Analysis of Mechanical Properties for Welded Cast Iron

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Abstract- Gray cast iron is most common type of cast iron and it can be successfully welded if cooling rates controlled during welding and after welding. Poor weldability of gray cast iron is due to the presence of much more carbon and silicon than in steel; which results in cast iron is less ductile hence weld is subjected to more metallurgical complications in both the weld metal and the heat-affected zone. During cooling the carbon is precipitated in the form of graphite flakes which are difficult to weld, the weld metal does not fuse to the graphite flakes. The welding was carried out with manual shielded metal arc welding and oxyacetylene welding, using nickel based filler metal and cast iron rod (RCI) respectively to join grey cast iron. Welding is carried with preheating and post weld heat treatment (PWHT). A preheating temperature at 350°C and post heating temperature 850°C for one hour which improves mechanical properties of welded piece. Micro hardness, tensile tests were studied to evaluate the quality of welded joints.

Keywords: Gray cast iron, welding, preheating, post welding heat treatment (PWHT), HAZ, hardness and tensile strength.

I. INTRODUCTION

Gray cast iron has an excellent compressive strength; graphite microstructure provides vibration damping for general engineering and automotive applications as dies, machine tool bases or engine blocks, crankshafts in large diesel engines etc. In a jobbing foundry producing few large complex castings, the cost of replacement of a defective casting may be very high and thus there is a strong incentive to make the casting serviceable by repair. For repairing minor cracks, blow holes, cavities welding process suits best using suitable grade of cast iron welding electrodes [1]. The three major areas of application of welding to cast iron,
(i) Repair of casting defects in foundry,
(ii) Repair of castings which are damaged or worn out in service,
(iii) Production of welded assemblies.

Shielded metal arc welding process (SMAW) and oxyacetylene welding are two most common welding processes which are used to cast iron welding. The welding was carried out with no preheating, preheating, post heating and preheating-post heating [2-13]. There were generally three types of filler metals available for welding
(i) Cast irons,
(ii) Mild/low carbon steel filler metal,
(iii) Cast iron filler metal and nickel/nickel–iron based filler metal [3-7].

II. WELDABILITY OF CAST IRON

Cast iron is considerably less weldable than the low- carbon steel. Cast irons contains much more carbon and silicon than in steel, with the result that cast iron is less ductile hence weld is subjected to more metallurgical complications in both the weld metal and the heat-affected zone. During cooling the carbon is precipitated in the form of graphite flakes which are difficult to weld, since the weld metal does not fuse to the graphite. The graphite flake reduces the ductility of area in which it occurs. [1, 2].

Most cast iron parts are made in gray cast iron, a weldable material. Malleable iron and nodular iron are also weldable, they require heat treatment after welding to restore their normal strength and ductility [3].

Cast iron is generally considered as a less weldable material. This is basically due to two reasons [4-7];
(i) Inherent brittleness of the cast iron and
(ii) The effect of weld thermal cycle on the metallurgical structure of the cast iron.

The preheating treatment improves the ductility of welded piece by minimizing hard and fragile microstructure [8].

The weldability of gray cast iron is significantly affected by 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 [9].

Weldability refers to the ability of a material to be joined under the fabrication conditions to form a structure that will perform satisfactorily in the application [10].
Weldability of cast iron depends on following factors [11-13]:
(i) Type of the cast iron,
(ii) Chemical composition of cast iron,
(iii) Chemical composition of filler metal,
(iv) Original matrix structure and

III. WELDING ELECTRODES FOR CAST IRON

ECI a covered electrode with cast iron core wire, must be applied on preheat parts. ECI provides welds most similar to that of the base metal of the casting. This electrodes requires extremely high preheat.

ENi a covered electrode with nickel base core wire provides welds are soft, ductile, machinable. Nickel based electrodes offer the highest crack resistance weld mainly because of their desirable mechanical properties and their ability to precipitates the carbon picked up from the base in its free form as graphite.

RCl intended for oxyacetylene welding, when color match FZ is required the best choice is oxyacetylene welding with cast iron rod RCI [2, 3].

In the case of cast iron filler metal, it is reported that the weld cracking due to formation of brittle phase in FZ is high portable when pre heat temperature is lower than 300°C [2-4].

IV. WELDING PROCEDURE USED FOR CAST IRON

Satisfactory joint have been obtained in gray, ductile and malleable cast iron by arc welding. Oxyacetylene welding widely used on gray cast iron, to a smaller extent on ductile iron and only minor extent on malleable iron. Cast iron filler metal is melted together with the base metal to form the joint. An oxyacetylene flame has a maximum temperature of about 6000 F, which is several thousand degrees less than that of welding arc. Gas welding is therefore slower and results in greater heat input and wider heat affected zone than arc welding. For this reason high preheats of 1100 to 1200 F are generally used for gas welding of cast irons.

The presence of brittle zone at the weld, caused by rapid freezing of weld metal and rapid cooling of weld metal and adjacent base metal, makes joint susceptible to cracking immediately after welding. The best method to slow the cooling rate is to preheat the casting to prevent the iron from rapidly absorbing heat from the weld area. Post weld heat treatment may consist of either full annealing or stress reliving at 850°C. Preheating and post heating are advisable, either to reduce joint brittleness and residual stress or to improve machinability [1-2].

Most small castings are welded satisfactorily without preheating. Where preheating not used, two-pass weld is recommended if a soft fusion zone is desirable. The first bead is serves as a preheating for the second bead which tends to slow the cooling and produce an annealing that makes a softer, more machinable fusion zone. The large parts can be welded without preheating; the primary goal is to keep casting cool as possible. Use small diameter of electrode and low currents. Deposite a short welds at intervals to allow casting to cool. The main objective is to keep temperature down to prevent warpage or breakage from uneven heating [3].

M. Pouranvari [4] carried out a study on welding cast iron using shielded metal arc welding with Nickel based electrodes. He also applied post weld heat treatment at 870°C, holding for 1 hr. and then furnace cooling. Nickel based filler material can prevent formation of hard brittle phase in fusion zone. PWHT helps to dissolution of martensite in heat affected zone and graphitization which results in reduction of partially melted zone hardness.

R. C. Voigt et al. [5] was studied heat affected zone structure in ductile cast iron. Shielded metal arc welding with ENi-CI filler material used with 316°C of preheating. Sub-critical annealing and full annealing is applied to the specimens. In as welded specimens carbides are formed surrounding the graphite nodules and in intercellular regions between nodules. It is concluded that this formation cannot be effectively prevented in partial melted zone. Martensite, observed in heat affected zone, cannot be overcome if the preheating temperature is sustained for sufficient time after welding. By application of subcritical annealing martensite was decomposed to ferrite and secondary graphite.

M. Pascual et al. [7] studied weldability of spheroidal graphite ductile cast iron using manual metal arc welding with Ni-Fe and pure Ni electrode. Preheating temperature at 350°C and post heating at 850°C for one hour carried out for mechanical properties improvement. They concluded that high purity Ni electrode showed better weldability than Ni-Fe electrodes and preheating treatment increases the ductility.

Further study was carried out by Pascual et al. [8] on welding of ductile cast iron with oxyacetylene (OAW) and shielded metal arc welding (SMAW) using 98.2% Ni and Fe-Cr-Ni alloy filler materials respectively. They have concluded that welding ductile cast iron with or without preheat is possible but preheating always increases weld quality and ductility. OAW gives results very poor weld metal properties whereas SMAW yields an amount of ductility in the weld metal. Furthermore, using Ni electrodes is another factor increasing the ductility which reduce the carbide formation.

J. H. Devltian [9] investigated weldability of gra cast iron using fluxes gray iron electrode for SMAW. The single and multipass welds were deposited by SMAW process with preheating temperature up to 830°C. Cracking tendencies in weld and HAZ were eliminated by maintaining cooling rate above 300°C. The weldability of gray cast 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. The fast cooling resulted in the highest hardness value in weld and heat affected zone, while the slow cooling weld resulted in lower hardness.

T. J. Kelly [10] investigated on welding of ductile cast iron with Ni-Fe-Mn filler metal, and they concluded that Ni-Fe-Mn filler metal capable to welding ductile cast iron without preheating or post heating and retaining 100% of the base metal tensile strength. By buttering the joint surfaces Shielded metal arc welding can be used with Ni-Fe-Mn electrode to obtain good welding joint and tensile properties.

E.M. E.L-Bana et al. [11] has investigated welding ductile cast iron in as cast using SMAW process with ENiFe-CI filler material. He has worked on different preheating temperatures and again concluded that ductile cast iron can be welded with or without preheating using Ni based electrodes but in order to achieve certain mechanical properties a preheat temperature of 300°C or 200°C is required.

Ravi Butola et al. [12] investigated that the formation martensite and carbide in fusion zone can be controlled by controlling rate and chemical composition of fusion zone. Pre heating as well as post heat treatment is requiring to obtain defect and stress free welding.

Further study carried out by E.M. E.L-Bana et al. [14] restoration properties of pearlitic cast iron using SMAW with various filler materials as Ni, Fe-Ni alloy, Ni-Cu alloy, stainless and ferritic steel. To study Effect of preheating three different pre heating temperatures was used 200°C, 300°C, and 400°C. MR size decreases with increases in preheating temperature to 300°C and then increases with further increases in temperature. The width of HAZ increases continuously with increases pre heating temperature. It is seen that PWHT has reduced the maximum hardness values slightly and multi pass welding lowers the width of melt region and micro hardness of HAZ. Using filler materials with Ni content can overcome carbide formation however; with ferritic filler a continuous carbide network is observed around the fusion line and heat affected zone yielded a martensitic structure.

V. REGIONS FORMED DURING WELDING

Some researchers [3-5, 11] studying the four distinct regions are formed during welding:

**Fusion Zone (FZ):** This is the zone in which the base metal is melted and mixed with filler metal. Cooling rates are high in this zone producing very hard, brittle ledeburitic carbides in as-welded condition.

**Partially Fusion Zone (PFZ):** In the neighborhood of the FZ, the portion of the matrix of the base metal near the primary graphite nodules melted during the weld pass, while the remainder of the matrix transformed to austenite.

**Heat Affected Zone (HAZ):** In this region, the peak temperature rises above the critical point. There is no melting but matrix transforms to austenite during heating. During cooling, a variety of transformation products are obtained. These events occur in a matter of very few seconds. Figure 5.1 shows the relationship between Fe-C phase diagram and temperature experienced by each microstructural zone [6].

![Fig.1 Temperatures experienced by various microstructural zones in a cast iron weld](image)

VI. SUMMERY

In this paper a collective summary of the effect welding on mechanical properties of cast iron and weldments was presented.

1. Rapid heating and cooling, characteristics of welding, produce a hard microstructure in the HAZ which is responsible for the property deterioration of welds.
2. In this study observed that formation of martensite and carbide in fusion zone can be controlled via controlling of cooling rate by preheating or post welding heat treatment and using nickel base filler material.
3. The preheating treatment increases the ductility of the welded piece through minimizing hard and fragile micro structures. An annealing treatment can be substituted for the preheating treatment which also improves the ductility.
4. Thermal treatment gives the following results,
   (i) Relieving residual stresses
   (ii) Decreasing cooling rate
(iii) Increase in fluidity and diffusion of filler material.

REFERENCES