A REVIEW ON WELDABILITY OF CAST IRON

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Abstract— The problematic welding characteristics of the cast iron originate majorly from the high carbon content of the material. Upon welding and cooling, the carbon makes formation of various undesired microstructures possible, reducing the weldability a great deal in all regions related to welding. There are two possible routes for welding cast irons which are named as cold and hot welding. These two methods are primarily separated from each other according to the preheating temperatures ranges. In cold welding, the lower preheating temperatures are not sufficient for lowering the cooling rate to the desired values and hence formation of brittle phases as martensite and carbides are encountered. For these cases generally Ni based electrodes are used. Ni based fillers are weaker than steel alloys and yields higher ductility. Increased ductility suspends crack formation especially in case of martensitic transformation and additionally Nickel bonds with Carbon preventing formation of iron carbide. Despite these superior properties, Ni electrodes provide relatively lower mechanical properties with respect to steel. When cast iron weldments are required to be operated at higher stress values, filler materials with similar properties to base metal are chosen. In order to prevent the formation of possible brittle phases with such fillers, the preheating temperatures get increased and these processes are named as hot welding.
Keywords-weldability,martensite,iron carbide

1. INTRODUCTION

Weldability of cast iron has been found to be very poor due to the heterogenity of matrix phase and non-wettability of the graphite phase. These phases undergo a series of microstructural changes in the HAZ during weld repairing by fusion welding the project discusses the nature of these changes occurring in the vicinity of the weld zone as well as method of controlling these to get satisfactory weldment.It further discusses the practical aspect of weld joint preparation, the selection of welding process and procedure, the choice of filler metal-composition etc. and degree of pre as well as post weld heat-treatment to obtain defect and stress free welding. The welding of ductile cast iron is not normally practiced in the foundry industry for the reclamation or fabrication of castings, due to the inconsistency of the mechanical and physical properties achieved. Grey irons contain higher amounts of carbon compared to steels which diffuses into the austenite during welding, forming hard brittle phases, namely martensite and carbides at the weld interface. These give rise to poor elongation properties and high hardness values. Weldability of ductile cast iron depends on its original matrix, chemical composition mechanical properties and structure of welding process and working condition .The preheating temperature range depends on the hardenability of the iron chemical composition or carbon equivalent, the size and complexity of the weld and the type of filler materials. Preheating must be sustained for a time sufficient to avoid martensite formation and to prevent secondary graphite from developing in the matrix upon annealing or multipass welding. The effect of preheat is to reduce residual stresses, distortion, prevent cold cracking and reduce the hardness in the HAZ In this study, the HAZ structures and mechanical properties of grey cast iron welds have been examined in the as-cast and fully ferritizing annealing conditions under preheat temperatures.

Ductile cast iron is an important cast material to the designer which combines the advantages of cast iron, such as cheapness, ease of machining, low melting temperature, good fluidity, good wear resistance properties, high damping capacity, excellent heat resistance properties and those of steel, such as high strength, ductility, toughness, hot workability and hardenability. Therefore, such material can economically replace steel in a very wide variety of applications. The poor weldability of ductile cast iron can be attributed to two factors, the formation of martensite in the heat affected zone HAZ, and the development of hard, brittle iron carbide in the zone of partial fusion. Most of the welding performed on cast iron is repair welding. It is either the repair of discontinuities produced during the casting process or those developed in the cast component itself while in service.

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. (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 micro structural changes. (iv) Base metal (BM) which its structure remains unaffected during weld thermal cycle. Shows relationship between Fe–C phase diagram and the temperature experienced by each microstructural zone 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. Weldability of cast iron depends on the several factors including (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. Grey cast iron is inherently brittle and often cannot withstand stresses set up by a cooling weld. As the lack of ductility is caused by the coarse graphite flakes, the graphite clusters in malleable irons, and the nodular graphite in ductile cast irons, give significantly higher ductility which improves the weldability. Ductile cast irons and malleable irons are less susceptible to form martensite in HAZ, therefore, they are more readily weldable, particularly if the ferrite content in their matrix is high. White cast iron which is very hard and contains iron carbides is normally considered to be unweldable. Arc welding processes and oxyacetylene welding are two most common welding processes which are used to cast iron welding. However, the application of diffusion bonding, friction welding and electron beam welding are evaluated by some researchers. 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. 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. (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. (iii) Due to high hardness in FZ and HAZ, preheating and post weld heat treatment (PWHT) is required. Preheating reduces cooling rate and therefore leave softer FZ and HAZ. Preheat temperature is usually in the range of 300–600°C. Preheating cannot be used, however, when minimum heat is to be applied to avoid distortion of the parts being welded. According to work of Kumar, a preheat temperature of 540°C is required to significant reduction of FZ and HAZ hardness. However, for more improvement in machinability of welded cast iron a PWHT is also required. When a color match FZ is required the best choice is cast iron rods. Also when pressure tightness and uniform thermal expansion is required such as on cylinder heads or steam turbines or pump cases the oxyacetylene welding with a cast iron rod is preferred process. In the case of cast iron filler metal, it is reported that the weld cracking due to formation of brittle phase in FZ is highly probable when preheat temperature is lower than 300°C. 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. Therefore, successful welding of cast iron requires more sophisticated understanding of interaction between the composition & microstructure of cast iron, filler metal composition and weld thermal cycle[1].

2. LITERATURE SURVEY

Pascual et al. [15] 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. [16] 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. [17] 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 20 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 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 HAZ yielded a martensitic structure.

Pouranvari.[18] 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. [19] 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.

Hatate et al. [20] have made a comparison of dissimilar welding of spheroidal graphite cast iron to mild steel between electron beam welding (EBW) and MAG welding. For this purpose a buffer layer of nodular cast iron with 35% Ni was inserted between the two types of materials in EBW welding and Ni alloy filler wire is used for MAG welding. Very high cooling rates and high hardness values were experienced in weld bead of EBW joints. Increasing the objective to focus distance ratio resulted a lower cooling rate and lower hardness but increased bead width. This modification has not affected bonding strength. Because of the lower heat input it is judged that EBW results and increased bonding strength with respect to MAG. Cementite formation in EBW welding is observed and successively prevented using Ni layer. It is seen HAZ region of cast piece in MAG welded joint is composed of cementite and martensite.

Sanghoon et al. [21] studied dissimilar weld joint between high silicon nodular cast iron and ferritic stainless steel using MAG welding with Ni Cr alloy filler material. A significant UMZ region is determined on the fusion boundary. This region with PMZ has yielded the highest hardness values and martensitic phases and carbide formation is examined in UMZ, PMZ and HAZ. Additionally in PMZ and HAZ parallel to the peak temperatures a carbon diffused layer is formed around the graphite nodules.

Tadashi kasuya et al. [22] searching the methods for predicting maximum hardness of Heat Affected Zone and selecting necessary Preheat temperature for Steel Welding concluded that the hard microstructure of the HAZ is responsible for the property deterioration of weld and cold cracking susceptibility.

Takamura et al. [23] While discussing the method for TIG welding 1.25Cr.-0.5 Mo steel pipe concluded that the technical problems associated with conventional steel materials welding can be eliminated without preheating and post heating treatments by applying TIG welding between two units of certain composition of steel pipes.

Schmidt J. et al. [24] While discussing the Alternative methods for postweld treatment of austenitic pipe welds to increase the operational safety of BWR examines past experience and more recent developments, in particular the latest results with pipe welds treated by means of welding processes (last pass heat sink welding). These measures are suitable for producing compressive stresses in the medium-swept IDHAZ of austenitic welds, or to at least significantly reduce the tensile stresses and thus practically eliminate the risk of IGSCC.

Scott Funderburk R. [25] 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 interphases temperature should be checked to verify that the minimum preheat temperature has been maintained just prior to initiating the arc for each pass.

Hisaki O and Ryochi K. [26] while studying the Preheating and Post heating suitable for avoiding the heat-affected zone cracking in 9Cr-1Mo-Nb-V Steel Concluded that the (1) minimum preheating temperature to prevent the cracking is about 200°C,which is lower than the values (300°C) estimated from the above steel chemistry;(2)The preheating temperature, however, becomes higher when the weld is made with an electrode of mild steel of 58 kg/mm2 tensile steel; and (3) use of a martensitic weld metal lowers the residual stress and results in low susceptibility to cracking.

3. Material (Cast iron)

Iron occurs in the native metal state as meteoric iron which was exploited by the North American Indians to make weapons. Since iron has a high melting point of around 1550°C it was commonly produced in the old world by reducing the ore to metal in the solid state to produce bloomery iron which was then wrought to give low carbon wrought iron (0.1-0.2 % C). The Hittite kingdom of the mid second millennium BC was one of the major early iron producing centers and was thought to have a monopoly of iron production, and iron production became widespread in Greece and the Mediterranean by the beginning of the 1st millennium BC. Iron seems to have been used in India from about the late second millennium BC and iron smelting and the use of iron was especially well established in the south Indian megalithic cultures of this period.

The forging of wrought iron seems to have reached its zenith in India in the first millennium AD. The earliest large forging is the famous iron pillar at New Delhi dated by inscription to the Gupta period of the 3rd. AD at a height of over 7 m and weight of about 6 tons. The pillar is believed to have been made by forging together a series of disc-shaped iron blooms. The famous Mysore Palace in Mysore near Bangalore built by the Wodeyars at the turn of the century was the first royal palace in India to make use of cast iron in architectural construction.

3.1 Cast Iron

Cast irons are the ferrous alloys having carbon content generally greater than 2.1 wt% and solidifying with a eutectic structure. By the eutectic solidification characteristics, cast irons can be liquid between 1150-1300°C and shows good fluidity and casting characteristics, making melting and casting a preferable production technique.

3.1.1 White Cast Iron

When the cooling is rapid, the carbon cannot form graphite instead remains as metastable iron carbide and large amounts of cementite is formed. Also graphitization may be inhibited by the alloy composition. The structure is very hard and brittle and unmachinable but can be used as a wear resistive material.

3.1.2 Malleable Cast Iron

If suitable heat treatment is applied to the white cast iron, annealing at 800-900°C for prolonged times, the carbon in the cementite precipitates as graphite having irregular shapes. The structure of matrix is determined by annealing process as ferrite or pearlite. Malleable cast irons yield high strengths and appreciable ductility

3.1.3 Gray Cast Iron

Gray cast iron is the most common type of cast iron. Generally it has about 1 - 3 wt% Si. Presence of silicon in combination with the slow cooling promotes the formation of graphite instead of iron carbide. In this type, graphite is in the form of flakes. General microstructure of gray cast irons consists of flakes distributed in pearlite matrix but addition of about 15% Ni to the composition may produce austenitic matrix. The graphite flakes behave like the cracks in the microstructure therefore gray cast irons show weak mechanical characteristics in tension whereas possess high strength in compression.

3.1.4 Chilled Cast Iron

When a localized area of a gray CI is cooled very rapidly from the melt, CI is formed at the place that has been cooled. This type of white CI is called chilled iron. A chilled iron casting can be produced by adjusting the carbon composition of the white CI, so that the normal cooling rate at the surface is just fast enough to produce white CI while the slower cooling rate below the surface will produce gray iron.

3.1.5 Spheroidal Graphite Cast Iron

Sulfur in CIs is known to favor the formation of graphite flakes. The graphite can be induced to precipitate in a Spheroidal graphite CI, Fe, 3.2 C, 2.5 Si, and 0.05 Mg wt%, containing graphite nodules in a matrix, which is pearlite. One of the nodules is surrounded by ferrite, simply because the region around the nodule is decarburized as carbon deposits onto the graphite spheroidal shape by removing the sulfur from the melt using a small quantity of calcium carbide (CaC_2).

3.1.6 Nodular Cast Iron

Nodular cast irons are produced adding magnesium or cerium to the gray iron composition. These elements act as nodulizers and change the flake like morphology of graphite into nodules, therefore the crack behavior of the graphite gets eliminated and the mechanical properties, especially in tension become improved. Mechanically nodular cast irons may have characteristics similar to steels. Thus, they combine the advantageous properties of steels and cast irons. Graphite nodules dispersed into pearlite and/or ferrite matrix constructs the characteristic microstructure of nodular cast iron [2-5]. \

4. CONCLUSIONS AND SCOPE FOR FUTURE WORK

In this study it is observed that formation of martensite and carbide in fusion zone can be controlled via controlling of cooling rate and chemical composition of fusion zone. Result of the current study showed that by using nickel base filler material, the formation of brittle martensite and carbide in fusion zone is prevented. It is of note that, the nickel base filler material has low coefficient of thermal expansion therefore it strains the cast iron HAZ much less than other filler metals, helping in reducing the risk of HAZ cracking.
Due to preheating following observation are made in this study

1. Preheating produces welding joints of higher strength and elongation but of lower hardness for FZ and HAZ at all cooling rates.
2. Higher cooling rates produce joints of higher strength and hardness but lower elongation.
3. Preheating increases the width of the FZ and HAZ.
4. Preheating produces larger grain size in FZ and HAZ under all condition of cooling.
5. In general preheating produces higher quality index for all cooling rates.

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