Welding of Cast Iron 21.05.19

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Background

Welding of cast iron is a must on-board all sailing vessels simply because it is intensively used and have a tendency to crack because of little elongation. When parts fail and crack, there is either no spare part in stock on-board or new part are either no longer available from manufacturer or have long delivery time.

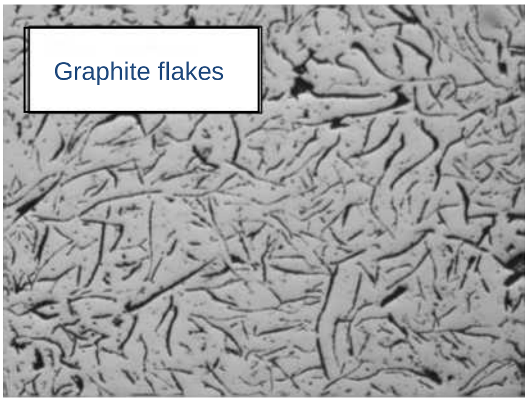
To approach welding of cast iron with any appreciable hope of success, the special properties of this material must be understood, and the techniques for joining it together followed.

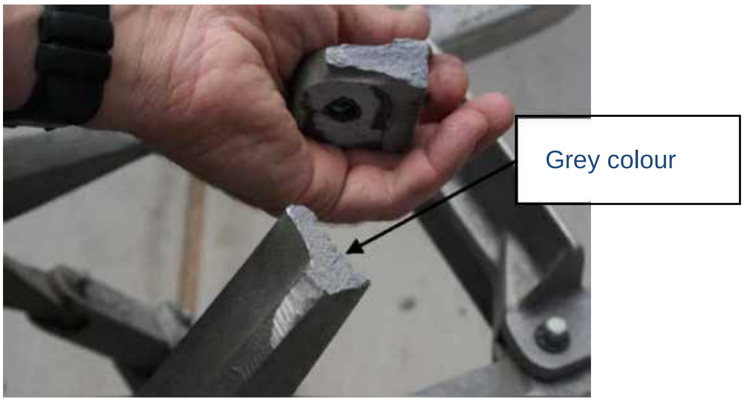
Welders who attempt to repair cast iron based upon their experience from welding steel, and on the assumption that “iron is iron" must often end up with grievous results without understanding why. Hence, cast iron repairs has been a feared operation to welders, surrounded by an aura of mystique, and better left alone in favor of replacing the defective party rather than trying to repair it.

By following the directions given in this article, you will find that many grades of cast iron can indeed be welded successfully. However, hard and fast rules for this type of welding cannot be laid down. Each job must be considered on its merits, and there is always a risk of failure. This risk is usually well worth taking, because welding can save enormous amounts of time and expense in salvage applications. The final result also depends on the skill and enthusiasm of the welder.

WHAT IS CAST IRON?

Cast iron is essentially an alloy of ferrum (iron), carbon and silicon. The carbon content ranges from 2.4% up to 4.5%, which means that it is present in excess of the amount that can be contained in solid solution. Although up to 6% of carbon can be dissolved in iron when molten, actually less than 1.75% can remain in solution when the metal solidifies. The excess carbon separates out during solidification and remains present and dispersed throughout the cast iron in the form of free carbon (graphite).





Two of the factors, which influence the amount of carbon, which separate out when the cast iron solidifies are the length of time it takes to solidify and the amount of silicon that is present. Silicon tends to drive out any carbon in solution as graphite if it is given enough time and temperature. Thus, the percentage of free graphite is a function of the cooling rate.

This excess carbon is the reason for many of the desirable properties of cast iron, such as high fluidity, low shrinkage, high damping capacity on vibrations and ready machinability.

However, the carbon is also source of problems. Due to its high content, the cast iron is brittle and has very little elongation when subjected to strain (Steel 20% elongation, Cast Iron 1% elongation). Because of this, it cracks easily when subjected to local heating and cooling, as is the case when welding. Thus, the welding properties of cast iron differ from those of steel.

While steel melts at approximately 1450°C (2642°F), the high carbon content of cast iron lowers the melting point to 1100 - 1300°C (2112 – 2372°F) depending on type, making it easier to melt and allowing it to run freely into a mold to assume the shape intended for the casting. On board ships cast iron has found wide usages as for instant engine blocks, heads, liners, water jackets, transmissions, pump and valve housings, manifolds, pipe fittings, cargo lines, etc.

There are five common types of cast iron: Grey, White, Malleable, Ductile and High alloy. These different cast irons cannot be identified by chemical analysis alone. It is the form of the excess carbon that determines the kind of iron that the melt becomes. With regard to the fifth type, high alloy cast iron, this is obtained by adding quantities of alloying elements to grey, white or ductile irons. In the following, we shall look at the characteristics of **Grey cast iron**

Grey cast iron is the least expensive and most commonly used of all cast metals. The raw materials - pig iron, cast iron scrap, steel scrap, limestone and coke - are all relatively inexpensive. We estimate that approximately 90% of all cast iron is in the form of grey iron.

When using casting molds of sand, the molten metal gets a slow rate of cooling. This gives most of the carbon time to collect as graphite flakes between the iron crystal borders. In small or thin-walled parts, the graphite is evenly dispersed throughout the material. In large-dimension castings, the material near the surface will contain comparatively small graphite flakes, as this is the part of the casting, which will cool off first. In the middle, the material will cool slower and contain fewer, but larger flakes.

The presence of the graphite flakes promotes ready machinability, useful damping properties and resistance to wear. However, the flakes also serve as crack-indicators, and grey cast iron cannot be bent or forged to shape, neither in cold nor in red-hot condition. Due to the presence of free graphite, a fracture will have a grey appearance, which gives the alloy its name.
The wide range of strengths in grey irons, from 137 MPa (19870 psi) to more than 390 MPa (56565 psi), plus manufacturing economy, explains the extensive use of these irons where high resistance to dynamic stress is not a governing factor.

General analysis of grey cast iron:

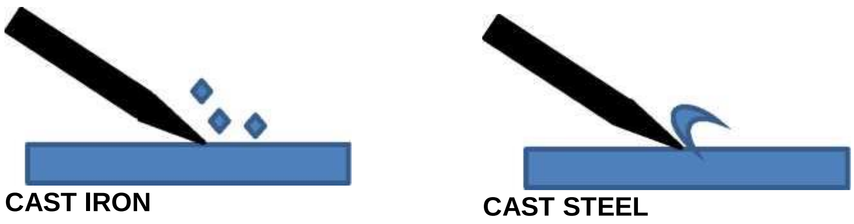
Carbon	3.0 - 3,25%
Silicon	2,0 - 2,4%
Sulphur	0,2% maximum
Phosphorous	0,2% maximum
Manganese	0,6 - 0,7%
Ferrum	Rest.

HOW TO IDENTIFY CAST IRON

Cast iron will, as the name implies, always be in the form of casting. Castings have one thing in common; they will have no welded joints, and they will have a visible casting line from the two halves of the mold.

One can easily identify a copper alloy or an aluminum alloy casting by their color. However, to distinguish between cast steel and cast iron by appearance alone is not easy. To help us establish which metal a casting is made from, we have a couple of easy tests.

The perhaps simplest method to distinguish cast iron from cast steel is to use a hammer and chisel on a place of the casting where a little chiseling will do no harm. Cast steel when chiseled will form a continuous chip, while the cast iron forms no chip but comes away in small fragments.



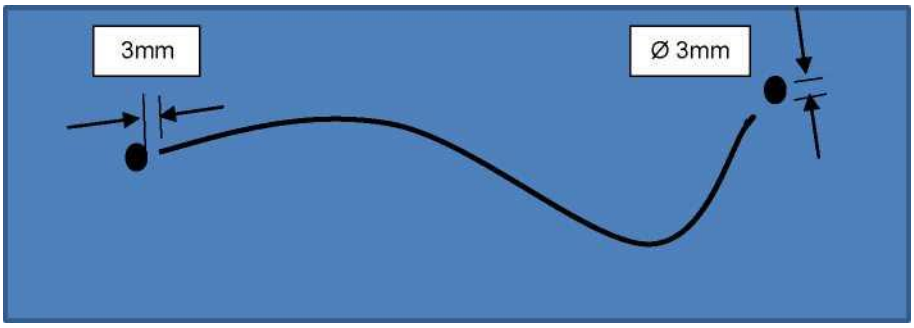
A spark test will also give ready identification between the types of ferrous metals. Cast iron will have weak red sparks, ending in yellow stars. Steel sparks separate at the end into small sparks.

EDGE PREPARATION

First, clean off all oil, grease, rust and paint from the surface, using a brush or by chemical means. Then remove casting skin to a width of 20 mm (25/32”) on both sides of the edges to be welded. A grinding machine may be used for this work. Remove imperfections in the weld area, such as blowholes, cracks, fatigue areas and porosities down to sound metal.

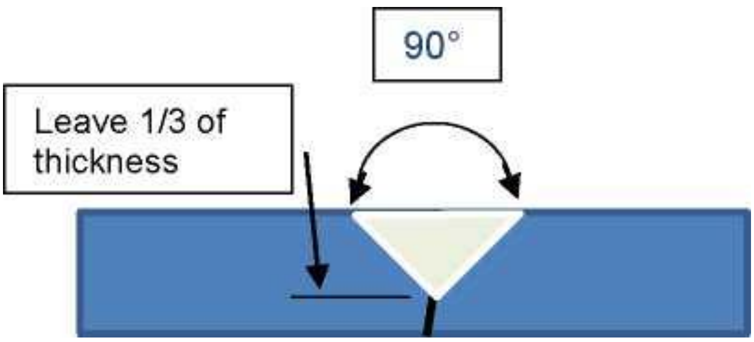
If the damage is in the form of a crack in the material, it may be difficult to determine where the crack actually ends. The use of a crack detector set to find the complete extent of the crack is absolutely recommended.

When this has been established, drill 3mm (1/8”) holes at a distance of 3mm (1/8“) from the ends of the crack. This will prevent the crack from opening further during the repair.
Cracks should be "V-ed" or "U-ed" out, using either a grinding machine or by a gouging electrode.

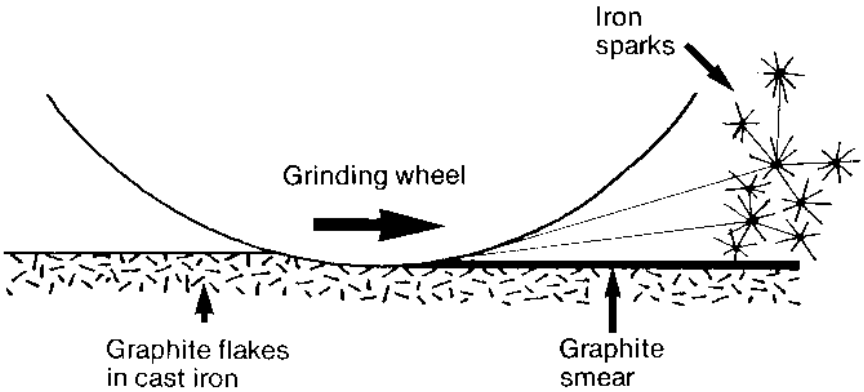


Groove preparation by grinding

Grind a 90° V-groove as indicated in the sketch below. If the part has broken into two or more pieces, the sides of the fracture should be ground to a 45° bevel.
Sharp corners and edges should be rounded off wherever possible, particularly on surfaces to be machined or filed later. This is necessary to prevent excessive melting of the base material in these areas during the welding process.

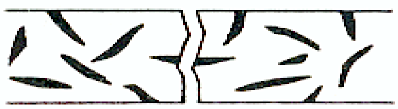


In preparing the casting by grinding, a certain amount of carbon (graphite) is removed from the metal and smeared over the surface to be welded by the grinding wheel. Before any welding can be done this carbon must be removed, as it will otherwise become part of the weld pool and combine with the iron to form a super hard zone of iron carbide in the weld. To avoid this, always remove a thin layer of the surface by a file after completing grinding. Use a steel brush to remove loos material.

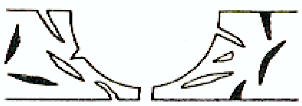


Groove preparation by electrode gouging

The most efficient method of removing unwanted metal and preparing surfaces for welding is to use gouging and chamfering electrode. Cast iron have an open structure and oil might have saturated the carbon flacks. If welded the oil comes boiling out causing porosity in the weld. In order to prevent this the best solution is to gouge out the crack with a gouging electrode. This method of groove preparation requires no other equipment than that used for ordinary arc welding and gives a very attractive U-shaped groove that is clean, bright and makes an ideal base for welding. In addition, it gives the advantage that if the part to be welded is oil-impregnated (as a number of cast iron parts are bound to be), the heat generated by the process will cause the oil to evaporate from the graphite flakes in the welding zone. Another advantage of using a gouging electrode to prepare the metal for welding is the small amount of heat imparted to the casting prior to welding. By removing the chill from the metal welding will be easier. The filler metal will have better flow characteristics and improved welds will be evident.



If the carbon flakes are saturated with oil?



Make use of a gouging electrode to make a grove and at same time burn out the oil

WHICH WELDING METHOD TO CHOOSE?
There are three alternative methods for joining broken or cracked cast iron parts:

Cold welding by Electric Arc

"Cold" electric arc welding is primarily used on larger components where preheating is difficult or impossible to arrange. Cold welding is the most common type for repair of cast iron, and the method, which should first be considered.

Hot welding by Electric Arc, Oxy /Acetylene Welding or Brazing

Hot welding can be used on smaller parts, which can be preheated with the welding torch to 500°C (932°F). As the means for preheating on board will normally be limited to the welding torch, it means that only such parts which are of rather limited size, and which can be dismantled and brought into the workshop can be hot welded on board. After welding, the finished welded part must then be allowed the slowest possible cooling down to room temperature. Burying the piece in kieselguhr, sand or cinders will help to give it a slow cooling rate.

Polymer repair

In some repair situations, the cast iron is so oxidized that welding is impossible. It can also be that “hot Work” is not allowed. In this kind of situations, Polymer repair products (plastic steel) should be considered.

Cold welding using electric arc welding will in most cases be the only practical alternative and what we will look more closely at.

COLD WELDING BY ELECTRIC ARC

Arc welding electrodes for cast iron

Below is a short description of the cast iron electrodes commonly in use.

NICKEL ELECTRODES (AWS A5.15 E Ni-CI):
For use on old, oil-impregnated cast iron and on thin material dimensions. Use this type of electrodes to “butter” the sides of oily cast iron to seal the surface. Then finish the filling-up to join the parts together with NICKEL IRON electrodes, which has grater tensile strength. Do not deposit more than maximum two layers using NICKEL electrodes.

NICKEL IRON ELECTRODES (AWS A5.15 E NiFe-CI-A):
To be used on cast iron that takes strain, vibrations and sudden loads. Also to be used for joining cast iron to steel, copper alloys and stainless steel. NICKEL IRON electrodes are used for multi-bead welding on heavy gauge material. It has greater tensile strength than NICKEL electrodes.

WELDING PROCEDURE

If the necessary equipment for preheating or for achieving the required slow cooling rate is not available, the alternative is "cold" arc welding. The method is so called because of the low heat input to the base material when correctly executed.

On board cold arc welding is by far the most commonly used method, and large cast iron parts, or parts, which are difficult or time-consuming to dismantle, should be cold-welded.

Amperage setting

When cold welding cast iron a low amperage setting should be used. Thereby deep fusion between the filler material and the base material is avoided. It should be remembered that deep fusion will dig up and bring into the weld pool more graphite than need be. This graphite will give rise to iron carbide, with resulting hard zones when the weld cools off. Deep fusion will also put lots of unwanted heat into the base material with increased risk of cracking.
Recommended amperages are as follows:

Electrode size mm	Amperage
2,5 (3/32”)	50- 80
3,2 (1/8”)	70- 110
4,0 (5/32”)	100- 140
5,0 (13/64”)	130- 170

The above settings are approximate. Setting will vary with the size of the job, type of machine, line load, etc. It is recommended practice to select a setting halfway between the figures and make a trial weld. Nickel electrodes has high ohmic resistance (not a good conductor). If the amperage setting is too high, the electrode may become red hot.

In general, the welding current should be as low as possible, consistent with easy control, flat bead contour, and good wash at the edges of the deposit. The amperages listed are for flat or down hand welding positions. Reduce the amperage range by 5-10% for overhead welding, and about 5% for vertical welding.

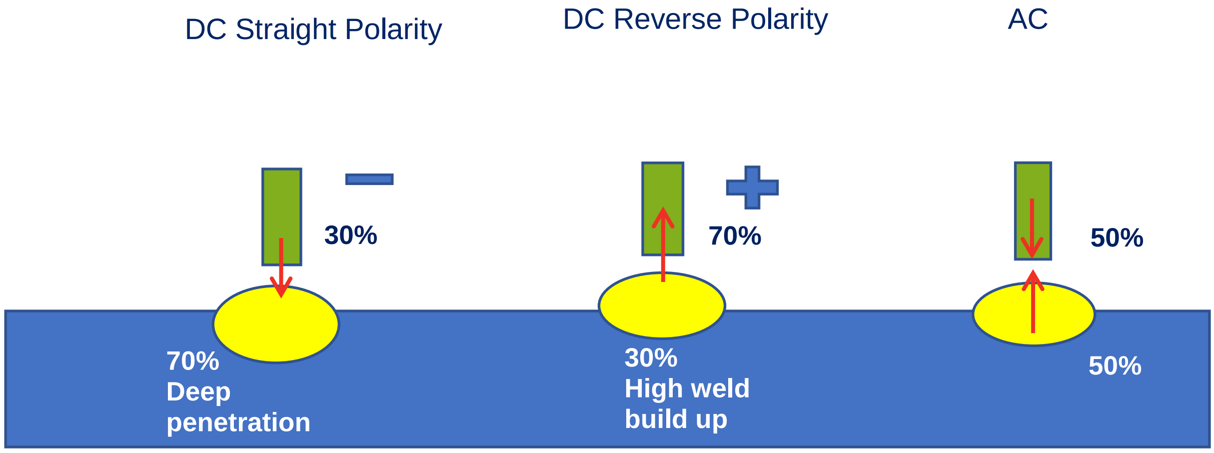
To ensure good electric conductivity the return cable clamp should be attached to the workpiece itself if possible.

Choice of polarity

If the current source is a welding rectifier (DC-machine), the choice of correct polarity will influence very much on the result of the work.

The operator must be aware of the effects of the different polarities, as the heat input and the melting of the base material varies considerably according to the polarity selected.

If the electrode is connected to the minus pole of the machine (straight polarity), we get high concentrated heat input to the base material. This will cause excessive melting and digging into the material. In addition to contaminants such as phosphorous and sulphur, cast iron contains quantities of the gases nitrogen, oxygen, carbon dioxide and carbon monoxide. Excessive melting will bring unwanted quantities of these impurities into the weld. The more impurities contained in the base material the lower the quality of the weld metal.



The high heat input will also cause the formation of iron carbides with hard zones in the weld and the heat-affected area.
If we connect the electrode to the plus pole (reverse polarity), we get a wide, shallow weld zone with minimal amounts of graphite, phosphorous, sulphur and gasses. The low heat input will reduce the formation of iron carbides.

When welding with DC, reverse polarity to the electrode should be the first choice. However, in cases where the cast iron is heavily contaminated and has poor weldability, straight polarity may be tried in the first run in order to use the higher heat input and melting to achieve bonding between the base material and the weld deposit.

Length of arc

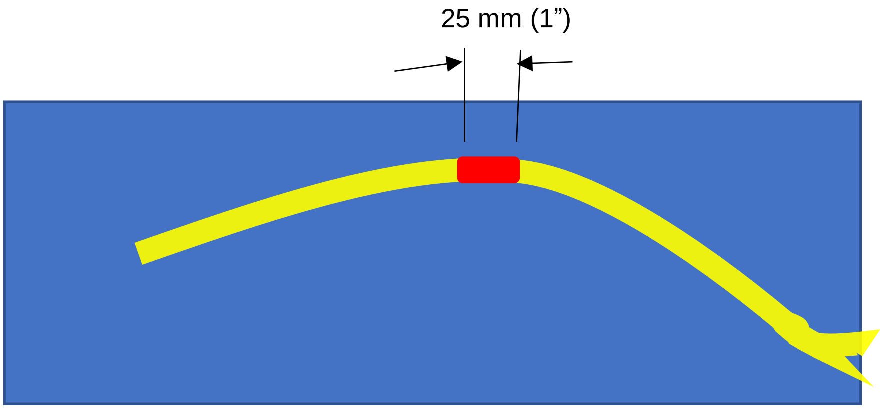
To reduce the voltage across the arc, and to help minimize heat input into the base material, the shortest practicable arc should be maintained. By experience, it may be found that the first pass should in some cases be done with a somewhat longer arc than the following runs. This would be in cases where the composition of the base material makes good bonding more difficult, and the first bead has to be "painted" on to it.

Correct size electrode

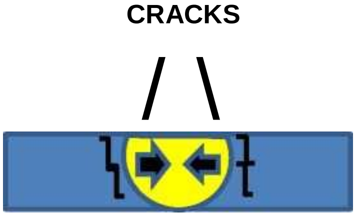
Always use the largest size diameter electrode that the groove can accept (but not at the expense of not getting down into the groove!). Using a large size diameter means that you reduce the heat input in relation to the amount of filler metal deposited. For instant a 4,0 mm (5/32”) electrode deposits four times as much weld metal at only two times as much amperage compared to a 2,5 mm (3/32”) electrode. However, if the first bead shows porosity, a small diameter electrode, low amperage setting and high welding speed should be used for this run to reduce heat input.

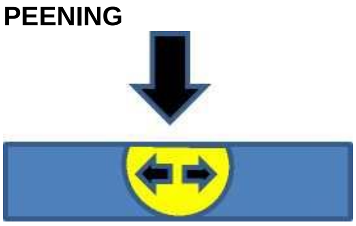
The welding

Remember that cast iron is very brittle, with only 1 - 2 % elongation. Should the shrink forces exceed the tensile strength of the cast iron it will crack. Hence, when welding it is crucial to the success of the operation that the heat input to the base material is kept to a minimum to avoid cracking.
The way to achieve this is to avoid putting down long, continuous beads (as when welding mild steel), and instead to weld short, straight stringer beads of maximum length 25 mm (1") at a time. Weaving should be avoided or kept to the minimum required and only to "wash out" the deposit and to catch the sides of the groves.



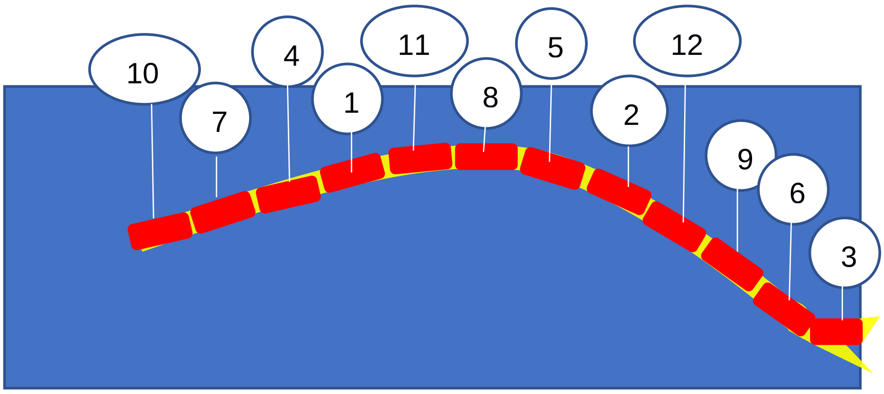
Do not wave in excess of one-half electrode diameter to each side of the direction of the weld. When each bead of 25 mm (1”) has been deposited, fill the crater and withdraw the electrode a little backward on the bead before breaking the arc.
While the bead is still hot, peen it with a round-nosed peen hammer. Since the casting is quite rigid, the filler metal must be ductile. Peening the bead immediately after depositing will stretch it to accommodate some dimensional change in the weld area, and will provide some stress relief.





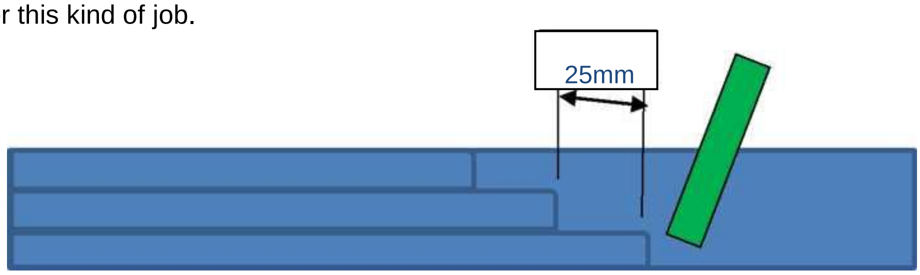
Always peen from the crater back to the starting point. Use rapid moderate blows; just hard enough to leave a slight indent on the weld deposit is usually sufficient. Too heavy blows may cause cracks, while too light peening will have little or no effect in relieving stresses.

After the initial bead has been deposited and peened, the next bead should not be put down until the bare hand can be laid alongside the first bead with comfort. If you burn yourself, it is too hot to go on with the welding. Take your time; do not spoil your work by trying to rush it.
Sometimes more than one short run can be done at a time, but only when the length to be welded is considerable, and the beads can be spaced well away from each other to prevent heat build-up. This technique is called skip-welding and speeds up the work considerably:



A way to reduce shrinkage stress

In order to reduce the shrinkage stresses, do not put down a complete root bead first, before proceeding to build up. "Stack" the beads stepwise as shown in the sketch, advancing each bead (starting always with the root bead) 25 mm (1”) forward at a time. Take care to keep the heat down (hand warm before proceeding each new bead!) and hammer each bead while still hot. A small pneumatic hammer is suitable for this kind of job.



CONCLUSION

Cast iron welding is demanding, but not impossible if one follows the above procedure and use electrodes of high quality.

WELDING CONSUMABLES FOR WELDING OF CAST IRON

Nickel Iron electrodes (AWS A5.15: E NiFe-CI-A):

Lincoln Electric	Esab	Bohler	Wilhelmsen Ships Service	Drew Marine	Kobe steel (Kobelco)
Softweld 55Ni Reptec Cast 31	OK 92.58	UTP 83 FN	Nife-334N	NI 60	CI-A2

Elga (ITW)	Kjellberg	BOC (Linde)	Philarc	Oerlikon (Air Liquide)	Hyundai
Elgaloy Cast-NiFe	Ficast NIFE	Smootharc C Cast Nife	Philcast Fe-Ni	Superfonte Ni Fe	S-NFC

Nickel electrodes (AWS A5.15: E Ni-CI):

Lincoln Electric	Esab	Bohler	Wilhelmsen Ships Service	Drew Marine	Kobe steel (Kobelco)
Softweld 99Ni	OK 92.18	UTP 8	Nickel-333N	NI 99	CI-A1

Elga (ITW)	Kjellberg	BOC (Linde)	Philarc	Oerlikon (Air Liquide)	Hyundai
Elgaloy Cast-Ni	Ficast NI	Smootharc C Cast Ni	Philcast Ni	Superfonte Ni	S-NCI

Gouging electrodes (exothermic type):

Castolin	Esab	Bohler	Wilhelmsen Ships Service	Drew Marine	Kobe steel (Kobelco)
EutecTrode	OK 21.03	FOX NUT	CH-2-382	CH	-

Elga (ITW)	Kjellberg	BOC (Linde)	Philarc	Oerlikon (Air Liquide)	Hyundai
Elgaloy Cut	Kjellgouge	-	Groove Arc	Citocut	-