specially prepared tensile specimens.

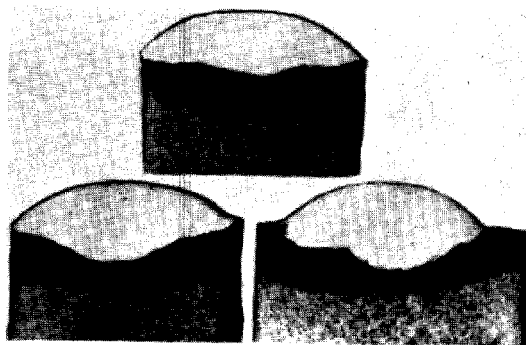
1 Two weld deposits made under identical welding parameters: (left) low dilution value, (right) high dilution



Source: Metal Construction and British Welding Journal, May 1971 (The Welding Institute)



2 Effect of a slag inclusion with incipient hot cracks ($\times 100$)

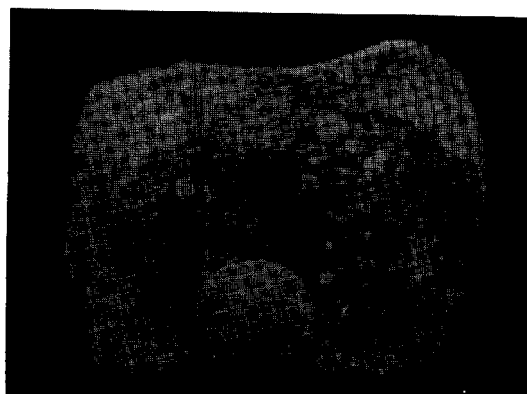


3 Effect of three different coatings on a 60/40 Ni:Fe alloy using identical welding parameters



4 HAZ cracking, using austenitic stainless steel filler ($\times 100$)

5 Formation of massive brittle Al:C:Fe nodules, aluminium bronze ($\times 10$)



The test programme indicates that an even wider range of electrode types with repetitive core wire chemistries will be required in the maintenance field of weld repairs to cope with specific problems. This could well illustrate the folly of grouping electrodes by core wire composition, and making a selection on economic grounds. (Figure 3 shows the effect of three different coatings on a 60/40 Ni:Fe alloy using identical welding parameters.)

Austenitic stainless steels

An austenitic stainless steel is sometimes favoured for the welding of cast iron where bonding problems are encountered. Although only a low percentage of presumably successful repairs have been made using this chemistry, it usually involves the deposition of only a small amount of weld metal. However, even a few successes will raise an obvious danger if this opinion becomes more widespread.

Investigations by the author have shown that in certain cases successful welds can be made on cast iron, using austenitic stainless steel electrodes, where the degree of restraint is low, or where the deposit is in compression to the base metal.

AWS E312/16 filler metal, popularly referred to as the 29/9 type (Cr:Ni), was also employed in the test programme; this seemed an obvious choice due to its high crack resistivity attributable to the high proportion of intergranular δ -ferrite which provides preferential precipitation sites for the dissolved impurities and certain elements melted from the base metal.

Various degrees of cracking were observed in the weld metal, due possibly to the excess precipitation of carbon at the ferrite/austenite phase boundaries. HAZ cracking was very prominent where restraint was inherent in the joint (Fig. 4).

HAZ cracking does epitomise the problem of using austenitic stainless steel filler materials; their undesirably high physical properties make the brittle HAZ even more pronounced and vulnerable to stress. The yield point of austenitic stainless steels exceeds the strength of the lower strength cast irons.

A further risk with the use of these welding materials is the introduction of chromium which increases the hardness of the austenitic transformation products and of the carbides formed, $\text{Fe}_3\text{C} \rightarrow \text{Fe/Cr}_3\text{C}$.

Tin bronzes were also investigated and three problems were confirmed: (a) weld metal cracking, (b) poor bonding, and (c) base metal cracking due to copper penetration of the grain boundaries.

Aluminium bronzes proved to be successful in many cases, especially with cladding operations on cast iron, but iron and carbon pick-up also proved to be highly detrimental on restrained joints, especially where higher than usual amperages were used on initial runs to overcome bonding problems, due to the formation of massive brittle Al:C:Fe nodules (Fig. 5). With heavy build-ups, cleavage of the initial run occurred, due to embrittlement in this area.

Tests using a nickel buffer layer and a low penetration technique (Fig. 6) minimised this problem. However, the high tensile strengths and low elongation values ($< 5\%$) developed with the heat-treatable aluminium bronzes as-deposited, make them a dubious choice for the general repair welding of cast iron.

Ferritic deposits

The use of ferritic deposits for the welding of cast irons is fraught with many problems. Figure 7 shows a grey

cast iron joint edge clad with two layers of a ferritic deposit; the extent of cracking can be seen.

With single deposits, cracking was in many cases not observed, but the structure consisted of a broken carbide network in a martensitic matrix. The average hardness of the single layer was 500 DPN.

There are cases in maintenance repair welding where the choice of this chemistry is a viable one, but it is incorporated sparingly and in individual stringer beads, usually in chamfered grooves to obtain high strength bonding.

Nickel-base electrodes

Electrodes containing >90% Ni and the 60/40 Ni:Fe type have undoubtedly emerged as the most satisfactory chemistries for the welding of cast irons, generally because of their desirable mechanical properties and ability to precipitate the carbon picked up from the base metal in its free form as graphite.

Figure 8 shows a 60/40 Ni:Fe deposit, consisting of a cored, solid solution structure containing graphite nodules and aggregates, the nodular form due to residual magnesium in nickel, used as a deoxidant.

Certain weaknesses can exist in a deposit containing a microstructure in which free graphite aggregates predominate. A preference for the formation of graphite spheroids + carbide is indicated and this can be encouraged with modification to the flux coating.

The high nickel electrode, while being more ductile, is prone to weld metal cracking under restraint during welding. However, on large fills, the higher strength nickel iron deposits can create a tensile stress on the HAZ and promote cracking problems in this area. The author devised a 'cross' technique which overcame these problems on a specific repair, and this is described later.

Tensile tests carried out on SG cast irons welded with a 60/40 Ni:Fe electrode, showed average values of 550 N/mm² on pearlitic structures, and 454 N/mm² on ferritic structures, elongation (50 mm) being 2% and 6% respectively.

In-service conditions

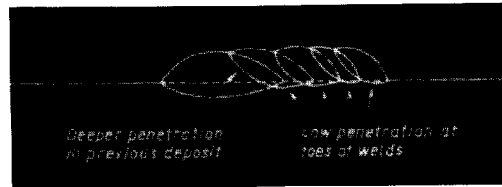
Grey flake cast iron has relatively low ductility and so its uses include in-service conditions which do not involve high fluctuating stresses or shock loading in which the SG irons are better employed. The welding of the SG irons for this kind of in-service condition is, however, not under discussion. Where tensile stresses are involved with grey iron casting then the framework is inevitably massive to provide a high safety factor.

Grey cast iron is widely used for machine tool castings, pump casings, bearings, heavy rolls, turbine casings, liquid containers and many more. There is a strong need in industry today to repair worn and broken parts to prevent downtime which is sometimes disastrously extended with long delivery dates. Without any doubt, the above applications constitute the largest proportion of cast iron welding.

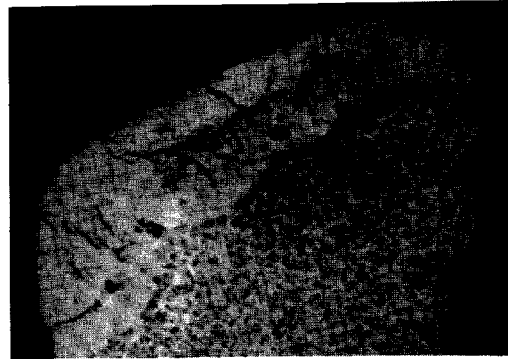
The problem facing the welding engineer is that the component should be restored to a mechanical condition which is comparable to the original casting. Many failures occur due to lack of knowledge of the problems which exist in the welding of cast iron.

The choice of weld metal chemistries has been shown to be vital, with the nickel-free chemistries providing minimum chance of success.

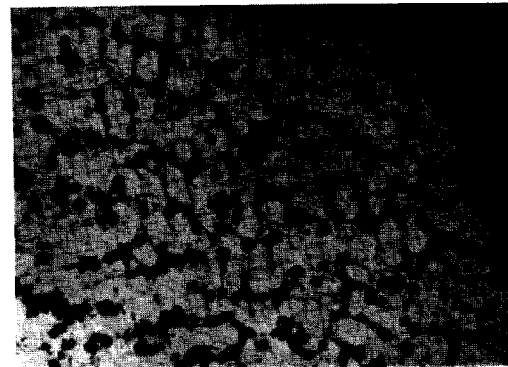
Failures which could have been avoided only strengthen opinion among some factions that cast iron cannot be welded with the metal arc process, and this could be no further from the truth.



6 Tests using a nickel buffer layer and a low penetration technique

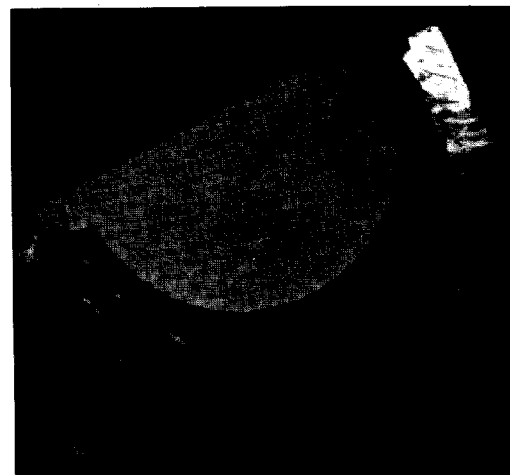


7 Grey cast iron joint edge clad with two layers of a ferritic deposit



8 60/40 Ni:Fe deposit consisting of a cored, solid solution structure containing graphite nodules and aggregates

9 Extent of wear in a segment of a steel half casing



Problems in welding

The main contributory factors to failure of a weld repair to a casting during welding, after welding, or while the component is in service are as follows:

Ferritic deposits. Ferritic deposits will harden when deposited on cast iron due to carbon pick-up and the high quench effect. Apart from their sensitivity to cracking, they also develop undesirably high physical properties, including high yield strengths.

Heat build-up. There is usually a heat build-up in the

casting unless long inter-weld pauses are observed. Expansion and contraction is unbalanced and cannot be tolerated on highly restrained areas of castings and especially thin sections. Grey cast iron has negligible ductility, and so the stresses developed cannot be absorbed by distortion in the casting.

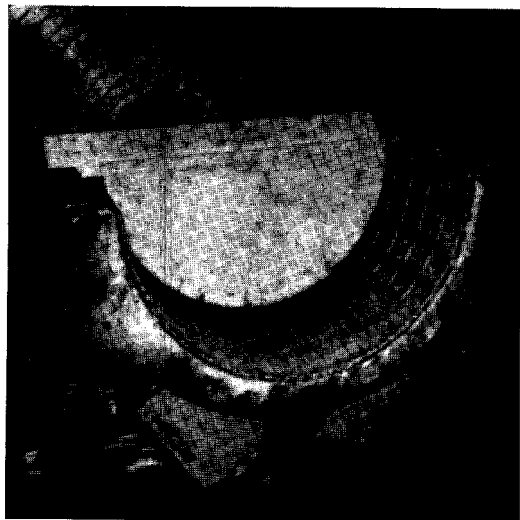
The MS Mf range for cast irons depends on a number of factors, but the Mf point generally is not below 90°C. Tests have shown that if the weld deposit length is curtailed to $\times 2$ the base metal thickness on thin sections, the temperature upon breaking the arc is below 100°C, falling in seconds to around 40°C on the first run. If an airline is employed to quench the deposit and remove the excess 20°C, then each and every run will be a facsimile of the preceding one. No detriment will result to the base metal by quenching from up to 90°C when this temperature is induced locally in the weld area with curtailed deposit length on a previously cold casting. The quenching of small castings would not be necessary where a uniform heat build-up can be obtained.

Crack susceptible weld metal chemistries. Deposits which have significant ductility dips and/or low melting intergranular films are not generally suitable for the welding of cast iron where restraint in the joint or repair area is encountered, this being frequently the case on massive castings.

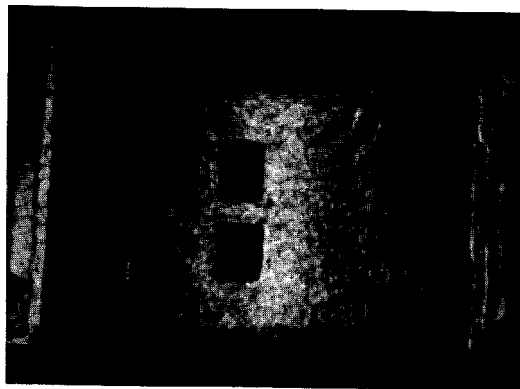
Improper welding techniques. It is generally advisable to deposit stringer beads when welding cast iron, so avoiding an excessive weaving motion. Craters must be filled both at the start and completion of a weld run. A parallel line of stops and starts should also be avoided. De-slagging must be judiciously exercised to avoid flux entrapment.

Heavy build-ups. Large deposits create an undesirable tensile contractional pull against the base metal, and so it is necessary to drastically reduce this by peening and other techniques like the 'cross' formation with a more ductile chemistry.

HAZ hardness and width. Ways of minimising the extent and hardness of the HAZ have been discussed, as this is the prime reason for cracking and failure of welds on cast iron. It has been proved conclusively that cutting stress grooves and so scolloping the joint surface, and consequently the HAZ, together with the use of low heat input chemistries and techniques, virtually resolves this problem. However, the geometry, design and spacing of the grooves is of the utmost importance and can vary with each repair.



10 Technique of depositing stringer bead 'squares'

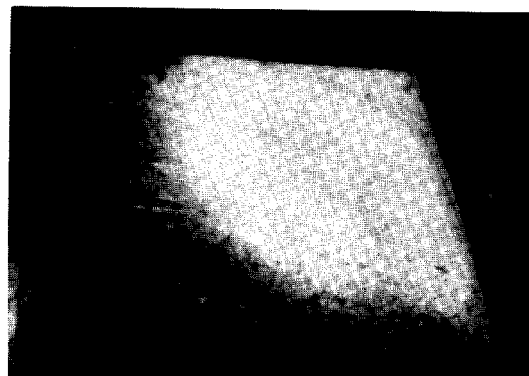


11 Half casing completed, showing extent of build-up

12 Stack cooler repair; a cross design was built in the centre of the defect



13 Stack cooler repair; line at weld/base metal interface caused by austenitic type filler metal and ferromagnetic casting creating north and south pole



Preparation. The importance of correct preparation of the defect or damaged area before welding cannot be over-emphasised. The area should be ground and dye-penetrant tested to ensure a sound base, with all corners and edges radiused. The casting should also be warmed to 20°C before the welding operation begins, as hydrogen induced HAZ cracking in the welding of cast iron cannot be ignored. It is also advisable to bake electrodes immediately prior to use. On no account should damp electrodes be used.

Some successful weld repairs

Half casing. In one example, taken from a major steel-works, extensive wear had resulted in severe damage to four bearing half casings from a large sheet steel cropping machine. The material was grey flake cast iron to BS 1452 Grade 14. Figure 9 shows the extent of wear on one of the segments. Numerous welding contractors were approached and all considered the repairs to be impossible.

A procedure was drawn up by the author which included preparing the surface and cutting stress grooves across the face. The grooves were filled with a low heat input electrode (60/40 Ni:Fe type). The area was then divided into squares, using stringer bead deposits (Fig. 10). These squares were then filled with the deposits transverse to those in the adjacent square to break up the stress pattern. A high nickel type deposit was also employed in the repair, observing techniques previously discussed.

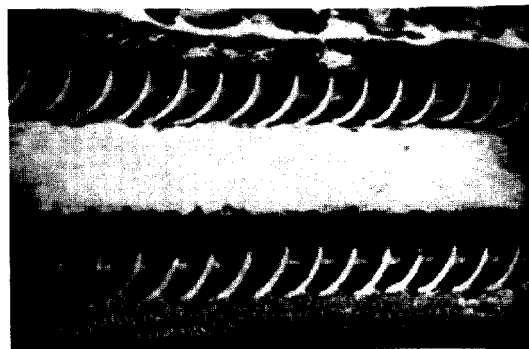
Figure 11 shows one half casing completed, and the extent of build-up can be seen. The nickel-iron type deposit was used on the final layers because of its better bearing properties. The repairs were completed eighteen months ago and the components are still performing satisfactorily.

Stack cooler. In another example, unavoidable sand scabs during the casting operation had resulted in defects in grey cast iron cooling panels for furnace lining in steel production. The section thickness of the panels was 125 mm, and the defects averaged 150 mm in diameter and up to 37 mm deep. It was important that the thermal transfer properties were not denuded by weld defects including cracks or porosity. Earlier attempts at a repair resulted in weld metal cracking and weld/base metal cleavage, the latter caused by an undesirable tensile contraction stress in the weld deposit.

The following technique was devised and proved completely successful in the nineteen repairs. The area was ground and dye-penetrant tested, and then warmed with a flame to 20°C. Stress grooves were cut around

the periphery, and filled with a low heat input metal arc 60/40 Ni:Fe type deposit. The low penetration buttering technique was carried out, followed by grinding and testing. A 'cross' design, using a high nickel electrode, was built in the centre of the defect (Fig. 12) and the intercross areas filled with the 60/40 Ni:Fe type previously used. Grinding of the surface and dye penetrant testing was observed at each fill-in stage of this first test.

The 'cross' technique was used on each layer built up, ensuring that the crosses were in different positions to avoid a straight-through layer of high nickel deposit. The final layer was ground and tested both with dye penetrant and the magnetic particle technique. Note the line at the weld/base metal interface, Fig. 13, caused by the austenitic type filler metal and ferromagnetic casting creating a north and south pole in much the same way as a discontinuity.



15 Ship's turbine repair, showing extent of cavitation (above), pad layer ground to size (centre), and (below) descaled area ready for welding



16 Stress grooves filled with a 60/40 Ni:Fe type electrode

14 Difficult working conditions for ship's turbine repair welding



17 Effect of peak technique for required build-up (peaks indicated by chalked arrows)





18 Finished repair after filling in inter-peak areas and grinding to size

Ship's turbine. A few years ago a weld repair operation was successfully carried out to two LP cast iron marine turbine casings on board the 28,000 ton P & O liner RMS Oronsay. The repair work was necessary owing to extensive metal loss, caused by water droplet erosion resulting from high velocity impingement of moisture beads expelled from the rotor blade tips. The casings were grey flake iron conforming to BS 1452 Grade 14, and the blades were of Monel.

Preferential loss of the cast iron base metal had occurred (a) on the surface and inside edge of the gasket face, (b) between the individual blades on the first rows of each casing, and (c) the spaces between the blades up to and including the first eight rows. The root lacing wires were also exposed on the first rows by loss of the low moor iron locking strips and spacers.

Metal arc welding was employed, using a 60/40 Ni:Fe soft brazing type electrode to replace the lost metal, to

consolidate the blades to the casing, and to fill in the inter-blade areas where loss of the spacers had occurred.

The quench weld technique, using an airline, was employed with peening of the deposits; 90% of the welding was carried out in the vertical-up position. The success of this repair resulted in a similar repair being carried out on the RMS Himalaya. The Oronsay repair has been described in detail elsewhere.²

Figure 14 shows the difficulties of the working conditions; Fig. 15 shows extent of cavitation (above) pad layer ground to size (centre), and (below) a descaled area. The need to obtain sound deposits can be appreciated as cleavage of the weld metal could cause extensive damage to the blades of the casings and rotors.

Wobblers in steel works. The wobbler ends of cast iron and steel rolls are subject to extensive wear. In this example, while welding of the steel wobblers poses no real problem, the SG cast iron wobblers had not been successfully reclaimed. The techniques outlined previously were conformed to, with air quenching exercised throughout the repair.

Stress grooves are cut across the worn face and then filled with a 60/40 Ni:Fe type electrode (Fig. 16). Due to the extensive build-up required, a 'peak' technique was devised (Fig. 17) which simulated small mountain peaks, indicated by arrows. The inter-peak areas were finally filled and the repair ground to size (Fig. 18). Four such welding operations are required on a single wobbler end. The repair gave eighteen months satisfactory service.

The author does not deny that the welding of cast iron is a difficult and complicated task. It requires specialised knowledge and, possibly, a welding technique tailored to each individual problem.

Welder training and absolute participation in the repair lay-out is vital. Nickel-free chemistries can, and indeed are, used in the welding of cast iron, but any preference for these should be calculated against a possible failure which would make the nickel-free types the most expensive ones.

Massive repairs on sections up to 1200 mm thick have not been discussed in this paper, although such repairs frequently have been carried out. One such repair to a massive cast iron frame in a steel works has been performing satisfactorily for over two years, with high tensile stresses on the joint area. However, techniques for these repairs are radically different from those that have been discussed, and fall outside the scope of this article.

References

- 1 Cookson, Clive. 'Repair of LP cast iron marine steam turbine casings'. *Weld. and Met. Fab.*, August 1969.
- 2 Cookson, Clive. 'Quench welding process for joining cast iron'. *Weld. and Met. Fab.*, August 1970.

Maintenance and repair welding of castings

By C. Cookson, FWeldI, LIM, AMIET

Well over 85% of all weld repairs in the field of service repair and maintenance welding are carried out on castings. In many respects the repair and maintenance technological side has to be highly alert, because modern engineering developments constantly create gaps in the acquired knowledge, gaps that have to be closed with the aid of welding engineering and metallurgical work. New concepts of weld metal chemistries also have to be developed to meet these contingencies and to maintain the repair and maintenance field as a specialised operation, even though largely operating outside that line of welding controlled or guided by national or international standards. Full metallurgical backing is just as essential as welding engineering, and both these functions are usually controlled by one man, the Welding and Metallurgical Engineer. His job is to examine a damaged component, assess all the facts, carry out the required tests, then draw up a welding technique and choice of welding material and often do the practical repair himself. Quality control of all welding products brought into the company may be his responsibility also, together with the development of custom-made weld metal chemistries and fluxes. Unfortunately a repair technique used on one casting is not a panacea: each repair must be considered individually. The case histories discussed in this Paper merely brush the myriad of problem repairs in the repair and maintenance field.

CASE HISTORY NO. 1

Metal-arc repair to cast iron bridge

In 1968 serious cracks were observed in the structural members of the Osney Bridge, Fig.1, which carried the A.420 over the River Thames in the western approach to the City of Oxford. The structural beams are cast iron similar to

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BS 1452, Grade 14. The cracks had propagated to the fillet area from focal stress points and in some instances had encroached into the cruciform section of the upright. Seventeen cracks were found, all similar in magnitude, every one on the side nearer the crown of the bridge section.

The exact cause of the damage was not known, but it is assumed to be associated with cyclic loading caused by the passage of heavy vehicles during the war periods, and the

Source: Welding of Castings, The Welding Institute, 1977

presence of large surface sand scabs in an area adjacent to the focal stress points.

In view of the extent of cracking a repair was necessary, and, because of the condition of the parent metal, it was necessary to effect the repair by metal-arc welding. A high safety factor was achieved by incorporating into the weld repair plain carbon steel bars, which extended across the front face of the web, thus giving an additional bond to more sound areas.

A section of the parent metal was removed for analysis which showed the phosphorus content to be 0.9%. A special welding procedure and technique had to be devised to minimise weld metal repulsion and to eliminate lack of fusion and cracking dangers.

The bridge, which was completed in 1888, consisted of eight arch ribs, two sections of which were more recent additions to widen it; these were sound. The remaining seven inner arch ribs contained 112 'junctions', seventeen of which had suffered extensive cracking.

A two-stroke, 200A, 450 cycle, AC welding machine was positioned on the bank, and the earth lead was fixed to the outside section of the bridge. The welding lead, which measured 100m was laid across the river bed and brought up into a barge to a receiving plate from which two electrode holders were taken.

In view of the amount of inter-deposit work of peening, deslagging and cooling, it was possible to have uninterrupted welding from both leads, though not simultaneously.

All the members of the bridge were ground and dye penetrant tested, Fig.2a. A 6mm diameter hole was then drilled at the termination of each crack which was afterwards cut through with a hacksaw, Fig.2b. The cracks were ground out U fashion, one-third from each side, and a nickel strip inserted. The insertion of the nickel strip was a new technique devised by the author, Fig.2c.

The electrode used for the entire repair was a 60%Ni-40%Fe type, of 3.2mm diameter, as this allowed better practical control during welding which was carried out in the flat, horizontal/vertical, and vertical up positions.

It was necessary, when welding began at 0800hr, to use a propane torch to warm the parent metal to $>30^{\circ}\text{C}$ to avoid condensation and any danger of hydrogen-induced heat-affected zone (HAZ) cracking.

The technique of inserting the nickel-iron strip into the hacksaw cut through the crack may be summed up as:

- 1 The hacksaw cut removes any rust and impurities which may cause outgassing

during welding, with subsequent disruption of the welding arc.

- 2 The metallurgical notch effect at the root is possibly minimised.
- 3 Practical tests and metallurgical examination of typical sections showed clearly that the weld metal on the initial weld beads on the outside of the joint was allowed to contract by the closing of the joint faces into the annealed nickel strip.
- 4 Although no significant additional strength would be achieved in the joint by welding each side into the nickel strip, the neatness of the joint and other attendant advantages can be appreciated.

The bar-reinforcing operation was pre-faced by a weld cladding operation. A 12mm diameter 0.4% carbon steel bar, bent to fit the configuration, was then positioned and fillet welded to the clad layer, Fig.3. The yield strength of the bar and weld metal was calculated at $>460\text{N/mm}^2$ which added a high safety factor to the repair.

It is suggested that in view of the excessive sand scabs, which had to be ground away at the joints, this repair was possible only by metal-arc welding. The success of this repair, after more than three years, may be of real significance, as this is, to the author's knowledge, the first of its kind.

CASE HISTORY NO. 2

Repair of a furnace roll

Attempts at weld reclamation on 25/12 Cr-Ni furnace rolls ($\text{C}=0.5\%$) from a Priest normalising furnace, which had been in service for some years, were unsuccessful because of the severely embrittled state of the parent metal; this had resulted in extensive cracking in both weld metal and parent material. The preweld solution heat treatment was not possible with the equipment available. The author was asked to investigate the problem.

The roll, which measured 5.5m in length, 419mm in diameter, with a wall thickness of 38mm, was constructed from a barrel, centrifugally cast in one piece, with a bell-end casting (static cast) welded into each end after shrink-fitting.

During service, the maximum live load of 1783kg is distributed over a 3.2m length, and the maximum temperature was estimated at 960°C , although this ceiling temperature

depended on the specific heat treatment being carried out. Each roll is driven from one end at 1rev/min.

Service failure of the rolls was caused by extensive cracking in the weld/parent area of the original fabrication, a situation which often results in complete separation of the bell-end casting from the barrel during service. This particular roll had been in service for seven years, and the problem seemed relevant to all the other rolls in the furnace as regular replacement was becoming necessary.

Preparation of weld area

Complete removal of the cracked and eroded weld metal and adjacent parent metal to provide a joint design free from defect, produced a channel 127mm wide; this promoted a condition which underlined the stress problem because of the extensive weld deposit then required.

A section of sound parent metal was removed from the joint area for metallographic examination. The structure, Fig.4, is basically austenitic with prolific intergranular $M_{23}C_6$ carbide, which has coarsened, presumably because of the relatively long periods at high temperatures. The presence of sigma is indicated by the random needle-like phase.

Further sections were taken of weld deposits, tests being carried out on joint faces in the repair area using conventional welding metal. The 'bead-on-plate' test was also conducted on various parts of the joint, and gross fissuring occurred around the entire periphery of the deposit.

The tests proved that a conventional weld repair was totally impractical, especially in view of the extensive joint preparation necessary to provide a sound parent area.

The embrittlement of high chromium and austenitic chrome/nickel steels by the formation of sigma and $M_{23}C_6$ carbide can occur when service temperatures in the range 680°-850°C are encountered. Although the degree of embrittlement may be extensive in many situations, experience indicates that the component can still continue to give satisfactory service, although any attempts at weld repairs are largely unsuccessful because of parent metal cracking caused by nonuniform expansion and contraction, and the stresses created by weld metal contraction.

Although the maximum operating temperature of the furnace, 960°C, is above the upper critical temperature range for the formation of sigma, it must be realised that such a furnace may frequently operate or be held for long

periods within the 600°-850°C range, and once the sigma phase has been formed the maximum operating temperature of 960° is too low for rapid dissolution.

Problems to be overcome

It was established from weld deposit tests that a number of problems had to be surmounted for a successful repair to be obtained.

Firstly, parent metal embrittlement, presumably caused by the prolific formation of $M_{23}C_6$ carbide and some sigma, reduced the parent metal ductility, and the stresses created by localised expansion and contraction, because of heat from the welding operation, could not be absorbed without cracking occurring.

Secondly, the extensive joint preparation required demanded a prodigious amount of weld metal which would produce very large strains on the joint walls.

This particular problem of embrittled cast austenitic steels is synonymous, from a practical point of view, with the low ductility found in certain grades of grey cast iron, although to a lesser degree. Newly developed techniques have now largely overcome this problem in welding cast iron.¹ The technique used involves depositing short stringer beads of weld metal which are rapidly quenched with an air line with extensive peening of the weld beam immediately the arc is extinguished. The technique achieves:

- (a) The peening operation which should reduce the height of the weld bead by one-third, using a three-pound ball-pane hammer, minimises the weld metal contraction stress which may be serious in large fills.
- (b) Quenching the weld bead maintains the casting at room temperature, thus alleviating the serious problem of localised expansion and contraction.

Extensive bead-on-plate tests were then carried out, observing the air quench and peening techniques, and fully crack-free deposits were obtained. It was, therefore, decided to proceed with the repair.

Repair technique

To minimise the reaction stress the entire joint area was clad, using a 'soft arc' coating 25/20 Cr-Ni type metal-arc deposit. A 3.2mm diameter electrode was employed to limit the region of contraction strain, before peening of the deposit reversed this stress to a compressive one to the base metal.

After the joint faces were completely clad a close inspection revealed no evidence, at this stage, of cracking in the weld or base metal. It was then anticipated that a limited degree of ductility would be afforded by the clad layer against contractional stresses which might exist when the joint itself was filled progressively.

The root deposit was completed next, using the back-step technique with air quenching and comprehensive peening. It was decided to incorporate 19mm round bar sections in the repair in a 'Jacob's Ladder' formation to reduce the amount of weld metal required by 6kg and thus the overall strain, Fig.5a.

AISI Type 304 bars were the only bar material available and although it is inferior to the furnace roll material, it was adopted because it would be well below the surface layers. The bars were raised and tacked at each end to allow complete root penetration from both sides, still using a 3.2mm diameter electrode. The bars were then dressed down with a hammer, having previously been bent to the required shape to produce a consistent root gap. The repair proceeded using the same technique of depositing short runs, immediately peening with a simultaneous quench, using an air line with a jet forced as high as could be tolerated.

The joint was filled in the next stage using a block sequence with 5mm diameter electrodes, and was finished in the inter-block areas after the entire circumference had been covered to reduce the degree of stress in the joint. A final capping layer was deposited without peening, Fig.5b.

It is appreciated that, in some quarters, peening is considered to be detrimental to the corrosion resistance of an austenitic stainless steel, and also that the susceptibility to the formation of the sigma phase may be enhanced by this operation. However, peening was a technique which was found to be essential in this repair. The capping weld deposits induced a certain amount of stress relaxation in the underlying beads (which had been work-hardened by peening), and thus some benefit would be obtained, even though the transformed area would extend through only that portion of the remelted bead and HAZ produced in that same bead.

This particular repair was in service for about three years when it was removed for another cause. Numerous rolls have been repaired using the same technique.

CASE HISTORY NO. 3

Repair of wet liner seal in ship's engine

When a ferromagnetic cast iron is welded without

preheat hard constituents are formed in the HAZ; these include carbides, martensite, and bainite. Where stresses are induced as a result of contractional strains, unless minimised by special welding techniques, this embrittled area can create cracking problems. However, cold welding is widely exercised, and is a viable method of repair and reclamation.¹ It is also a proven method of welding white cast irons.² However, it is incorrect to assume that a preheat should not be used whenever possible. In fact it is highly desirable to preheat pearlitic SG cast irons to around 250°C to avoid cracking, and even grey flake irons benefit enormously from some degree of preheat.

The repair to a ship's wet liner seal was a typical example of a repair where preheating could not be used. However, owing to the importance of the operation it had to be shown quite clearly that a sound technique was to be used. The area to be welded, Fig.6, was tested to ascertain the extent of the damage. The broken-out section, Fig.7, was also damaged and this was prepared and preheated to 400°C, then heavily clad on the joint edges and outside faces, where two high tensile bars were to be positioned. A postweld heat treatment of 900°C was carried out to dissolve the carbides in the HAZ.

The object of welding the broken section in this way was to achieve a mechanical joint in addition to the joint proper; Fig.8 shows the general idea. The joint faces of the main casting were then clad, using short runs and peening, and maintaining a localised interpass temperature of 100°C with large soft flame burners.

The patch was fitted into position and welded in the same manner, i.e. short runs and peening.

The two bars (12.7mm diameter) were of En 110. These were initially clad with the TIG process and a nickel wire containing titanium (employing a 250°-300°C preheat) to allow the relatively cold welding of the bars to the casting at a later time, and so avoid HAZ cracking in the bars. Figure 9a shows the completed repair with one bar visible.

The final stage of the repair was the tinning of the inside face of the broken section, using a tin-based solder having a high melting point. This was then scraped in to within 0.025mm using an accurately ground template, Fig.9b.

It will be appreciated that, apart from a sound weld repair, a mechanical joint of some strength was achieved, and in addition there

were two high tensile bars overlapping the joints. Reference to Fig.8 will show that the heat-treated broken section will really comprise the full wedge shape, as illustrated, thus giving a mechanical joint of some strength.

Bronze castings

Aluminium bronzes occupy a pre-eminent position in many industries because of their mechanical strength and resistance to attack to a wide variety of corrosive media. The duplex aluminium bronzes in the cast form find a wide outlet for pump castings, shafts, valves, and gear wheels, etc.

The welding of aluminium bronze is heavily documented in technical literature. However, there are a few slants on the welding of castings in the repair and maintenance field that are worthy of mention.

The attack caused to component parts working in liquid media can be a complex combination of corrosion, cavitation, pitting, deposit attack and impingement attack, or any single one of these. Figure 10a shows damage caused mainly by cavitation to an aluminium bronze impeller in the paper industry. Figure 10b shows the completed repair. This is interesting from the point of view that Superston-40 weld metal was used to repair this duplex bronze, using the TIG process. An increase in the working life was obtained with an increase in efficiency. No postweld heat treatment was employed.

Stainless steel rings have also been used in this particular area on pump impellers in the mines, but loosening of the rings caused problems. Experimental work was carried out and a successful result obtained by depositing an 18/8/3 Cr-Ni-Mo weld metal to the face. To achieve a weld deposit which would exhibit adequate ductility a thin layer of copper was deposited on the aluminium bronze, using TIG AC, and then a layer of nickel, TIG DC-. The

final two layers of austenitic stainless steel were then deposited. When these particular impellers were due for repair, only a deposit of austenitic stainless steel was required. To ensure this the area was initially cut back to allow an adequate deposit of the final layer.

Aluminium castings

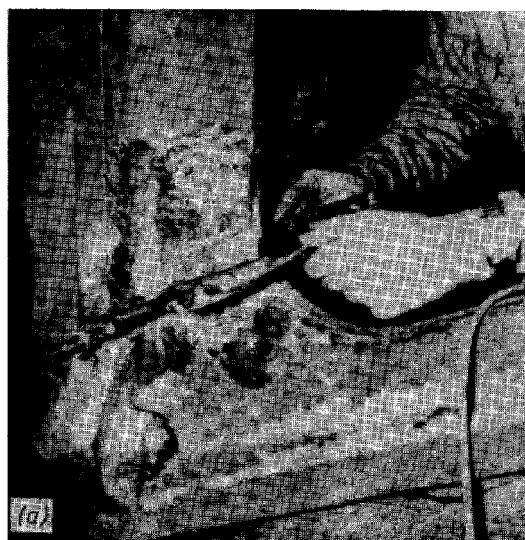
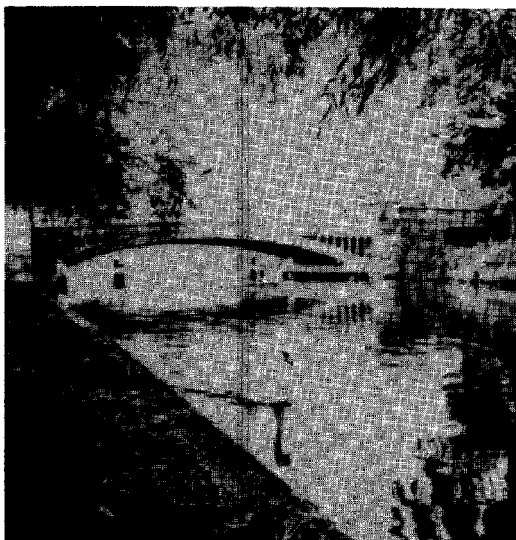
Like aluminium bronze, aluminium castings are also widely used and well documented with regard to welding. However, the gear pump casting, Fig.11, was repaired in an interesting way. The worn internal bores were degreased, rotary wire brushed, and the casting preheated to 200°C. Using an oxyacetylene torch and a special flux a tin-based alloy was deposited without fusion. Metallographic examinations have shown that a bond is achieved by the weld metal dissolving the surface of the aluminium, or interalloying. The weld metal used is a derivative of a bearing metal, i.e. tin-based and containing antimony to form SbSn cubes, and copper to form Cu₆Sn₅ needles. A super wear surface is obtained after boring, and field tests have proven this method.

CONCLUSIONS

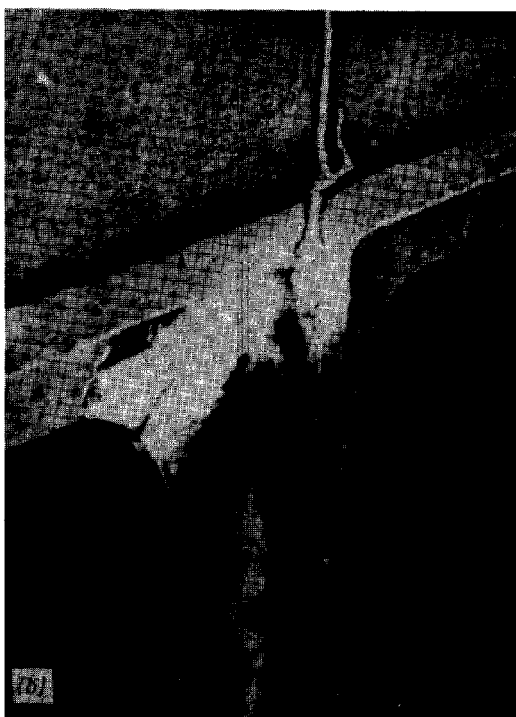
Various selected repairs of castings have been discussed in some detail, even though these repairs do not portray in any depth the full range of problems met in service R and M welding. It is hoped that a general idea has been portrayed to those unfamiliar with this line of repair.

REFERENCES

- 1 COOKSON, C. 'The metal-arc welding of cast iron for maintenance and repair welding'. Metal Constr., 3 (5), 1971, 179-84.
- 2 COOKSON, C. 'Metal-arc welding of white cast iron'. Metal Constr., 5 (10), 1973, 370-73.



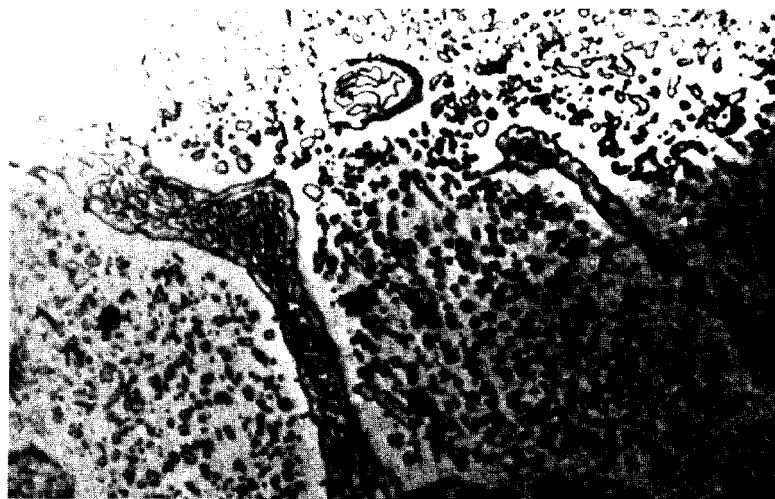
1 Osney Bridge



2 Osney Bridge showing: (a) cracks, dye penetrant tested, (b) cutting with hacksaw, and (c) nickel strip in place



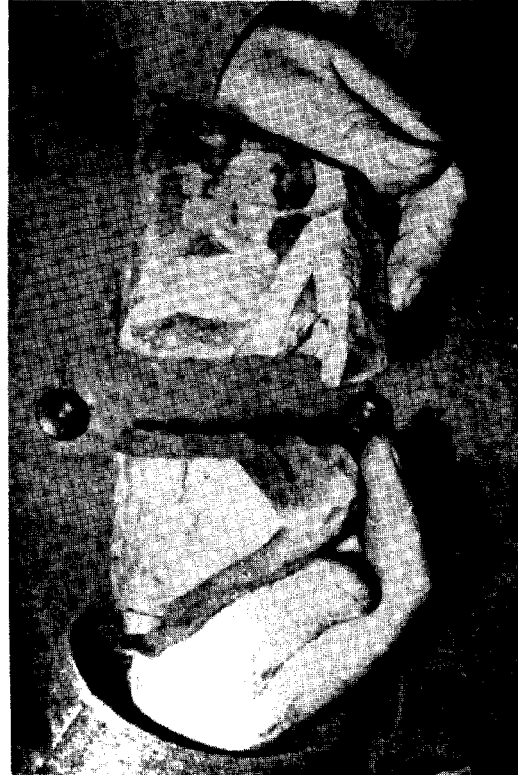
3 Repaired section showing bar in position



4 Structure of furnace roll x500



6 Area of wet liner to be welded



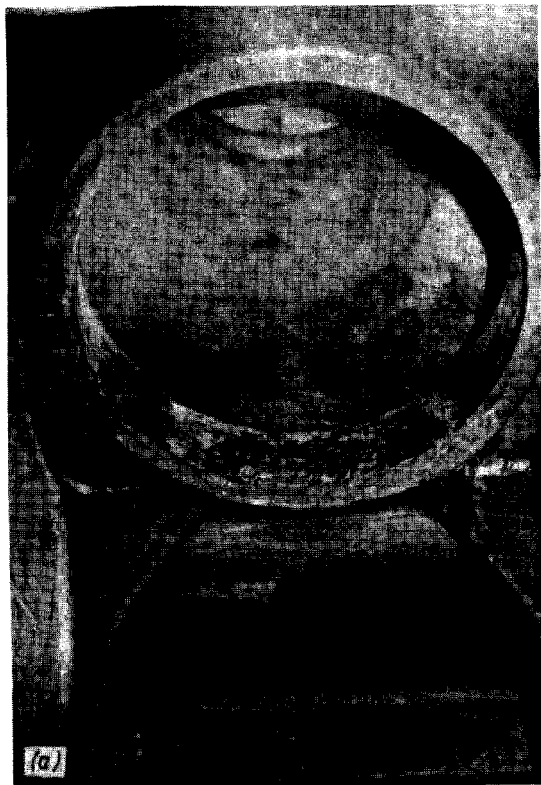
7 Damage to broken-out section



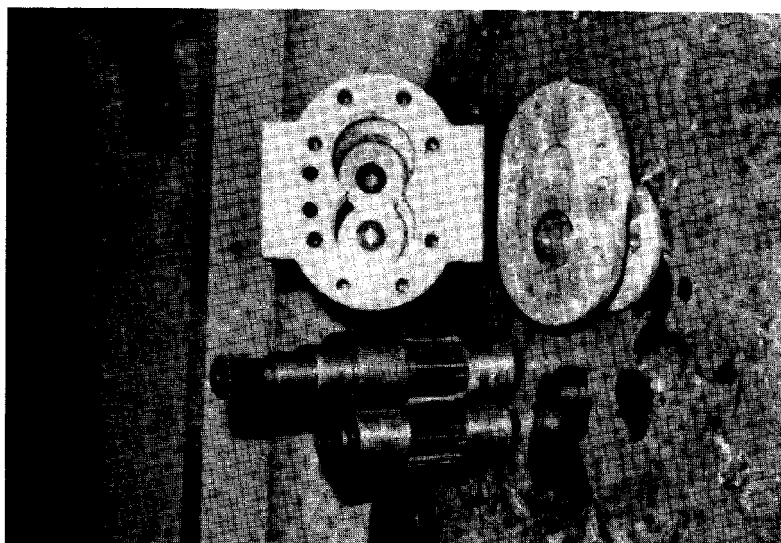
5 Furnace roll showing: (a) clad faces and bars in position, (b) completed roll



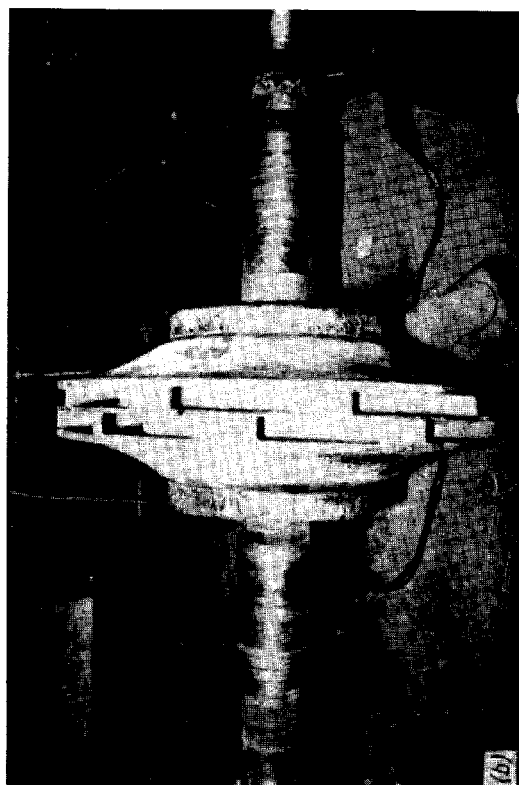
8 Drawing of technique, ...HAZ



9 (a) completed repair, (b) scraping in operation



11 Aluminium gear pump casting



10 Aluminium bronze impeller showing: (a) close up of cavitation damage, (b) repaired impeller

Heat control: key to good cast iron arc welds

by

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THE MODERN, nickel base arc welding electrodes provide a practical method for arc welding many of the cast irons. Today's problems are not in the weld metal, they are in the thin envelope which unavoidably surrounds every weld and which has been heated to a temperature above that at which the carbon (graphitic or combined) goes into solution. It is this carbon solution at temperatures above the so-called critical temperature that makes heat treatment, including hardening and annealing of iron base alloys, practical. It is a fact that while a welder does not intentionally heat treat the material he is welding, he can not avoid doing so, at least in the boundary zone. This means that the key to successful cast iron arc welding lies in control of the cooling rate in the zone wherein the metal was unavoidably heated to above the solution temperature of the carbon. Whenever an iron base alloy is so heated, then the rate of cooling from that temperature controls the hardness of that portion of the metal which was so heated. It is true that the envelope surrounding a weld is very thin, in cast iron, it is rarely over fifteen thousandths of an inch thick, but this envelope is critical. It is through this zone that the weld bead fractures and curls up leaving a typical cast iron fractured surface below it. This is because all metals are good conductors of heat and in such cases the heat was very rapidly removed by conduction back into the mass, so much so as to have a quenching effect. This both embrittles and cracks the metal in this thin envelope. The prevention of this undesired cracking lies in control of the

cooling rate after the weld is laid down. This involves many factors with mass, ambient temperature, heat input and metal quality, among the more important, as will be seen from a brief look at them.

Mass is important because the greater the amount of metal below the weld the more rapidly is the heat conducted away. Hess and his associates in a classical article published over twenty years ago showed that with all other factors held constant including heat input the rate of cooling in the boundary zone of a weld on one inch thick plate was ten times as fast as for the same weld on quarter inch plate. Thus mass is an important factor in cast iron welding and a technique that would be completely satisfactory on quarter inch-thick material would not be useful on inch-thick stock.

Ambient temperature is important, it is clear that the less the differential the slower is the heat transferred. This too was illustrated by Hess and his data shows that a four hundred degree preheat results in approximately half the rate of cooling in the boundary zone when compared with exactly the weld made with a 72 degree Fahr. ambient temperature. This is an illustrative figure with no magic in four hundred degrees since the less the differential the slower is the heat transfer.

Heat input is also an important factor; in general, the less the heat input the narrower, the more severe and dangerous is the boundary zone with a greater probability for severe cracking. This is due to the fact that the less heat there is to be dissipated the faster does it occur.

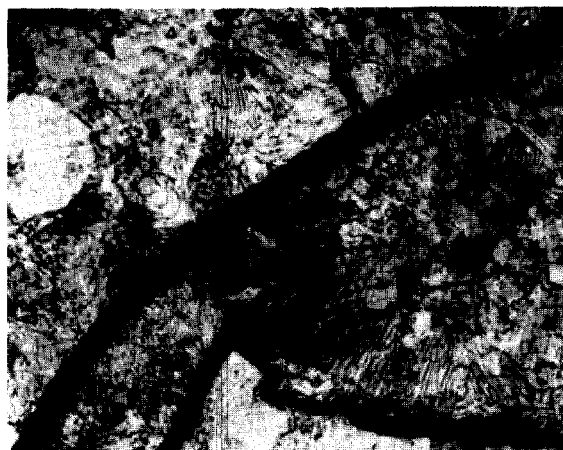
PHOTOMICROGRAPH etched to show graphite flakes. Each black wiggle is a flake of graphite (100 diameters).



RELATIVELY LOW GRADE iron, etched in 5% Nital. Grey areas are areas containing combined carbon as carbides. (100 diameters).



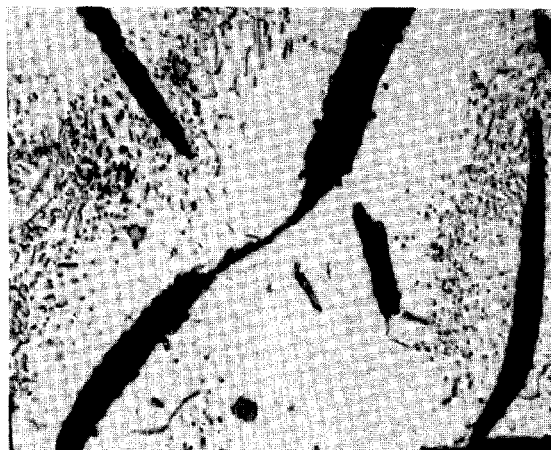
Source: Canadian Welder and Fabricator, November 1969



PHOTOMICROGRAPH at 1,000 diameters. Thumb-print-like lines are iron-carbide laminae; iron-carbide is hard and contributes little to material strength.

Metal quality is yet another important factor. Every welder is aware that he must use vastly different techniques on high carbon steels than on low carbon steels. A similar situation exists with cast iron. In general the higher the grade of cast iron and the higher its strength, the higher is the proportion of the carbon that is present as carbides. Carbides are much easier to place in solution on heating than is graphitic carbon though the latter does go into solution also, thus the higher the grade (strength) of the iron the easier it is to harden and the more care is required in hardening. Most cast iron welding is a repair operation with little or not data available as to the quality of the iron, in such cases there is only one thing to do, assume that it is high grade iron and act accordingly. If you have low grade iron, no harm has been done but if you assume that your casting is a low strength metal and it should be of the high strength type then you are likely to get an unsuccessful weld so the best plan is to assume high grade metal whenever there is any doubt about it.

In arc welding cast iron it is usual to hold the heat input down in order to avoid excessive contractional stresses. This is generally good practice but we must keep in mind that the cooling rate must be controlled to prevent the excessive hardness that results from rapid cooling. Thus if we are to use low heat inputs and gain the minimum contractional stresses then we must compensate for it by reducing the temperature differential. This means



PHOTOMICROGRAPH of relatively low grade annealed cast iron. (1,000 diameters).

higher preheat. In development work done by the writer he found that on half inch thick, high grade cast iron (45,000 psi iron) with low heat inputs a preheat of 600 degrees Fahr. was essential to prevent any trace of microcracks in the heat affected zone while if it is desired to have a truly machinable boundary zone then the preheat must be raised to 800 degrees Fahr.

Mass is beyond the control of the welder but he must understand it and work with it. He must keep in mind that as metal thickness increases, so does the rate of heat extraction by conduction back into the mass. The curve of heat conduction rates flatten out with increasing thickness and become pretty much of a constant between one and one and a half inch thick material. From there on increasing thickness merely increases the rigidity of the components and this too must be considered when welding heavy sections.

Thus the key to successful arc welding of cast iron lies in the metal immediately adjacent to the weld rather than in the weld itself. The truly critical area is an envelope of less than 1/32 of an inch thick that surrounds the weld and which has been heated above the temperature at which the carbon is dissolved making it available for hardening as the heat is transmitted away from the weld area by conduction. This in turn means that boundary zone cooling rates are a true measure of successful cast iron welding if we may assume good electrodes and techniques.

IMPROVING THE PROCESS OF GAS WELDING CAST IRON

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SYNOPSIS

It is shown that the properties of cast iron filler wires can be improved by holding in a crucible of a melting furnace at 1400–1580°C. Self-fluxing filler wires alloyed with copper, nickel and tin, and with additions of boron (to 0.03%) and rare earth metals (to 0.12%), have been developed for the welding of cast iron.

On the basis of the type of thermal cycle, the gas welding of cast iron can be divided (provisionally) into three groups (according to the data supplied by VNIIVTOGENMASH and the Stankolit plant). These are as follows:

1. Welding with the general preheating of components to 600–700°C in heating devices of various types, followed by cooling after welding (under asbestos sheet) from the liquid pool temperature to 400–450°C at a rate of $\sim 0.7^\circ\text{C}/\text{sec}$.
2. Welding with local heating of a defective area to 600–700°C (for instance, with additional portable torches, or directly with the welding torch) and with cooling in air after welding (under asbestos sheet) at a rate of $\sim 3^\circ\text{C}/\text{sec}$.
3. Welding after preheating a defective area to red heat, followed by cleaning the surface by melting and fluxing. After welding, the defective area is covered with asbestos. The rate of cooling of deposited metal in this welding technique is approximately $7^\circ\text{C}/\text{sec}$.

The task of obtaining the required quality of deposited metal at a given thermal cycle is reduced to the manufacture of cast iron filler rods, which make it possible to produce a deposited metal with a structure corresponding to the parent metal and containing no gas pores.

It is recommended that rods with a grey cast iron structure should be used. The formation of cementite of the surface of these rods is unacceptable (1–3).

Investigations show that the nature of droplet formation and of the interaction of the droplet with

parent metal is determined by the structure of the cast iron rod (4). On using rods with a ferritic structure and coarse graphite the droplet separates very slowly from the rod (8–10 sec) as compared with rods with a chilled cast iron structure or a refined structure (2–3 sec). In the first case, a thicker oxide film forms on the droplet, and the spreading of the droplet over the surface of parent metal is poor (despite the fact that the droplet had separated at a higher temperature). Consequently, in the case of using rods with a coarse cast iron structure (cast iron with coarse graphite inclusions), the temperature in the zone of contact between the deposited and the parent metal is considerably higher and the duration of the surfacing process is 1.5–2 times longer than it is with chilled cast iron rods.

During surfacing, the burn-out of carbon and silicon from the rods made of a cast iron with a coarse structure amounts to 22.3 and 20.4% respectively (1.3 and 10.1% for chilled cast iron or for refined cast iron rods). These results can be explained as follows. In the period of droplet formation, an important role is played by the viscosity of liquid cast iron, which, other conditions being equal, is determined by its initial structure. The viscosity of white cast iron at 1300°C is approximately half the viscosity of grey cast iron of the same composition (5,6). This is explained by the presence of graphite blocks undissolved in the iron melt (with a grey initial structure). The process of the dissolving of graphite starts prior to the melting of iron, and it depends on the rate of diffusion of carbon.

Thus, temperature delays occur prior to the separation of the droplet. For cast irons with a coarse structure such a delay takes place at 1450–1500°C, which corresponds to the temperature of dissolving of graphite blocks in the melt (6,8). In this case the duration of the temperature delay prior to the separation of a droplet in these cast irons is approximately three times longer than with chilled cast

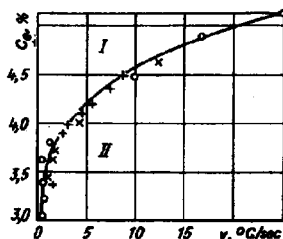


Fig. 1. The structural diagram of cast iron: I — grey cast iron (ferrite, pearlite, graphite); II — white and mottled cast irons (pearlite, cementite, graphite).

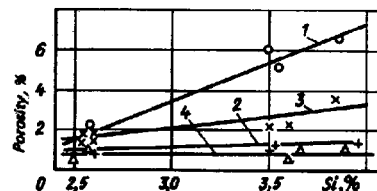


Fig. 2. The dependence of the porosity of cast iron deposits on the silicon content of rods and the melting conditions of rods: 1 — overheating 1450°C, 5 min; 2 — the same, 1450°C, 20 min; 3 — the same 1600°C, 5 min; 4 — the same, 1600°C, 20 min.

Source: Svarochnoe Proizvodstvo (Welding Production), 23(11), 1976 (Translation published by the British Library)

Fig.3. The dependence of the porosity of cast iron deposits on the content of ferro-silicon FS75 in the charge in the production of rods: 1 - overheating at 1450°C, 5min; 2 - the same, at 1600°C, 5min.

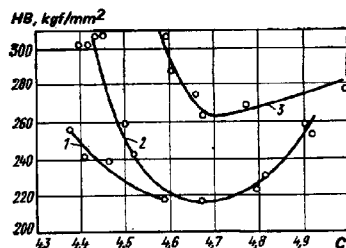
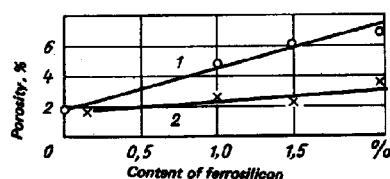


Fig.4. The dependence of the hardness of deposited metal on the carbon equivalent of rods with various C and Si contents: 1, 2, 3 - 4.0-3.6C, 2.6-2.8Si; 2, 3 - 4.0-3.6C, 3.0-3.5Si; 3 - 3.2-3.4C, 3.8-4.6Si.

irons.

Therefore the ledeburitic structure of cast iron results in higher technological properties of the rods, and the deposited cast iron consequently has a more favourable structure and hardness.

Defects in cast iron castings (2,3,7,8-11) are repaired mainly with cast iron filler rods whose composition corresponds to the eutectic condition ($C_e = 4.3\%$). Figure 1 shows the structural diagram of a cast iron constructed in the co-ordinates 'carbon equivalent - the cooling rate v of cast iron'. Analysis of the relationship ($C_e = 3.47 v^{0.12}$) confirms that at cooling rates typical of gas welding ($v = 7^\circ\text{C}/\text{sec}$) the carbon equivalent of the cast iron of the filler rods must not be lower than 4.3-4.4%.

The recommended compositions of cast iron filler rods (GOST 2671-70) are characterised by very wide ranges of the content of elements (for instance, the range of the carbon and silicon contents is 3-4.5 and 2.5-4.5% respectively). But an increase in the silicon content to the upper limit increases the hardness of the metal of the welded joint, as a result of the formation of silico-carbides and alloyed ferrite, and also because of the unavoidable reduction in the contents of total and free (in the form of graphite) carbon. In addition, the susceptibility of deposited cast iron to the formation of pores increases. To ensure that repaired defective areas have the grey cast iron structure and that their properties satisfy the standards for castings of metal-cutting machines, the carbon and silicon contents of the cast iron rods should be 3.3-3.6 and 3.4-3.9% respectively.

TABLE 1.

Melt No.	Content of elements*, %										Comment
	C	Si	Mn	S	P	Cr	Ni	Ti	Sn	Cu	
1	3.2-3.6	3.4-4.0	0.4-0.7	0.04	0.15	0.10	0.1-0.2	0.1-0.2	0.3-0.5	-	For repair of defects revealed during machining
2	3.0-3.4	3.0-3.6	0.4-0.7	0.04	0.15	0.10	0.4-0.6	0.1-0.2	-	2.0-3.5	The same, after surface hardening
3	3.0-3.4	3.0-3.6	0.4-0.7	0.04	0.15	0.10	0.2-0.5	0.1-0.2	0.1-0.3	1.0-2.0	The same, on scraped surfaces

* In all cases the contents of hydrogen, oxygen, sulphur, phosphorus 0.0065, 0.04, 0.15 and 0.10% respectively, and the contents of manganese and titanium should be within the range 0.4-0.7 and 0.1-0.2% respectively.

In this case it must be taken into account that, during welding, a large amount of silicon is burnt out (up to 20%) at a relatively low burn-out of carbon (5-6%).

The properties of deposited metal are affected also by the conditions of manufacture of rods. A long-term holding (to 15-20min) of cast iron in the crucible of a melting furnace at the melting temperature (1400-1580°C) reduces the viscosity of liquid iron and improves wetting.

Examination of the microstructure of deposited cast iron shows that an increase in melting temperature and in holding time above the optimum values is associated with the de-activation of nuclei of graphite formation, with an excessive refining of graphite, and with the possible formation of supercooled structures in the deposit.

Experience obtained with the application of rods of the cast iron of the proposed composition indicates that efforts to produce a grey cast iron structure in deposited metal are often associated with difficulties caused by the formation of gas pores in the deposit. The principal reason for the formation of pores in deposited cast iron is evidently the presence of hydrogen transferred from the flame of the gas acetylene torch. Under welding conditions, the gas phase contains up to 40% hydrogen, of which 30% can be dissociated into atoms.

The gas bubbles nucleate (at the usual degrees of supersaturation of the metal with the gas being released) on non-wetted inclusion (silicates and aluminates) - liquid metal interfaces.

TABLE 2.

Filler material (content of elements, %)	Flux	Characteristics of deposited cast iron		
		Machinability	Porosity, %	Hardness HB, kgf/mm ²
Cast iron (3.42C, 3.5Si, 0.63Mn, 0.2P, 0.05S, 0.45Ni, 1.52Cu)	Without flux Borax	Good	0.231	224
		Good	0.060	220
Cast iron (the same + 0.03B)	Without flux Sodium carbonate	Good	0.537	236
		Good	0.150	230
Cast iron (the same + 0.2B)	Without flux Sodium carbonate	Satisfactory	0.032	264
		Satisfactory	0.017	289
Cast iron (the same + 0.05Ce and 0.03Y)	Without flux Boric acid	Good	1.812	236
		Good	0.120	229
Cast iron (the same + 0.07Ce and 0.05Y)	Without flux Boric acid	Satisfactory	4.9	235
		Satisfactory	2.3	248
Cast iron (3.44C, 3.62Si, 0.45Mn, 0.13P, 0.06S, 0.48Ni, 2.26Cu, 0.02B, 0.08Ce, 0.04Y)	Without flux	Good	None	202

The risk of pore formation can be reduced by lowering the content of various non-metallic inclusions in the cast iron, by selecting a suitable chemical composition of the cast iron for rods, and by adhering to the optimum casting conditions.

The investigations conducted at the Stankolit plant, at the Moscow Institute of Steel and Alloys, and at VNIITVOGENMASH (12), show that an increase in the silicon content of rods increases the susceptibility of deposited cast iron to the formation of pores (see Fig. 2), especially with an increasing fraction of ferro-silicon in the hot metal charge in the melting of iron for rods (see Fig. 3). A relationship has been determined between the formation of pores and the number and nature of non-metallic inclusions in the cast iron of the rods. The composition of inclusions, and their nature and dimensions, determine the overall adsorptive effect. Non-wettable silicates are the most 'dangerous', because they increase the interfacial area, and consequently reduce the work of formation of a gap pore. An increase in melting temperature, and particularly in holding time in the furnace, in the melting of cast iron for rods facilitates a more complete removal of gases and non-metallic inclusions from the cast iron, and the porosity of cast iron in repaired areas in castings consequently decreases. In the melting of cast iron in induction furnaces, the optimum melting temperature (1400-1580°C) depends on specific conditions. The optimum time of holding the cast iron in the furnace prior to pouring into moulds is 15-20min.

The predetermined ratio of carbon to silicon in cast iron, and the conditions of melting in the

manufacture of rods, made it possible to produce poreless deposits. But the strength and wear resistance of the welded joint decreased (due to the presence of up to 70% of ferrite in the joint).

The results of investigations into the effect of various alloying elements, added to the rods, on the properties of deposited cast iron show that completely poreless deposits, with the structure and hardness corresponding to that of grey cast iron, can be produced as a result of alloying with nickel, tin and titanium, with nickel, tin and copper and with nickel, titanium, tin and copper* (see Table 1).

In the welding of cast iron, the flux is usually represented by borax, which decomposes at high temperatures to boron anhydride and sodium oxide. The sodium oxide facilitates binding of the oxides (mainly FeO and SiO₂) present in the cast iron, and also those formed during welding, in complex compounds. The presence of boron leads to the formation of low-melting compounds in the form of a dense film on the surface of the weld pool. But a uniform supply of flux is required to produce a continuous slag cover, and this cannot be achieved even by using various devices. Consequently, the deposited metal often contains a large number of pores.

A continuous slag cover can be formed with self-fluxing cast iron rods containing boron and elements that form basic type oxides with a low dissociation tension (e.g. cerium and yttrium).

The rods with up to 0.2%B and up to 0.7% of rare-earth metals (REMs) can be used for the welding

* Author's Cert. No. 339366.

of cast iron without the need to add any additional quantities of flux to the weld pool.

To clarify the effect of alloying elements on the technological properties of the welding process, experimental deposits were made with and without flux. In deposition with cast iron rods containing boron the flux was represented by sodium carbonate (Na_2CO_3), and borid acid was used with rods of a cast iron alloyed with rare-earth metals. Both boron and the REMs, added to the cast iron of the rods, exert the fluxing effect during welding (see Table 2). This reduces the porosity of cast iron deposits. The burn-out of boron in welding varied from 30 to 65%.

Increasing the REM content of the rods increased the porosity of cast iron deposits (this increase was especially pronounced at REM contents of more than 0.3%). The machinability of deposited metal was impaired also. The higher hardness of deposited cast iron, as compared with the parent metal, is obviously due to the greater burn-out (to 30%) of silicon during welding.

Experiments in which boron, cerium and yttrium were added separately to the cast iron of the rod (see Table 2) gave the following results: the addition of boron facilitates the formation of a dense film of slags on the pool surface, but the characteristic feature of the process is a high viscosity of the metal of the pool. This extends the duration of deposition, and it increases the burn-out of silicon; the hardness of cast iron deposits consequently increases until chilled cast iron structures are formed; the addition of cerium and yttrium satisfactorily deoxidises the metal being deposited, but it increases the porosity of the deposit.

The combined addition of boron, cerium and yttrium (at a specific ratio) increases the quality of welded joints, and it creates favourable conditions for the self-fluxing of filler material in the course of welding.

The highest properties of cast iron deposits were obtained with rods with carbon equivalents of $C_e = 4.6-4.8\%$ and with $2.6-3.5\%\text{Si}$ (see Fig. 4).

At silicon contents in excess of the above limit, the hardness of the cast iron deposits increased to a

considerable extent as a result of the formation of silicocarbides. Annealing at a temperature of $500-600^\circ\text{C}$, corresponding to the decomposition temperature of the silicocarbides, reduced the hardness of the deposits.

CONCLUSIONS

1. It has been established that holding in the crucible of a melting furnace at $1400-1580^\circ\text{C}$ has a beneficial effect on the properties of cast iron filler rods.
2. Self-fluxing filler rods, alloyed with copper, nickel and tin, and with additions of boron (to 0.03%) and REMs (to 0.12%), have been developed for the welding of cast iron.

REFERENCES

1. ELISTRATOV, P.S. Metallurgical fundamentals of the welding of cast iron. Mashgiz, Moscow, 1967.
2. KRANKE, R. Schweisstechnik, 1962, No. 5.
3. BLANK, G.M. Zeitschrift für Schweisstechnik, 1966, No. 11.
4. LEVI, L.I., et al. Weld. Prod., 1971, No. 4.
5. NAKAGAWA, N. Collection: The physico-chemical fundamentals of metallurgical processes. Moscow, Nauka, 1961.
6. LEVI, L.I., et al. Izv. VUZ, Chernaya metallurgiya, 1973, No. 9.
7. VERTMAN, A.A. and SAMARIN, A.M. The properties of iron melts. Moscow, Nauka, 1969.
8. ASINOVSKAYA, G.A. and ZHURAVITSKII, Yu.I. The gas welding of cast iron. Moscow, Mashinostroenie, 1967.
9. VOSHANOV, K.P. The repair of equipment by welding. Moscow, Mashinostroenie, 1967.
10. A Welding Handbook, Part 4. Moscow, Mashinostroenie, 1971.
11. STERENBOGEN, Yu.A., et al. The welding of cast iron. Kiev, Naukova Dumka, 1968.
12. ASINOVSKAYA, G.A., et al. Weld. Prod., 1967, No. 12.