Microstructure Analysis of Arc Welded Mild Steel Plates

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Abstract. In order to perform arc welding, mild steel plates of variable thickness i.e. 5 mm, 6 mm and 8mm has been chosen as parent material. Total nine numbers of experiments were conducted by considering the two factors and three levels of design according to Taguchi method. The welding current and material thickness has been selected as variable input parameters with 5mm, 6 mm, 8mm level of material thickness and 90 A, 100A, 110A level of current respectively. The microstructure of the all the nine welded material has been analysed with the help of an optical microscope which is interfaced computer. The results of microstructure obtained from the microscopic investigation have been shown. The effect of current and material on the weldment microstructure is investigated. The result also shows that the coarse structure is formed in fusion zone and fine structure is formed in Heat affected region.

1. Introduction
Welding is a process in which localised coalescence (permanent joint) is produced with or without the application heat with or without the application of pressure or pressure alone or with or without the application of filler material to joint similar or dis similar material. In welding permanent joint is formed by the fusion of two welded material. Filler material is usually added to strength the joint. Welded joint is more reliable and economical. Karadeniz et al. [1], investigate the effect of welding parameter on the penetration of the weld joint. Boob et al. [2] proposed heat input is the most significant factor for controlling width of Heat affected zone (HAZ) with increase in heat input width of HAZ increases. Talabi et al. [3] suggested Increase in the arc voltage and welding current result in increased hardness values and decreased yield strength, tensile strength and impact toughness. Norman et al. [4] studies the effect on the microstructure on Al-Mg-Cu-Mn by TIG welding. The welding current taken is 100-190A and the welding speed varies from 420-1500mm/min. Hargopal et al. [5] et al. investigates the influence of welding parameter in mechanical properties of Al-65032 alloy with Taguchi’s method. Sharma et al. [6] the author investigates the effect of welding parameter like welding speed, voltage and current on the depth of penetration of welded joint. Chandel et al. [7] derive a relationship between the bead height, bead width, melting rate, depth of penetration in terms of current, voltage, electrode diameter, electrode extension in submerged arc welding. Furuya et al. [8] investigate the actual toughness in the weld zone. They established relationship between the toughness in HAZ with the chemical composition. Both the single layer and multi-layer weld joint is used for the measurement of toughness in HAZ. Irfan et al. [9] have investigated the effect of welding parameter of galvanised steel on the depth of penetration in MIG welding. Lienert et al. [10] validated the feasibility of friction stir welding (FSW) for joining of mild steel. Defect free ultrahigh carbon steel was friction welded by Sato et al. [11] by employing polycrystalline cubic boron nitride tool. They also investigate the microstructure and effect of process parameters on weldment. In order to weld and study the
relation between failure mode and weld fusion zone, austenitic stainless steel and galvanized low carbon steel they have used resistance spot welding. The result of the work by Marashi et al.[12] concludes that the strength of spot weld in the pull-out failure mode is organized by the strength and fusion zone size of the galvanized steel side. Saeid et al. [13] focused on the effect of the welding speed on the microstructure and mechanical properties of the stir zone (SZ) in friction stir welding (FSW) of SAF 2205 duplex stainless steel.

2. Materials and Methodology
Mild steel is one of the cheap materials among steel and it is very commonly used in all application. It can be easily welded by all common welding technique. It can rust when it comes in contact of oxygen but still it is very hard and durable. It is used where a large quantity of iron is required. It contains a maximum of 0.29% carbon, manganese up to 0.9% along with small amount of phosphorous, sulphur and silicon. Electrical current can easily transferred through it without leaving any effect on the internal structure of the metals. It has Superior welding properties than steel. Table 1 shows the mild steel chemical composition. The thermal and mechanical property of mild steel is given below in the Table 2.

**Table 1:** Chemical composition of mild steel

| Element | C   | Mn    | Si     | S     | P    |
|---------|-----|-------|--------|-------|------|
| Percentage | 0.16-0.18 | 0.70-0.90 | 0.40 (Max) | 0.40 (Max) | 0.40 (Max) |

**Table 2:** Various properties of mild steel

| Property       | Value | Unit       |
|----------------|-------|------------|
| Conductivity   | 42    | W/m K      |
| Specific heat  | 481   | J/Kg-K     |
| Density        | 7872  | Kg/m       |
| Poisson’s ratio| 0.27-0.30 |           |
| Elastic Modulus| 190 to 210 | GPa       |

2.1. Welding machine
The welding machine used is a general welding machine (Fronius MW 2200). The technical specification of the machine is given below in figure 1. Table 3, shows the specification of the welding machine used for the experiment.

![Figure 1: Arc welding machine [Fronius, Model- NW2200]
Table 3: Specification of welding machine

| Specification         | MW 2200                      |
|-----------------------|------------------------------|
| Range                 | 10-180 A                     |
| Primary voltage       | 230 V, 50-60 Hz              |
| Open circuit voltage  | 88 V                         |
| Operating voltage     | 20.4-27.2 V                  |

2.2. Electrode material
The electrode used for welding was of configuration AWS/SFA 5.1 E-6013 of 3.15 mm diameter and 450 mm long is given in fig 2. The chemical composition of electrode is shown in table 4.

Figure 2: Welding electrode

Table 4: Chemical composition of E6013 Electrode

| Element | C   | Mn  | Si  | S   | P   |
|---------|-----|-----|-----|-----|-----|
| Percent (%) | 0.07 | 0.44 | 0.22 | 0.02 | 0.02 |

2.3. Experimental parameter
In welding process current was varied along with the thickness of work piece. The current is varied in three steps as shown in following Table 5.

Table 5: Experimental parameter

| Welding current in Amp | Material Thickness in mm |
|------------------------|--------------------------|
| 90                     | 5                        |
|                        | 6                        |
|                        | 8                        |
| 100                    | 5                        |
|                        | 6                        |
|                        | 8                        |
| 110                    | 5                        |
|                        | 6                        |
|                        | 8                        |

2.4. Experimental methodology
For conducting the experiment, 18 specimens of thickness 5, 6 and 8 mm are considered. Before welding the specimens are cleaned from dust, oil to avoid impurity in molten metal pool. Since welding was made by closed butt joint thus edges of the work piece are suitably prepared. In order to perform welding, the work pieces are kept in relative position. The safety precautions & corrective measures were taken to avoid accidents and to get good quality weld bead.
V-groove is prepared for the experiment by considering the following parameters: Bevel angle ($45^\circ$), Thickness of work piece (5, 6, 8) mm, $A =$ Root Gap (2mm) and $B =$ Root face.

2.5. Experiment procedure

- 2 factors and 3 level design is selected to calculate the design of experiment (DOE) for 9 samples.
- First 18 specimens of variable thickness cut from mild steel flat bars.
- 6 specimen of the size 100 mm lengths x 50 mm width x 5mm thickness, 6 of 100 mm lengths x50 mm width, 6 mm thickness and another 6 specimens of 100 mm lengths x 50 mm width x 8 mm thickness have been taken for the experiment.
- 45 Single V edge preparations were made on these specimens.
- Set-up was made by tack welding. Root gap and root face 2 mm kept each.
- 9 weld joint are formed by 1G welding position as shown in figure 4. Welding ampere was 90, 100, 110 and direct current electrode positive (DCEP) welding polarity was considered.

In figure 4 and figure 5, the experimental set-up and final welded joint are shown respectively.

3. Results and discussion

The microstructure investigation of the welded mild steel plates has been performed by the help of an optical microscope. The optical microscope with an interfaced computer in which microstructure study was done is shown in the Fig 6. Figure 7 (a) and (b) shows the difference in microstructure between the heat affected zone (HAZ) and the fusion zone (FZ). From the figure, it can be clearly seen that the more coarse grain structure is formed in fusion zone. The temperature in the fusion zone is having more than the melting temperature of the metal so a new coarse grain is formed after welding. The HAZ experiences less than the melting temperature but due to high temperature recrystallization takes place and small fines grain structure is formed which is having high hardness and toughness value. Figure 8, 9 and 10 show the microstructure of the fusion zone of 5 mm, 6 mm and 8mm thick plates due supply of current 90 A, 100 A and 110 A respectively. As shown in figure as the current increases

![Figure 3: Mild steel work piece with V edge, (a) modelled V edge, (b) V edge on work piece](image-url)
the heat input increases results in formation of coarse grain. The structure becomes coarser when there is increase in current.

Figure 6: Picture of optical microscope with interfaced computer [Axiocam ERc5s]

Figure 7: (a) and (b) shows the micro structure of the FZ and HAZ

Figure 8: Microstructure of weld zone of thickness 5 mm (a) 90A, (b) 100A, (c) 110A

Figure 9: Microstructure of weld zone of thickness 6 mm (a) 90A, (b) 100A, (c) 110A

Figure 10: Microstructure of weld zone of thickness 8 mm (a) 90A, (b) 100A, (c) 110A

The above figures show that when the welding current increases the heat input also increases. As the heat input increases, smaller grains due to rapid cooling and the solidification time also decreases.
Consequently, there is drop in cooling rate that produces coarse grain. The lower hardness and low strength and increase in porosity of the weld bead are caused by the coarse grain in the microstructure. For same thickness of metal, with increase in current value the structure becomes coarse.

4. Conclusion
This research presents an experimental study of effect of welding parameter on the weld quality of mild steel plate of variable thickness of work piece in arc welding. The microstructural properties of the welded joint have been discussed. The results shows that coarse structure is formed in fusion zone and fine structure is formed in Heat affected region. So the hardness value in more in HAZ region as compare to FZ and base metal as there is fine structure in the HAZ area. In future, the mechanical properties of the same weldment and the effect of process parameter on weld performance will be studied. The optimal process parameters combination will be found out for the best weldment.

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