EFFECT OF POST WELD HEAT TREATMENT ON WELDABILITY OF CAST IRON USING NICKEL BASED FILLER MATERIAL

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This is to certify that report entitled **"Effect of post weld heat treatment on weldability of cast iron using nickel based filler material"** by **Mr. Gaurav Pratap Singh** is the requirement of the partial fulfillment for the award of Degree of **Master of Technology (M.Tech.)** in **Production Engineering** at **Delhi Technological University**. This work was completed under my supervision and guidance. He has completed his work with utmost sincerity and diligence. The work embodied in this project has not been submitted for the award of any other degree to the best of my knowledge.

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ABSTRACT

The weldability of cast iron is considered very difficult because of excess carbon, lower ductility, high content of sulphar and phosphorus and effect of weld thermal cycle on the metallurgical structure of the cast iron.

The experimental study is carried out for the analysis of effect of post weld heat treatment on weldability of cast iron using nickel based filler material. Microstructures of different zones of interest like weld metal; HAZ and base metal under two different welding conditions like simple welding and welding with post weld heat treatment were viewed and captured with an optical microscope coupled with an image analyzing software. The hardness of different zones of the weldments were measured using Rockwell hardness testing machine on (C) scale. Tensile strength and toughness of welded specimen were also determined to assess the change in ductility of the material in different conditions.

Metallurgical investigations determine the variation of hardness across the different zone of the welded work piece like weld metal zone, heat affected zone and the base metal.

Keywords: weld zone, base metal, HAZ, PWHT, SMAW

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NOMENCLATURE

SYMBOL	**NAME**
BM	BASE METAL
WZ	WELD ZONE
HAZ	HEAT AFFECTED ZONE
PMZ	PARTIALLY MELTED ZONE
PWHT	POST WELD HEAT TREATMENT
SMAW	SHIELDED METAL ARC WELDING

CHAPTER 1

INTRODUCTION

All types of cast irons available have common problems affecting their weldability, these are as follows-

(a) Much carbon content
(b) High content of phosphorus, sulphur and oxygen
(c) Lower ductility
(d) Casting defects

The following paragraphs will discuss each of these problems regarding difficulty of weldability of cast iron

(1) Under the welding thermal cycle, the cast iron base metal adjacent to the weld metal is locally heated to an extremely high temperature, and the cooling rates of entire heat affected zone are quite high. As a result of this, iron carbide tends to precipitate in the heat affected zone adjacent to the weld metal (referred to as the white-cast-iron zone), and the remainder of the heat-affected zone tends to form high-carbon martensite (the martensite zone).Both the white-cast-iron and martensite zones are characterized by the hard and brittle nature. In addition, the white-cast-iron zone is apt to contract much more than does the unaffected base metal. Therefore, with the brittle structure and high contraction stresses, the heat-affected zone tends to generate cracks either spontaneously or under load during services. The degree of brittleness and propensity to cracking depend, to some extent, upon the type of cast iron and the welding procedure [1].

(2) Fusion welding involves localized heating and cooling and thus causes thermal stresses in the weld area being accompanied by expansion on heating, and by contraction on cooling. The base metal should be capable of local plastic deformation to accommodate the welding stresses, thereby preventing the occurrence of crack. Cast irons are generally liable to produce cracks because their low ductility may not be able to withstand the contraction stresses arisen by the cooling weld during fusion welding [1].

(3) High phosphorous content of cast irons tends to form hard metallic compounds with ferrous and carbon, which make the castings brittle. High oxygen and sulphur are apt to accelerate the precipitation of carbides, thereby causing a hard and brittle white-cast-iron microstructure. Phosphorous, sulphur and oxygen dissolved in weld metals can cause cracking of the weld metal.

(4) Cast irons often contain casting defects such as sand inclusions and shrinkage cavities, which prevent complete fusion or better wetting of molten weld metal onto the base metal.

(5) Cast irons after service are often contaminated with impregnated oil which causes welding defects such as blowholes and cracking.

So in the cast iron different phases present undergoes a series of microstructural changes. The project discusses the different type of these changes occurring in the vicinity of the weld zone their nature as well as method of controlling these to get satisfactory weldment.

During the project two factors has been discussed in details. These are as follows-

(a) Selection of filler material or electrode

(b) Post weld heat treatment (PWHT)

These two factors have a great role in getting the sound and stress free weld. The welding of ductile cast iron is not normally practiced for the reclamation or fabrication of castings, due to the inconsistency of the mechanical and physical properties achieved. Weldability of ductile cast iron depends on its original matrix, chemical composition mechanical properties and structure of welding process and working condition.

Cast irons contain higher amounts of carbon which diffuses into the austenite during welding, forming hard brittle phases, namely martensite and carbides at the weld interface. As a result of the formation of martensite and carbide at weld interface high hardness are obtained.

In order to avoid the formation of martensite and carbide preheating can also be done. Preheating can be useful in order to avoid the formation of hard martensitic structure in HAZ.

Generally there are four distinct regions which are formed during welding of cast iron. These are as follows-

(a) BASE METAL(BM)-it is that part which structure remains unaffected as it does not go under weld thermal cycle.

(b) FUZION ZONE (FZ) - it is that part where actual welding is carried out. In this part microstructure change takes place due to weld thermal cycle and this is the zone where carbide formation takes place.

(c) PARTIALLY MELTED ZONE (PMZ) - which is the area immediately outside the FZ where liquation can occur during welding.

(d) HEAT AFFECTED ZONE (HAZ) - this is the zone where melting does not take place but undergoes microstrutural change due to rapid cooling and in this zone martensite formation takes place [2,3].

All these areas formed have been shown diagrammatically in the below figure

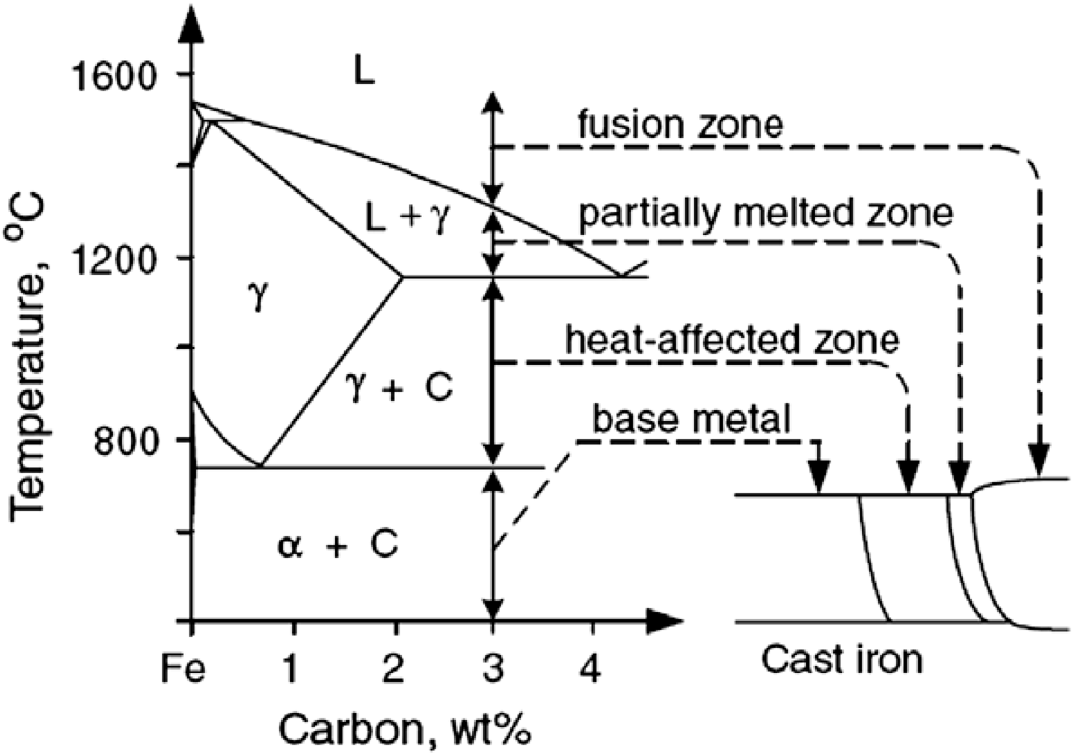

Fig .1.1 Temperatures experienced by various microstructural zones in cast iron weld [3]

So we can conclude that there are basically two problems which cause the variation in the welded cast iron parts physical properties and leads to its high brittleness. These are as follows-

(a) Formation of carbide in the fusion zone
(b) Formation of martensite in the HAZ

In order to overcome these problems different methods are employed. Each of these methods have their own advantages and restrictions as well. In order to restrict the formation of martensite in the HAZ either preheating or PWHT can be performed.

The hardness of the heat-affected zone can be decreased by preheating the base metal because preheating can reduce the cooling rate of the heat-affected zone. Slower cooing rates can suppress the formation of iron carbides and martensite structures in the heat-affected zone, which in turn reduce the propensity for weld cracking, by decreasing the hardness of the weld.

PWHT decompose the cementite formed during welding, transform martensite to a less brittle microstructure (troostite) and relieve the residual stresses. It can be carried out in the controlled way thus reducing the chances of deformation of plates which generally occurs with preheating at high temperature. Also PWHT is required to improve the machinability.

To get the lower hardness in WZ or to restrict the formation of iron carbide ($Fe3C$) in the WZ filler material plays a great role. There are basically three types of filler material which are available for the welding of cast iron are-

(a) mild/low carbon steel filler metal
(b) Cast iron filler metal
(c) nickel/nickel–iron based filler metal

Some researchers used mild steel (MS) electrode for welding of the grey cast iron. The main driving force behind using mild steel electrodes is their low cost. However, these electrodes suffer from some metallurgical problems. These problems include-

(i) Steel shrinks more than grey cast iron during solidification; therefore, tensile stresses may generate in FZ which can make it susceptible to shrinkage cracking.

(ii) Despite the dilution of mild steel electrode with high carbon cast iron, the carbon content in FZ is sufficient for formation of hard and brittle product in FZ. This reduces the impact properties of the welded material. Apart from this the inability of FZ to yield and relieve welding stresses can result in cracking in adjacent cast iron heat affected zone. That is why 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 leaves behind softer FZ and HAZ. The preheat temperature is usually in the range of 300–600^{O}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 ^{O}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 [3].

CHAPTER-2

THEORY

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.

2.1 Types and features of cast irons

Cast irons used for industrial general purposes contain 2.0-4.5% carbon, 1-3% silicon, and manganese. Alloy cast irons also contain other elements which are added deliberately to provide desirable properties as per the requirement such as strength, hardness, hardenability, or corrosion resistance for specific applications. Common alloying elements are chromium, copper and nickel. Cast irons have lower melting points (e.g. 1150 °C to 1300 °C for general cast irons) than that (approx. 1500°C) of steels as a result of this it offer fluid characteristics in molten state, and undergo very little shrinkage during solidification and cooling. These physical features make it suitable for better cast ability in casting complex shape moulds. The mechanical properties of a cast iron depend on its microstructure as well as the distribution of the free graphite (uncombined carbon). The amount and shape of the graphite particles affect the strength and ductility of the cast iron. As a result of this, cast irons can be classified by the characteristics of the graphite as it appears in a polished section. There are four basic types of cast irons these are gray iron, malleable iron, spheroidal graphite irons (ductile or nodular iron), and white irons. The characteristics of these different types of cast irons are outlined in the following sections.

2.1.1 Gray cast iron

Gray cast irons contains free carbon in the form of graphite flakes in the matrix which is commonly pearlite, ferrite or their mixture, as shown in Photo 2.1. Gray cast irons have very low ductility because of the flake form of graphite. It is named gray cast iron because of the gray appearance of a fractured surface.

Figure 2.1 Microstructure of gray cast iron[1]

gray cast irons generally contains 2.5-4.0% carbon, 1.4-2.5% silicon, 0.4-1.0% manganese, 0.05-1.0% phosphorus, and 0.06-0.15% sulphur. Typical applications of the gray cast iron are motor vehicle parts, pump housings, bedplates, and machine tools [1].

2.1.2 Ductile cast iron

The mechanical properties of gray cast irons are very poor and can be greatly improved by treating the molten gray cast iron that contains 3.2-4.5% of carbon and 1.8-2.8% of silicon with magnesium or cerium additions before casting. This special technique produces irons with the graphite in nodular or spheroidal form instead of flakes. This specific cast iron is known as nodular cast iron, spheroidal graphite cast iron, or ductile cast iron. Ductile cast irons contain very low amount of sulphur (e.g., 0.08% max) and phosphorus (e.g., 0.02% max) than gray cast irons, thus help in the formation of spheroidal graphite. The compact shape of graphite obtained improves the mechanical properties of the cast irons resulting in considerably high ductility and tensile strength as compared to gray cast irons. Ductile cast irons are more resistant to mechanical wearing and have much less thermal expansion under cyclic heating thus reduces the chances of residual stresses generated during the welding and consequently reduces the chances of cracking . Therefore, they are used in crankshafts, engine liners, gears, mill rolls, ingot cases, and water and gas pipes [1].

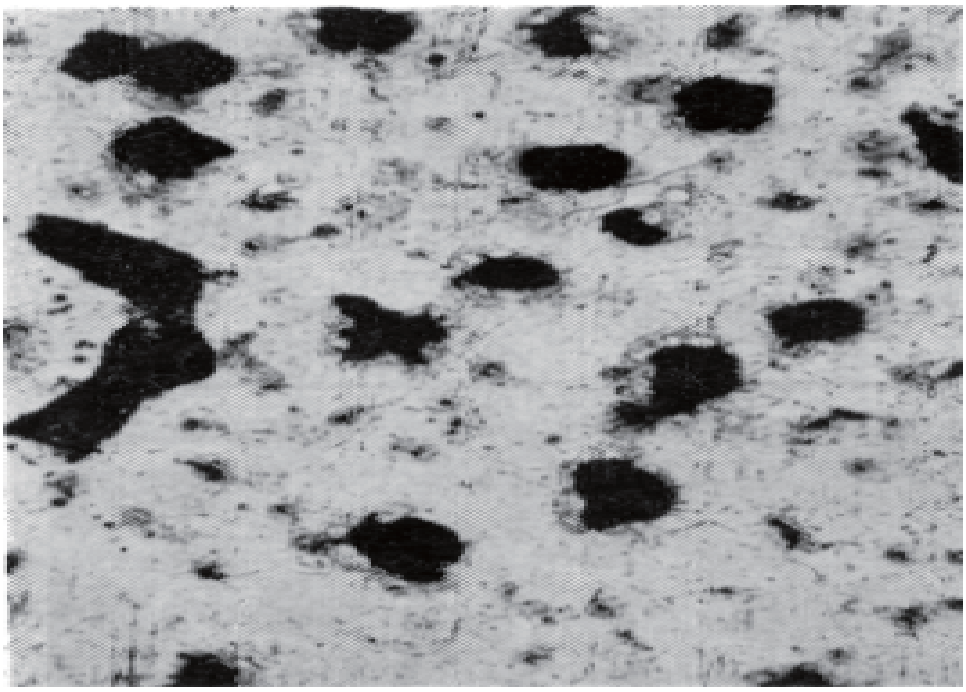

Figure 2.2 Microstructure of ductile cast iron [1]

2.1.3 White cast iron

When cast irons contain smaller amounts of carbon (1.8-3.6%) and silicon (0.5-1.9%) than in the case of typical gray cast irons, the carbon present in iron cannot precipitate as graphite during solidification process but remains in as cementite (Fe3C). Iron carbide, or cementite, is brittle and hard. White cast iron thus obtained has higher compressive strength and wear resistance as compared to cast iron. This type of cast iron is called "white cast iron" since it has a white crystalline fracture appearance. Rolls and mill balls are typical applications for white cast irons.

2.1.4 Malleable cast iron

Malleable cast irons are produced by heat treatment of white cast irons, which can be grouped into three types, blackheart malleable cast iron, whiteheart malleable cast iron, and pearlitic malleable cast iron. Typical applications are motor vehicle parts, pipe fittings, rolling stock, machine tools, and ship parts.

Blackheart malleable cast irons are produced by annealing white cast irons at 900-950 °C for the first stage, followed by the second stage annealing at the temperature around the A1 transformation point. By this combind annealing processes, the cementite in white cast irons is decomposed and become graphite ($Fe3C \rightarrow 3Fe + C$). The microstructure of blackheart malleable cast irons consists of a ferrite matrix and aggregate graphite dispersed in the matrix as shown in Photo 2.3. The compact shape of graphite improves the ductility and strength of iron castings. The fracture appears black in the internal areas.

Figure 2.3 Microstructure of blackheart malleable cast iron [1]

Whiteheart malleable cast irons can be produced by annealing white cast irons kept in contact with a decarburizing medium (ferric oxide) at 950-1000°C for long hours in order to decarburize the cementite of the white cast irons. The decarburized surface areas consisting of ferrite features have improved ductility. Most of the cementite in the internal areas is decomposed to become spheroidal graphite in the pearlitic matrix. It is named as white cast iron because the fracture appears white in the internal areas. The application for whiteheart malleable cast irons is limited to thin products in order to use a uniform decarburized structure.

Pearlitic malleable cast irons is also produced by annealing white cast irons. The first-stage annealing cycle is similar to that for the blackheart malleable cast irons; however, in the second-stage annealing, the cooling rate is increased in order to form a pearlitic structure by restricting the decomposition of cementite [1].

2.2 Weldability of cast irons in fusion welding

Arc welding is generally used particularly for repairing foundry defects contained in iron castings and parts damaged or worn out in service. All types of available cast irons except white cast irons are considered to be weldable but to a lesser degree than steels. However, the weldability varies depending on the type of cast iron. Some types of cast irons are readily welded while others require some special welding procedures.

2.3 Common problems in weldability

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. Under a welding thermal cycle, the cast iron base metal immediately adjacent to the weld metal is locally heated to an extremely high temperature, and the cooling rates of the entire heat affected zone are quite high. Consequently, iron carbide tends to precipitate in the heat affected zone adjacent to the weld metal (referred to as the white-cast-iron zone), and the remainder of the heat-affected zone tends to form high-carbon martensite (the martensite zone), as shown in Fig. 2.4.

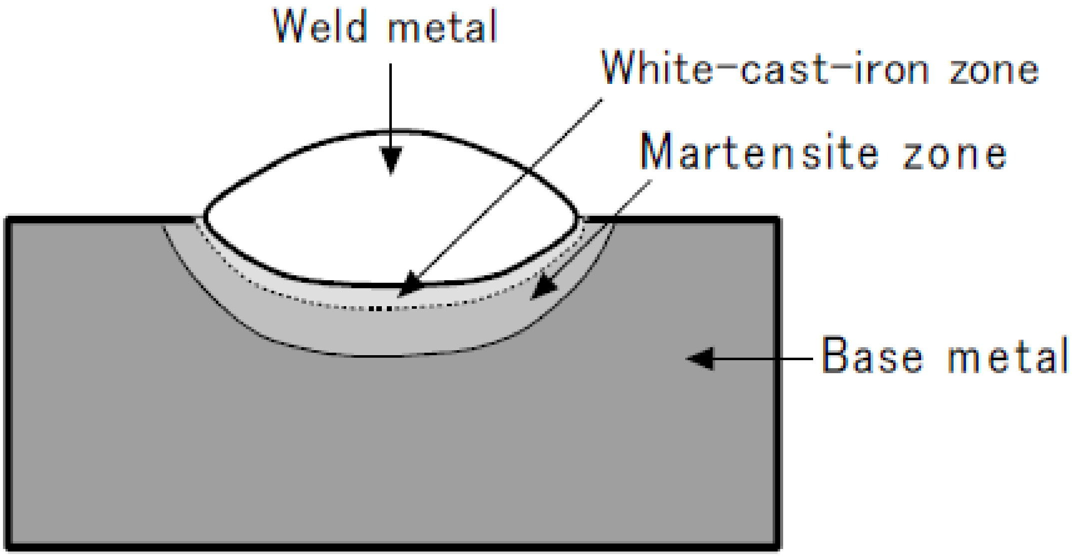

Figure 2.4 different zones formed during welding of cast iron [1]

Both the white-cast-iron and martensite zones are characterized by the hard and brittle nature. In addition, the white-cast-iron zone is apt to contract much more than does the unaffected base metal. Therefore, with the brittle structure and high contraction stresses, the heat-affected zone tends to generate cracks either spontaneously or under load during services. The degree of brittleness and propensity to cracking depend, to some extent, upon the type of cast iron and the welding procedure.

2.4 Effects of graphite form on weldability

In order to minimize the formation of large amount of carbides and high-carbon martensite, it is most helpful to have graphite present as spheroids, because it has a low surface-to-volume ratio. As the surface area of the graphite in contact with the austenitic matrix goes down, the amount of carbon in the microstructure decreases at room temperature. Graphite flakes in gray cast irons shows the greatest tendency to dissolve in austenite because of their larger surface area. Gray cast irons are inherently brittle and often cannot withstand the contraction stresses arisen by welding. Lack of ductility is caused by graphite flakes, and those cast irons which contain long graphite flakes are more brittle and less weldable than those with short flakes or spheroids. Ductile cast iron has graphite in spheroidal form and thus better ductility; as a result of this, this type of cast iron has superior weldability

2.5 Welding processes

2.5.1 Shielded metal arc welding

Shielded metal arc welding (SMAW) process accounts nearly 80 percent of the welding performed on the cast irons. 50 percent of which is used for the salvage new castings in the foundry and about 40 percent of which is for the repair of parts that have worn out or have failed in service or otherwise require some modification. The remaining 10 percent is used for the fabrication of assemblies to join two or more cast iron parts or to join a cast iron part to another metal.

In the welding of the cast irons, the weld metal should be able to tolerate an increase of carbon content caused due to the dilution with the base metal. This is the reason why non-ferrous, nickel alloy and low-carbon steel type covered electrodes are used as filler material. In particular, AWS: ENi-CI, ENiFe-CI, and ESt are some typical grades of the electrodes being used extensively in the repair and reclamation of iron castings.

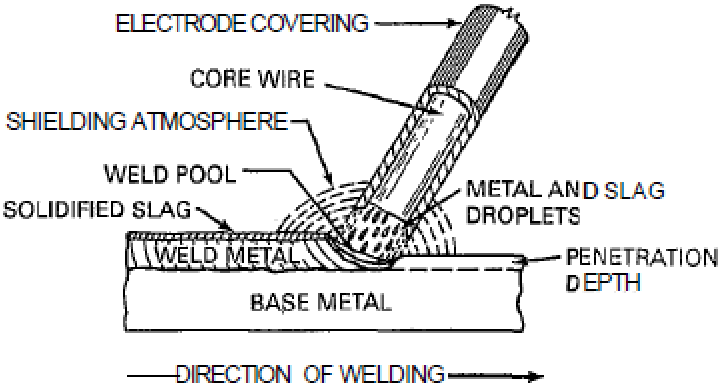

Figure2.5 Shielded metal arc welding [15]

2.5.2 Gas metal arc welding

Gas metal arc welding (GMAW) process is generally used for the repair and fabrication of iron castings. The low heat input supply such as short-circuiting metal transfer and pulsed-current arcs metal transfer can restricts the maximum heat affects on the base metal, thereby minimizing the chances of the formation of brittle iron carbides in the heat-affected zone (HAZ) with better crack resistance. In addition, minimized dilution of the weld zone (WZ) by the base metal (BM) will decrease the tendency of weld cracking. The spray transfer mode is basically used for the production of simple welds in high-ductility grades of cast irons.

Solid wires and flux-cored wires are available for the welding of the cast iron. 98%Ar-2%O2, 75%Ar-25%CO2, or 100%CO2 is used in solid wires and flux cored wires as the shielding gas. AWS ERNi-CI and ERNiFeMn-CI are some of the common grades of solid wires for this purpose. Flux-cored wires for cast iron utilises nickel-iron type and nickel-iron-manganese type filler material. ENiFeT3-CI is a special type of flux-cored wire that uses no shielding gas, the typical application of this flux cored wire is overlaying ingot moulds (gray cast iron), and welding end caps of made up of ductile cast iron to cylinders of low-carbon steel pipe.

2.5.3 Gas tungsten arc welding

Gas tungsten arc welding (GTAW) process is suited for the repairing of gas cavities (porosity) formed during casting. Typical filler metals used for this purpose are the ductile cast iron, nickel-iron, and nickel-iron-manganese types electrodes.

2.5.4 Submerged arc welding

The ERNiFeMn-CI solid wire or ENiFeT3-CI flux-cored wire with the suitable flux has enabled submerged arc welding process for the welding of ductile cast irons. However, the submerged arc welding process for the cast iron uses small-size wires, low welding currents, and less travel speeds than in the welding of steels.

2.6 welding electrode for the cast iron

2.6.1 Nickel type (ENi-CI, DFCNi)

Nickel type electrodes can overcome the problem of carbon pick-up from the cast iron base metal because carbon can be dissociated in the form of fine, dispersed graphite in the weld metal, thereby providing readily machinable and ductile characteristics. In addition, nickel type weld metals suppress the carbon diffusion at the interface between the base metal and the weld metal, thereby decreasing the formation of the white-cast-iron microstructure in the heat-affected zone

2.6.2 Nickel-iron type (ENiFe-CI, DFCNiFe)

Nickel-iron type electrodes are used for welding gray, malleable and ductile cast irons. These electrodes are more economical than the nickel type electrodes due to lower content of nickel, and the weld metal is less susceptible to the solidification cracking caused by phosphorus and sulphur. The weld metal has higher tensile strengths, hardness, and thus lower machinability as compared with nickel type electrodes. The colour matching with the base metal is as poor as with nickel type weld metals. This type of weld metal offers lower thermal contraction, which is preferable for preventing the occurrence of crack. The nominal nickel content of the undiluted weld metal of this type of electrode is 53% but that of the diluted weld metal can fall, depending on the penetration, in the range 35-45%, which offers relatively lower linear expansion coefficient as shown in Fig. 2.6. This is why the contraction stresses can be lower, which in turn offers better crack resistance [1].

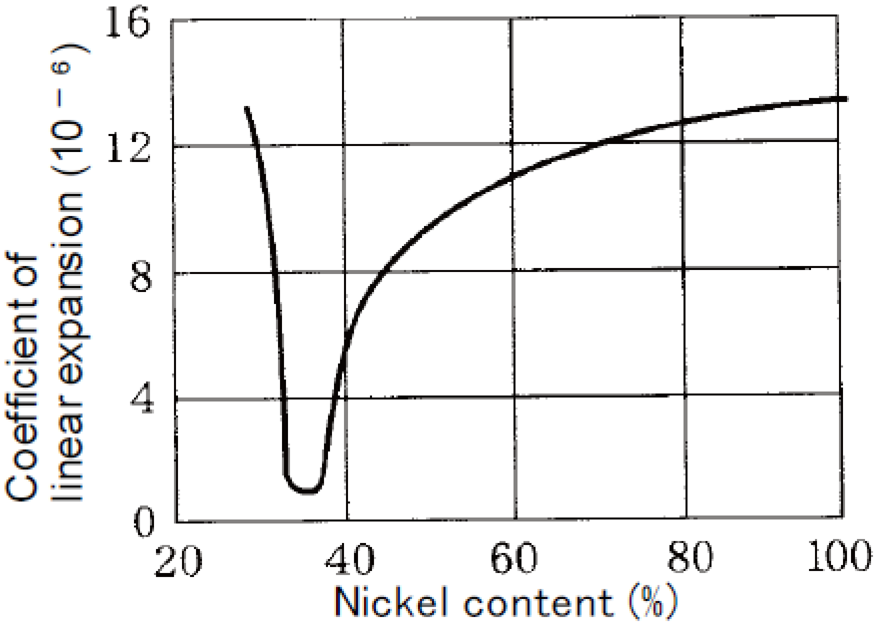

Figure 2.6 Coefficient of linear expansion of Fe-Ni alloys [1]

2.6.3 Low-carbon steel type (Est, DFCFe)

This type of electrode offers better wettability with the base metal when compared to nickel-type and nickel-iron-type electrodes. The coating flux of the electrode contains a special agent that promotes carbon to become graphite, which provides the fusion zone with lower hardness than with ordinary mild steel covered electrodes. However, it is virtually impossible to prevent the formation of a hard zone or layer in the weld metal because of dilution from the base metal. The diffusion rate of carbon from the base metal to the weld metal is relatively high; consequently, the fusion zone tends to form the white-cast-iron microstructure. In addition, the shrinkage of steel is greater than that of cast iron, thereby developing higher stresses on cooling the weld. Because of these reasons, in order to prevent weld cracking, this type of electrode uses higher preheating temperatures than with the nickel-type and nickel-iron-type electrodes, and the application is limited to the repair of small pits and cracks where colour matching is desirable and post weld machining is not of major concern.

2.7 Concept of preheating and post weld heat treatment

Preheating and post weld heat treatment are the two well known methods which is used to eliminate the formation of martensite in heat affected zone. Preheating also eliminates the chances of the formation residual stresses which take place due to instantaneous heating and cooling thus eliminating the chances of cracks after welding. However it is difficult to determine the exact preheating temperature and a high preheating temperature causes the distortion of the plate to be welded. The hardness of the heat-affected zone can be decreased by preheating the base metal because preheating can reduce the cooling rate of the heat-affected zone. Slower cooing rates can suppress the formation of iron carbides and martensite structures in the heat-affected zone, which in turn reduce the propensity for weld cracking, by decreasing the hardness of the weld.

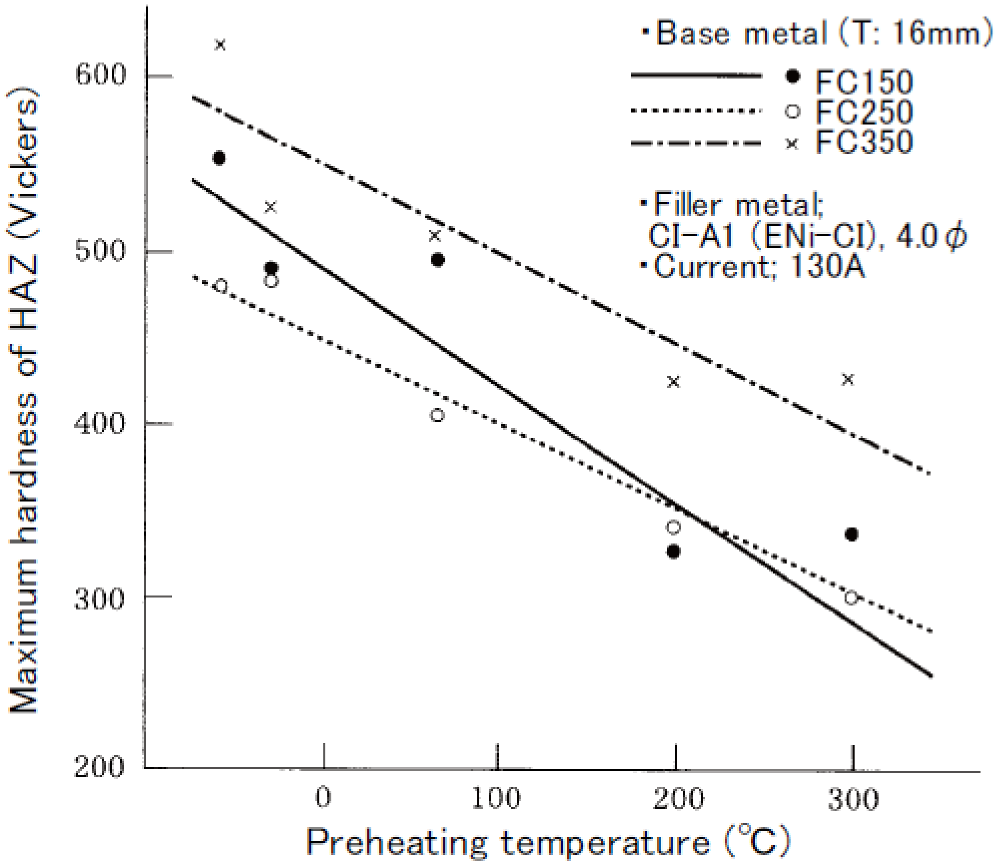

Figure 2.7 Effect of preheating temperature on the maximum hardness of the heat affected zone of the weld with a gray cast iron base metal and nickel-type filler metal [1]

The low-temperature-preheat procedure (also known as “cold welding procedure”) is commonly used for repairing a large casting or a cast part installed in a machine where it is very hard or unpractical to heat the work in the high temperature range (500^{O}C) which is suitable for the high-temperature preheat procedure (also known as “hot welding procedure”),

In contrast, the hot welding procedure solidifies the molten weld metal under the stable condition being close to the equilibrium, using very slow cooling rates from the molten state. This procedure prevents completely the formation of cementite, promoting the graphitization of carbon.

After welding, heat treatment of a cast iron weldment may be necessary for the following purposes:

(a) Improve the ductility of the heat-affected zone (HAZ).

(b) Improve the machinability of the weld and HAZ.

(c) Decompose the cementite formed during welding.

(d) Transform martensite to a less brittle microstructure (troostite).

(e) Relieve residual stresses.

Fig. 2.8 shows the effect of PWHT temperature on the hardness of the heat-affected zone of the gray cast iron base metal welded with an ENi-CI electrode. As shown in the figure, with a higher PWHT temperature, the hardness of the heat-affected zone decreases.

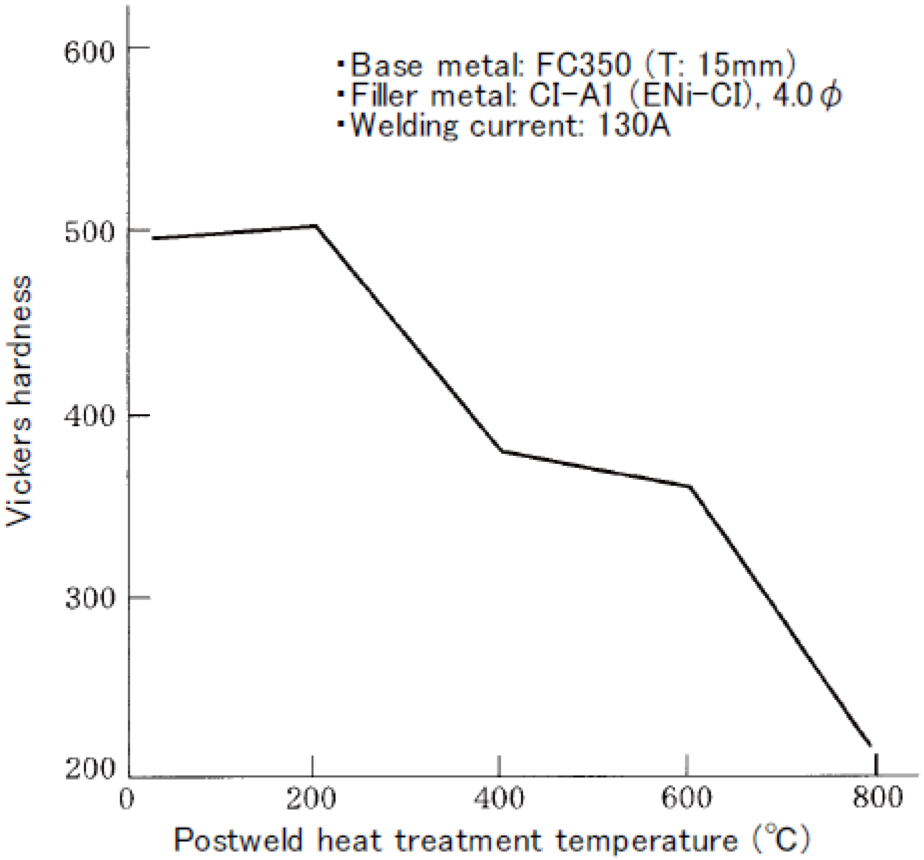

Figure 2.8 Effect of post weld heat treatment temperature on hardness of the heat affected Zone of a gray cast iron welded with an ENi-CI electrode [1]

Normally stress relief is performed by increasing the temperature of the entire casting, immediately after welding. However, practically, the finished weldment may be required to cool to the room temperature before PWHT. When heat treatment cannot be started right after welding, the casting should be cooled slowly from the welding temperature to the room temperature. This slow cooling is to prevent thermal stresses, thereby preventing the occurrence of weld cracking [1].

CHAPTER 3

LITERATURE SURVEY

Pascual et al. [2] carried out the study of welding nodular cast iron with oxyacetylene (OAW) and manual metal arc welding also called shielded metal arc welding (SMAW) using 98.2% Ni and Fe-Cr-Ni alloy electrode materials respectively. They reached to a conclusion that welding cast iron with or without preheat is possible but preheating increases weld quality as well as ductility. OAW results into the poor weld metal properties whereas SMAW causes an amount of ductility in the weld metal. Furthermore, using Ni electrode is another factor which increases the ductility and also restricts the formation of iron carbide (Fe3C) since nickel has high reactivity with carbon and picks the carbon before iron picks and forms nickel carbide (Ni3C).

Pouranvari.[3] studied the welding of cast iron using shielded metal arc welding (SMAW) process. In their study he used Ni based electrodes and also applied PWHT to the welded pieces. After the application of these two factors its effect on microstructure and hardness was analyzed. For the post weld heat treatment a temperature of 870 ^{o}C was maintained and kept the work piece at this temperature for 1 hour. Due to use of Ni based filler metal formation of hard brittle phase in fusion zone is avoided. However before the post weld heat treatment in the heat affected zone (HAZ) there was the formation of hard martensitic structure. But after the application of PWHT dissolution of martensite and graphitization takes place in HAZ resulting in uniform hardness and increased ductility.

El-Banna. [4] Studied welding of ductile cast iron using SMAW process with ENiFe-CI filler material. He worked on different preheating temperatures and concluded that ductile cast iron can successfully be welded with or without preheating using Ni based electrodes but in order to get certain mechanical properties a preheating temperature of 200-300°C is required.

El-Banna et al. [5] carried out the study of restoration properties of pearlitic cast iron using shielded metal arc welding (SMAW) with various filler materials namely Ni, Fe-Ni alloy, Ni-Cu alloy, stainless and ferritic steel. The main focus was directed at the parameters affecting the weldability of pearlitic cast iron using ferritic steel as filler metal main reason being their low cost. During the study annealing at 677°C was done. In addition Effect of heat input, preheating temperature and filler materials was examined. While using the ferritic filler material, preheating at 300°C seems to be the best option for narrowing the melt region (MR) and HAZ with discontinuous carbide and bainitic microstructure. It is seen that PWHT leads to the reduction of the maximum hardness values slightly. Finally multipass welding narrows the width of melt region and lowers the micro hardness of HAZ. The use of filler materials with Ni content can overcome carbide formation by picking the carbon before iron picks the carbon thus forming nickel carbide in the place of iron carbide.Ni3C has lower hardness than Fe3C ,thus lowering the hardness of WZ.

DISSIMILAR WELDING OF CAST IRON

M.Hatate et al. [6] carried out the study of dissimilar welding of spheroidal cast iron (SG) with mild steel using electron beam welding process and studied their bonding characteristic, microstructure and mechanical properties obtained. During the study a ferrous high-Ni materials was inserted between the two parent materials as it restrict the formation of Fe3C. Welding of these two materials were also carried out using metal active gas (MAG) process and also using a Fe–Ni wire as a molten weld metal.
In the case of Electron beam welding process, the volume of the material which is to be melted is much smaller than that in Metal active gas welding process, and the electron-beam is directly focussed on the insert material but heat is supplied also to the mother materials in MAG process. As a result of this the amount of heat-energy-input is much smaller in EBW process than in MAG process. During the welding using two different process he did not measure the temperature of the materials however he concluded that the much smaller amount of heat-energy-supplied in EBW process compared to that in MAG process resulted in the temperature of the melted material which is lower for EBM process and the heat affected area in EBW process as a result of this is smaller than those in MAG process. This difference caused by smaller amount of heat-energy-input are estimated to be the main reasons to prevent the formation of carbide in EBW process. He also concluded that bonding strength obtained is always higher for EBM process as compared to MAG process. After the welding when material was tested fracture took place on spheroidal cast iron (SG) side .This suggests that the bonding strength is determined mainly by the

microstructure of the HAZ of SG iron side after welding. EBW process with inserted 35%Ni SG iron can prevent the formation of cementite at the FCD 450 side but in the case of MAG welding process using a Fe–40%Ni wire the formation of cementite at the FCD 450 side was not prevented perfectly.

R. Winiczenko et al. [7] Carried out the study of friction welding of ductile cast iron with stainless steel and analyzed the mechanical properties and microstructure obtained. Scanning electron microscopy (SEM) was used in order to determine the fracture morphology and phase transformations which take place during friction welding process. He concluded that Friction welding is accompanied by the transport of atoms in both the directions across the ductile iron-stainless steel interface. This results in the enrichment of stainless steel with carbon, and ductile iron with chromium and nickel atoms. Stainless steel carbon enrichment results in the formation of chromium carbides that are distributed mostly at the grain boundaries. Iron enrichment in Cr and Ni resulted in the creation of an alloy ferrite. Cr was found also in a carbide eutectic. The range of Cr and Ni diffusion in iron generally does not exceed 50 µm. The depth of the diffusion of carbon in the case of a joint subjected to a double thermal effect is 150 µm and higher than for a sample subjected to one step friction welding.

B. Kurt et al. [8] carried out the study about the effect of heating and cooling rate on interface of diffusion bonded gray cast iron to medium carbon steel. Diffusion bonding does not involve melting or gross macroscopic interface distortion; the microstructure of the bond region is similar to that of regions remote from the joint and has parent metal properties. Thus, diffusion bonding seems to be a proper method for joining these dissimilar materials. In this present study, a gray cast iron and a medium carbon steel material were diffusion bonded at the temperatures of 850, 900, 950 and 1000 ^{O}C and under a constant pressure of 8 MPa for 30 min, and the effects of temperature and high heating and cooling rate on interface formations and microstructure were investigated. After diffusion bonding, scanning electron microscopy, shear test measurements and micro hardness measurement of interface region were made. The microstructure at the inside of medium carbon steel of bonded couple consisted of martensite. As a result, from the micro structural observations, a good bonding along the interface of the bonded couples and the interface is free from voids and micro cracks.

F. Malek Ghaini et al. [9] carried out the study about the Characteristics of cracks in heat affected zone of ductile cast iron in powder welding process. He studied that Cracking can occur in the HAZ of ductile cast iron hardfaced with nickel base self-fluxing alloy using oxyacetylene powder welding. Since there is no partially melted zone and almost no dissolution of graphite nodules, the cracking has metallurgical characteristics, which differentiate it from the cracks reported in the case of arc welding processes. The cracks initiate within the graphite nodules and propagate through the martensitic matrix. He studied that the cracking process is predominantly controlled by the residual stresses. He also showed that hardfacing of ductile cast iron with powder welding using a nickel base self-fluxing alloy; the heat affected zone can crack given the combination of a hard deposit and high cooling rates arising from welding thickest parts. The cracks are normally hidden under the weld bead and can go undetected, resulting in the loss of integrity of the component in services concerning impact loading. These cracks differ in morphology from the cold cracks previously reported in the case of arc welding of ductile cast irons. Graphite nodules are the initiation sites for the cracks which can then propagate in a martensitic matrix. The cracking process is predominantly controlled by the residual stresses.

S. Kolukisa[10] studied the effect of the welding temperature on the weldability in diffusion welding of martensitic (AISI 420) stainless steel with ductile (spheroidal graphite-nodular) cast iron. He studied the effect of welding temperature on the weldability during the diffusion welding of martensitic (AISI 420), stainless steel with ductile (spheroidal graphite-nodular) cast iron. It was investigated experimentally under protective atmosphere and at various temperatures and constant prescribed pressure blows those which would cause macro deformation. After thease operations microstructure examinations were carried out by SEM and EDS simultaneously hardness values were measured by Hv scale under a load of 200 g along the weld interface. During the study mutual chrome and carbon diffusion were observed on ductile cast iron side and stainless steel side, respectively. On the other hand, as a function of temperature elevation, increase in the amount carbon and chrome atoms migrated toward to interface, reduction at nodular graphite diameters was also noticed. As a result of all evaluations and tests carried out, it was concluded that, best gathered mechanical and metallurgical properties were observed at the specimen bonded at 1100 ^{O}C process temperature at 12MPa, for 20 min.

M.Ebrahimnia et al. [11] carried out the study of Effect of cooling rate and powder characteristics on the soundness of heat affected zone in powder welding of ductile cast iron. Metallurgical investigations pointed out that the main reason to be mainly related to the presence of micro cracks in the heat affected zone of the oxyacetylene powder weld surface repairs. Using controlled cooling conditions in order to simulate repair of large forming dies, powder welding with nickel base self-fluxing alloys was carried out. It was shown that in certain conditions involving high cooling rates which could be encountered when welding very large parts with standard preheats combined with the use of the harder nickel base powders, micro cracks can form in the heat affected zone of ductile cast iron. He studied that cracking process is proposed to be dominated by the stress fields induced on the toe of weld deposit by the shrinkage effect of the hard nickel base alloy. He also concluded that the cracks initiate mostly at the interface of graphite nodules and then propagate through the martensitic matrix.

CHAPTER 4

EXPERIMENTAL WORKS

4.1 Materials used for experiment

Two materials were used for experimental purpose. One is the base metal that is gray cast iron. Its composition is given in the following table.

Table 4.1 composition of base material

ELEMENT	Fe	C	Si	Mn	P	S	Mo	Ni	Cr
%COMPOSITION	94	3.24	1.76	0.354	0.182	0.078	0.093	0.124	0.039

Nickel based filler material which has been used as electrode; its composition has been given in the following table.

Table 4.2 composition of filler material

ELEMENT	C	Mn	Si	Ni	Fe
%COMPOSITION	0.90	0.70	0.90	54	43.5

AWS/A5.15: ENiFeCI is the grade of nickel base filler electrode, these electrodes have high mchineability.

In this experimental work, process involved during the fabrication of defect free test specimen like machining, grinding and welding etc. are discussed.

4.2 Grinding work

Cast iron work piece are worked over grinding machine in order to get clean surface since these cast iron work piece is obtained by sand casting process in which smooth and clean surface is not obtained.

Figure 4.1 Pedestal grinding machine

4.3 machining work

Cast iron work piece are cut on power hack saw in welding lab. After cutting final dimension of work piece becomes, 60mm length, 50mm width and 6mm thickness.

Figure 4.2 Power hack saw cutting machine

For making groove of welding specimen, one edge of the plate is cut at 22.5^0 so that when two specimens are matched angle of 45^0 is obtained. Edge cutting on all workpiece is done on shaper machine in machine shop. Single v weld specimen has been prepared since thicknesses of the plates are less.

4.4 WELDING OF PLATES

4.4.1OPERATION OF SMAW

It utilises the heat of the arc to melt the base metal and the tip of a consumable covered electrode. The electrode and the work in SMAW are part of an electric circuit. This circuit begins with the electric power source and includes the welding cables, an electrode holder, a work piece connection, the work piece, and an arc welding electrode. One of the two cables of the power source is attached to the work. The other is attached to the electrode holder. Welding process commences when an electric arc is struck between the tip of the electrode and the work. The intense heat of the arc melts the tip of the electrode and the surface of the work close to the arc. Tiny globules of molten metal rapidly form on the tip of the electrode, then they transfer through the arc stream into the molten weld pool. In this way, filler metal is deposited as the electrode is progressively consumed. The arc is moved over the work at an appropriate arc length and travel speed, melting and fusing a portion of the base metal and continuously adding filler metal. Since the arc is one of the hottest of the commercial sources of heat [temperatures 5000^{O}C have been measured at its center], melting of the base metal takes place almost instantaneously upon arc initiation. If welds are made in either the flat or the horizontal position, metal transfer is induced by the force of gravity, gas expansion, electric and electromagnetic forces, and surface tension. For welds in other positions, gravity works against the other forces. The process requires sufficient electric current to melt both the electrode and a proper amount of base metal. It also requires an appropriate gap between the tip of the electrode and the base metal or the molten weld pool. These requirements are necessary to set the stage for coalescence. The sizes and types of electrodes for shielded metal arc welding define the arc voltage requirements (within the overall range of 16 to 40 V) and the amperage requirements (within the overall range of 20 to 550 A). The current may be either alternating or direct, depending upon the electrode being used, but the power source must be able to control the level of current within a reasonable range in order to respond to the complex variables of the Welding process itself.

4.4.2 WELDING MACHINE SETTINGS:

Shielded metal arc welding process was carried out at:-

Welding current- 130 Ampere

Electrode diameter- 3.15mm

Figure4.3 simple welded plate

Figure 4.4 welded plate with PWHT

Figure 4.5 set up of shielded metal arc welding machine

4.4.3 OPERATIONS PERFORMED

1. During welding plate is provided appropriate fixtures so that bending of the plates could be avoided which occur due to sudden contraction of weldments.

2. During welding weld is completed in two runs of electrode since the whole groove cannot be filled in a single pass. After each pass slag is cleaned by hammer on weld and then after cleaning by wire brush second pass of welding is performed.

3. Welding process is performed on several plates in two ways one with simple welding (normal welding) and second with heat treatment (post weld heat treatment).

4. Post weld heat treatment of welded plate was conducted in the furnace. The plate was gradually heated to a temperature of 850^0 C and kept at that temperature for nearly 1 hour. After heat treatment work piece was left in the furnace so that its temperature falls slowly.

Figure 4.6 Electric furnace for post weld heat treatment

Types of plates made after welding

1. Normal weld plate
2. Post weld heated plate

4.5 Preparation of test specimen

For each type of welded plate separate test specimen is prepared. These are as follows-

1. Microstructure test specimen
2. Hardness test specimen
3. Tensile test specimen
4. Charpy test specimen

4.5.1 Preparation of microstructure test specimen

In this microstructure analysis the whole process consists of following steps.

1. Dry polishing.
2. Wet polishing - In wet polishing alumina powder and water was used.
3. Etching - In this process, solution of HNO3+alcohol was used. The purpose of etching is to remove thin layer on the surface. Secondly, the etchant attacks the surface with preference for those sites with the highest energy, leading to surface relief which allows different crystal orientation, grain boundaries, and defects to be distinguished in reflected light microscopy.

Figure 4.7 setup of machine for dry and wet polishing

After performing these operations microstructure was observed by Olympus GX 41 Microscope with META-Lite software. Olympus GX 41 microscope has magnification range from 25x to 100x

Fig.4.8 Olympus GX 41microscope

4.5.2 Preparation of hardness test specimen

1. Specimen is cut from welded parts with the help of hand saw fixing into vice.
2. Specimen is cut from welded plate in such a way that weld zone, heat affected zone and base metal comes in a single piece.
3. Separate test specimen is made for both normal welded plate and post weld heat treated plate.

4.5.3 Preparation of charpy test specimen

1. Test specimen is cut from welded parts such that welded section comes in the middle of the specimen.
2. Specimen is cut with the help of hand saw fixing into vice.

3. Notch on the specimen is cut on milling machine using milling cutter of angle 45^o
4. Charpy test dimension is length is55 mm, width is 10 mm and thickness is 5 mm.
5. Notch is made at the center upto a depth of 2mm with an angle of 45^o.
6. After notch is made effective width below notch is 8mm.

CHAPTER 5

RESULT AND DISCUSSION

5.1 ROCKWELL HARDNESS TEST

The Rockwell Hardness test is designed to give the engineer a basic idea of the qualities of the metal he has just cast or forged, and it is relatively non-destructive. The Rockwell Hardness test uses a machine to apply a certain load and then measure the depth of the resulting impression. The indenter may be a steel ball of some specified diameter or a spherical diamond-tipped cone of 120° angle and 0.2 mm tip radius. Firstly a minor load of 10 kg is applied, which causes a initial penetration to seat the indentator and remove the effects of any surface irregularities. After this the dial is set to zero and the major load is applied. Upon removal of major load, the depth reading is taken while the minor load is still on. The hardness number may then be read directly from the scale. The indenter and the test load used determine the hardness scale that is used (A, B, C, etc).

For most of the soft materials like copper alloys and aluminium alloys a 1/16" diameter steel ball is used with a 100-kilogram load and the hardness is read on the "B" scale. In testing harder materials, hard cast iron and many steel alloys, a 120 degrees diamond cone is used with up to a 150 kilogram load and the hardness is read on the "C" scale.

Some important points concerning Rockwell hardness testing include the following

1) Indenter and anvil should be clean and well seated.
2) Surface should be clean, dry, smooth, and free from oxide
3) Surface should be flat and normal

A primary advantage of the Rockwell hardness test is that it is automatic and self contained thereby given and instantaneous readout of hardness which lends itself to automation and rapid through put.

Figure 5.1 Rockwell hardness testing machine

5.2 HARDNESS TEST RESULT

Hardness of cast iron has been measured on c scale.

(a)Hardness value of different regions for simple welded plate

Table 5.1 Hardness value of different region for simple weld

REGION	RUN 1	RUN 2	RUN 3	AVERAGE
BASE METAL	18	18	18	18
WELD ZONE	14	15	15	15
HAZ	24	26	25	25

(b) hardness value of different region of the welded plate with PWHT

Table 5.2 Hardness value of different region of welded plate with PWHT

REGION	RUN 1	RUN 2	RUN 3	AVERAGE
BASE METAL	16	15	16	16
WELD ZONE	14	13	14	14
HAZ	13	13	12	13

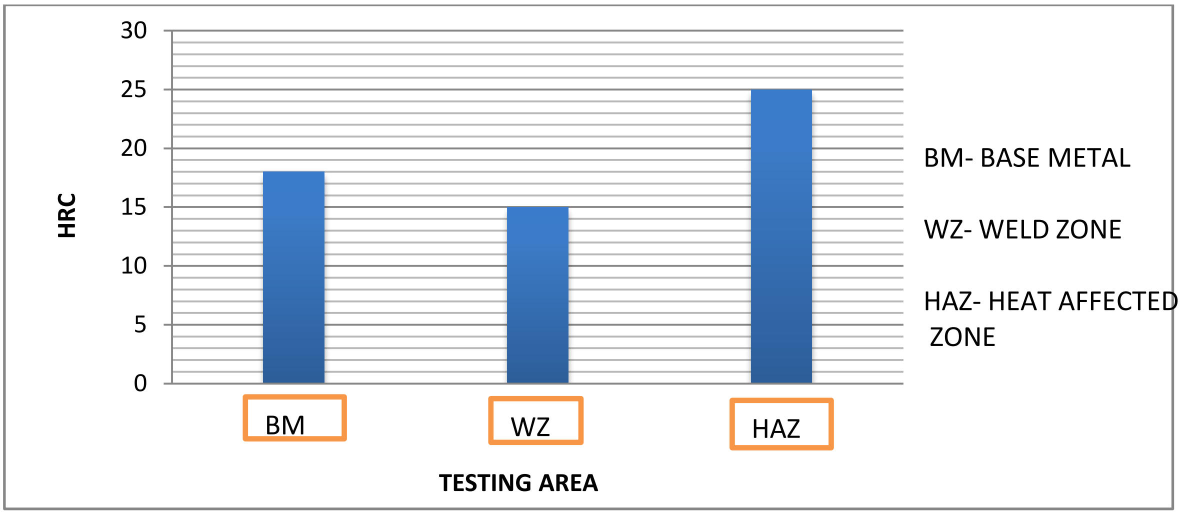

Figure 5.2 graph between hardness and testing area for simple weld

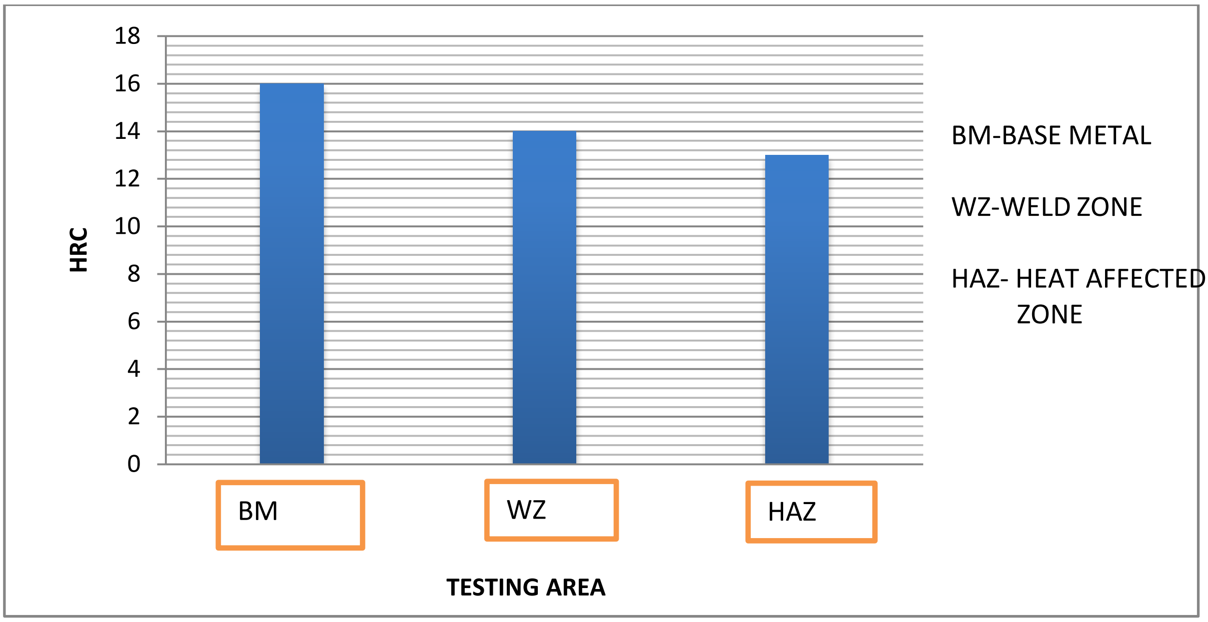

Figure 5.3 graph between hardness and testing area with post weld heat treatment

1. Hardness value of the different region depends upon the phases present in it and its microstructure. During experiment it was found that high value of hardness is in the heat affected zone. The reason for its high hardness is presence of martensite in it which occurs due to fast cooling rate of this zone.

Hardness value of welded region is less as compared to both HAZ and base metal. This happens due to the use of nickel based filler material which has high machinability and is ductile in nature. This nickel picks carbon before iron picks and thus forming iron carbide which is ductile in nature. In the microstructure of the welded part there is nodular graphite in the ferrite matrix and it is ductile in nature which in turns lowers the hardness of weld region.

2. In post weld heat treatment welded plate is heated up to 850 ^{0}C for 1 hour and after heat treatment plate is allowed to cool down there. this furnace cooling lowers down the hardness drastically because hard brittle phase present in different phases present decomposes to ferrite and pearlite.

5.3 MICROSTRUCTURES

Microstructure of different region of welded work piece (base metal, welded zone, and heat affected zone) in different welding condition i.e. simple welding and post weld heat treating are given below with 100 X magnification.

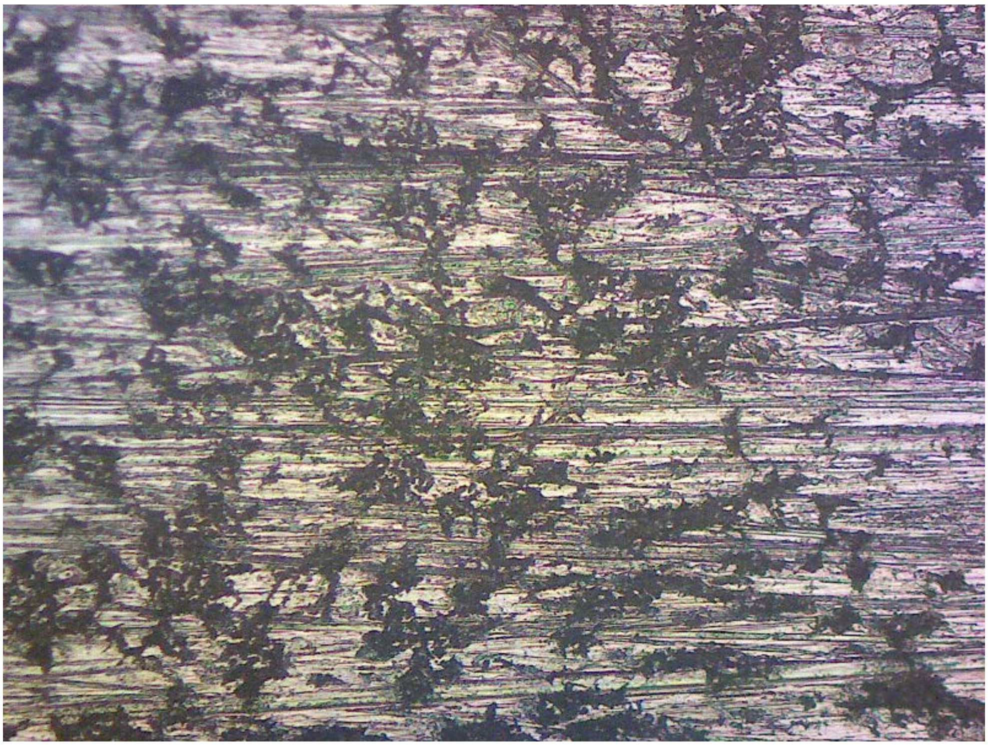

Figure 5.4(a) Microstructure of base metal with simple weld

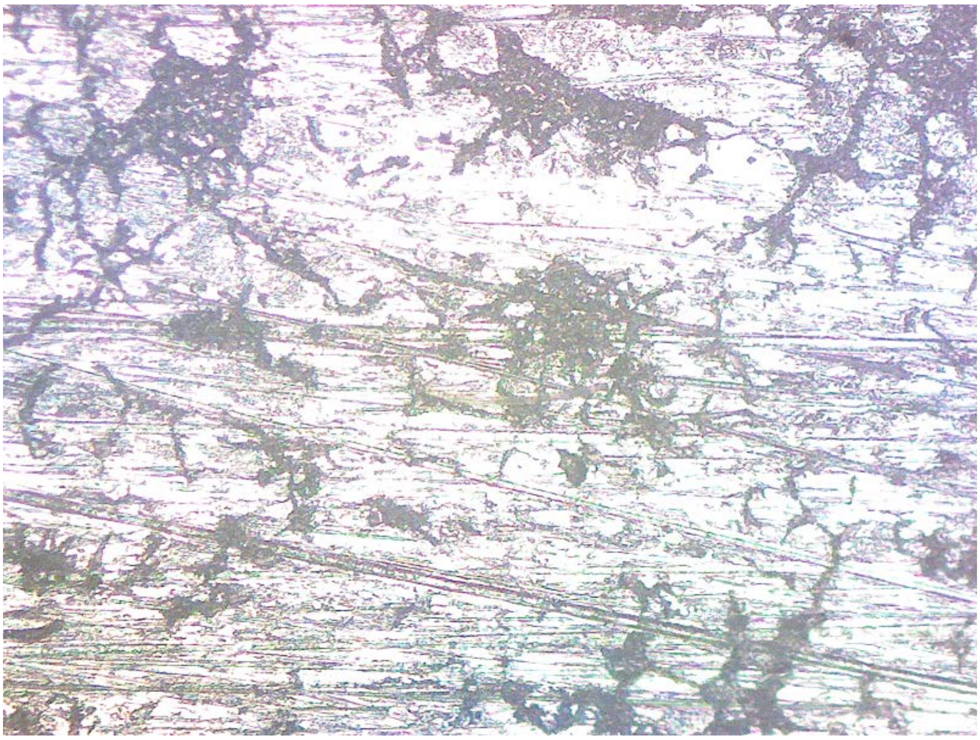

Figure 5.4(b) Microstructure of weld zone in simple welding

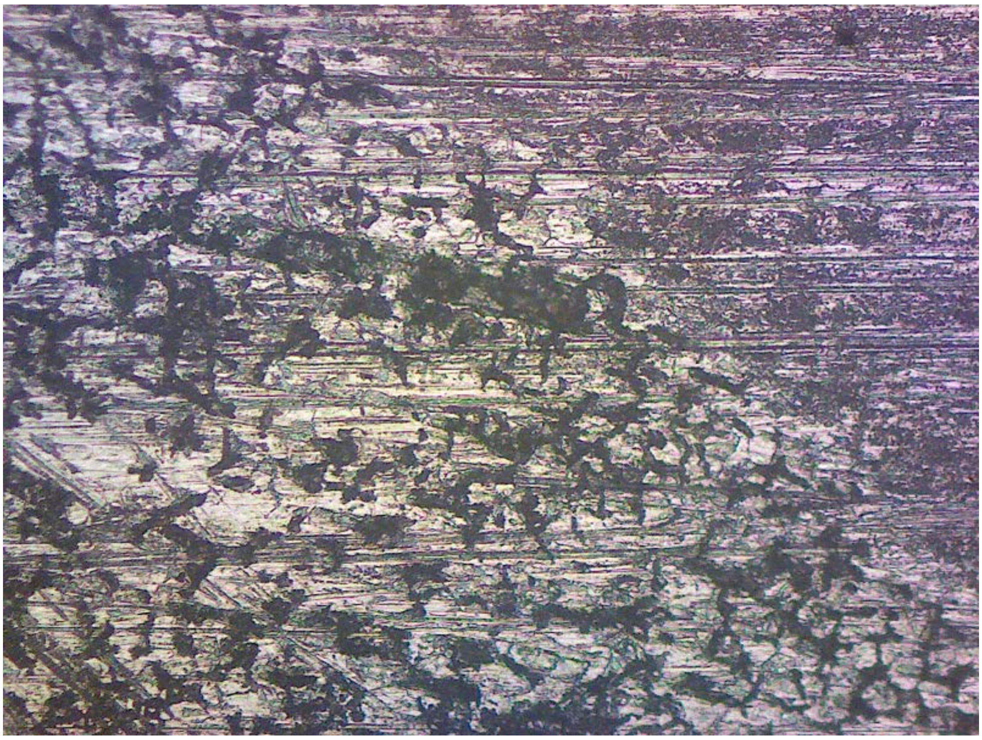

Figure 5.4(c) Microstructure of the combined weld zone and HAZ in simple weld

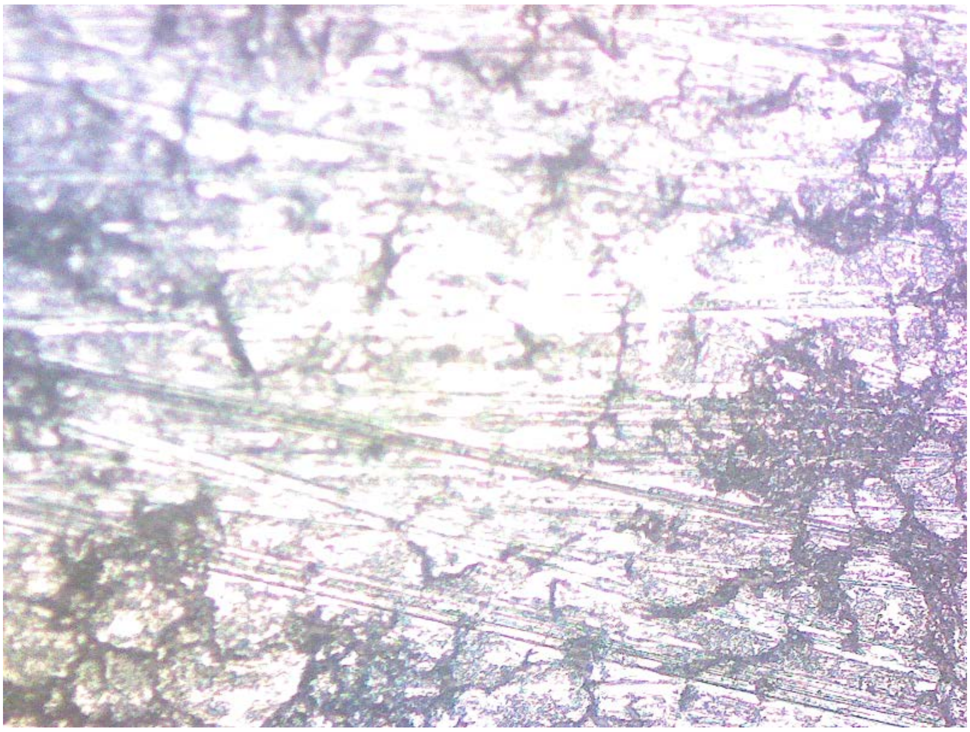

Figure 5.4(d) Microstructure of HAZ in simple weld

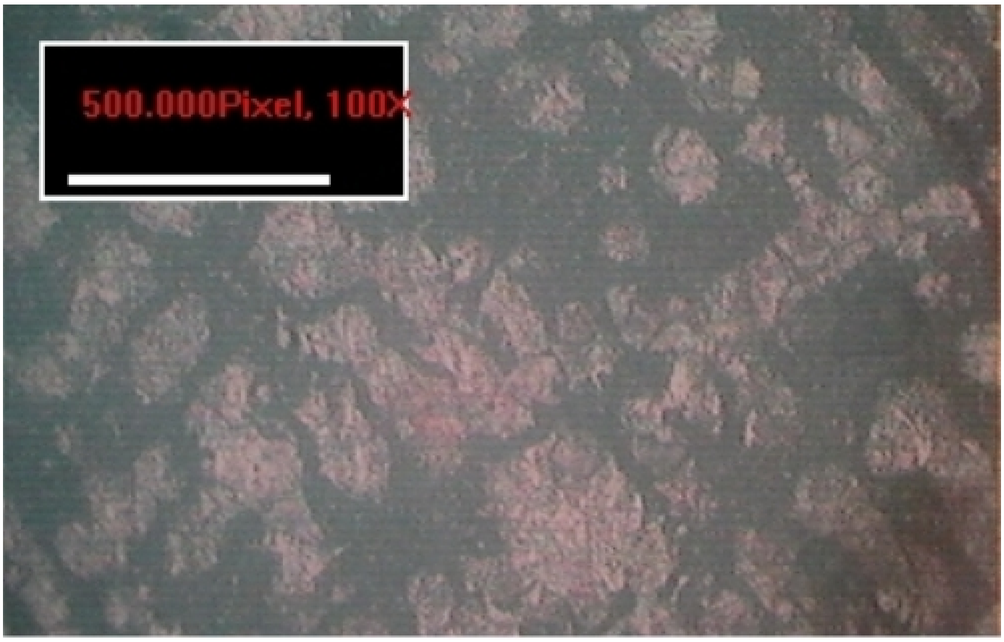

Figure 5.4(e) Microstructure of base metal with post heat treatment

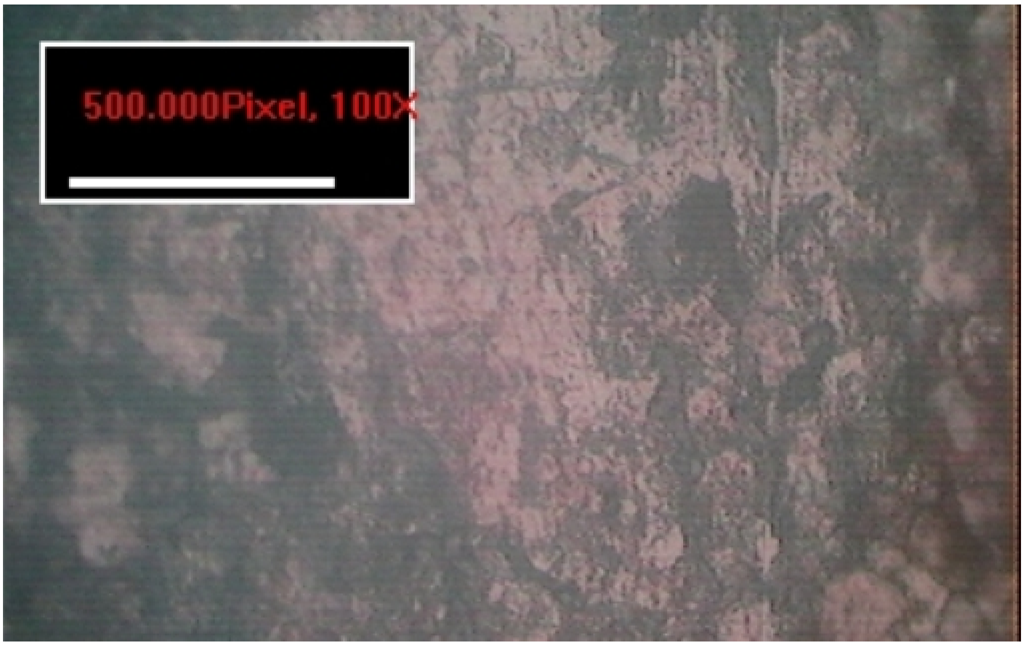

Figure 5.4(f) Microstructure of weld zone with post heat treatment

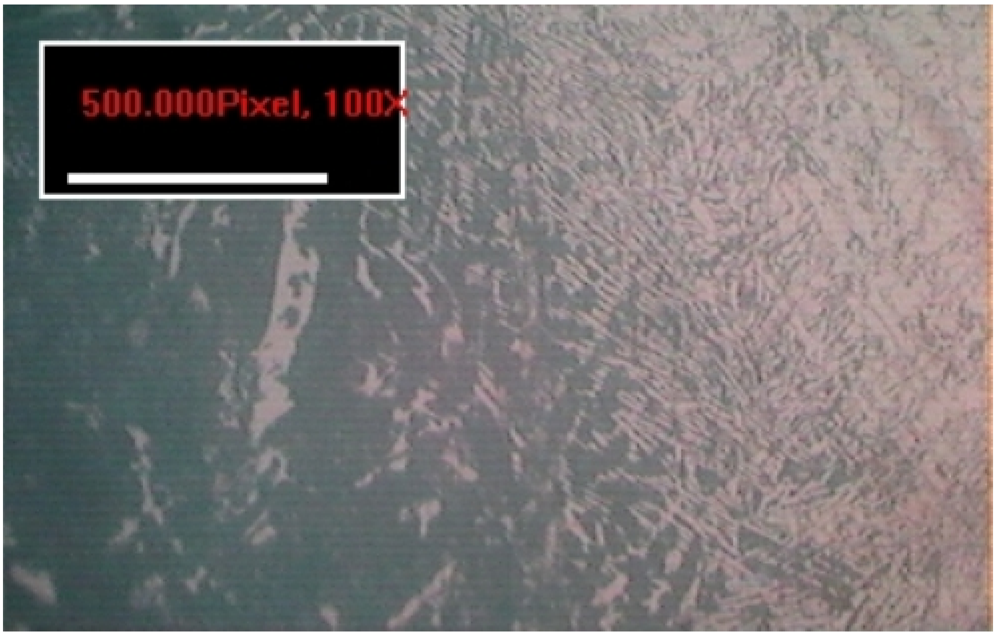

Figure 5.4(g) Microstructure of both weld zone and HAZ with post heat treatment

Figure 5.4(h) Microstructure of HAZ with post heat treatment

5.4 Microstructure test result

The phases and composition present in the welded plates has been discussed for different weld conditions.

5.4.1 Microstructure of simple weld

Figure5.2 (a) shows the microstructure of the cast iron in which graphite is present in ferrite and pearlite matrix.

Figure5.2 (b) shows the microstructure of the fusion zone in which basically austenitic matrix is present and there is also nodular graphite structure.

Figure5.2(c) shows HAZ and WZ microstructure together.

Figure5.2 (d) demonstrates the microstructure of HAZ which contains large amount of martensite which is hard and brittle in nature.

5.4.2 Microstructure with PWHT

Post weld heat treatment (PWHT) is the most effective method to restrict the formation of large amount of carbide and martensite in HAZ and WZ. Two most common PWHTs methods that is available for cast iron welded plates are subcritical tempering and ferritizing annealing. There are chances that Low temperature tempering might reduce hardness of martensite; however, higher tempering temperature is required for the graphitization of the eutectic carbides. Secondary graphitization reduces the hardness of HAZ and improves its impact properties. However, too much graphitization can reduce the ductility of weldment. PWHT as compared to subcritical tempering gives better microstructure control and the chances of excessive graphitization and formation of chain-like graphite is eliminated. Therefore, in this study a full annealing PWHT was chosen including heating up to 850°C, holding for 1 hour at 850°C and then furnace cooling.

Figure 5.2(e,f,g,h) shows the various microstructures present in welded plate after post weld heat treatment.

From the available microstructure it is clear that FZ remained unchanged after PWHT thermal cycle. However the HAZ microstructure is significantly affected by PWHT. The microstructure of the HAZ consists of graphite flakes in ferrite matrix. Upon post weld heat treatment the carbide and martensite phases formed in the HAZ gets dissolved and provide ductility to the weldment. So due to PWHT hardness of weldment gets reduced.

5.5 TENSILE TEST RESULT

Tensile test were conducted for both simple weld and post weld heat treated plate. The load required to break the plate was more with PWHT as compared to simple weld. This clearly indicates that with post weld heat treatment ductility of the weldment has increased.

Cross sectional area of gauge:
Width = 10.36mm
Thickness = 5.33mm
Area = 55.2mm^2

Figure 5.5 Tensile test specimens

Maximum load was evaluated directly from testing machine-

1. For simple weld maximum load =8445.6 N
2. Tensile strength for simple weld= 153 Mpa
3. Maximum load with PWHT= 10212 N
4. Tensile strength with PWHT= 185 Mpa

During tensile testing brittle material does not show any appreciable elongation. However with heat treatment tensile strength is increased which indicates ductility has increased.

5.6 Charpy test result

This test is conducted in order to determine the toughness of the material. Toughness is the measure of the energy required to break the material.

In order to obtain accurate impact strength,

(1) Loss due to the positioning needle and

(2) Loss due to air resistance and friction due to machine bearings as factors comprising the energy loss due to the test machine were excluded from the absorbed energy.

The specific method is used in order to determine factor (2) are as follows.Without any impact test the workpeice being loaded on the test machine, the pendulum was raised to a prescribed angle of elevation (α) and then allowed to swing idly. This angle of upward swing (β) was then measured and the energy loss is calculated using the relation given below.

$$U = U_i - U_f = WR(\cos\beta - \cos\alpha).$$

Where **W** is the weight of pendulum and **R** is the radius of curvature.

Figure 5.6 Charpy impact test machine

NOTCH IMPACT STRENGTH

Notch impact strength (I_S) is determined using the following relation-

$\mathbf{I_s = U/A_e}$

Where Ae is the effective cross sectional area of the specimen below the notch made before the test is made.

MODULUS OF RUPTURE

Modulus of rupture (U_r) is determined using the following relation-

$\mathbf{U_r = U/V_e}$

Where V_e is the effective volume of the specimen. All these results can be calculated once the rupture energy is known by the charpy test.

FOR IMPACT TEST SPECIMEN; L=55 mm, B=10 mm, H=5 mm

Notch is made up to a depth of 2 mm, so effective width=8 mm

EFFECTIVE AREA=40 mm^2

EFFECTIVE VOLUME=2200 mm^3

FOR SIMPLE WELD

1. Rupture energy= 24 J
2. Notch impact strength=0.6 J/mm^2
3. Modulus of rupture=0.0109 J/mm^3

FOR WELD WITH PWHT

1. Rupture energy=27 J
2. Notch impact strength=0.675 J/mm^2
3. Modulus of rupture=0.0122 J/mm^3

Result clearly indicates that with heat treatment toughness has increased.So with heat treatment mechanical properties have improved. In other words weldability has improved.

CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1 CONCLUSION

In this project work it was observed that formation of hard and brittle phases like martensite and carbide in fusion zone can be effectively controlled by controlling the cooling rate and using the filler metal of suitable chemical composition. Result obtained during this study clearly shows that by using nickel based filler material, the formation of brittle phases like martensite and carbide in fusion zone is prevented. Here it is important to note that, the nickel base filler material has very low coefficient of thermal expansion therefore it strains the cast iron HAZ much less than other filler metals in this way it helps in reducing the chances of HAZ cracking.

For post weld heat treatment workpiece were heated to a temperature of 850^0C and kept at that temperature for 1 hour and then furnace cooling was done. This post weld heat treatment was successful in the dissolution of martensite in HAZ and graphitization of this zone. Applied PWHT was successful in producing a weld with nearly uniform hardness profile.Therefore it can be concluded that welding of grey cast iron with a nickel filler metal coupled with applying a proper full annealing (ferritizing) PWHT can serve as solution for grey cast iron welding problems.

6.2 SCOPE OF FUTURE WORK

1. Preheating of the workpiece can be done in order to minimize the chances of cracking by reducing the cooling rate.
2. Welding of cast iron can be done under different preheat temperature in order to determine the effect of different preheat temperature.
3. Welding of cast iron can be done by using different welding process under different preheat temperature in order to determine an optimum pre heat temperature.
4. Welding of cast iron can be done under different post weld heat treatment temperature and different welding parameter.
5. Welding of cast iron can be done with different type of filler electrode and measuring its machinability and weldability.

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