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*Research Paper*

# ANALYSIS OF MICROSTRUCTURE AND PHASE DEDUCTION IN SAW

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To determine the stress carrying capacity of a weld, the study of microstructure of weld bead geometry is important. For the same reason, a detailed study on the microstructure and phase analysis of weld metal, heat affected zone and base metal of 16 mm thick mild steel plate were carried out by using Olympus GX 41 microscope in conjunction with META-Lite software. The relative content of pearlite and ferrite in the weld metal zone, heat effected zone and base metal also studied.

Keywords: Microstructure, Weld bead

## INTRODUCTION

A reviewed paper published by Bipin kr, on ferrous metals/alloys, which describe the effects of arc welding parameter on mechanical properties. Their study also concluded that the selection of the process parameter are very important for obtaining acceptable heat affected zone properties, optimized bead geometry and minimum residual stresses. Some researchers observed that there is great influence of weld bead geometry and shape relationship on the mechanical properties of weld and mechanical properties less influenced by composition of the base metal. Some of the researcher observed the effect of electrode stick out, by increasing the electrode stick out, hardness of weldment increases and the value of yield strength and impact decreases, ultimate tensile strength of the joint first decreases then increases by keeping welding current and voltage at constant level. From the above mentioned discussion, it is observed that in SAW process, the main factors affecting the bead geometry are arc voltage, current, travel speed and nozzle to plate distance (Srivastav *et al.*, 2010). Eroglu *et al.* carried out investigations based on the mechanical properties and microstructure of weld and HAZ of low carbon steel. They studied the effects of initial coarse grain size with varying heat inputs. A submerged arc welding machine with

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heat input of 0.5, 1 and 2 KJ/mm is used for welding original and grain-coarsened specimen. From the above test, various features were investigation from heat effected zone and weld metal. A relationship between initial grain size, microstructure, hardness, and toughness of weld metal and HAZ were established from the result. From the result this can be concluded that there is major effect of initial grain size on microstructure, hardness and toughness of weld metal and HAZ of low carbon steel, considering the heat input only (Aksoy and Orhan, 1999). Welding metallurgy may be defined as the changes that occur in metals due to welding process. These changes are noticed by observing the changes in mechanical properties of the weld metal. Whenever the discussion about metallurgy begin, we observe the changes in the microstructure of the base metal and hence due to this change mechanical properties of the base metal also changes, as a result of the welding (McGrath *et al.*, 1988).

In welding metallurgy, we are concerned about the two thing, first is, is the rate at which the heat energy is applied to the base, and second with the time the material is at an elevated temperature during welding. The rate at which the heat energy is removed during cooling after welding also an important factor of concerned. Mild steel is an alloy of Iron and Carbon having carbon content from 0.5% to 0.3%, 0.4%-0.7% manganese, 0.1%-0.5% Silicon and some constituents of other elements such as phosphorous.

## MICROSTRUCTURE OF MILD STEEL

The micro structural changes that taking place in mild steel can be easily understand through the Fe-C equilibrium diagram.

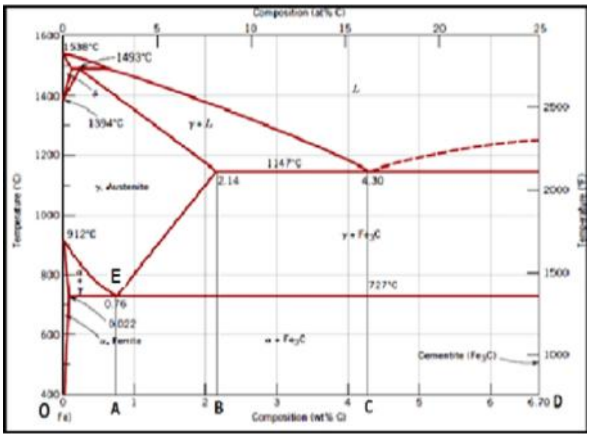
The different allotropic forms of iron as shown in the figure. The different allotropes of iron are:

**Alpha Ferrite:** This is the solid solution of carbon in iron at 0% C, this is pure iron having crystal structure BCC. At 723 °C,the maximum solubility of carbon in iron is 0.02%. The solubility falls to 0.008% at 0 °C temperature. The atoms of carbon are located in the crystal interstices.

**Austenite:** The solid solution of carbon in c.) Cementite: Cementite contains 6.67% C and 93.3% Fe and this is an inter metallic compound. Crystal structure of cementite is orthorhombic each unit cell has 12 Fe atoms and 4 C atoms and is a hard brittle compound. When thes olubility limit of carbon in ferrite is exceeded below 727 °C (for compositions within the alpha + Fe3C phase region) then Cementite (Fe3C) formed. As indicated in above Figure, between 727 and 1147 °C the gamma phase of Fe3C also coexist. The strength of some steels is greatly enhanced by its presence because cementite is very hard and brittle.

**Delta Ferrite:** This is having a a BCC crystal structure and has a solid solution of carbon in iron. The maximum percentage of solubility of C in Fe is 0.09% at 1493 °C. This has no real practical significance in engineering. Point E in Figure 1 where austenite converts into ferrite and cementite, is called eutectoid point, or, upon cooling, the solid austenite phase is transformed into iron and cementite. The steel is classified on the basis of the carbon content in it. Steel in the region:

Figure 1: Iron-Iron Carbide Phase Diagram



OA - Hypo Eutectoid steel

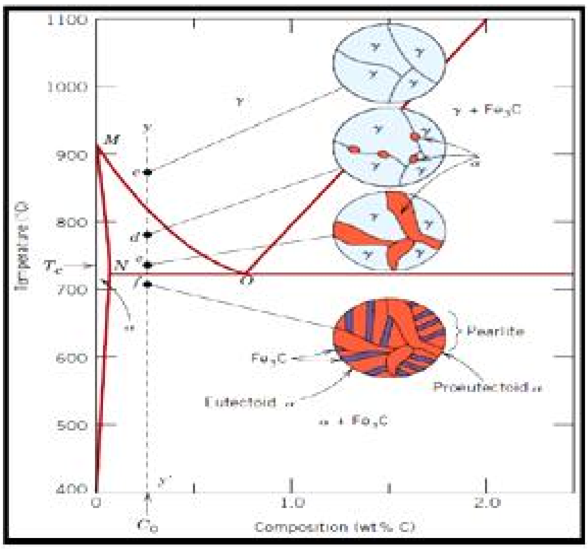
AB - Hyper Eutectoid steel

BC - Hypo Eutectic steel

CD - Hyper Eutectic steel

Solubility for carbon compared with a steel containing the mild steel with maximum Carbon content of 0.3%. In the when mild steel cools from a higher temperature to room temperature, the phase changes which is shown in Figure 2. Crystal and having FCC structure. The carbon atoms are dissolved interstitially. The solubility reaches a maximum of 2.08% at 1148 °C steels. At 723 °C, the solubility decrease to 0.8%.

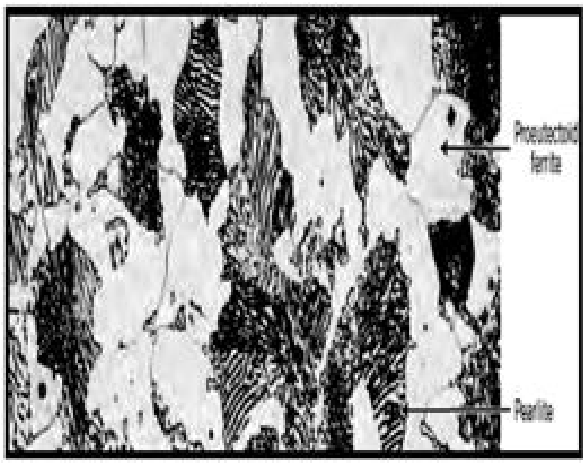
Figure 2: Microstructure Showing Pearlite and Ferrite



From Figure 2, at point c, the microstructure will consist of grains of the gamma phase at about, 875 °C, as shown in the figure. At about 775 °C, in cooling to point d, alpha + gamma phase region both coexist as in the schematic microstructure. The small alpha particles will form along with the original gamma grain boundaries. Just above the eutectoid point, but still in the alpha + gamma region, Cooling from point d to e will produce an increased fraction of the alpha phase and a microstructure similar to that also shown. Larger alpha particles have grown. As the temperature is lowered just below the point f, to point eutectoid, all the gamma phase will transform to pearlite that was present at temperature Te (and having the eutectoid composition),according to the eutectoid reaction. No change in the alpha phase have been observed in crossing temperature, that existed at point e—it will normally be present as a continuous matrix phase surrounding the isolated pearlite colonies. The microstructure at point f can be observed in Figure 2. Thus the pearlite and also as the phase that formed while cooling through the alpha + gamma phase region contain the pearlite phase. The ferrite that is present in the pearlite is called eutectoid ferrite, whereas the other, that formed before eutectoid is termed proeutectoid ferrite.

Figure 3 is a photomicrograph contains large white regions which correspond to the proeutectoid ferrite 0.38 wt% C steel. For

Figure 3: Photomicrograph of Hypo Eutectoid Steel Cooled from a High Temperature to Room Temperature



pearlite, the spacing between cementite and Fe3C layers varies from grain to grain; some of the pearlite appears dark because there are many close spaced layers are difficult to unresolved at the magnification of the photomicrograph in Figure 3. In a single grain, Pearlite is mixture of alternate layers of ferrite and cementite. The distance between the plates and thickness of the plate is dependent on the cooling rate of the material. Slow cooling rate give coarser structure which leads to less toughness and fast cooling creates thin plates that are close together. At 0.76% Carbon, a fully pearlitic structure occurs. Further increases in carbon at the grain boundaries will create cementite, which improves the hardness of the steel but reduces toughness. When steel is cooled rapidly from austenite, Martensite is produced, there is transition of F.C.C structure to Body Centred Tetragonal (BCT) leaving insufficient time for the carbon to form pearlite. This results in formation of fine needles which is a distorted structure.There is no transformation of martensite, it either forms or it doesn't. However, the part which cools firstly, formed martensite.In a thick section it will only form to a certain depth, and if complex shape concerned, it may formed in small pockets. The hardness of martensite is dependent on carbon content; it is normally considered very high, unless the carbon content is exceptionally low.

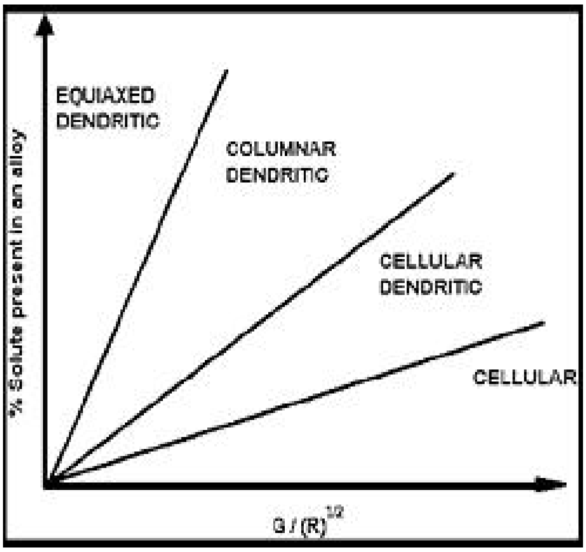
## SOLIDIFICATION OF WELD POOL

Most of the knowledge about weld pool solidification is obtained from the extrapolation of the knowledge of freezing of castings, ingots, and single crystals at lower thermal gradients and slower rate of growth. Therefore, the parameters which are important in determining microstructures in casting are growth rate (R), temperature gradient (G), under cooling ($\delta T$), and alloy composition; they all together determine the development of microstructures in welds. However, because of physical processes that occur due to the interaction of the heat source with the metal during welding, microstructure development in the weld zone is becomes more complicated, including re-melting, heat and fluid flow, vaporization, dissolution of gasses, solidification, subsequent solid-state transformation, stresses, and distortion. Weld pool solidification and microstructure affected by these processes and their interactions. During welding process, where the molten pool is moved through the material, the growth rate and temperature gradient vary across the weld pool area. The growth rate is low while the temperature gradient is steepest along the fusion line.

As the weld approaches centreline, the growth rate increases while the temperature gradient decreases. Consequently, there is variation in the development of microstructure from the edge to the centreline of the weld. In welds, weld pool solidification occurs by epitaxial growth of the partially melted grains. Since solidification of the weld metal continue by epitaxial growth of the partially melted grains in the base metal so the weld zone grain structure is determined by the base metal grain structure and the welding conditions. Grain growth influenced by crystallographic by favoring growth in a particular crystallographic directions.

One of the easy growth directions coincides Figure 5. Zones of weld area with the heat-flow direction. Thus, among the randomly spaced grains in a specimen, the grains that have one of their easy growth with heat flow direction will grow at the expense of their neighboring less favourably oriented grains, This is called competitive growth. A columnar grain structure formed when there is no additional nucleation. Low values of G/(R)1/2 indicate as increased tendency for super cooling thus favouring the mode of dendritic growth of solidification. On the other hand, steep temperature gradients in the liquid and slow growth rates favour cellular growth.

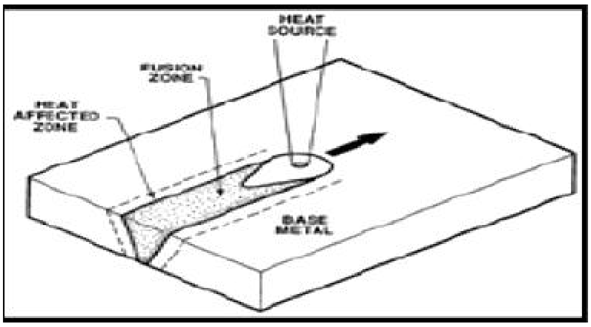
Figure 4: Influence of Grain Growth Rate R and Temperature Gradient G, on the Pattern of Solidification



## WELD METAL ZONES

Zone consist a mixture of parent metal, electrode, filler metal; the ratio depending upon the welding process used, the type of joint plate thickness. Weld metal zone that has cooled is a cast composition of mixture of metal. Its microstructure reflected by the the cooling rate in the weld. A very high cooling rate indicated by the presence martensitic structure and this formation of structure depends upon the chemical composition. Fine pearlite and coarse pearlite indicate slower cooling rates. The first metal solidifies epitaxially upon the solid grains of the un-melted base metal as we see the molten weld pool. Weld solidifies in a cellular or dendritic growth mode and this solidification process depends upon the composition and solidification rates. The weld metal is less homogeneous on the micro level than the base metal due to the segregation of alloying elements and that is why its properties are expected to have different from wrought parent

Figure 5: Weld Metal Zones



metal. But if the filler metal having the same property as that of parent metal then same property formed as that of wrought parent metal.

It consists of parent metal that but was heated to high temperature for a sufficient period of time and in that time grain growth occurred and mechanical as well as micro structural properties have been affected by the heat of welding. The HAZ is subjected to high thermal cycle in which all temperatures are involved from the melting range of the steel to much lower temperatures. A variety of microstructures can be observed in HAZ. The range of these structures may very narrow regions of hard martensite to coarse pearlite. This causes HAZ the weakest area in weld and the second weakest area consist of weld defects, where most welding failures originate in the HAZ. In SAW the HAZ consists of 4 sub zones:

**Grain Growth Region:** It is just next to the weld metal zone. The parent metal has been heated well above the upper critical temperature, in this zone. As the cooling rate decreases, this zone results in grain growth or coarsening of the structure.

**Grain Refined Region:** In this region the parent metal has been heated to just above upper critical temperature. Complete recrystallization has taken place in this zone and finest grain structure formed due to complete refinement of grains.

**Transition Zone:** The Temperature exists in between the upper and lower recrystallization temperature where partial allotropic recrystallization takes place.

**Unaffected Parent Metal:** The base metal which exist outside the HAZ was not affected by the thermal cycles during welding.

## EXPERIMENTATION

Mechanical properties of the weld influenced by microstructure of weld metal and adjacent metal, welding process and welding procedure. This is because welding results in development of a temperature gradient which varies from the highest temperature encountered in the centre of the weld pool to the ambient temperature along the transverse direction to the weld axis (Parmar, 2010). In order to understand and predict the mechanical properties of a weldment, it is essential to study microstructure in various zones of weldment. The heat input rate is one of the most important variables in fusion welding, since it governs heating rates, cooling rates and weld pool size. If V represents arc voltage, I arc current, S welding speed and ¦ is the proportion of arc energy that is transferred as heat to the work piece, and then the heat input rate per unit length of weld is ¦ VI/S. Here in this study it is assumed that ¦ = 1 for calculating heat input per unit length. Then Heat input (kj/cm) = [V (volts) XI (amps) X 60]/[S (cm/min) X 1000]. This chapter presents the experimental results of microstructure photomicrographs and analysis of phases of the specimens which prepared for study of weld bead geometry and shape relationships.

### Experimental Procedure

To carry out the experiment, A 3.2 mm diameter copper coated mild steel wire was used. Test specimens were prepared from 16 mm thickness AISI 1012 Mild steel plate. Dimension of each plate were 200 x 75 x 16 mm and an agglomerated flux was used, then welding is done on the plate as per the Value given to avoid systematic error. Value for maximum heat input and minimum heat input are given below:

Table 1: Value of Maximum and Minimum Heat Input

| S. No. | V | A | S | N |
|---|---|---|---|---|
| **Maximum Heat Input** | | | | |
| 1. | 36 | 525 | 8.75 | 27.5 |
| **Minimum Heat Input** | | | | |
| 2. | 28.5 | 375 | 16.25 | 32.5 |

After Welding, the specimens prepared for study of weld bead geometry and shape relationships were cut in the transverse direction from the welded plates then polished with various grades of emery papers, starting with 100, 220, 320, 400, 600, 800 and 1200. After that dry and wet polishing done on the specimens by rotating disc with paste of alumina abrasive powder, water were used as coolants. Finally the specimens were etched by 2% natal (98% alcohol and 2% nitric acid) and then washed off with water. Then the specimens were dried by means of blower. To study the microstructure Olympus GX 41 microscope was used in conjunction with META-Lite software.

## Microstructure Analysis for the Maximum Heat Input

Microstructure Analysis were carried out for the Maximum Heat Input. From the data given in the above table it is clear that, the value of Current and Arc Voltage is maximum and the travel speed is minimum for maximum heat input. The microstructure at Base metal, HAZ, and Weld metal for maximum heat input were shown in Figures 6, 7, and 8 respectively.

The structure of base metal consists of grains of 34.13% ferrite and 61.87% pearlite and this is the zone which is not sufficiently heated to cause a change in its microstructure.

Figure 6: Base Metal Zone

Figure 7: Heat Affected Zone

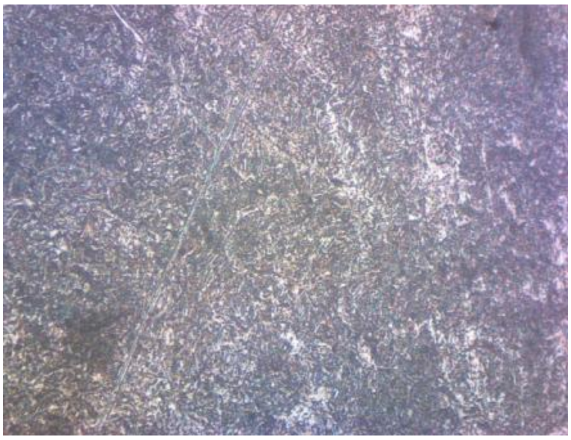
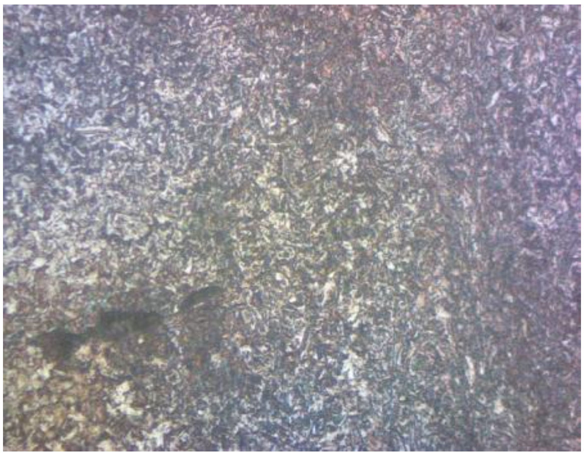


Figure 8: Weld Metal Zone



The structure of HAZ consists of coarse grains of 74.30% pearlite surrounded with 25.69% of ferrite. The Pearlite content is higher than base metal, thus the microstruture is finer than the base metal.

The structure of weld metal consists of 65.91% of Pearlite and 34.09% of Ferrite. The phase composition is almost same as that of base metal.

In SAW the welding is carried out under the cover of a granulated flux. So the rate of cooling of the weld is slower as compared to shielded metal arc welding. So the microstructure resulting from higher rates of cooling viz. Martensite, upper Bainite, Lower Bainite, etc. are not observed. In the present study the thickness of the plates was 16 mm, so the heat carried away by conduction was also very less. In welding of plates with higher thickness microstructure characteristic of faster rate of cooling may be observed.

## Microstructural Analysis for Minimum Heat Input

From the Table 1, we see that the value of Current and Arc Voltage is minimum and the travel speed is maximum for minimum heat input. In the microstructural analysis the different phases present in the microstructure along with their respective percentages were found.

The structure of base metal consists of grains of 67.98% ferrite and 32.02% of pearlite grain.

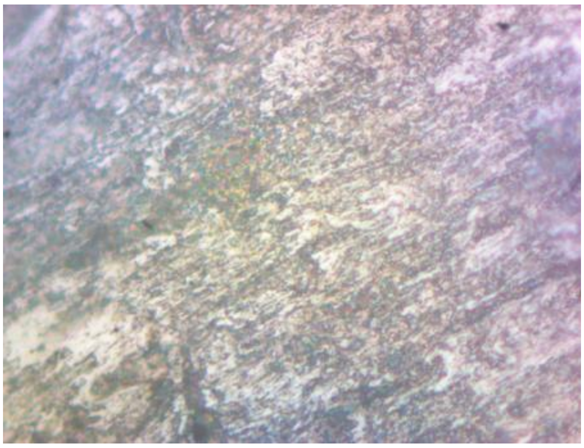
The structure of HAZ consists of coarse grains of 68.81% pearlite surrounded with 31.19% ferrite grain.

The phase composition is almost same as that of base metal. The structure of weld metal

Figure 9: Base Metal Zone

Figure 10: Heat Effected Zone

Figure 11: Weld Metal Zone



consists of elongated grains of 33.53% ferrite and 66.47% of pearlite grains.

From above figure, we can observe that the variation in the pearlitic content in the considered regions for the minimum heat input is not as pronounced as that for maximum heat input. In fact it is almost identical for the base metal and the weld zone. Also we can observe that the pearlitic content in the weld zone is higher in minimum heat input as compared with the maximum heat input, this could be attributed to the fact that; for the minimum heat input the cooling rate is higher which inhibits the formation of pro-eutectoid ferrite and larger portion of Austenite gets converted to Pearlite upon crossing the eutectoid line (Parmar, 2010).

## CONCLUSION

- The microstructure mainly consists of Ferrite and Pearlite. The formation of microstructure resulting from higher rates of cooling viz. Martensite, upper Bainite, Lower Bainite etc. are not observed, this could be due to the covering of weld region by a granulated flux which reduces the heat carried away from the weld zone.
- No formation of cementite or flake graphite is found in the microstructure, this could be due to the reason that the Carbon content in the base metal was very low.

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