Chapter-1

INTRODUCTION

1.1 Introduction

Welding of cast iron is of very much importance because less work has been done in earlier stages. It has uneven distribution of carbon content which worsens the case and makes it heterogeneous. As the higher carbon content in comparison to steel it is very tough for a person to select the right process for welding. So study of various changes occurring in the weld zone as well as in the heat affected zone is of utmost importance.

Change in the heat affected zone and weld zone occurs due to thermal cycles it has to pass. Further the use of heat treatment affects the thermal cycle so the microstructure. Welding techniques for cast iron are less used in the industry because of its poor mechanical properties, residual stresses developed and unavailability of suitable electrode. In addition to these chances of martensite formation due to fast cooling makes it very difficult. So the controlling of thermal cycles through heat treatment is important as well as deciding factor because of its effects on microstructural level.

The effect of heat treatment can be seen on the microstructural level. As the heated temperature and the cooling rate change the changes in the microstructural level occurs and the microstructure changes. Grey cast iron is very brittle material and cannot withstand stresses which occur due to cooling cycles of the weld and chances of martensite formation are higher. As the carbon content increases the weldability decreases because chances of flake formation are higher. Due to this fact ductile cast iron is most suitable for welding because of presence of cast iron in nodular form. For welding pieces of high carbon content gas welding (oxyacetylene) and arc welding is used. In arc welding the selection of electrode is an important criteria. Sometimes the heating of electrode gives significant changes in the weld zone. Electrode which are generally used in cast iron welding are nickel based, steel electrodes and cast iron rods.

Above discussion shows that the combination of weld metal, electrode material and weld thermal cycle play important role in the acceptable welding of cast iron. In addition to this it gives good mechanical properties also. Their only disadvantage is the cost of these electrodes. For repair work welder or the owner cannot afford the cost of the electrode In this study work has been done to know the effects of heat treatment on the weldability of cast iron and effect of current on mechanical properties of specimen. In the primary stage material is welded and samples are heat treated. Then samples are made for different tests. After the testing of these samples results are compared to check the effects of heat treatment.

1.2 Iron Carbon Diagram, Steel, Cast Iron

Iron is the basic need of any society because it is a major material in the infrastructure industry, automobile industry, marine industry etc. As the society or the country grows in these fields, prosperity comes and economy booms. It is a fact that materials have their direct impact on the economic growth of the country. So a small advancement in the field of material processing can change the scenario of the economy as well as the society. Iron is known to humans from the old days. Even a specific period of the history is known as iron age. History tells us about its use in the various fields. Its processing becomes very important and crucial when it has a direct impact on all these fields. A small amount of carbon when added to this it property enhances and it is called steel. Up to two percentage carbon it is known as steel and after it is called cast iron. Both are iron alloyed with carbon but their properties vary as the carbon content varies. Moreover as the cooling pattern changes the properties change significantly. Steel is also divided into three parts namely mild steel or low carbon steel, medium carbon steel, high carbon steel. If the carbon percentage is more than two it is known as cast iron.

To know the distinction between various types of cast iron and steels one has to know about iron carbon diagram. Carbon is an interstitial impurity in Iron. It forms solid solution with α,ϒ, δ phases of iron. Microstructure depends on composition and heat treatment. Iron Carbon diagram is the temperature composition diagram which shows the stability of various phases. As the diagram shows up to 0.8% of carbon it is called hypo eutectoid steel and after this it is called hypereutectoid steel. A Eutectoid reaction occurs at this composition and temperature 1333^{o} F (722^{o} C). Left to this line is ferrite plus pearlite and right is pearlite and cementite. Combination of these two is known as pearlite. It is a layered structure of ferrite and cementite. At exactly this line after cooling it is known as pearlite. If the composition is more than 0.8% it is pearlite plus cementite. In the left of this line microstructure is ferrite plus pearlite.

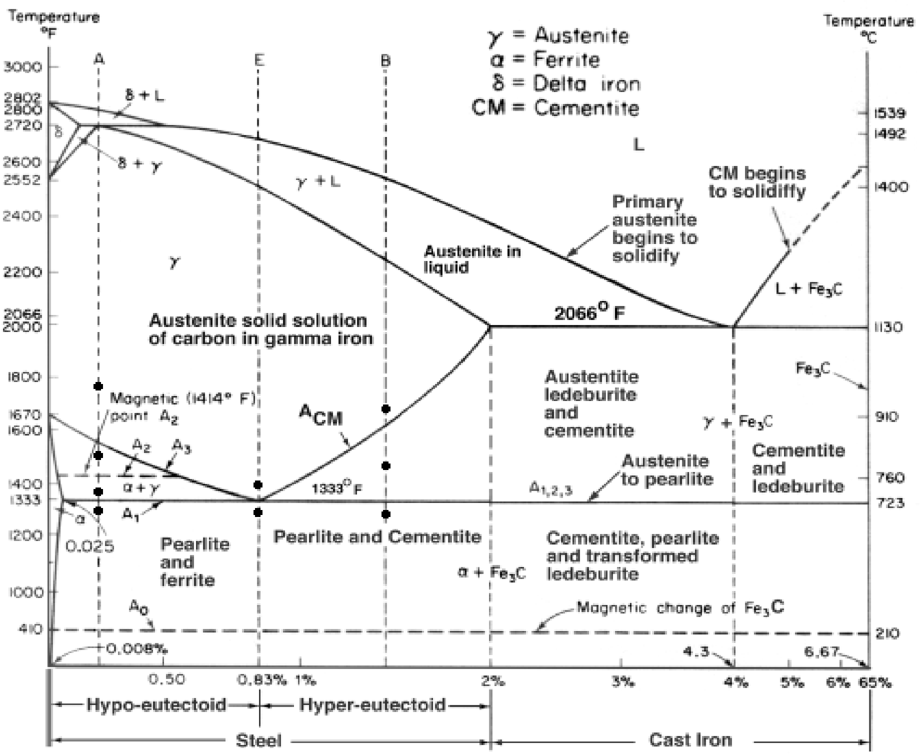

Fig 1.1 Iron carbon diagram(www.sv.edu)

Like this point a hyper eutectoid point comes at 2066 F (1147^{o} C). For this the composition is 4.3 %. Austenite when cooled at this temperature it transforms into lediburite which is the combination of cementite and austenite. Upto 4 % it is called hypo eutectic cast iron. After this it is called hyper eutectic cast iron.

Iron Carbon Diagram is very important for the knowledge of different phases present and their effects on the properties of material. At the time of welding as the material melts microstructural changes occurs. These microstructural changes are responsible for the change in properties. Also with the application of heat treatment properties can be controlled. For this knowledge of Iron Carbon diagram is essential.

So the material which falls in this region is cast iron either hypo or hyper eutectoid. As material chosen in this project is cast iron so emphasis will be given to cast iron and its welding. We have to study the two basic things for understanding this project. One is the welding technique and other one is properties of cast iron.

1.3 Welding

Welding is a joining technique in which coalescence takes place due to application of heat and pressure. The heat is generated through the application of mechanical energy (friction welding), electrical energy (arc, resistance welding) etc. Further there are two more joining process namely soldering and brazing. These processes are similar to welding but its fundamentals are different from welding.

Welding is the need of any manufacturing industry because fabrication of small pieces to make large big size component is necessary. There are some other processes available for joining like riveting, bolting etc but some excellent advantages makes welding a widely used process.

1.3.1 Arc welding

Arc welding is one of several fusion processes for joining metals. By application of intense heat, metal at the joint between two parts is melted and caused to mix or more commonly, with an intermediate molten filler metal. After cooling and solidification a bond is created between the two parts. As the joining of parts occur the strength of joint is similar to the base metal. In non fusion processes like soldering and brazing mechanical and physical properties change occurs. This is the advantage of welding over them.

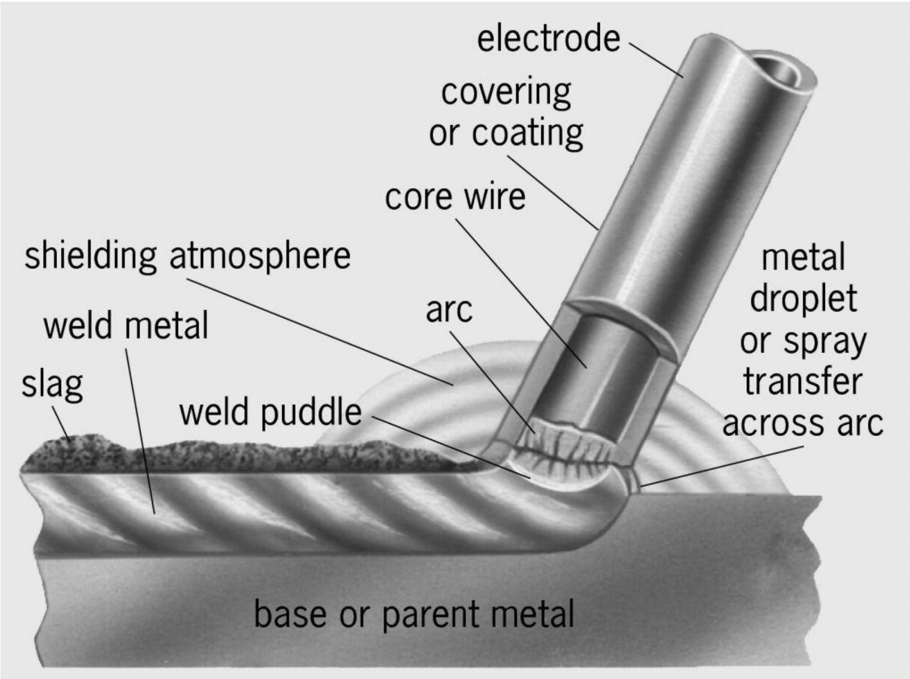

Fig. 1.2 Arc welding setup (www.hotrodders.com)

1.3.2 Shielded Metal Arc Welding

Shielded metal arc welding is an arc welding process in which coalescence of metals is produced by heat from an electric arc that is maintained between the tip of a covered electrode and the surface of the base metal in the joint being welded. The electrode may be casted or drawn rod. This rod conducts the current and due to generation of heat melts and works as a filler material. The functions of the coating are to provide arc stability and protect the molten metal from the atmospheric gases. Both functions are very critical for sound welding.

The composition of the electrode covering varies according to the type of electrode .Shielding and electrode wire is responsible for the mechanical properties, chemical composition as well as mechanical properties of the joint.

1.3.2.1 Principle of Operation

Welding is started when an electric arc is struck between the tip of the electrode and the work. The heat generated from this melts the electrode as well as the base metal which is near to electrode. Small globules forms due to melting and drops on the joint. So the electrode melts and material for joining reaches at the surface of the joint and joining takes place. So by moving the electrode with an optimum travel speed over the joint the joint is made. There are several mechanisms of transfer of molten electrode from the tip to the base metal like gravity, electric forces, magnetic forces, surface tension forces, transfer in the form of mist etc. Gravity is predominant in vertically downward cases. Sufficient electric current is needed to melt the electrode and join the material. It also requires an appropriate gap between the tip of the electrode and the base metal or the molten weld pool.

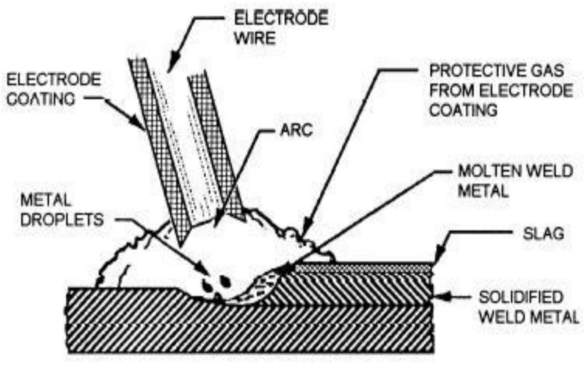

Fig.1.3 Shielded metal arc welding(www.corrosionist.com)

1.3.2.2 Arc Initiation, Electrode and Arc Length

In arc welding the heat is generated through electric arc. The arc is formed between the metal and an electrode (stick or wire) that is guided along the joint. Arc is formed by touching the electrode momentarily on the piece other than work. Once ignited the electrode is moved on the metal which is to be joined. The electrode can either be a rod with the purpose of simply carrying the current between the tip and the work. Most welding in the manufacture of steel products uses the second type of electrode.

The electrode diameter selected for use depends on the thickness of the material to be welded, the position in which welding is to be performed, and the type of joint to be welded. In general, larger electrodes will be selected for applications involving thicker materials.

The arc length is the distance between the tip of the electrode to the surface of the base metal. Proper arc length is necessary for the sound welding joint. Metal transfer from the electrode to the joint is not a smooth process because voltage varies. Even if constant arc length is maintained then also the voltage varies and transfer is not smooth. However, any variation in voltage will be minimal when welding is done with the proper amperage and arc length. For smooth operation of the welding a proper electrode feed is required. In shielded metal arc welding the movement of electrode is by hands. In this welding operator has to adjust two motions. First is maintaining the distance from the work piece to maintain the arc and the other is to travel in the direction of weld. As the electrode diameter, type of covering changes arc length also changes. It is also dependent on the welding position and amperage value. As the electrode diameter is increased the arc length also increases. It also increases with increase in current. Arc length must not increase from the wire diameter of the electrode. If the arc length is very small chances of short circuit are higher. If the arc is too long it will lack direction and intensity due to this scattering of the molten metal takes place as it travels from electrode to the work piece. If the arc length is higher the gas generated by the electrode is not effective in shielding the arc Due to this chances of atmospheric contamination are higher. Oxygen and nitrogen present in the atmosphere reaches the molten metal and chances of porosity are higher. So control of the arc length is very necessary.

1.3.2.3 Prevention From Atmospheric Contamination

For sound welding joints the joint should be prevented from any atmospheric contamination. It can be prevented by a positive pressure at the weld zone. This is done by covering the electrode with the material which when burns generates gases.

Coating which is present on the electrode not only protects it by making pressurized atmosphere but also forms slag which comes at the top surface of the welding and chipped away. The slag is made by flux reacting with the impurities incorporated in the metal. These impurities are of less density and come up when metal is melted. An ionized column of gas is created between the electrode and weld zone in which the molten metal travels.

1.3.2.4 Generation of Arc and Metal Transfer

There are different methods of metal transfer from the electrode to the base metal. Surface tension force, electromagnetic force, gravity force, electric force comes into picture when metal transfer comes into picture. In the case of consumable electrodes, the tip of the electrode melts under the heat of the arc and molten droplets are detached and transported from the electrode to the weld metal through the arc column.

If the electrode is consumable most part of the heat generated by the arc is transferred to the weld zone. This produces higher thermal efficiencies and narrower heat-affected zones.By only striking the electrode on the metal not generates the arc. It needs an ionized path to travel. So at first ionization of the path is necessary. The arc is ignited. The initial voltage is kept high so that as the electrode is touched to the work and detached the contact area is heated.

Arc welding can be performed with AC as well as DC. The type of current and polarity depends on the type of electrode, arc atmosphere, base metal etc. In Direct current welding according to our need we can control the heat produced in particular area. If we need more heat at the base metal we use Direct Current Straight Polarity in which electrode is made negative and base metal positive. By this the high speed electron strikes the base metal and nearly two third of the heat is produced at the base metal. Its opposite is Direct Current Reverse Polarity where one third of the heat is produced at the weld metal.

The arc produced with direct current is stable than the arc produced with alternating current. In Direct Current the polarity does not change so stable arc is generated. Some electrodes are used with straight polarity and some with reverse polarity. Actually electrodes when manufactured have the specification for the use of polarity. The direct current arc produces stable arc as well as uniform joint. DC is preferred when to join thin sections due to greater control. Most electrodes perform better with DC when compared to Alternating Current. The disadvantage of Direct current is arc blow. When arc blow is predominant alternating current is used for welding.

1.3.2.5 Power Sources

Primary function of power sources is to reduce voltage supplied from the line to a suitable voltage range. There are two types of power sources used namely constant current power source and constant voltage power source. Constant current power sources are those which has means for adjusting the load current and which has a static volt-ampere curve that tends to produce a relatively constant load current.

The load voltage, at a given load current, is responsive to the rate at which a consumable electrode is fed into the arc, except that, when a non consumable electrode is used, the load voltage is responsive to the electrode-to-work distance. These characteristics are such that if the arc length varies because of external influences which result in slight changes in arc voltage, the welding current remains substantially constant. The no-load or open circuit voltage of constant-current arc welding power sources is considerably higher than the arc voltage.[l]

These power sources are generally used for manual welding like shielded metal arc welding. When a power source is selected several factors are considered like type of welding current required, welding position, amperage range required etc. Selection of type of current used for welding also depends on the type of current and type of electrode. For ac, a transformer or an alternator type of power source may be used. For Direct Current, transformer rectifier power sources are available. When both ac and dc will be needed, a single phase transformer-rectifier or an alternator-rectifier power source may be used. Otherwise, two welding machines will be required, one for ac and one for dc. The amperage requirements will be determined by the sizes and types of electrodes to be used. When a variety will be encountered, the power supply must be capable of providing the amperage range needed.[1]

The positions in which welding will be done should also be considered. If vertical and overhead welding are planned, adjustment of the slope of the V-A curve probably will be desirable**.** If so, the power supply must provide this feature. This usually requires controls for both the output voltage and the current.[1]

1.3.2.6 Application of SMAW

The shielded metal arc welding machine can be used to join most of the common metals and alloys. This includes the carbon steels, the low alloy steels, the stainless steels, and cast iron, as well as copper, nickel, and aluminium and their alloys. Chemically dissimilar metals can also be joined with the shielded metal arc welding process.

1.4 Cast Iron

Cast iron is the term used for a series of ferrous alloys that normally contain more than 2 percent carbon and 1 to 3 percentage of silicon. Some amount of sulphur and phosphorus is also there. To get the desired properties some elements are added to this. The properties like strength, corrosion resistance, hardness, hardenability is improved by adding these alloying elements. Chromium, Copper, Molybdenum, and Nickel is generally added to enhance the properties. The very basic condition of cast iron is it must have more than two percent carbon.

Mechanical properties of cast iron depend on the microstructure of the casting. The microstructure of the matrix surrounding the graphite particles also influences the mechanical properties of a casting. The matrix is basically ferritic, pearlitic, austenitic, or martensitic. The specific matrix in a casting will depend upon the chemical composition, cooling rate, and heat treatment of the casting. Cast Iron is a very important material when it comes to manufacturing industry because of its dampening property. It dampens the vibrations so it is used in making of lathe beds. Also its machining is very easy because it has graphite flakes which act as a lubricant in machining. Cast Iron has some varieties due to changes in its microstructure.

1.4.1 White cast iron

White cast iron is formed when the carbon does not precipitate as graphite during solidification. It remains in combination with iron, chromium, or molybdenum. It remains as carbide. This iron is hard and brittle, and has a white crystalline fracture appearance. White cast iron is normally considered un weldable because of the absence of adequate ductility to accommodate thermal stresses in the base metal. If the material is ductile appearance of cracks is less observed and welding joint produced has sound welding properties.

1.4.2 Grey cast iron

Grey cast iron is iron-carbon-silicon alloy. It contains un combined carbon in the form of graphite flakes. The appearance of cast iron is grey that is why it is called grey cast iron. Hardness, matrix microstructure, chemical composition, pressure tightness, and radiographic soundness in various combinations are sometimes specified to meet service requirements. Compression strength of grey cast iron is higher than its tensile strength. Graphite flakes are like cracks in their microstructure. This is the region of low tensile strength.

The tensile strength, hardness, and microstructure of a grey iron casting are influenced by several factors including chemical composition, design, the characteristics of the mould, and cooling rate during and after solidification. Castings with similar properties can be produced using different raw material mixes.

Various alloying elements are added to this to enhance mechanical properties. Copper, chromium, molybdenum, and nickel are frequently added to grey cast iron to control matrix microstructure and graphite formation. Addition of chromium makes it excellent against resistance to corrosion. Castings are heat-treated to obtain desired mechanical properties. Grey iron, like steel, can be hardened by quenching from a suitable temperature but it will be brittle. Tempering after quenching is necessary to improve toughness and decrease hardness.

Quenching makes the casting hard. It can be done in different mediums like water, brine solution, oil bath etc. Each has its own advantages. Grey iron has flake form of carbon that is why its ductility is very low. So when load is applied in the tensile test although the proportionality limit of cast iron is higher but its stress strain diagram is small and it has less ductility.

Fig. 1.4 Grey Cast Iron

1.4.3 Ductile Cast Iron

Ductile cast iron and grey cast iron are similar with respect to carbon and silicon contents, and in terms of general foundry practice for the production of castings. However, they differ in the geometric form assumed by the free graphite. In ductile cast iron, the graphite is caused to nucleate throughout the metal matrix in the form of spheroids. This causes high strength and ductility of ductile cast iron when compared to grey cast iron of similar composition. The production of ductile iron castings does not require the long time heat treatment required to produce malleable iron castings.

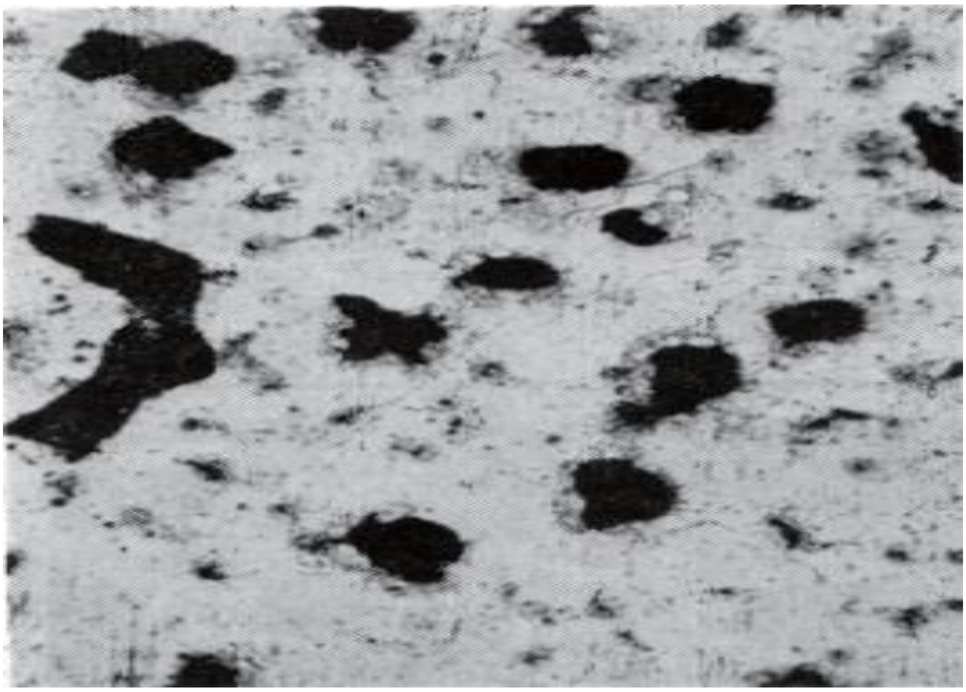

Fig. 1.5 Ductile Cast Iron

When it comes to composition it is almost same of grey as well as ductile cast iron. It is the difference of flakes which makes DCI ductile in nature. Spheroidization is achieved by introducing magnesium or cerium into a low-sulphur melt, preferably one containing not more than 0.02 percent sulphur. A low sulphur level is usually achieved by adding calcium oxide, calcium carbide, or sodium carbonate to the molten iron.[1]

1.4.4 Malleable Cast Iron

Malleable cast iron is produced with the heat treatment of white cast iron with suitable composition. The initial formation of white cast iron is promoted by low carbon and low silicon contents, the presence of carbide forming elements such as chromium, molybdenum, and vanadium, and rapid solidification and cooling. The white iron casting is then heated in a controlled atmosphere furnace to a temperature above the eutectoid temperature and held for several hours. This treatment permits dissolved carbon in the austenite to precipitate as nodules of graphite, known as temper carbon.

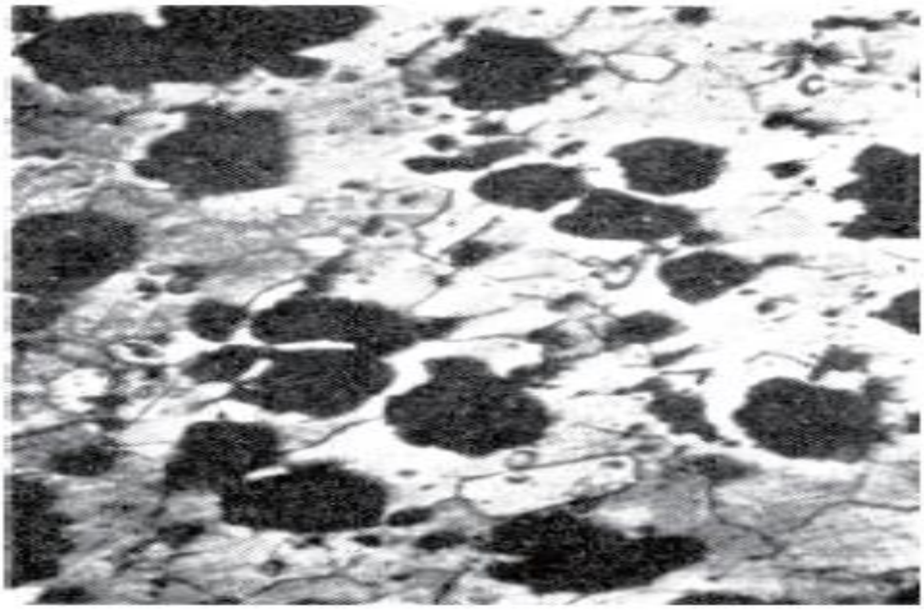

Fig. 1.6 Malleable Cast Iron

In the above discussion we have seen different types of cast iron which vary from one another slightly in composition, microstructure and processing. All types of cast iron have different set of properties and used in different applications. Some are very tough to be welded like white cast iron. Some show very less ductility. One thing common in all these is their carbon percentage is in the range of two to four percent. Addition of some metals makes them suitable for certain purposes. In this chapter we have studied about the different types of cast iron.

1.5 Weldability

Weldability is the ability of a material to be welded. All materials show different weldability according to their microstructure and elements present in it. Generally cast irons are considered very difficult to be welded and their weldability is very low. Certain processes are there to weld the cast iron but the difficulties we go throw in the process are of very high grade. The higher percentage of carbon makes cast iron tough to be welded. When welding is performed in cast iron the material gets heated and when it cools the material adjacent to the joint shows formation of carbides due to higher percentage of carbon. The material away from the joint shows formation of martensite due to rapid cooling which is very hard and brittle. Also the welded piece gets distorted due to thermal cycles. Cracks also appear in the weld zone which is very harmful to any joint and makes it weak.

In cast irons ductile cast iron is better than other type of cast irons because it has the capability to sustain some plastic deformation. So in ductile cast iron chances of cracks are less that is why it is better than other type of cast iron in welding.

Some other constituent (materials) has so much impact on the weldability of cast iron. Addition of certain materials makes the welding easier or tougher accordingly.

Weldability of cast iron is affected by various parameters like filler material, microstructure, preheating, cooling pattern, electrode selection etc. Presence of graphite in the microstructure affects the weldability of the cast iron.

1.5.1 Effect of filler material on weldability

Different filler materials are used and all show different characteristics. Suppose if carbon rods are chosen for welding it has high carbon content. As after welding the cast iron mixes with the filler materials. In this case carbon percentage in the joint increases and chances of crack formation are very higher.

The mechanical properties of the weld metal employed on cast iron can play a major part in the success of the operation. When the yield strength of the weld metal is low, the stresses imposed on the cast iron during cooling are relatively low. This reduces the likelihood of cracking. During service, a soft weld metal can creep and relieve stresses in the cast iron. Nickel or nickel alloy weld metal is very effective in this respect, and considerable use is made of nickel and nickel alloy filler metals for arc welding cast iron. Another advantage of these types of weld metal is the ease with which they can be machined in the as-welded condition. Machining of joints which are welded with cast iron rod is very tough unless post weld heat treatment is not done. Cast iron rods are preferred for repair works. The cost of these electrodes is very less and makes it suitable for welding. The machining of joints made with cast iron electrodes is tough.

1.5.2 Effect of Graphite flakes on weldability

Graphite flakes have high surface area. Spheroidal cast iron have less surface area to volume ratio so it is easy to weld. It is ductile also that is why in general we say ductile cast iron is easy to weld. The reason of ductile cast iron having good weldability is absence of graphite flakes.

The composition and microstructure of a cast iron affect the amount of carbon in the heat affected zone that is dissolved during welding. This, in turn, influences the brittleness and crack susceptibility of the welded joint. To minimize the formation of massive carbides and high-carbon martensite, it is most helpful to have the carbon present as spheroids that have a low surface- to-volume ratio. The smaller the surface area of the graphite in contact with an austenitic matrix, the lesser is the amount of carbon in the microstructure at room temperature. Graphite flakes in grey cast iron display the greatest tendency to dissolve in austenite because of their relatively large surface area. However, graphite in any form dissolves slowly and often remains in the weld metal. In general, melting during fusion welding is a reversal of the casting solidification process, and those areas last to solidify during casting are the first ones to melt during welding.

1.5.3 Effect of Heat Treatment on Weldability

If we can control the cooling rate or if we can slow the cooling rate by any means it will make the weld zone crack free because chances of formation of martensite and carbide are less. This can be achieved by preheating. The formation of a hard and brittle heat affected zone can lead to cracking during cooling or in service. Low heat input with arc welding limits the width of the heat-affected zone but a band of hard brittle iron can still form adjacent to the weld metal. Heat-affected zone hardness can be limited by preheating in combination with slow cooling after welding. Preheating provides lower cooling rates in both the weld metal and the heat-affected zone than occurs without it. A low cooling rate during and after austenitic transformation reduces the amount of martensite formed and thus the hardness. Preheating reduces the width of the heat affected zone and lowers the cooling rate. The formation of hard martensitic zone is avoided. The preheat temperature and extent of preheating depend upon the type of cast iron being welded, the mass of the casting, the welding process, and the type of filler metal. In general, ferritic ductile and ferritic malleable cast irons can be arc welded with lower preheat than from the pearlitic types because ferritic cast irons have better ductility. High preheat is needed when using a cast iron filler metal because the weld metal has low ductility near room temperature. A filler metal that deposits relatively low strength, ductile weld metal, can be used with the base metal at or slightly above room temperature.

The weld metal will yield during cooling and relieve welding stresses that might otherwise cause cracking in the weldment. Cracking from unequal expansion can take place during the preheating of complex castings or when the preheating is confined to a small area of a large casting. Local preheating should be gradual. Preheating of either a large section of the casting where the welding is to be done or the entire casting in a uniform manner is recommended. In any case, the preheating temperature should be maintained during welding, and welding should be completed before the casting is cooled slowly to room temperature.

With the post weld heat treatment the chances of cracks are reduced . But for post weld heat treatment time is very important factor. As after welding the specimen starts cooling. So prevention from atmosphere is necessary. Otherwise the specimen will cool before heat treatment and there is no purpose of heat treatment. In some cases the weld is kept in a powder. It can also be kept in a insulating box to take it from welding lab to furnace.

Chapter-2

LITERATURE REVIEW

2.1 Literature Review

There are numerous research papers published in the area of welding and cast iron in various journals. In these papers weldability is discussed and the effect of weldability on the properties materials is considered. The following papers make an attempt to provide an insight in to the mentioned area.

L. Collini [9] told that the mechanical properties of structural materials depend on the microstructure. In this paper he correlated the microstructure and mechanical properties of the pearlitic grey cast iron. He performed the test on cast iron obtained from three different foundries. He told that reduced graphite content increases the tensile strength. He told that mechanical properties of grey cast iron show high variability.

Xiaohui Zhi[10] studied the effect of heat treatment on the properties of cast iron. With the increase of heat treatment temperature hardness increased at the temperature of 1000^0 C. Also with the increase of heat treatment temperature austenite content also increased.

Hatate et al[5] made a comparison between electron beam welding and metal active gas welding. He joined spheroidal graphite cast iron and mild steel. To make it happen a layer of nickel is placed between two plates. All the conclusions were made by studying microstructure of the weld area. Nickel alloy is used in the metal active gas welding as a filler material. Very high hardness values were experienced in weld bead of electron beam welding joints. He observed that electron beam welding results in increased bonding strength with respect to MAG welding. So he concluded that electron beam welding is faster but hardness values are much higher.

Sanghoon *et al.* studied weld joint between high silicon nodular cast iron and stainless steel using MAG welding with Ni Cr alloy filler material. A significant UMZ region is determined on the fusion boundary. This region with partially melted zone showed the highest hardness values and martensitic phases. Formation of martensitic phases concluded that welded joint is hard and brittle.

Pascual *et al*.[11] studied welding nodular cast iron with oxyacetylene welding and shielded metal arc welding .He did this with 98.2% Ni and Fe-Cr-Ni alloy filler materials. He found that welding ductile cast iron with or without preheat is possible. He observed that Nickel prevents the formation of graphite. Ultimately Nickel increases ductility. He also observed that preheating increases weld quality and ductility. Shielded metal arc welding shows some ductility in the weld metal. The joint made by the oxyacetylene welding showed less ductility.

El-Banna.[1] studied welding ductile cast iron. Its microstructure was ferritic. SMAW process was used. Filler material was ENiFe-CI. He studied and concluded that welding of ductile cast iron was possible without preheating if nickel electrodes are used. If preheating is done it improves the weld quality.

D. Seceleanu[4] did his experiment on cast iron and heated the sample, kept it for 30 minutes and measured the tensile strength, impact strength, hardness, elongation and ductility. He concluded that the hardness and tensile strength are in linear relation with heat treatment parameters. Impact strength and elongation are in polynomial dependence with the heat treatment parameters.

Mirjana Philipovic[16] compared the heat treated and as cast samples of cast iron. The results were obtained by examining hardness¸ wear resistance and toughness. By increasing the Niobium content hardness and wear resistance is increased. Addition of 3% Niobium in the alloy increases fracture toughness by 30% and 30% increase in wear resistance.

Pouranvari. did a study on welding cast iron using shielded metal arc welding with Ni based electrodes. He did not use preheating. Post weld heat treatment was done. This excess amount precipitated as graphite in fusion zone. There was no formation of cracks. He concluded that with post weld heat treatment and nickel electrode crack free welding is possible. Reduction in cracks may be due to reduction in hardness and change in grain size and entry of Ni in the HAZ.

Pouranvari M. studied the welding of grey cast iron with nickel based filler material and found that post weld heat treatment is good for getting sound welding. With the application of post weld heat treatment thermal cycles are reduced and crack free weld are produced.

Scott Funderburk R. did the study and told that with the application of preheating of sample higher quality weld are achieved. . Preheat should be used to minimize cracking. In some cases preheating cannot be used. In all cases it prevents cracking due to reduction in thermal cycles. Reduction in thermal cycles decreases formation of hard carbide and improves the joint which improves the mechanical property.

F. Malek Ghaini studied the heat affected zone and concluded that if residual stresses be controlled cracks can be controlled. He studied the sample and told that cast iron welding could be crack free if residual stress be eliminated. To control residual stresses heat treatment is a good method.

Mark Hebda did the welding of steel and presented a programme for evaluating the weldability of steel. The soft computing technique provided an alternative method for learning, Predictive modelling, Optimisation and control of weld quality. The result obtained showed that whether the selected pair of material is suitable for mutual solubility (welding).

Jan Voracek formulated a computational technique to relate many possible combinations of constituent of the cast iron with their properties. This would be helpful for evaluation of new material and to get desired properties. All measurements were realized in a stable technological process. It also means that the proposed method is directly applicable to the industrial environment, where larger series of castings are manufactured.

2.2 Summary

All these papers tell about the properties of cast iron and weldability of it. Different electrodes give different results. Also by varying the current output is different and we get different results. After the review of these papers it was decided to work on weldability of cast iron and effect of heat treatment and current on weldability. The literature also focusses on the mechanical properties of cast iron and its microstructure. All the properties are explained through microstructure of the material. In some papers welding of cast iron is done with different processes and they are compared.

Chapter-3

EXPERIMENTAL SETUP

3.1 Material Properties

To conduct the experimental work there is need of two types of materials.

- Cast Iron work-piece on which welding is performed.
- Electrodes to weld the specimen

Cast iron pieces are taken for the experimental work. Its thickness was 6 mm. Chemical composition of the material is of great significance.

Table 3.1: Chemical Composition of Cast Iron in percentage

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Mg	Cu
percentage	3.24	1.76	0.35	0.18	0.07	0.03	0.09	0.12	0.004	0.002	0.05

Cast iron electrodes are used for welding the cast iron. The electrodes purchased for the work are from Maruti Electrodes of AWS/A5.1 E7016 grade. The weld produced from this is of radiographic quality.

Table 3.2: Chemical Composition of Cast Iron Electrode

Element	C	Si	Mn	P	S
Composition	0.08	0.66	1.40	0.017	0.011

Rest of the percentage is of iron in the electrode.

Table 3.3 : Mechanical Properties of Cast Iron Electrode

Property	Y.S.	T.S.	% elongation	Impact Value
Value	560 N/mm^2	641 N/mm^2	30.4	68 J

3.2 Cutting and Cleaning Work

1. After getting the material it was cut into pieces with the help of band saw. The dimensions of the piece are 60mm×50mm. So the overall dimension of the piece became 60×50×6 mm.

2. The material got from the foundry was corroded due to atmospheric contamination. So it was cleaned by grinding it in the forming lab.

Fig 3.1 Pedestal Grinder

3. Proposed work is to make single V joint so each plate has given 22.5^o so that after joining the two pieces angle was 45^o. Edge preparation is done on shaper.

4. Material if left for some days it again get corroded so at the time of welding it was again cleaned.

3.3 Welding of Plates

1. Welding of plates is done at room temperature.
2. Welding is performed by meeting the two pieces. The angle of joint was 45^o.
3. Welding parameters are as follows.

Manual arc welding machine

Electrode Diameter	=	3.15 mm
Welding Current	=	120A, 125A, 130A, 135A, 140A

4. Welding is done in single pass. After welding the welded piece is hammered to clean the slag.
5. Simple welding specimens were ready.
6. In the same manner other pieces were welded.

3.3.1 Welding Machine Specification

The welding machine is of ador welding limited. It is ideally suitable for light, medium and heavy duty, all purpose industrial, structural welding applications. It has wide current control range, suitable for thin sheet to thick sheet welding applications. The welded products are of good weld bead shape. It is immune to supply voltage fluctuations from +10% to -15% on 415 volt. It has constant current characteristic with current control up to 1% on set value.

Open Circuit Voltage	=	80 Volts
Current Range	=	10 to 400 ampere
Type of cooling	=	Forced Air

Fig. 3.2 Welding machine

7. For post weld heat treated specimen pieces were taken to the metallurgy lab where heat treatment was done. The pieces are heated to 850° C. The furnace took around fifty minute to reach this temperature. After reaching this temperature plates are kept at this temperature for one hour. After maintaining the pieces at this temperature for one hour electric supply was cut and pieces were left in the furnace for slow cooling. It was taken out after twenty four hours.

Fig. 3.3Temperature control unit of furnace

8. After getting all the pieces ready for the specimen preparation these are divided into two groups.

- Normal weld plates with subgroups of different currents (120A, 125A, 130A, 135A, 140A)
- Post weld heat treated plates with 120 A, 125A,130A,135A,140A currents

Fig. 3.4 Furnace used for heat treatment

3.4 Test Specimen Preparation

Different test specimens were prepared for tests. The types of specimen prepared are written below..

1. Microstructure and scanning electron microscope test specimen

2. Tensile test specimen

3. Charpy impact test specimen

4. Hardness test specimen

3.4.1 Microstructure Test Specimen

1. Weld plate is shortened by cutting the extra parent metal by power hacksaw. Both sides of the parent metal are cut with this. Now only the welded part is left.

2. It was cut into small pieces from the welding side by grinder. It was not possible to cut it by ordinary application or manual cutting because its hardness was increased.

3. Now its un even surface was made plane with the help of grinder.

4. Now polishing is performed. First it was done manually by taking grade of 250 and others.

5. Dry polishing is performed in the machine for every sample.

Fig. 3.5 Power hack saw

Fig. 3.6 Mechanical polishing Machine

Fig. 3.7 Polishing setup

6. Wet polishing is done in second rotator by keeping the sample stationary.

Fig. 3.8 Wet Polishing

7. After this etching is performed by keeping the sample dipped in the nitric acid and alcohol for small amount of time.

8. Samples were viewed with the help of microscope. These are of different magnification. Microstructures were viewed in the computer attached to it and saved.

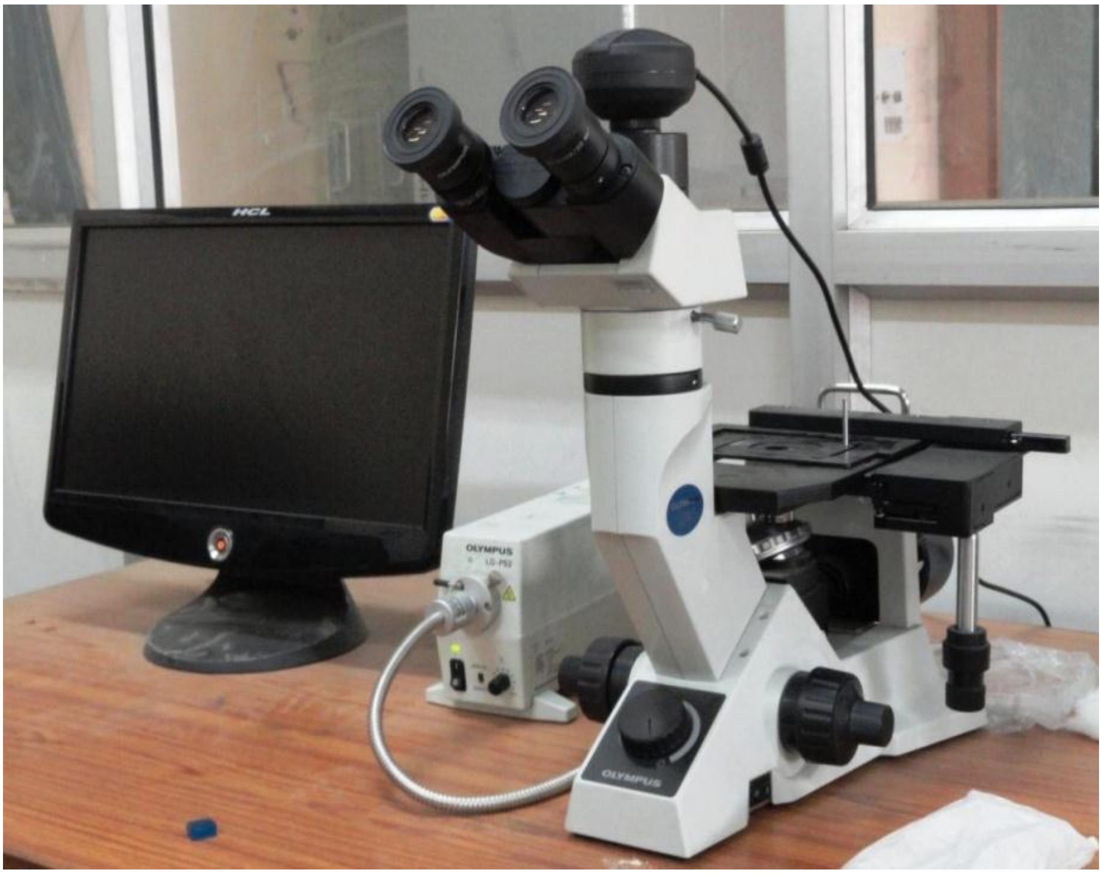

Fig. 3.9 Optical Microscope Set up

3.4.2 Hardness Test Specimen

1. The welded specimen was cut from the base metal side so that only welded portion was at the specimen.

Fig. 3.10 Preparation of hardness test specimen

2. Then the joint is cut into two small parts of sufficient length so that hardness test could be performed of three different zones namely heat affected zone, weld zone, base metal.

Fig. 3.11 Rockwell hardness test

3.4.3 Charpy Test Specimen

1. The specimen was cut from the welded plate.
2. A notch was made on the specimen.

3.4.4 Tensile Test Specimen

The specimens made for tensile testing are shown below.

Fig. 3.12 Tensile Test Specimen

Chapter-4

RESULTS & DISCUSSION

4.1 Rockwell Hardness Test

Rockwell hardness test was done with the cone of 120^0 angle and 0.2 mm radius. First a minor load of 10 kg was applied which caused small penetration. Then the dial was set to zero and major load was applied. Then the major load was removed and minor load was still applicable. Then the reading shown by the scale was the hardness value.

Hardness was read on C scale because of hardness of the material (cast iron). The load used was 150 kg. Hardness was taken of three areas namely heat affected zone, weld zone, base metal.

Table 4.1 Hardness values of different regions of simple specimen with 120 A current

Area/ Reading No.	First Run	Second Run	Third Run	Average Value
Weld Zone	27	29	29	28
HAZ	28	29	27	28
Base Metal	22	22	22	22

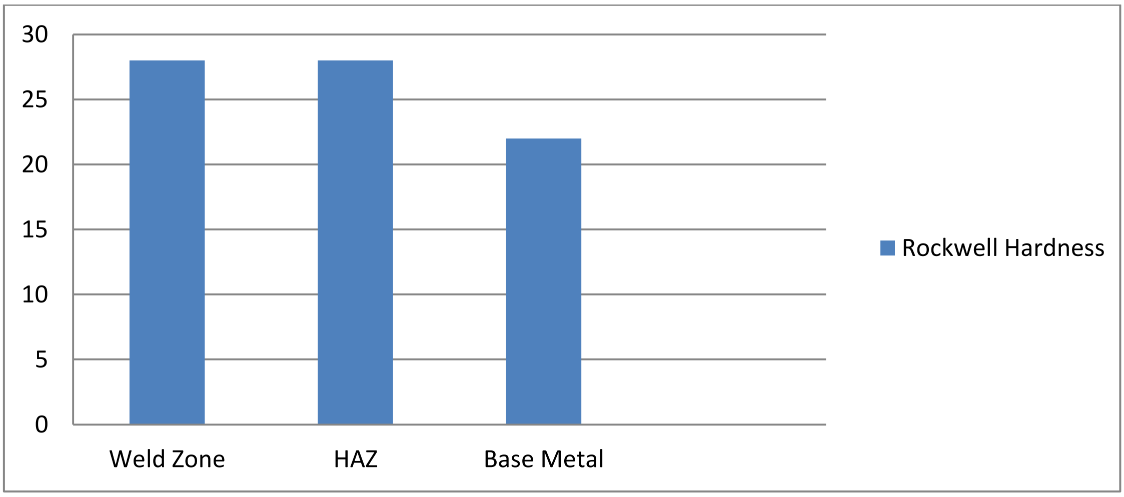

Fig. 4.1 Hardness comparison of different zones of simple specimen with 120 A current

Hardness depends on the microstructure of the area for which the test is performed. Due to air quenching of the specimen rapid cooling takes place. As result of this martensite is formed. It is the hardest phase of carbon. Austenite has more density in comparison to martensite. Hardness of HAZ is higher because it undergoes fastest cooling in all these three areas. Weld zone shows nearly same hardness as of HAZ. It also undergoes phase transformation. Its hardness is also dependent on the materials of filler rod. Base metal faces less thermal cycles. Its hardness is lowest in comparison to the other region.

Table 4.2 Hardness Values at different regions of heat treated Sample with 120 A current

Area/ Reading No.	First Run	Second Run	Third Run	Average Value
Weld Zone	21	22	21	21
HAZ	23	22	22	22
Base Metal	20	20	20	20

The average values of hardness are shown in the bar chart below.

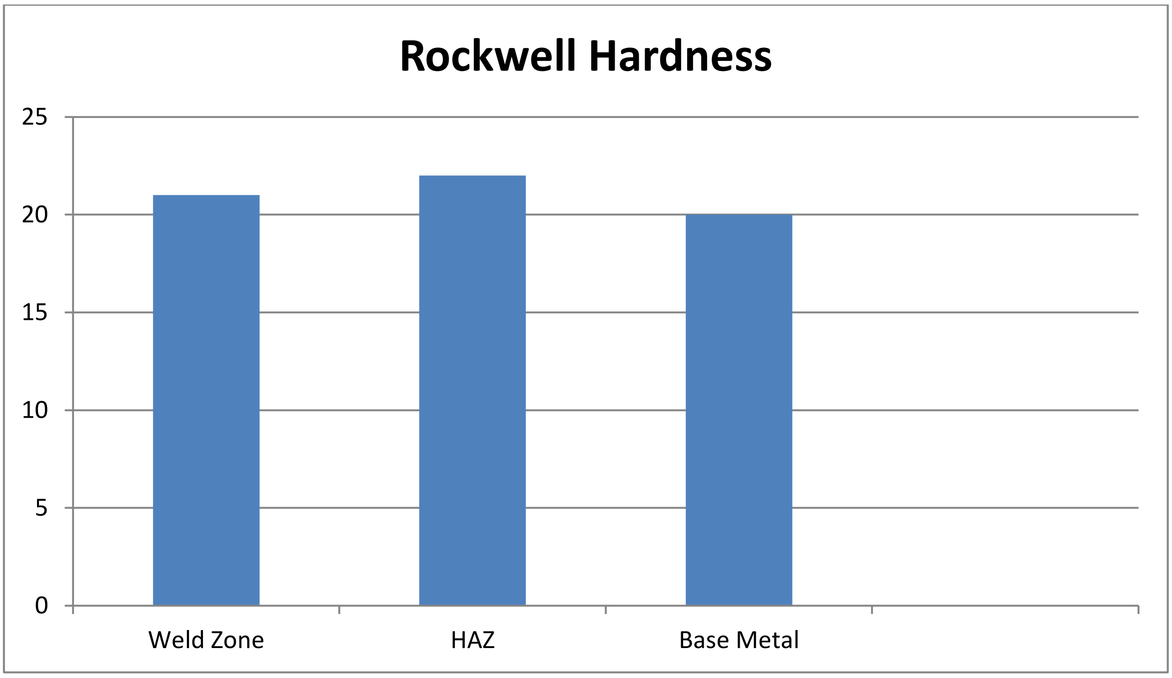

Fig.4.2 Hardness comparison of different zones of 120 A current heat treated specimen

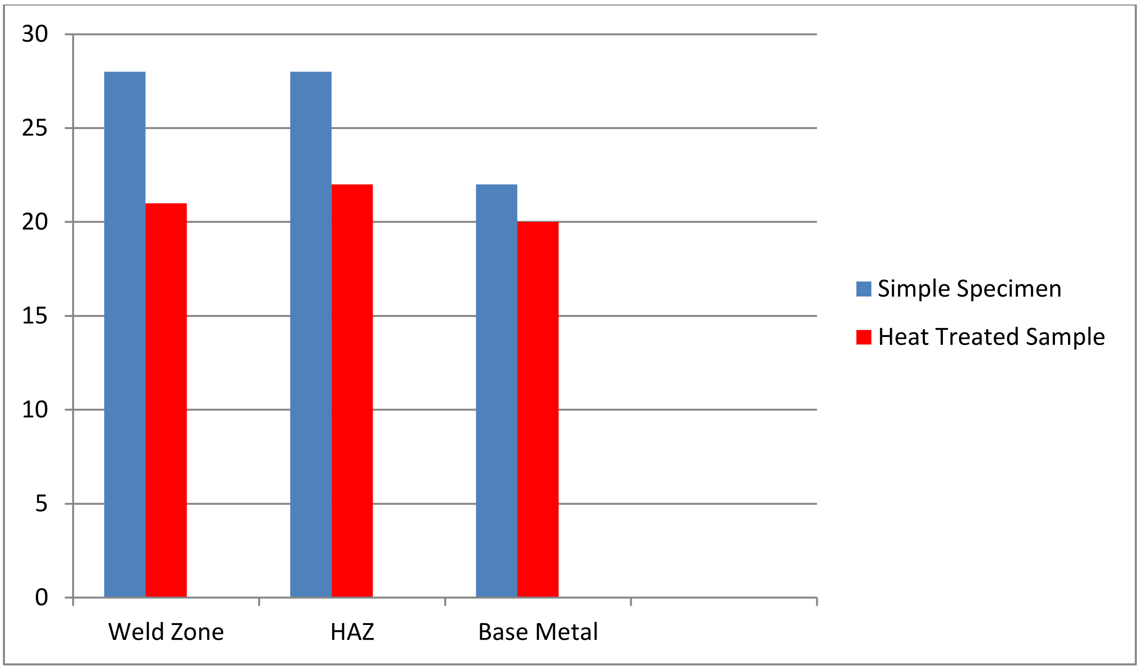

Fig.4.3 Comparison of hardness of simple specimen and heat treated specimen with 120 A

In post weld heat treatment specimen is heated to 850^{0} C and kept at this temperature for one hour. After that it is cooled in furnace. Slow cooling takes place in this specimen. Due to slow cooling chances of formation of martensite were reduced. Here the hardness pattern is more uniform. It was due to almost equal cooling rates of all parts. Chances of martensite formation were reduced in this case due to slow cooling.

Table 4.3 Hardness Values of Simple Specimen with 125 A current

	First Run	Second Run	Third Run	Average Value
Weld Zone	26	26	26	26
HAZ	27	28	28	28
Base Metal	22	22	22	22

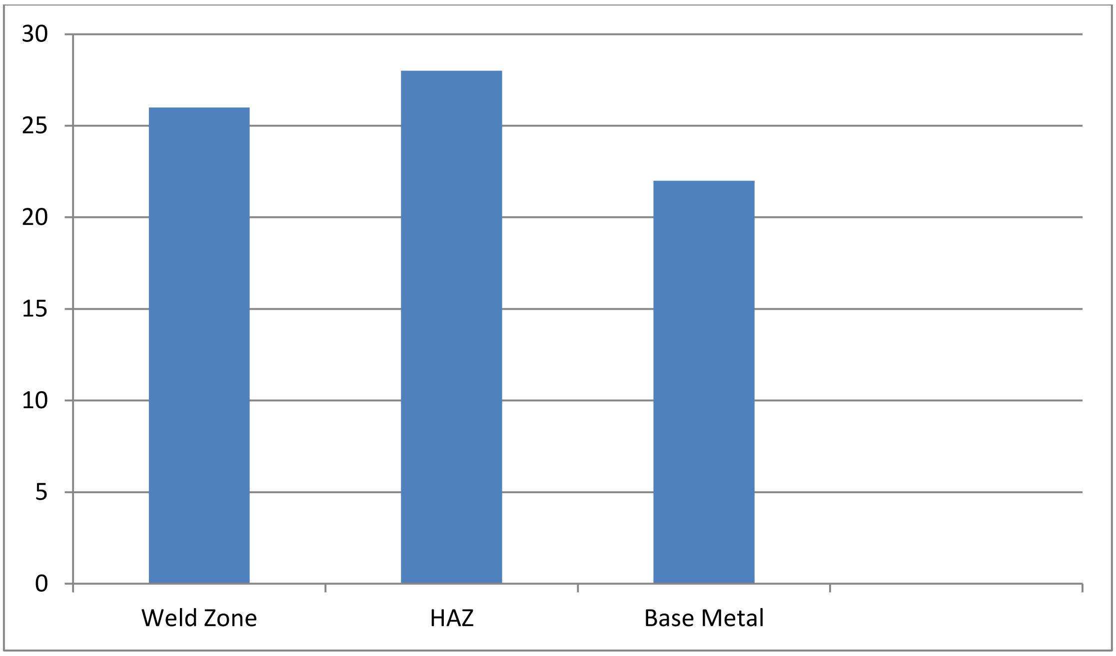

Fig. 4.4 Hardness comparison of different zones of 125 A current simple specimen

Table 4.4 Hardness Values of heat treated specimen with 125 A current

	First Run	Second Run	Third Run	Average Value
Weld Zone	21	21	21	21
HAZ	23	22	22	22
Base Metal	20	20	20	20

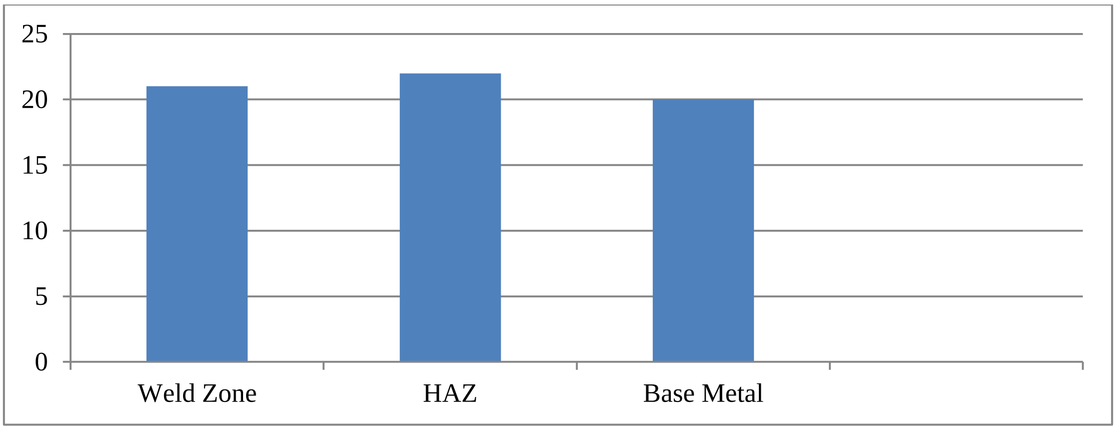

Fig 4.5 Hardness comparison of different zones of 125 A current heat treated specimen

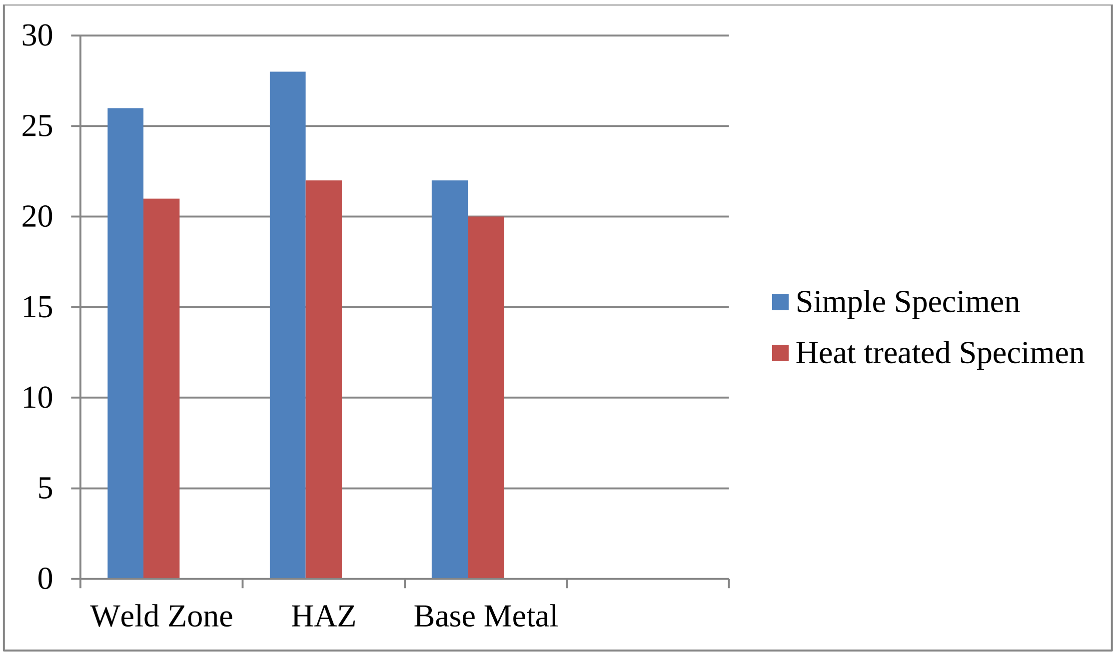

Fig 4.6 Comparison of hardness of simple and heat treated specimen with 125 A

Table 4.5 Hardness Values of Simple Specimen with 130 A current

	First Run	Second Run	Third Run	Average Value
Weld Zone	25	26	26	26
HAZ	28	27	28	28
Base Metal	22	22	22	22

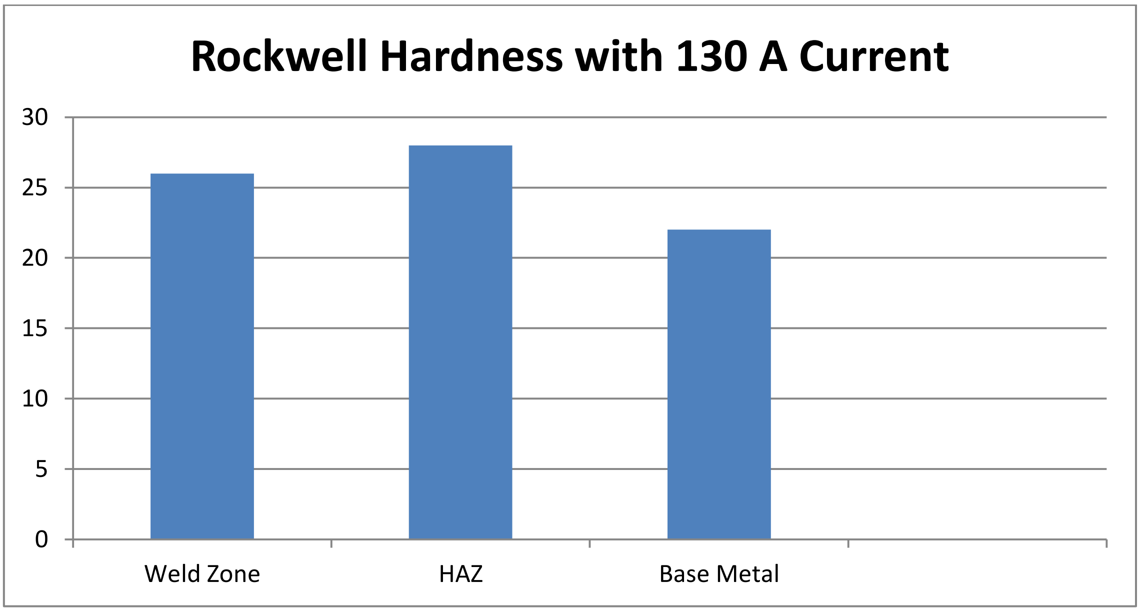

Fig.4.7 Hardness with 130 A current simple specimen

Table 4.6 Hardness values of heat treated specimen with 130 A current

	First Run	Second Run	Third Run	Average Value
Weld Zone	21	21	21	21
HAZ	23	22	22	22
Base Metal	20	20	20	20

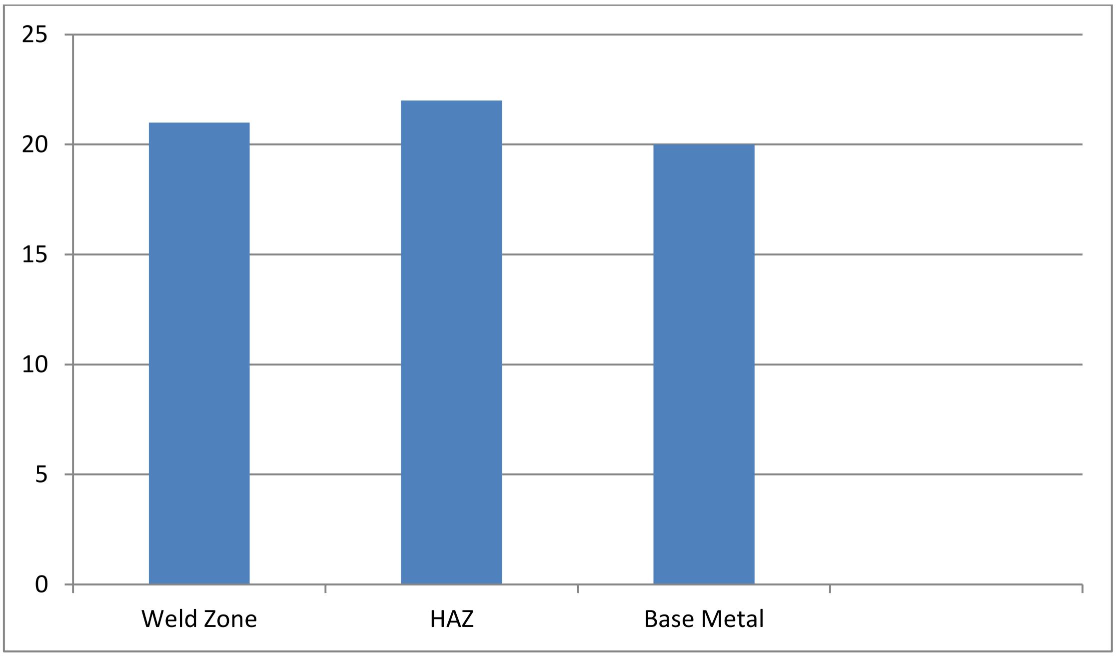

Fig 4.8 Hardness values of heat treated specimen with 130 A current

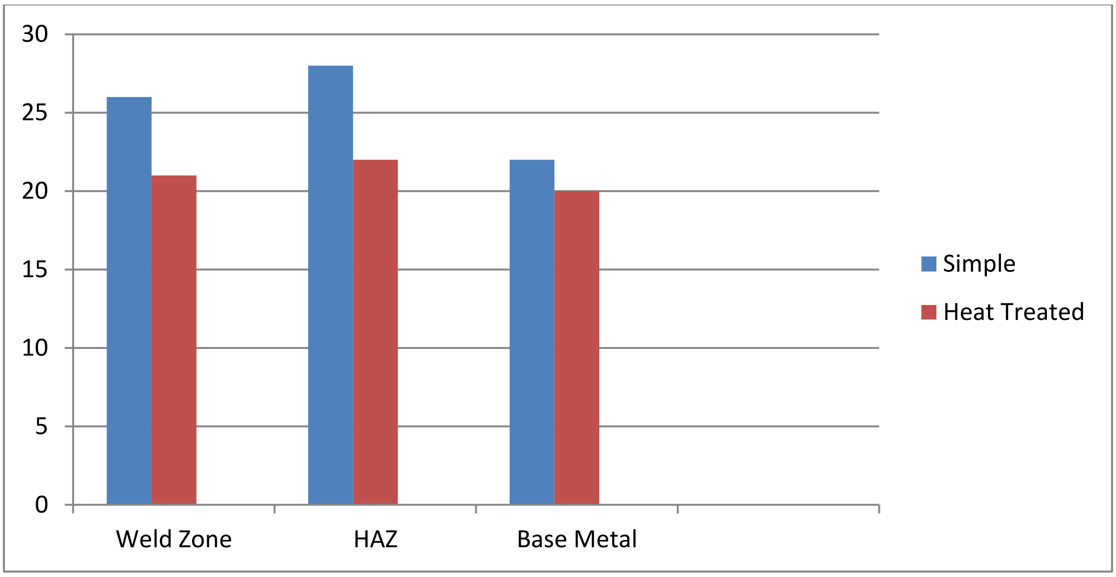

Fig 4.9 Comparison of hardness of simple and heat treated specimen with 130 A current

Table 4.7 Hardness values of simple specimen with 135 A current

	First Run	Second Run	Third Run	Average Value
Weld Zone	26	26	26	26
HAZ	28	28	28	28
Base Metal	22	22	22	22

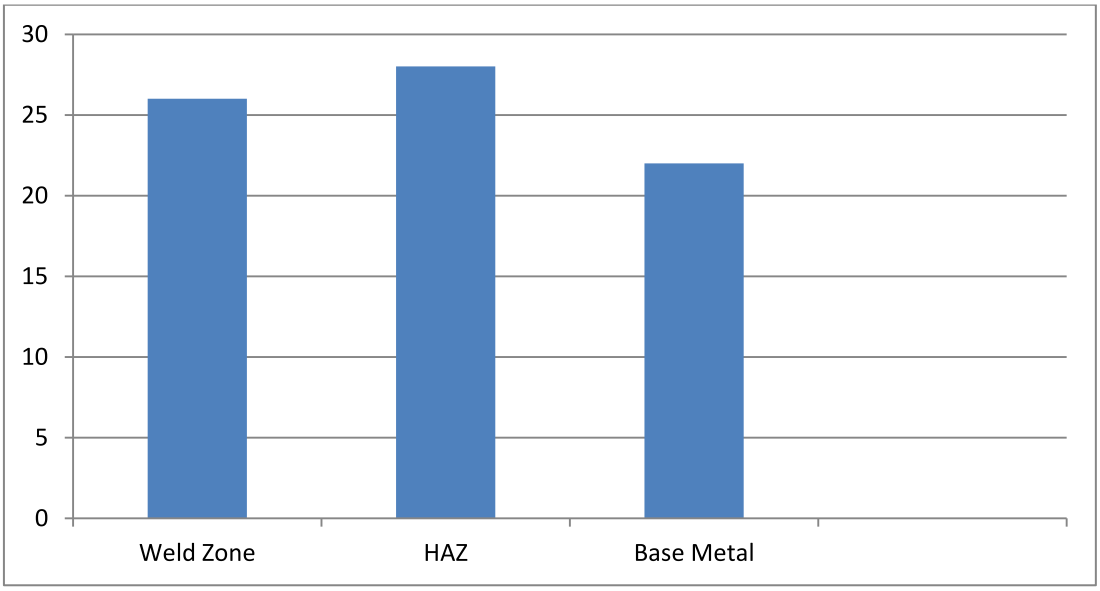

Fig. 4.10 Hardness with 135A current simple specimen

Table 4.8 Hardness values of heat treated specimen with 135 A current

	First Run	Second Run	Third Run	Average Value
Weld Zone	21	21	21	21
HAZ	22	22	22	22
Base Metal	20	20	20	20

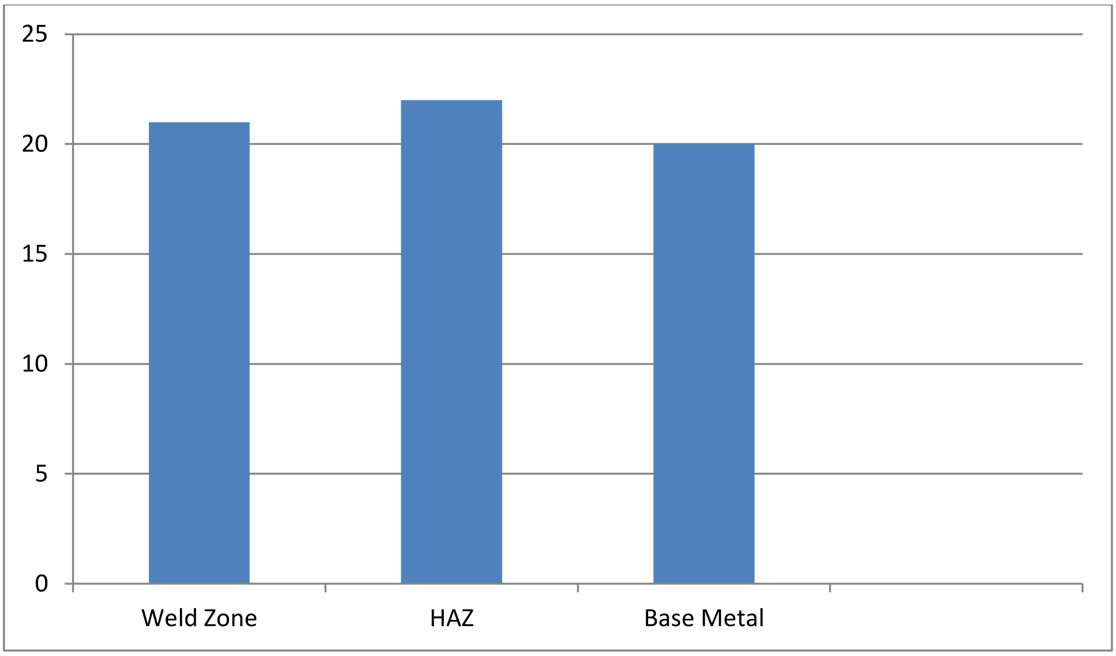

Fig 4.11 Hardness of heat treated specimen with 135 A current

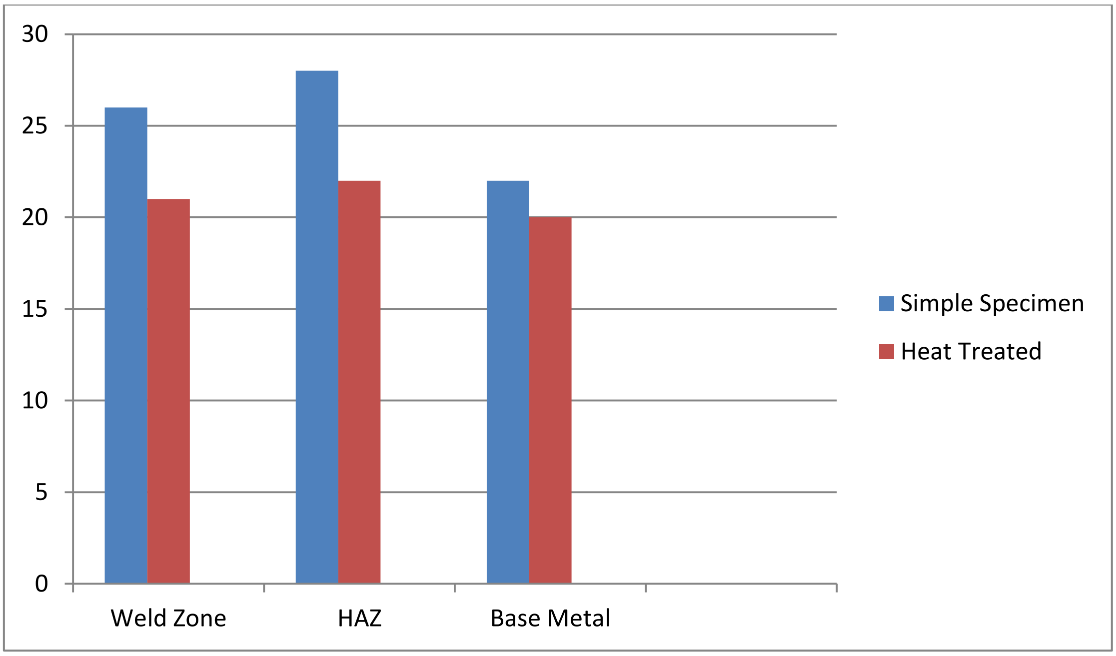

Fig 4.12 Hardness comparison of simple and heat treated specimen with 135 A current

Table 4.9 Hardness values of simple specimen with 140 A current

	First Run	Second Run	Third Run	Average Value
Weld Zone	24	24	24	24
HAZ	27	27	26	27
Base Metal	22	22	22	22

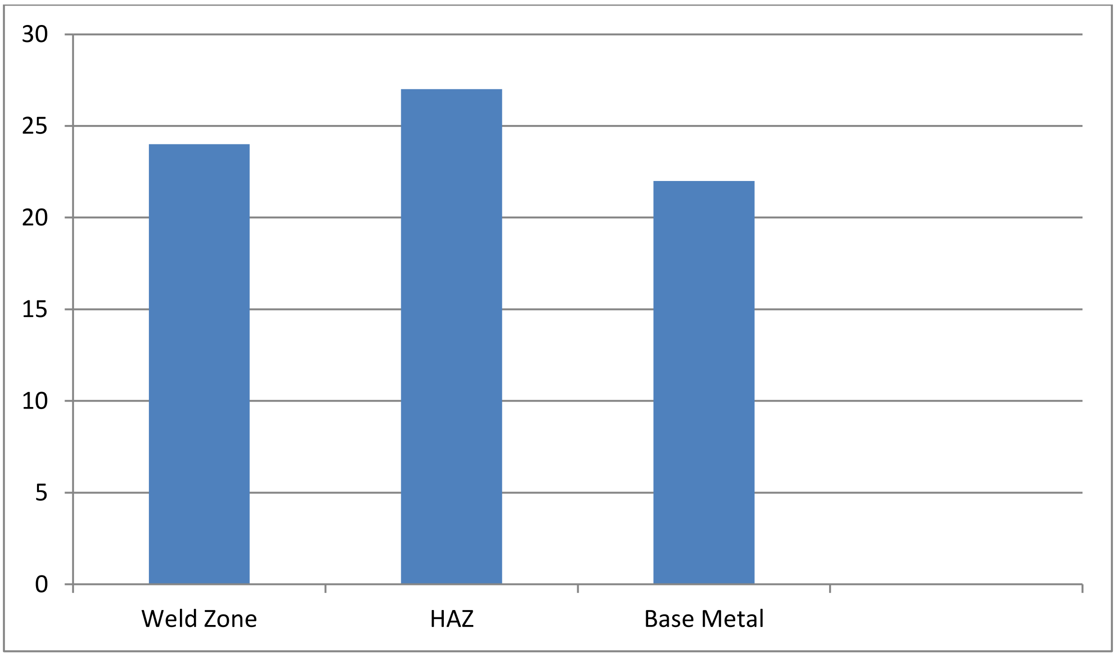

Fig. 4.13 Hardness of simple specimen with 140 A current

Table 4.10 Hardness values of heat treated specimen with 140 A current

	First Run	Second Run	Third Run	Average Value
Weld Zone	21	21	20	21
HAZ	22	22	22	22
Base Metal	20	20	20	20

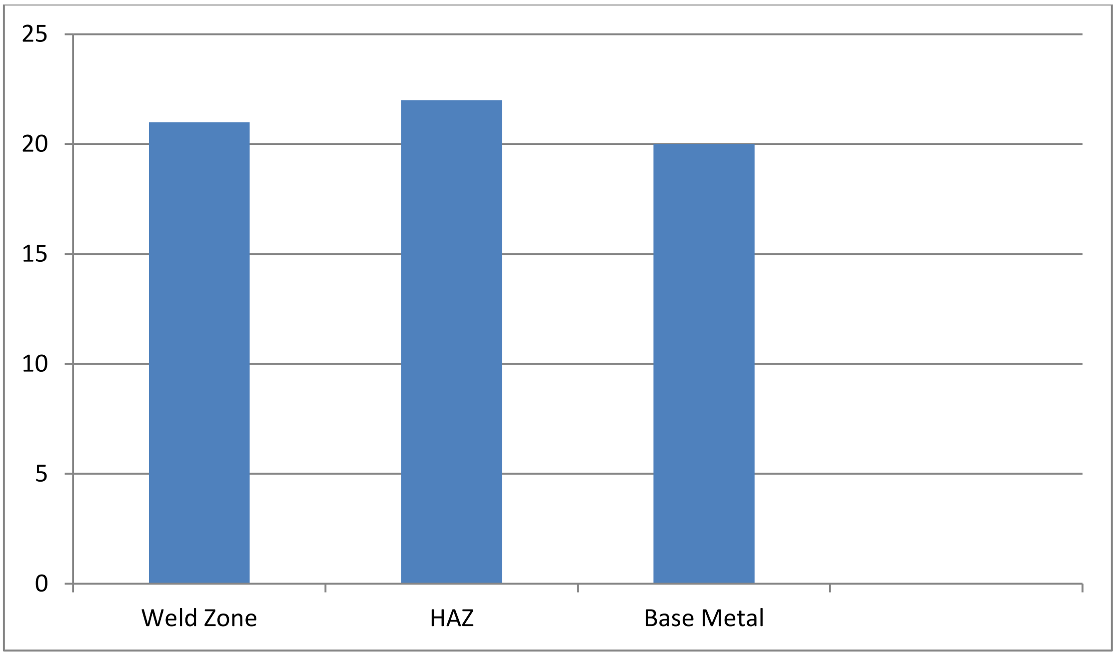

Fig 4.14 Hardness values of heat treated specimen with 140 A current

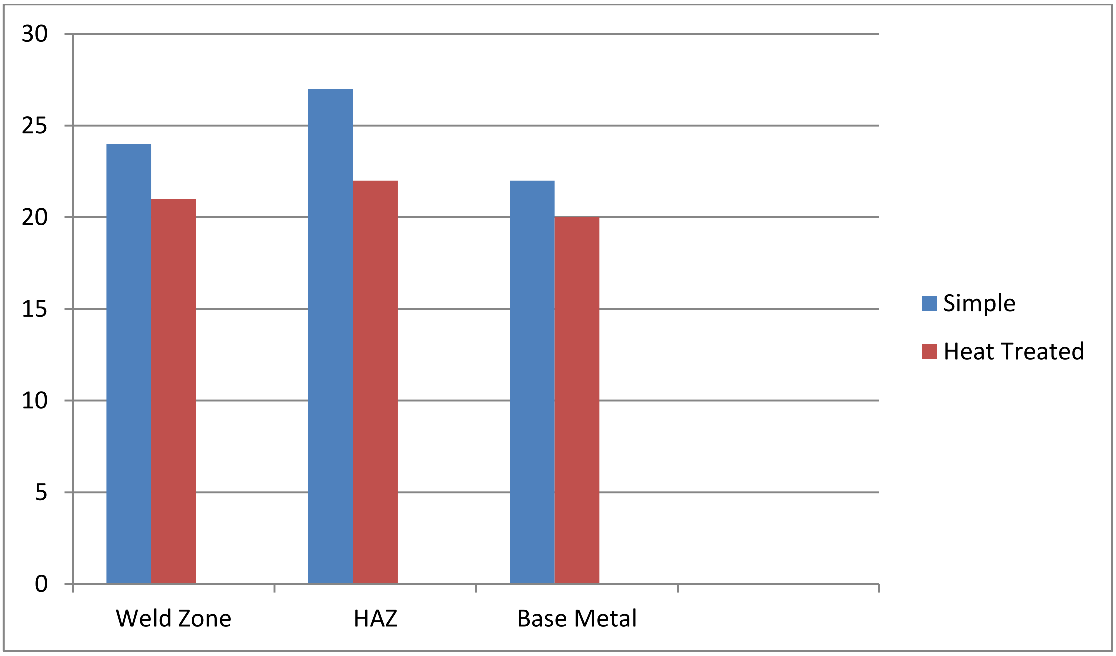

Fig 4.15 Hardness comparison of simple and heat treated specimen with 140 A current

Due to increase in current heat input is increased. This increase in heat input causes slow cooling and grains formed at the weld zone are coarser. This is the reason for the decrement in hardness of weld zone. Hardness of HAZ is decreased when current is increased from 135A to 140 A. The hardness of the base metal is constant. The effect of heat is predominant up to the heat affected zone that is why hardness of base metal is unaltered.

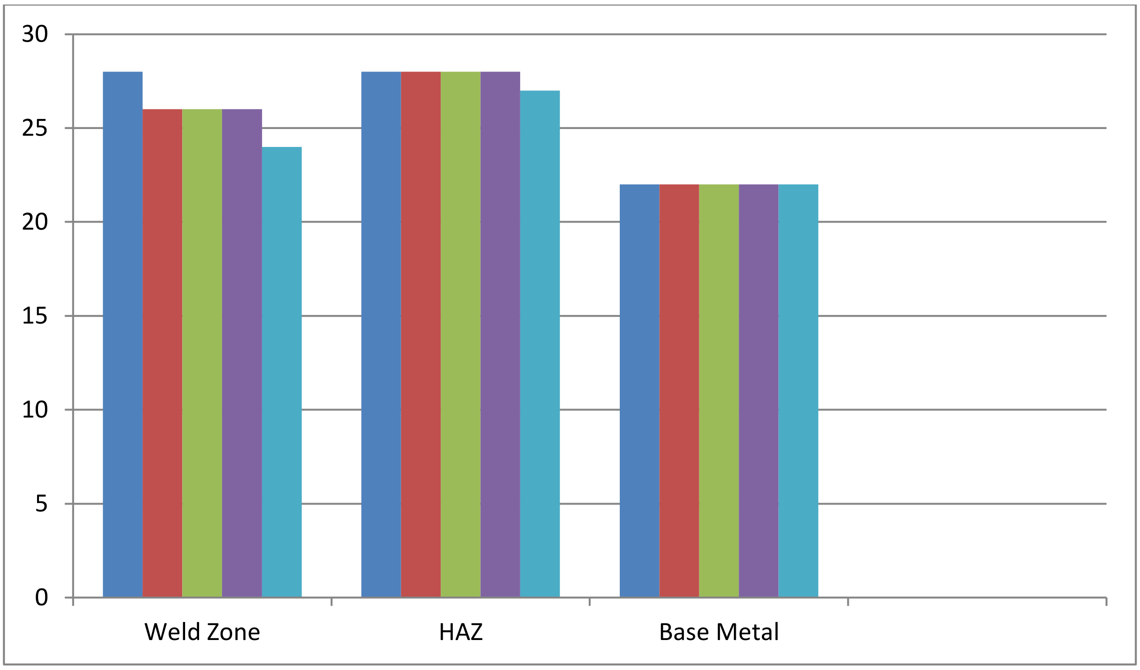

Fig.4.16 Comparison of Hardness Between different currents simple specimen

4.2 Microstructure and scanning electron microscope test result

This test shows the phases of carbon present at different regions of the specimen. First the specimen was checked at the weld zone, then HAZ, and at last base metal. These tests were conducted through the Metalite software and Mirero software. First the piece was put on the table below which the microscopes were present. Microscopes of different magnification factor are on the present set up. After catching the image it was saved in the hard disc of the computer attached to it.

Different zones of microstructures were taken and are as follows with their phase identification and reasons for their hardness.

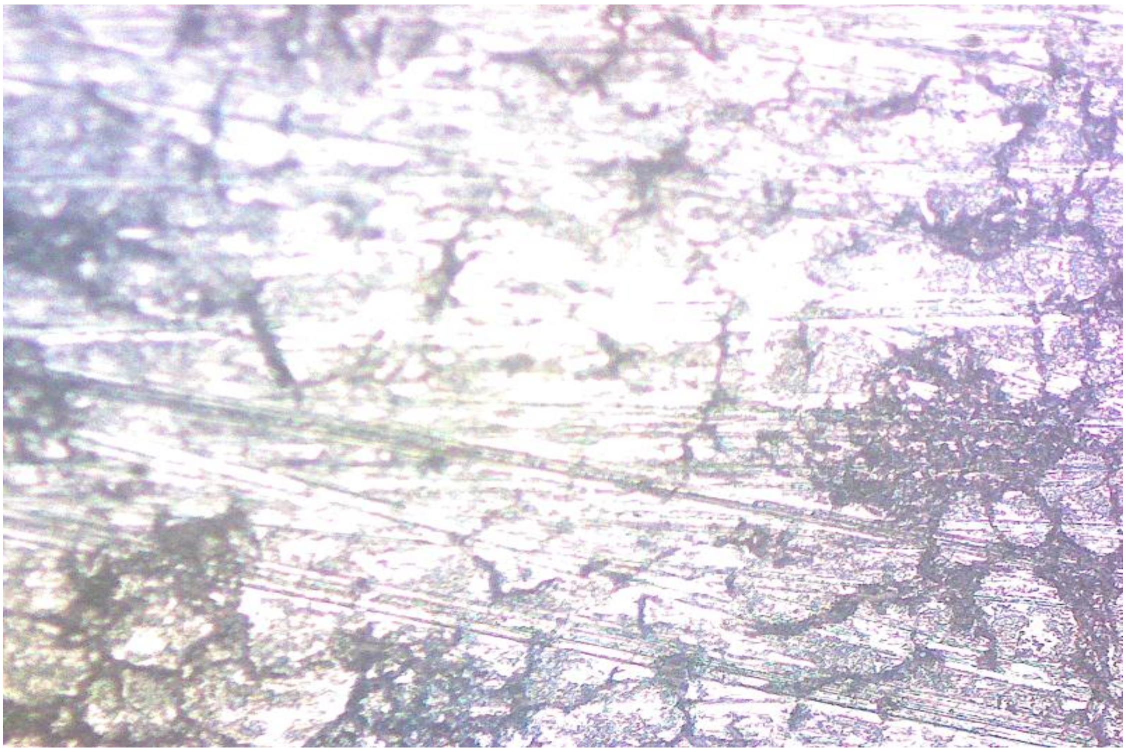

Fig 4.17 Microstructure of HAZ of post weld heat treated sample

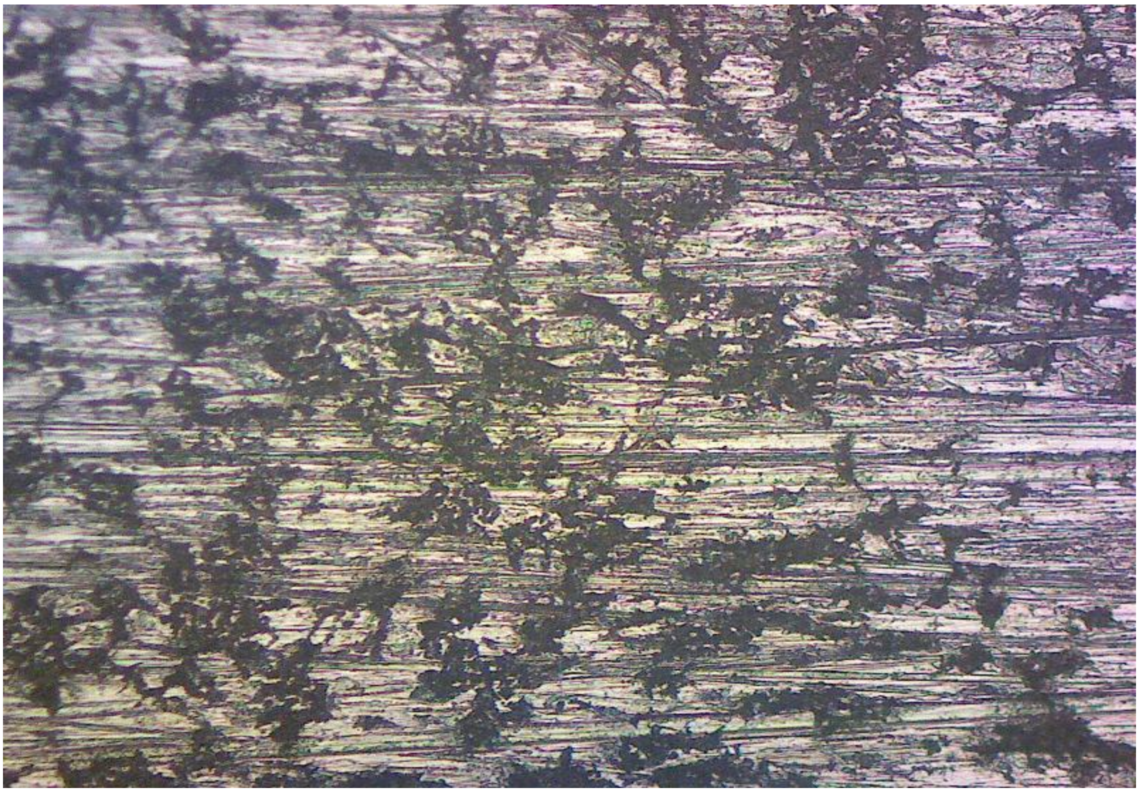

Fig. 4.18 Microstructure of weld zone of post weld heat treated sample

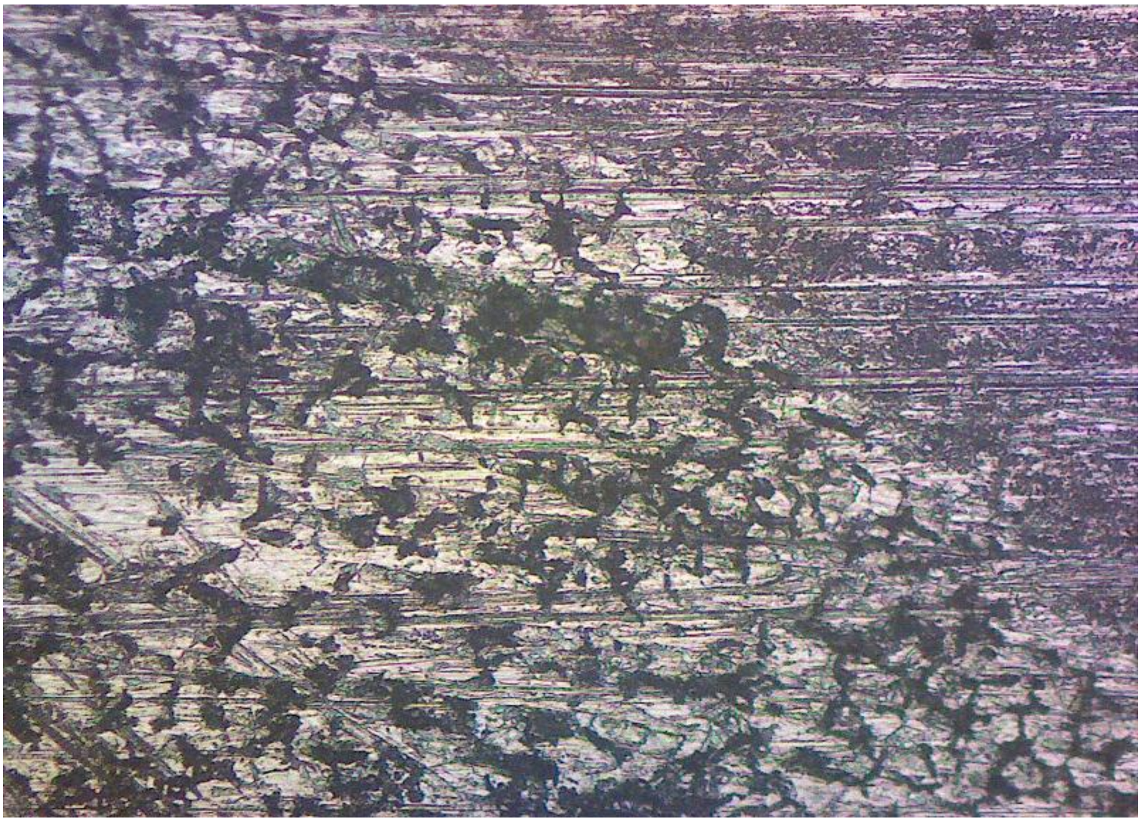

Fig.4.19 Microstructure of HAZ and weld zone of post weld heat treated sample

Fig 4.20 Microstructure of Base metal of Post Weld Heat Treated Sample

Fig.4.21 Microstructure of HAZ of Simple Sample

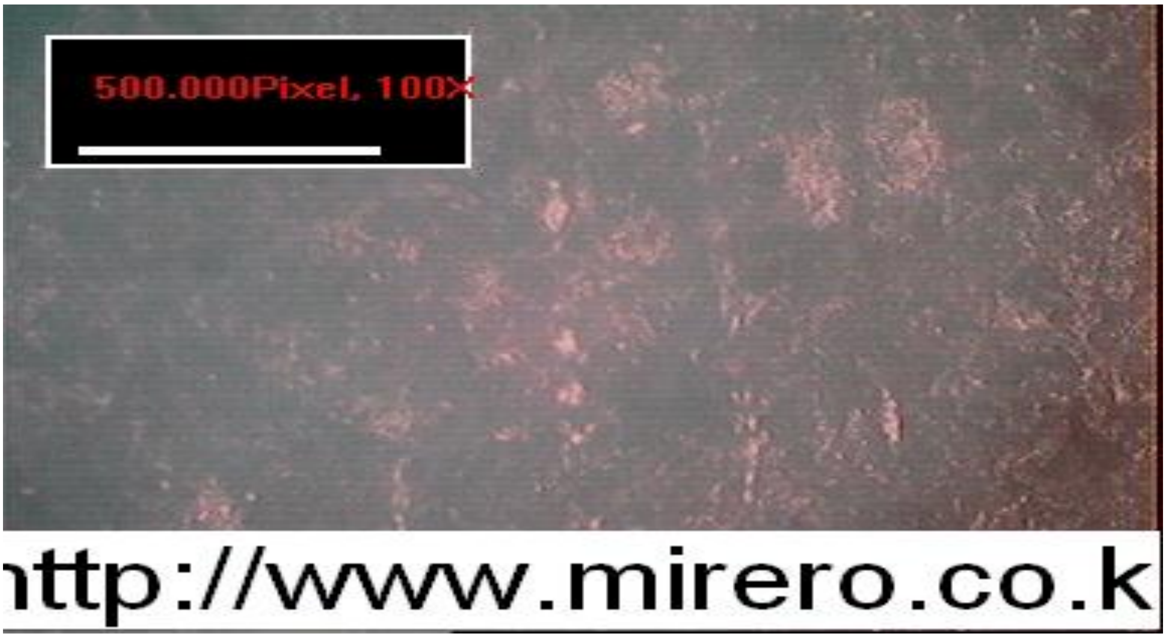

Fig.4.22 Microstructure of weld zone of simple specimen

Fig.4.23 Microstructure of HAZ and weld zone of simple specimen

Fig.4.24 Microstructure of base metal of simple specimen

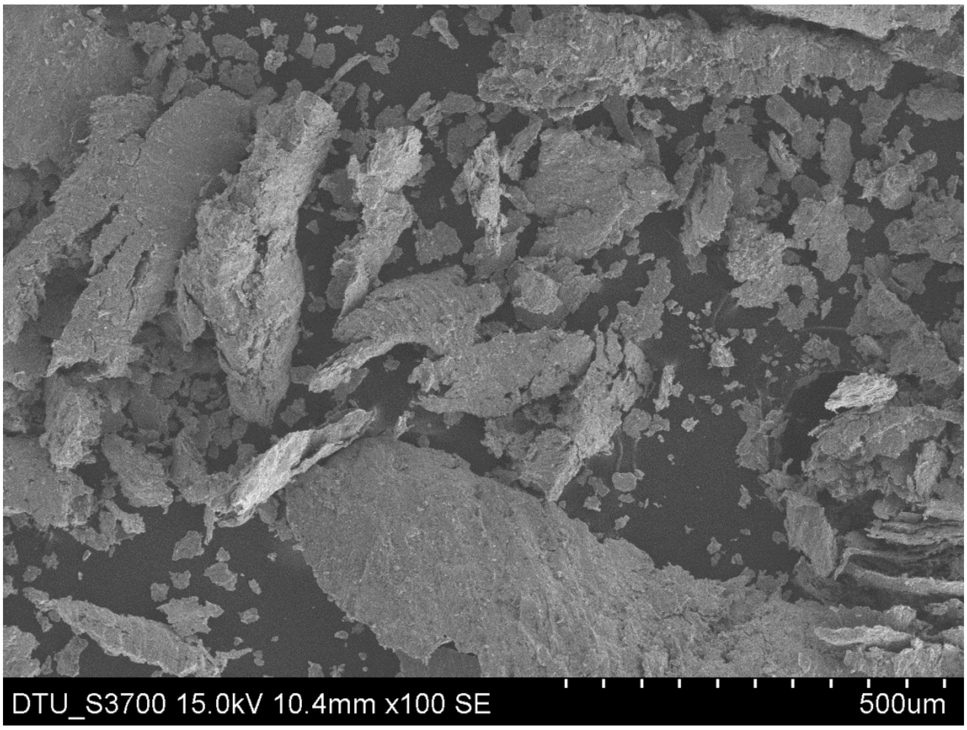

Fig 4.25 Image of weld zone of simple specimen at 100x [SEM]

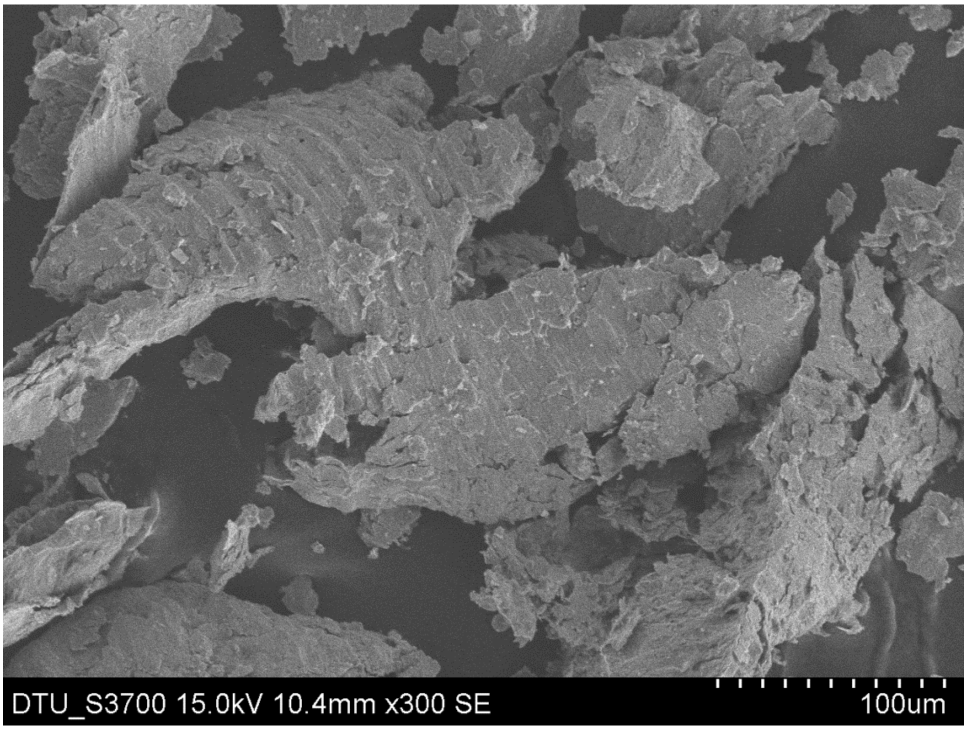

Fig 4.26 Image of weld zone of simple specimen at 300x [SEM]

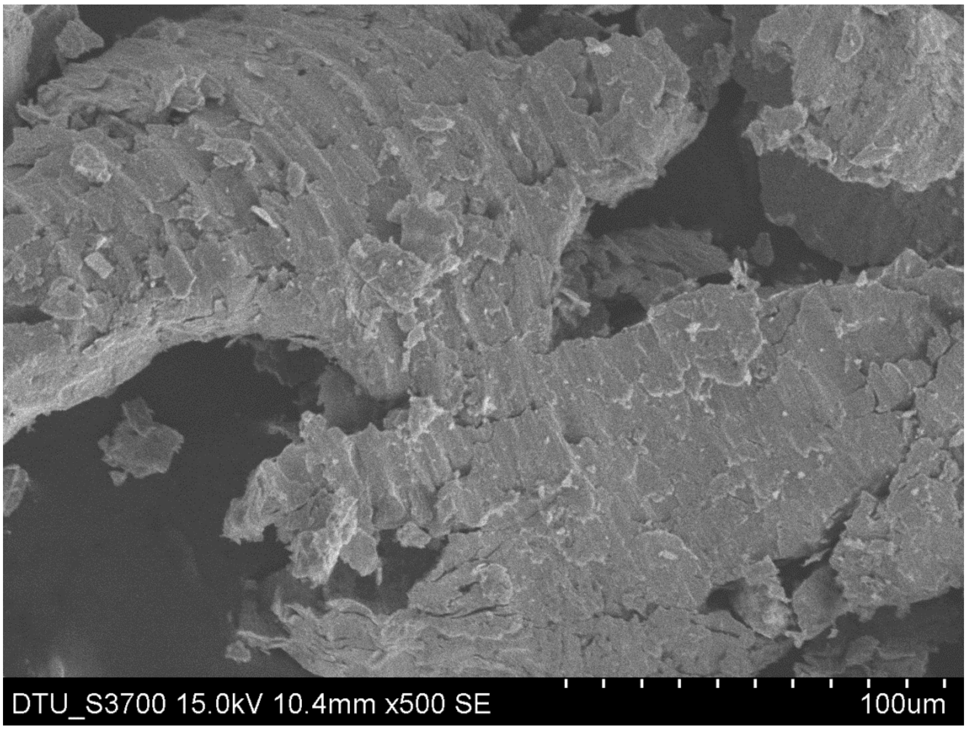

Fig 4.27 Image of weld zone of simple specimen at 500x [SEM]

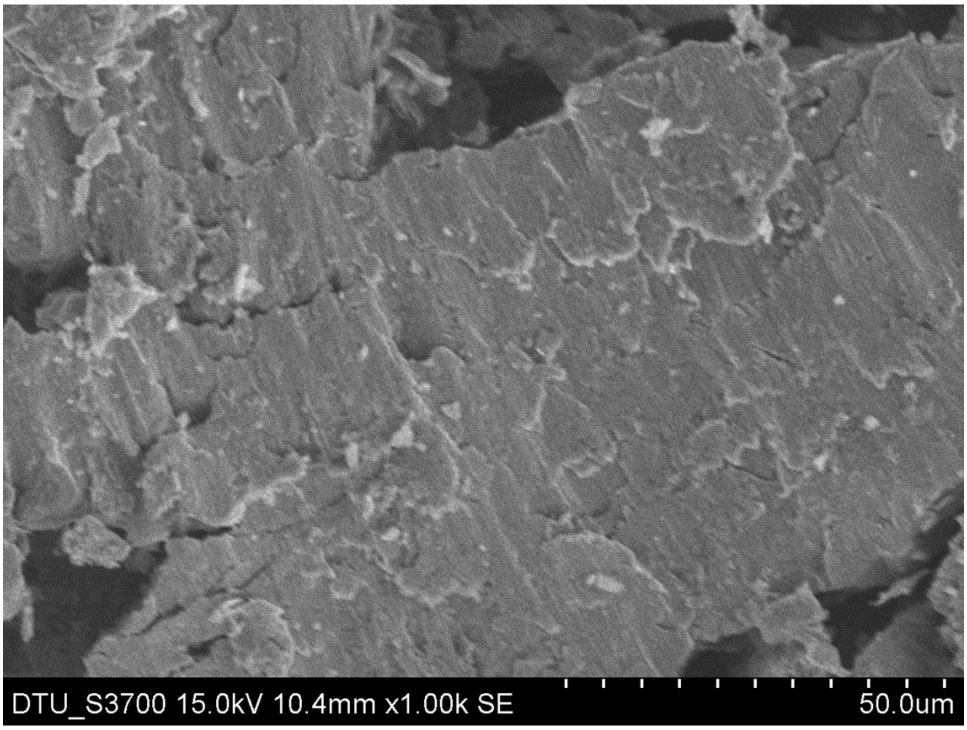

Fig 4.28 Image of weld zone of simple specimen at 1000x [SEM]

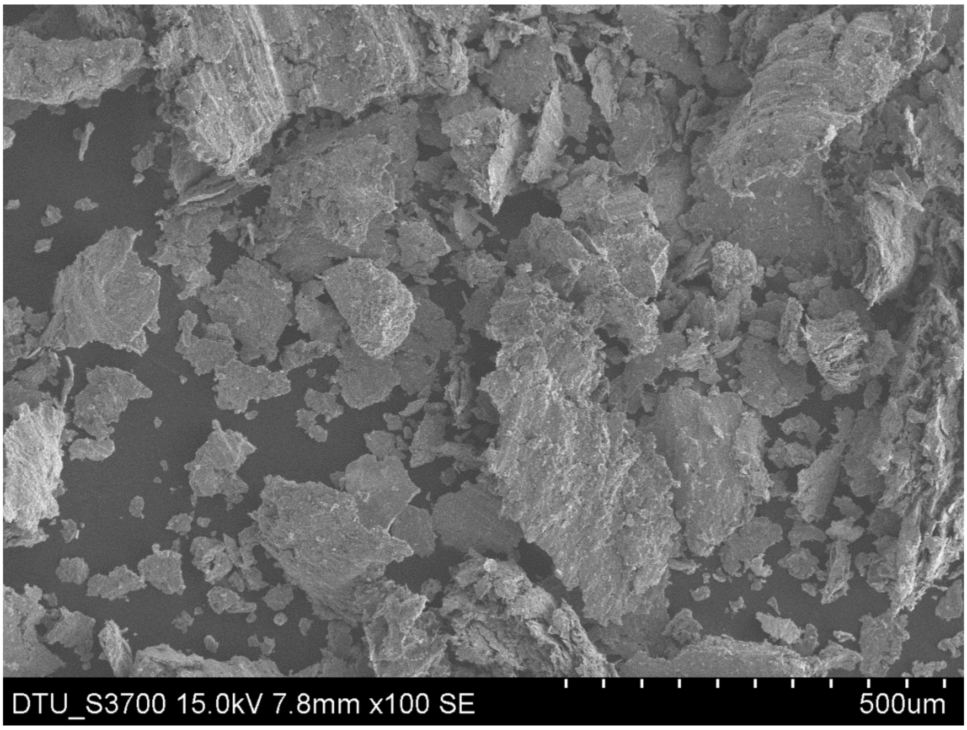

Fig 4.29 Image of weld zone of heat treated specimen at 100x [SEM]

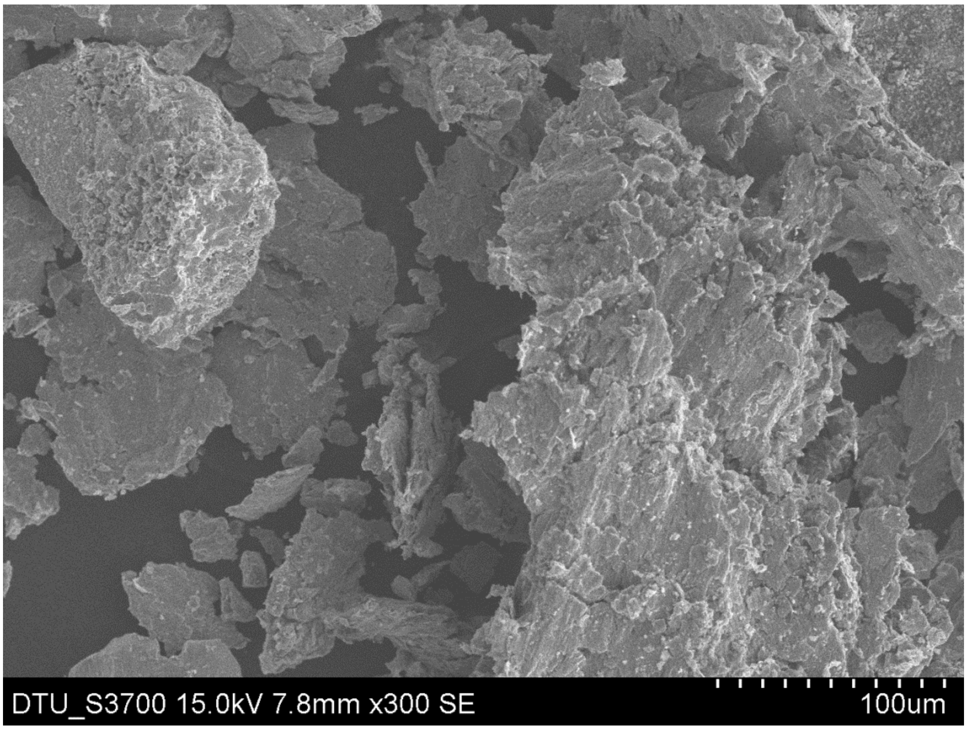

Fig 4.30 Image of weld zone of heat treated specimen at 300x [SEM]

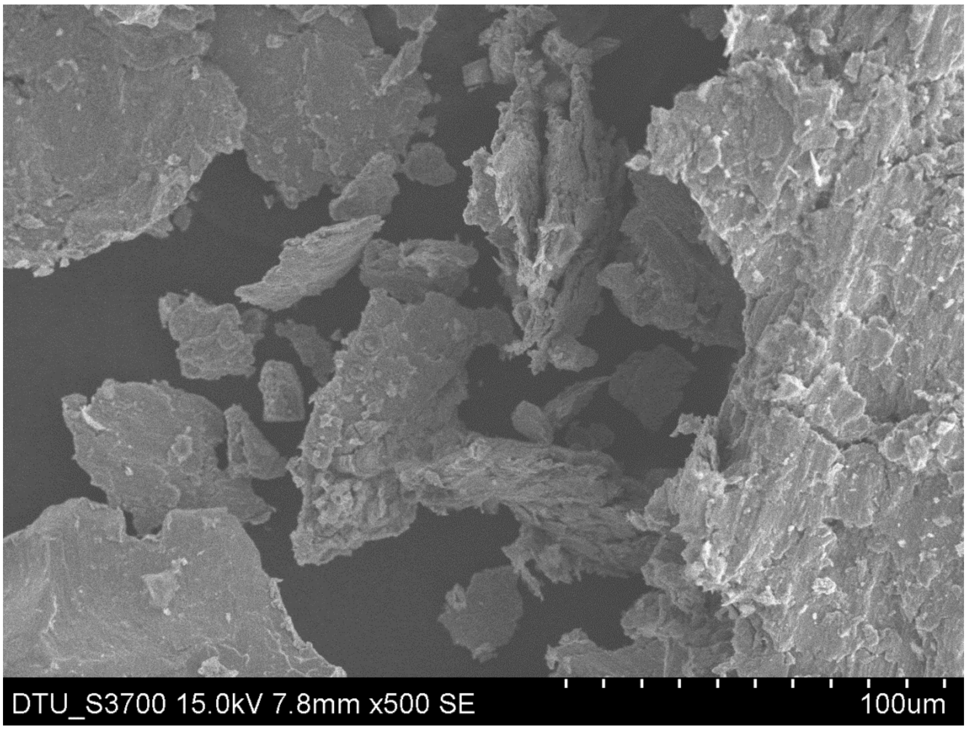

Fig 4.31 Image of weld zone of heat treated specimen at 500x [SEM]

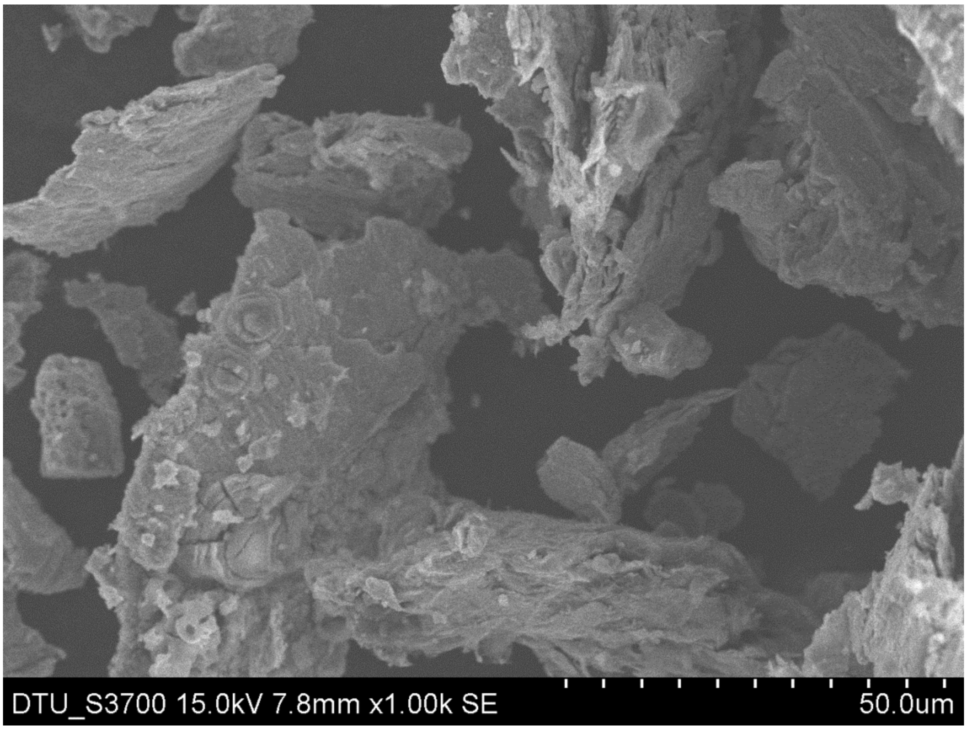

Fig 4.32 Image of weld zone of heat treated specimen at 1000x [SEM]

If a comparison is done in the images of similar areas with or without heat treatment certain changes can be seen.

HAZ of post weld heat treated specimen is more uniform than simple specimen. It is due to the slow cooling. Also it is the region of reduction in hardness of this region. The formation of martensite is reduced due to slow cooling. The shape of graphite present is also changed in the heat treated specimen. As martensite formation is controlled HAZ of post weld heat treated specimen is less brittle in comparison to simple weld.

In overall comparison we conclude that the reduction in hardness is occurred due to absence of martensite which is due to controlled cooling. Change of graphite from flake form to nodular form is also responsible for the increase in ductility.

4.3 Tensile Test Results

4.3.1 Simple Weld with 120 A

Ultimate Tensile Strength = 147.6 MPa

4.3.2 Heat Treated Weld with 120A

Tensile Strength = 171.9 MPa

4.3.3 Simple Weld with 125 A current

Ultimate Tensile Strength = 147 MPa

4.3.4 Heat Treated weld with 125 A current

Ultimate Tensile Strength = 171 MPa

4.3.5 Simple weld with 130 A current

Ultimate Tensile Strength = 146.1 MPa

4.3.6 Heat Treated weld with 130 A current

Ultimate Tensile Strength = 171 MPa

4.3.7 Simple Weld with 135 A current

Ultimate Tensile Strength = 145 MPa

4.3.8 Heat Treated weld with 135 A current

Ultimate Tensile Strength = 170.3 MPa

4.3.9 Simple Weld with 140 A current

Ultimate Tensile Strength = 141 MPa

4.3.10 Heat Treated weld with 140 A current

Ultimate Tensile Strength = 168.9 MPa

4.3.11 Effect of heat treatment on Tensile strength

Ultimate tensile strength of heat treated sample is significantly higher than tensile strength of simple specimen. It is due to increase in ductility due to heat treatment. The cooling is slow. Due to this ductility is increased and increased tensile strength.

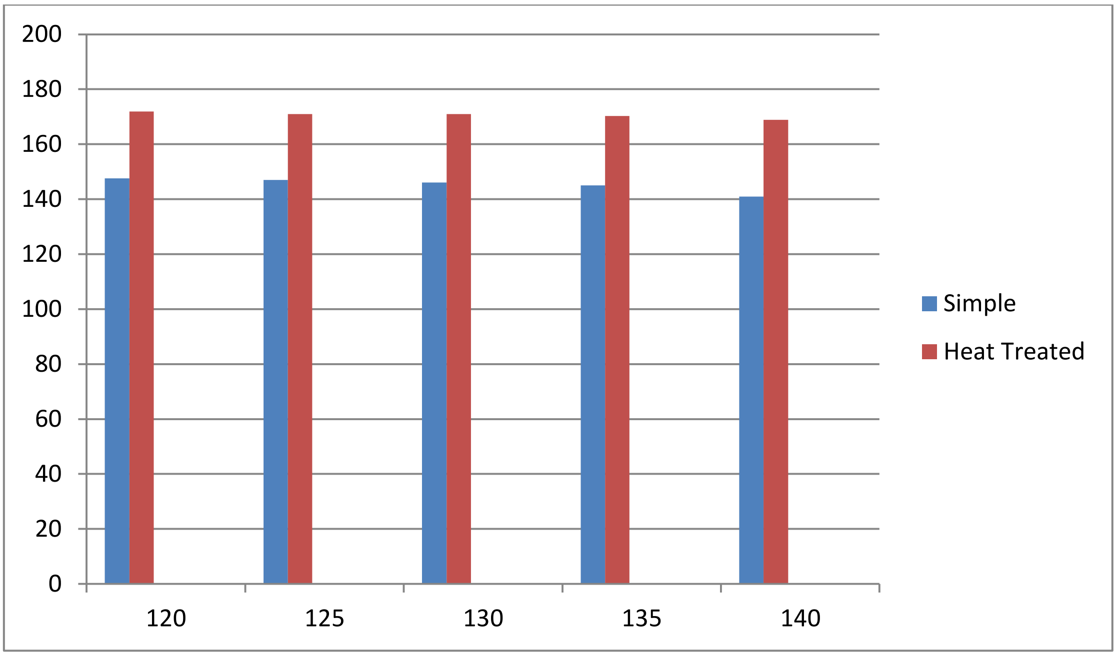

Fig. 4.33 Effect of heat treatment on tensile strength

4.3.12 Effect of current on Tensile strength

As the heat input is increased the specimen cools slowly and coarse grains are formed. Cooling become slower as current is increased. It is responsible for decrease in ultimate tensile strength. Increased heat input is responsible for the decrease in tensile strength. As the grains become fine tensile strength increases. Slow cooling produces coarse grains and tensile strength is reduced.

4.4 Impact Test Result

Rupture Energy of simple specimen of 120 A current = 30 Joules

Rupture Energy of heat treated specimen with 120 A current = 34 Joules

Rupture Energy of simple specimen with 125 A current = 30 Joules

Rupture Energy of heat treated specimen with 125 A current = 34 Joules

Rupture Energy of simple specimen with 130 A current = 30 Joules

Rupture Energy of heat treated specimen with 135 A current = 34 Joules

Rupture Energy of simple specimen with 135 A current = 30 Joules

Rupture Energy of heat treated specimen with 140 A current = 34 Joules

Rupture Energy of simple specimen with 140 A current = 30 Joules

Rupture Energy of heat treated specimen with 140 A current = 34 Joules

4.4.1 Effect of Heat Treatment on Rupture Energy

Due to heat treatment rupture energy is increased. This is due to change in microstructure.

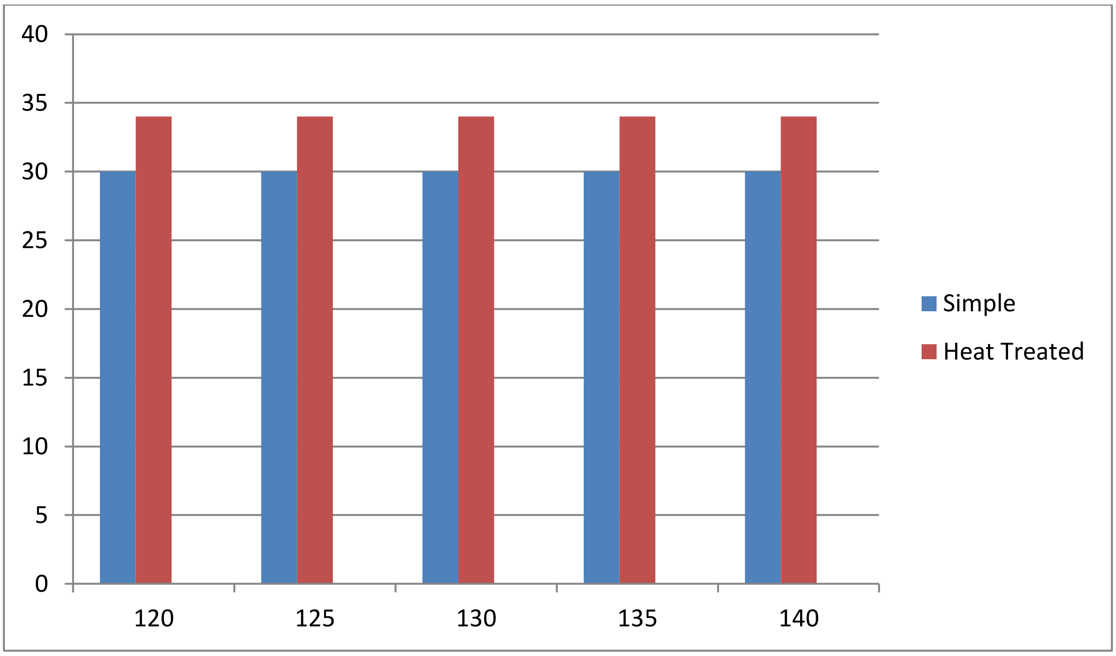

Fig. 4.34 Comparison of Rupture Energy of Simple and heat treated sample

4.4.2 Effect of current on Rupture Energy

Rupture energy is same for all current settings.

Chapter-5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

So the project is about effects of post weld heat treatment and current on the weldability of cast iron. In the first part effect of heat treatment are concerned and in second the effects of current on the weldability. The effects of heat treatment are following.

1. Chances of martensite formation and carbides are reduced which causes reduction in hardness.
2. Tensile strength is increased.
3. Hardness of HAZ is decreased.
4. Cracks are reduced with the application of post weld heat treatment.

The change in these properties is explained from microstructure. As the heat treatment is done and martensite formation is reduced. Due to this hardness is reduced and increased ductility.

The effects of change in current are following

1. Hardness is decreased by increasing the current.
2. Tensile strength of the sample is decreased.
3. There is less variation in the rupture energy.

The reasons of these changes are increase in heat input. Due to increase in heat input cooling is slow and coarse grains are formed. Fine grains are responsible for more hardness.

So the effects of heat treatment (heating the specimen up to 850^0 C and cooling in furnace) are significant and it is concluded that heat treatment is the effective method to get sound welding properties.

5.2 FUTURE SCOPE

1. By designing a motor for the movement of electrode speed can be controlled. After that speed will be controlled automatically. So speed can be taken as a variable in the modelling and relation of the properties with speed can be formulated.
2. By measuring the percentage of different phases present in the microstructure a model can be formulated.
3. Different electrodes can be taken and their comparison on the weldabilty of cast iron can be done by measuring the properties.
4. Surface roughness can be taken as a parameter.
5. Heat treatment temperature can be varied. Also the timing of the furnace cooling can be varied and compared with each other.

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