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Editorial Note

As my nomination as an Subject Expert and Editor for this Special Issue on Engineering & Technology 2012, I have worked a lot to make it successful. I do whatever task is at hand to the best of my ability. I take pride in my work and give hundred percent every time. For those submissions that were not suitable for publication, we tried to let authors know very quickly of our decision, giving them a chance to submit their manuscript to another journal if they so desire. I am fully aware that the prestige and quality of an ANVIKSHIKI Journal depends upon the altruistic participation of reviewers and the fairness and promptness with which the review process is conducted. In this regard, I wish to express my sincere gratitude to all board members for their nice cooperation and sustained effort. However, because of the increased number of submissions and the diversity of research fields involved, we have a difficult task ahead of us requiring a more rapid tempo of review. At the same time, from now on the authors themselves should assume their own inescapable responsibilities. The editor will return immediately any manuscript that is incomprehensible to reviewers on account of substandard grammar and syntax.

Finally, it is a pleasure to thank my Editor in chief for their nice cooperation and valuable suggestion. Now, we all look forward to embarking in a journey that can take ANVIKSHIKI on to the next plateau of excellence.

I hope you will enjoy reading this issue and we welcome your feedback .

With best regards,

Jyoti Prakash

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A REVIEW ON METALLURGY OF WELDING OF CAST IRON AND EFFECT OF PREHEAT

PRADESHI RAM*, S.P. TEWARI** AND JYOTI PRAKASH***

Declaration

Abstract

Most of the welding of cast iron is repair welding. Carbon pickup and resulting cracks are the main concerns when welding CI. The casting process is never perfect, especially when dealing with large components. Instead of scrapping defective castings, they can often be repaired by welding. Naturally, the very high carbon concentration of typical CIs causes difficulties by introducing brittle martensite in the heat-affected zone of weld. It is therefore necessary to preheat to a temperature of 450 °C, followed by slow cooling after welding, to avoid cracking. The effect of preheat temperature on the microstructure obtained in the heat-affected zone HAZ and the carbide zone in the weld metal adjacent to HAZ has been studied in multipass welds for the as ductile cast irons. The welding was carried out with manual shielded metal arc welding using ENiFe–CI filler metal. Ultrasonic, microhardness distribution, tensile and impact tests were conducted to evaluate the quality of welded joints.

Keywords : Heat-affected zone (HAZ); Weld metal (WM); Microstructure; Toughness; Post Weld Heat Treatment (PWHT); Carbon Equivalent (CE);cast iron (CI);

1. Introduction

Cast iron is generally considered as a difficult material to be welded. This is basically due to two reasons: (i) inherent brittleness of the cast iron and (ii) the effect of weld thermal cycle on the metallurgical structure of the cast iron. Typically, four distinct regions are formed when cast iron is welded, as follows:

(i) Fusion zone (FZ) which is melted during welding process and is resolidified upon cooling.

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(ii) Partially melted zone (PMZ) which is the area immediately outside the FZ where liquation can occur during welding.
(iii) Heat affected zone (HAZ) which is not melted but undergoes microstructural changes.
(iv) Base metal (BM) which its structure remains unaffected during weld thermal cycle.

Fig. 1 shows relationship between Fe–C phase diagram and the temperature experienced by each microstructural zone [1]. High carbon content of the cast irons leads to formation of hard brittle phases, namely martensite and carbides in the FZ, the PMZ and the HAZ. Both carbide and martensite, being hard and brittle, are detrimental to the ductility, toughness and machineability of the weld and also may cause cracking in the joint [2-5]. Weldability of cast iron depends on the several factors including [4-11]: (i) type of the cast iron, (ii) chemical composition of the cast iron, (iii) chemical composition of filler metal, (iv) original matrix structure and (v) welding process and preheat/post heat treatment.

Arc welding processes and oxyacetylene welding are two most common welding processes which are used to cast iron welding There are generally three type available filler metals for welding cast irons: mild/low carbon steel filler metal, cast iron filler metal and nickel/nickel–iron based filler metal. Some researchers used mild steel electrode for welding grey cast iron. The main driving force for using mild steel electrodes is their low cost [21]. However, these electrodes suffer from some metallurgical problems including:

(i) Steel shrinks more than grey cast iron during solidification; therefore, tensile stresses generated in FZ can make it susceptible to shrinkage cracking [13,14].
(ii) In spite of dilution of mild steel electrode with high carbon cast iron, the carbon content of FZ is sufficient to formation hard and brittle product in FZ. This reduces the impact properties of the weldment. Moreover, inability of FZ to yield and relieve welding stresses can result in cracking in the adjacent cast iron heat affected zone. Therefore, the use of steel electrodes should be restricted to application where the joint is not loaded in tension or in bending 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.

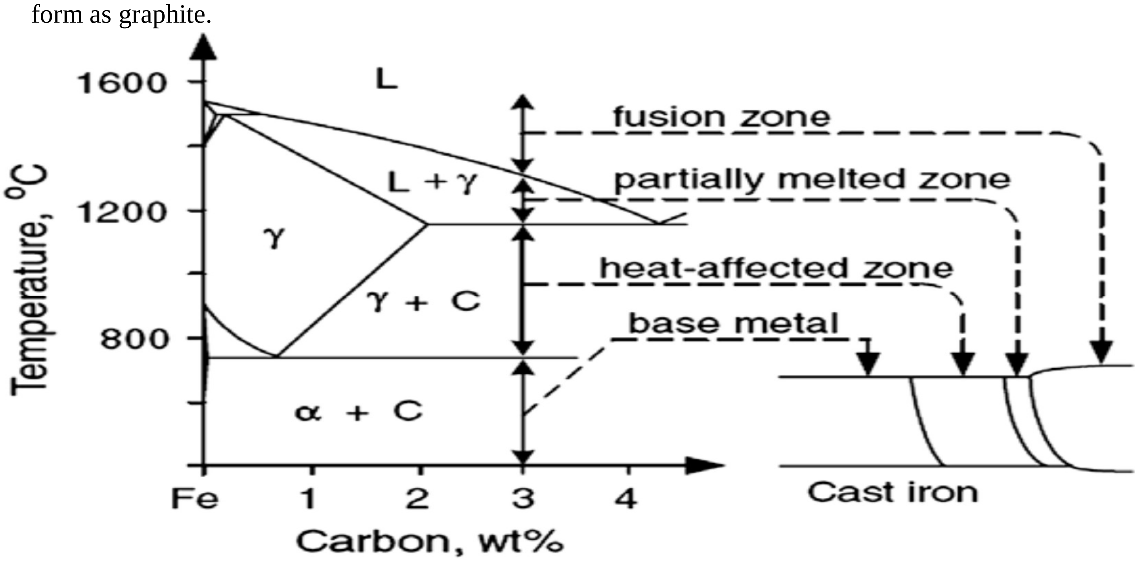

Fig. 1 *Temperatures experienced by various microstructural zones in a cast iron weld [1].*

2. Weldability Of Cast Iron

Weldability of the cast iron is commonly characterized by calculation of the carbon equivalent (CE). By CE no-crack temperature for the cast iron is determined. No-crack temperature is the preheating temperature, above which the cooling rates will be lowered enough that the material will not cause formation of any cracks due to welding. CE is calculated using the weight percents of the elements in the chemical composition according to Equation 1 [12] below:

The no-crack temperature is correlated with the CE by Figure 2. The lower the no-crack temperature is the more weldable the cast iron is. Here the preheating is determined by CE and main structure of the cast iron to be welded. Additionally, the thickness of the material will be another factor determining the cooling rate after welding. Increased thickness causes an increase in cooling rates thus weldability of the thicker pieces will be lower requiring increased preheating temperatures.

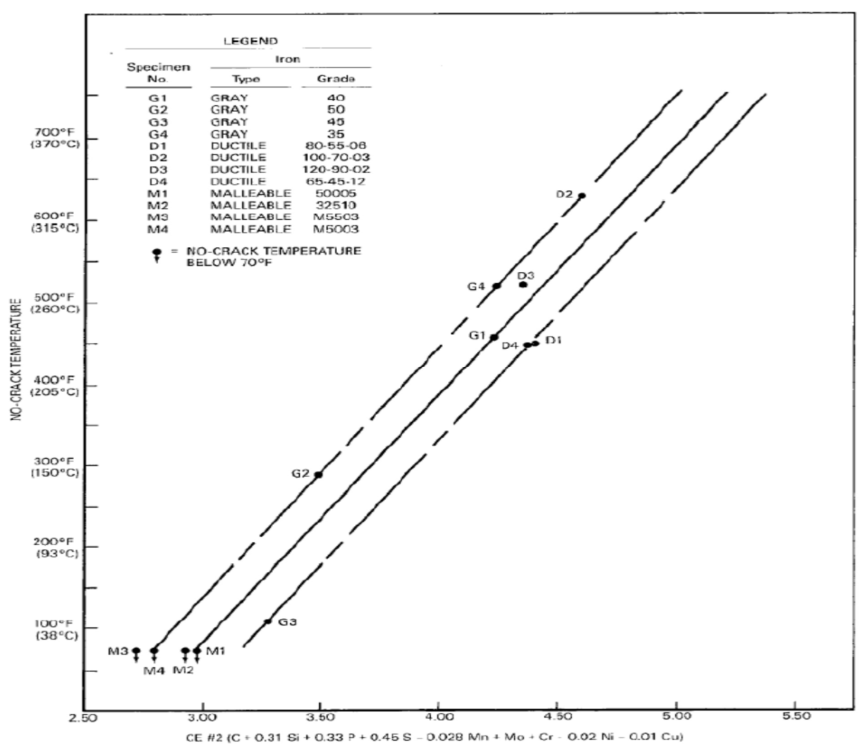

Figure 2. *Effect of CE on no-crack temperature for selected grades of iron castings*

3. Welding of Cast Iron

Ab Pascual et al. have studied welding nodular 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 almost always increases weld quality and ductility. OAW 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 hinders the carbide formation. El-Banna has studied welding ductile cast iron in as-cast and fully ferritized states using SMAW process with ENiFe-CI filler material. He has worked on different preheating temperatures and again concluded that ductile cast iron can successfully be welded with or without preheating using Ni based electrodes but in order to achieve certain mechanical properties a preheating temperature of 200-300°C is required. Additionally he stated that Rm values required from the base materials can only be met in ferritized components. In as-welded specimens ledeburitic carbide structures and local melting around the graphite nodules are observed. With application of preheating various pearlite and martensite ratios instead of carbide were formed. Again in a study carried out by El-Banna et al. restoration properties of pearlitic cast iron using SMAW with various filler materials as Ni, Fe-Ni alloy, Ni-Cu alloy, stainless and ferritic steel is studied. Also subcritical annealing at 677°C is applied. Effect of heat input, preheating and filler materials was examined. When using the ferritic filler material, preheating at 300°C becomes the best option for narrowing the melt region and HAZ with discontinuous carbide and bainite. It is seen that PWHT has reduced the maximum hardness values slightly and finally multipass welding lowers the width of melt region and microhardness 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 HAZ yielded a martensitic structure. Pouranvari carried out a study on welding cast iron using SMAW with Ni based electrodes. He also applied PWHT to the welded pieces. Due to possibility of increasing amount and continuity of carbides preheating is not used and formation of cracks was not reported. Material was fully annealed and a nearly uniform hardness profile is achieved. Again nickel based filler is used to prevent ledeburitic carbide formation in the structure of the weld piece but due to dilution very high carbon contents are come across which cannot be compensated with Ni. This excess amount precipitated as graphite in fusion zone. In PMZ ledeburitic and martensitic structure formation occurs, constructing a hard and brittle network among fusion line. Voigt et al. have studied general HAZ structures of ductile cast irons. SMAW with ENi-CI filler material used with about 300°C of preheating. Sub-critical annealing and full annealing is applied to the specimens. In as weld 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 PMZ. Martensite, observed in HAZ, cannot be overcome if the preheating temperature is sustained for sufficient times after welding. By application of subcritical annealing martensite was decomposed to ferrite and secondary graphite.

4. Fundamentals of Preheat

The operation of heating metal to some pre determined temperature before engaging in actual welding is called preheating . The details and the modes may be different in various situations but in general the purpose is to influence the cooling behavior after welding so that shrinkage stresses will be lower (relative to welding without preheating) and cooling rate will be milder [27].

Pre-heating prepares metal to make it more receptive to welding. The importance of preheating increases with the thickness of the base metal because of the rapid self quench capability, and with the rigidity of the welded structure because of the derived constraints. In general the higher the preheat temperature and the lower the heat input, the conditions are more favorable for limiting martensite formation and its hardness, hopefully contributing to higher quality welds[23].

The minimum preheating temperature to be assured to avoid cracking depends on the following factors:

- Carbon equivalent expressing carbon and alloy content,
- Condition of base metal prior to welding,
- Thickness of base material,
- Constraint level,
- Hydrogen available risk.

Usually, rapid heating and cooling, characteristics of welding, produce a hard microstructure in the HAZ [18, 24]. The hard micro structure of the HAZ is one factor responsible for the property deterioration of welds. The heat-affected zone (HAZ), which is cooled at different rates and includes different regions of microstructure, is often considered the source of failure in a welded joint [25,26].

4.1 Effect of Preheat and HAZ Cracking

R. Scott Funderburk [22] while writing the fundamental of preheat concluded that (a) preheat can minimize cracking (b) Preheat must be used whenever applicable codes so specify (c) Annex XI of AWS D1.1-96 provides guidelines for alternative methods of determining proper amounts of preheat (d) Finally, the interpass temperature should be checked to verify that the minimum preheat temperature has been maintained just prior to initiating the arc for each pass

4.2 Fatigue Behavior of Cast Iron

Very high cycle (1010 cycles) fatigue behavior of nodular cast iron is studied by Xue et al. [13] Fatigue behavior and effect of frequency is not observed. Crack initiation takes place on surface graphite nodules or subsurface nodules. Mechanisms of crack propagations of cast irons with various pearlite and ferrite ratios are investigated by Cavallini et al. [14] Common damaging mechanism for crack propagations is determined to be the debonding of the graphite elements which is characterized by the morphology depending on microstructure. Microstructure 23 influences the crack propagation resistance only at higher stress ratios while at lower ones no variations can be determined. Pearlite results in a completely fragile debonding mechanism whereas ferrite yields higher ductile deformation during debonding. Pearlitic ferritic structure fractures at intermediate values. The ductile debonding mechanism acts as an important crack closure mechanism. Finally it is concluded that phase distribution in the structure, like bull’s eye structures, acts as a secondary crack closure mechanism.

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