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International
Journal
Of Modern Engineering Research (IJMER)

Effect of Cooling Rate on Microstructure of Saw Welded Mild Steel Plate (Grade C 25 as Per IS 1570)

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ABSTRACT: *Cooling rate of weldment is depends on the heat input by the welding arc to the weldment. Heat input is controlled by the three variables current, voltage and travel speed. The present experimental study shows the effect of cooling rate on the microstructural changes of weldment, which is mostly responsible for failure of weld. Temperature profile at various cooling rates can help in better understanding and optimisation of submerged arc welding process. Microstructure of HAZ plays important role in strength and durability of weldment and hence by controlling welding parameters we can reduce the risk of weldment failure.*

Keywords: *Cooling Rate, Current, Microstructure, SAW Welding, Thermocouple, Voltage, Welding*

I. INTRODUCTION

With the higher heat input the cooling rate is slower and vice-versa. Microstructure and micro-hardness are depend on the cooling rate, faster the cooling rate fine grains are formed and the hardness is increased and by the slower cooling rate coarse grains are formed and hardness is reduced. Submerged arc welding (SAW) is used for heat input because of high heat input the other processes [1] Heat input is increased with increasing wire feeding speed but increasing welding speed decreases the welding heat input. When heat input increases, the cooling rate decreases for weld metal and increases the volume fraction of tempered martensite and coarsening of the microstructure of weld zone. With increasing the wire feeding speed or preheating temperature, brinel hardness of weldment decreases but effect of welding speed on hardness is reversed to other parameters. When welding speed increases the weld hardness also increases [2].
Equation shows the relation between the welding parameters and heat input.

$$\textbf{Heat input} = \frac{\mathbf{K \times V \times I \times 60}}{\mathbf{S \times 1000}} \frac{\mathbf{KJ}}{\mathbf{mm}} \qquad (1)$$

Where 'V' is arc Voltage in Volts, 'I' is welding current in Ampere, and 'S' is welding speed in mm/min. 'K', the thermal efficiency factor for the welding process, The value of K = 1 is taken here for Submerged arc welding.[3]

Table 1: Specifications of Submerged arc welding machine

Manufacturer	M/S Kanubhai Electrical Pvt. Ltd., Calcutta
Current range	60-1200 Amp
Maximum welding current at 60% duty cycle	1200 Amp
Maximum welding current at 100% duty cycle	900 Amp
Operating voltage	26-44 V
Electrical supply	415

1.1 Base plate

Mild steel plates having size 300×100×12 mm were used in this investigation. The plates were cut into required length with the help of a power hacksaw as shown in Fig: 1

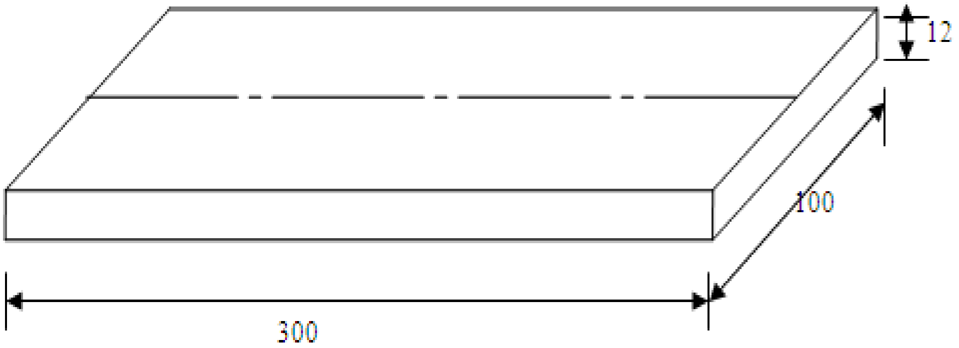


Fig 1: Base plate dimensions (mm)

Table 2: Material composition

Composition of Mild Steel plates					
Element	Carbon	Manganese	Sulphur	Phosphorus	Ferrous
Percentage	0.280	0.533	0.030	0.037	rest.

1.2 Electrode wire

The electrode wire used for the welding was Auto melt Grade - A of 3.15 mm diameter conforming to AWS SFA 5.17, EL-08. [4]

1.3 Flux

An agglomerate flux and crushed slag was used in this investigation. The specification of flux used for welding is AWS 5.17 OK FLUX 10.71 L, F7AZ - EL 8.

II. METHODOLOGY

To study the effect of cooling rate on microhardness the following steps were followed.

- Preparation of base plate
- Identifying the process parameters and their limits.
- Developing the design matrix.
- Conducting the experiments as per the design matrix.
- Measurement of temperature during experimentation.
- Calculating the cooling rate.
- Testing

2.1 Temperature Measurement

For the investigation the K-type thermocouples were used. Type K (chromel–alumel) is the most common general purpose thermocouple. It is inexpensive and available in a wide variety of probes. They are available in the −200 °C to +1350 °C range. The range of thermocouples used for experimentation from 1^0 C to 1200^0 C. Each thermocouple was connected to the digital meter for the recoding of temperature at same time interval [5]. Four blind holes (each hole was 6 mm deep) were produced to the opposite of weld surface in each plate, for the positioning of thermocouples during welding. First hole was made at the centre of bead and next holes were 1mm apart from its previous hole in perpendicular direction to the bead axis. The dimensions, positioning of holes and actual plate are illustrated in fig: 3.

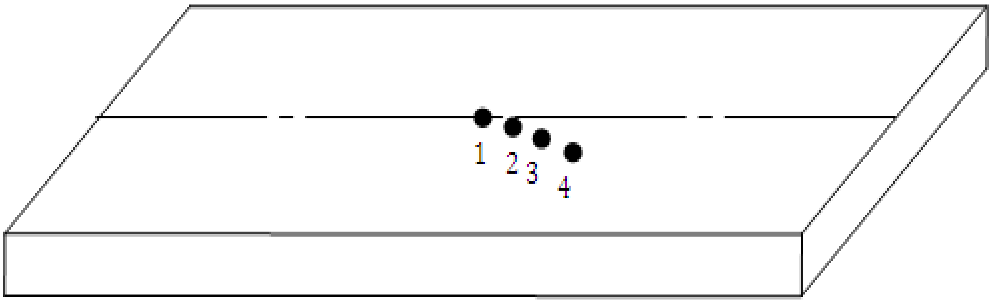


Fig: 2 Thermocouple position

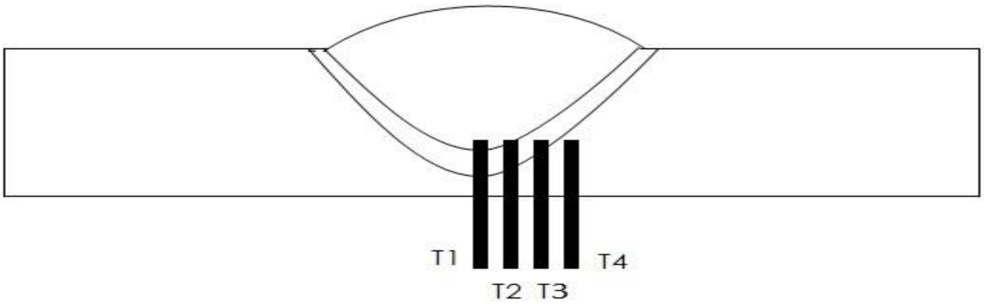


Fig: 3 Insertion of thermocouple

Each hole is 5 mm deep and having 1.5 mm diameter. The holes were drilled by the vertical pillar drilling machine in the machine shop, SLIET, Longowal. 20 plates were prepared for the experimentation.

2.2 Identify the process parameters

Extensive trial runs were carried out to find out the working range of input welding parameters for producing sound welding. By the trial runs following parameters were selected given in table 3

Table 3: Process parameters and their levels

S. No.	Parameters	Units	Symbols	Low Level (-)	High Level (+)
1	Current	Amp	A	325	650
2	Voltage	Volts	V	32	42
3	Welding Speed	mm/min	S	225	425

2.3 Preparation of Design Matrix

After the selection of welding parameters and their levels on the basis of trials the design matrix was prepared [6]. Table 4 shows the design matrix with different heat input.

Table 4: Design matrix

S. No.	Current (A)	Voltage (V)	Welding Speed (m/mm)
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

"+" and "-" shows the High and Low levels respectively.

Modeling of process parameters and design of experiments have been done with Design Expert software. Fractional factorial design technique was used for the experimentation. There were three factors and two levels for developing the design matrix, according to the Full Factorial design (2^n) eight set of heat input are designed with different combinations of SAW welding parameters [7].

III. EXPERIMENTATION

The four thermocouples were positioned in to the holes of base plate and weld bead is deposited on the opposite surface to the surface where thermocouples are situated. According to the design matrix eight plates were welded using 3.15 mm diameter conforming to AWS A5.17- 69, EL-08 wire and with the use of fresh flux [8]. Electrode positive reverse polarity was used. A constant potential transformer-rectifier type power source with a current capacity of 1200 amperes at 60% duty cycle and 900 amperes at 100 % duty cycle, an OCV of 32 to 42 volts was used. The complete set of eight trials was repeated twice for the sake of determining the variance of parameters and variance of adequacy for the model. Fig: 4 show the welding setup, base plate and position of thermocouple.

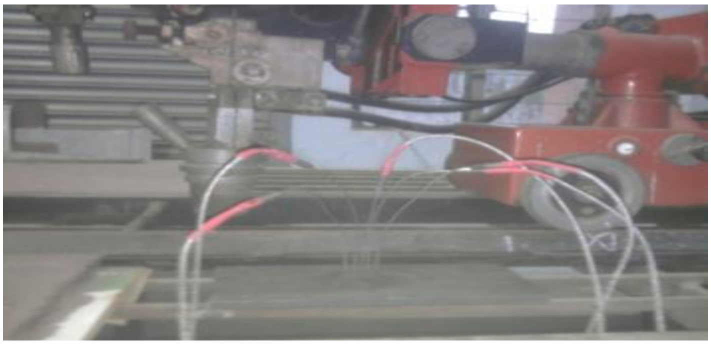


Fig: 4 welding setup, base plate and position of thermocouple

With the help of thermocouple and digital meter the temperature during cooling is recorded at four positions of thermocouple with the interval of 5 seconds. The cross-section view of weld bead with thermocouple is illustrated in figure 5. The temperature is recorded up to 7 minutes. This recorded temperature helps to draw the thermal histories.

3.1 Preparation of test specimen

After welding, transverse section of the weld beads were cut from the middle portion of the plates as specimens as shown in figure 4.6. These specimens were prepared by standard metallurgical polishing methods [9]. After applying the 1000 grade of sand paper the micro hardness was carried out in metallurgy lab, SLIET Longowal.

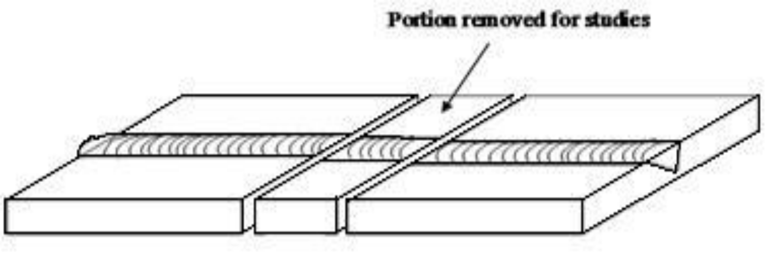


Fig: 5 Removal of specimen from the work piece

IV. RESULT AND DISCUSION

In the present study, the effect of cooling rate on microstructure of mild steel plate has been investigated. The properties of steel welds are affected by their cooling rates in the 800^0C to 500^0C range where the phase transformations important for the evolution of final weld microstructure occur [10]. The effect of cooling rate is not limited to solid state transformations.Cooling rate of weldment is depends on the heat input by the welding arc to the weldment. Heat input is controlled by the three variables Current, Voltage, travel speed. With the higher heat input the cooling rate is slower and vice-versa. The effect of cooling rate on microstructure was investigated [11].

4.1 Cooling rate

Cooling rate is calculated from 800^0C to 500^0C, because this temperature range is useful to phase transformation. It is observed that when heat input is increased the cooling rate of weldment is reduced. Cooling rate is calculated by the following equation. Table 5 shows the calculated heat input and cooling rate. Heat input is calculated from welding parameters and cooling rate is calculated from thermal histories.

$$\text{Cooling rate } = \frac{\text{Temp range from } 800^0\text{C to } 500^0\text{C}}{\text{Time taken from } 800^0\text{C to } 500^0\text{C during cooling}}$$

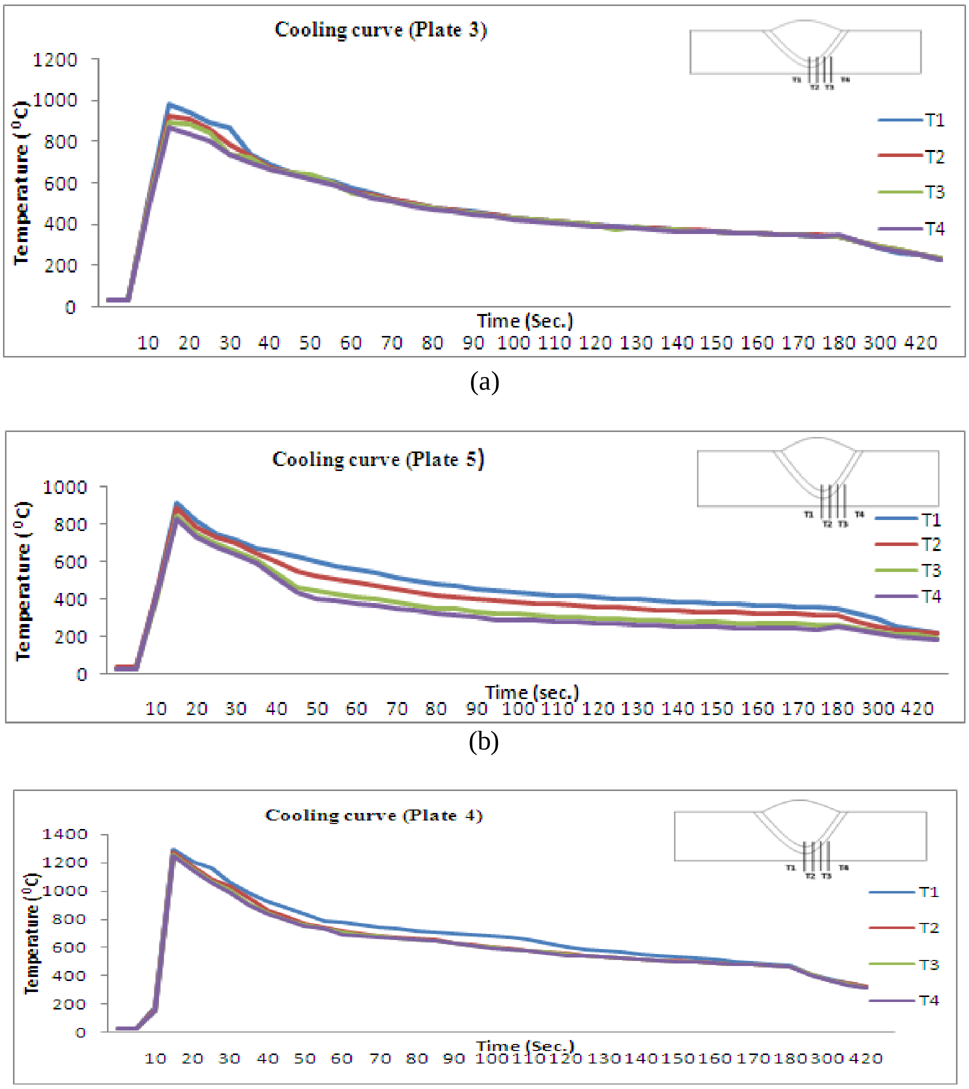
Table 5: Calculated heat input and cooling rate

plate no.	current	voltage	speed	HI in KJ/mm	CR (800-500)
1	325	32	225	2.77	8.5
2	650	32	225	5.54	3.2
3	325	42	225	3.64	6.2
4	650	42	225	7.28	2.5
5	325	32	425	1.46	12.5
6	650	32	425	2.93	8.2
7	325	42	425	1.92	9.5
8	650	42	425	3.85	5.6

Table 5 illustrates the relation between the heat input and cooling rate of weldment. It is observed that with the increasing in heat input from 1.46 KJ/mm to 7.28 KJ/mm the cooling rate is reduced from 12.5^{0}C/sec to 2.5^{0}C/sec. so with the reduction in heat input the cooling rate is increased.

4.2 Temperature histories

During welding, temperature is measured as a function of time, by thermocouple for different points. These readings of temperature are useful to draw temperature histories. Thermal histories play important role for finding the cooling rate of weldment for different ranges. Fig: 7 shows the temperature history of weldment [12], welded at Low medium and high cooling rates.



(a)

(b)

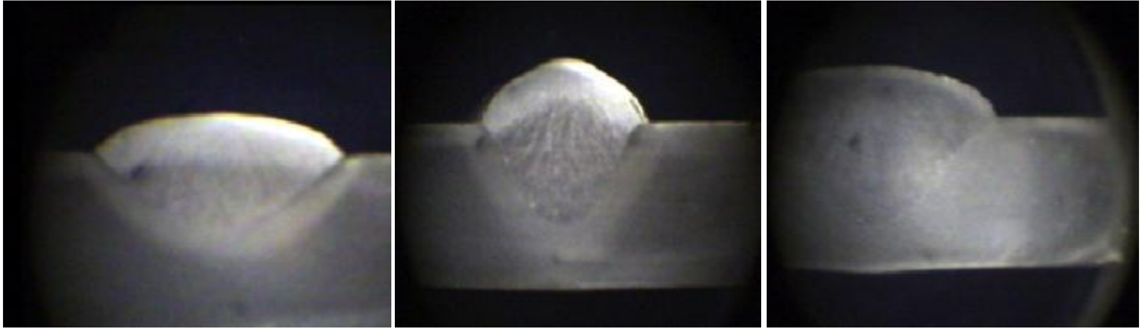
(c)

Fig: 6 Cooling Curve at (a) Medium (b) High and (c) Low Cooling Rate

V. MICROSTRUCTURE

According to heat input (high, Medium and low heat input) three specimen were selected (plate no. 3,5 & 4) and these specimens were properly polished and etched with 2% Nital solution for 3 seconds, which was followed by investigation of microstructure. Macrostructure is carried out at "7X" and microstructure is conducted at "100X"

Fig: 7 show the macrographs of three different weldments. It is observed from the micrograph that with the increasing heat input and decreasing cooling rate the HAZ area is increased [13].



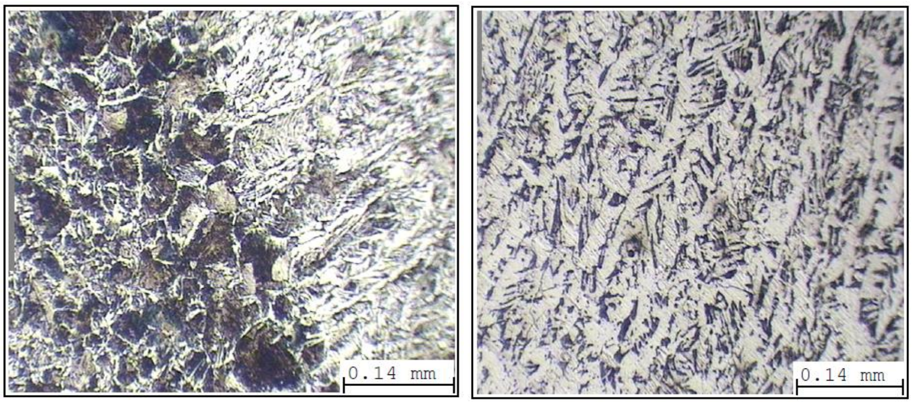
(a) Fast cooling rate
Low heat input

(b) Medium cooling rate
Medium heat input

(c) Slow cooling rate
High heat input

Fig: 7 Macrographs of weldment at different cooling rate and heat input at 7X magnification

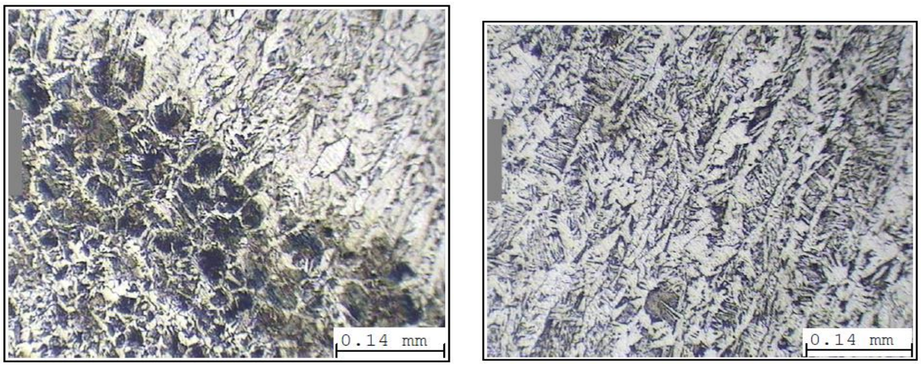
Fig: 8 illustrate the micro graph of the weldment with different cooling rate (slow, medium and fast cooling rate). Fig: (i) stands for microstructure of HAZ and figure (ii) stands for the microstructure of weld bead [14]. At the slower cooling rate grains in fusion boundary zone are larger in size as compared to the weldment having Medium and fast cooling rate. By the faster cooling rate finer grains are formed and finer grain produces the higher hardness. Columnar grains are formed in weldment. The larger columnar grains are formed by slow cooling as compared to medium and fast cooling rate. It is also observed that the spacing between dendrites are more in the weldment with slower cooling rate, less spacing between dendrites results the more hardness [15].



(i) Fusion boundary & HAZ

(ii) Weld bead

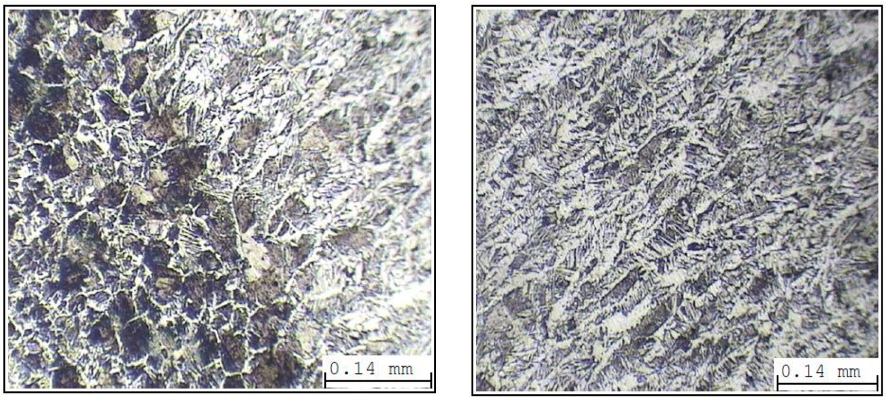
(a)



(i) Fusion boundary & HAZ

(ii) Weld bead

(b)



(C) (i)Fusion boundary & HAZ (ii) Weld bead

Fig: 8 Optical macrographs showing microstructure of [a] Low, (b) Medium and (c) fast cooling rate (100 X magnifications)

VI. CONCLUSION

The following conclusions may obtain from the experiments:

1. The process parameters are directly affect the cooling rate, with the increase of welding Current, voltage and decreasing of welding Speed the cooling rate is decreased and with the decreasing of current, voltage and increasing of welding speed the cooling rate become fast.
2. The grains forms with higher cooling rate are much finer as compare with low cooling rate.
3. The microstructure of base metal with medium heat input is pearlitic/ferritic grain structure with banding at some areas.and in heat affected zone is course as well as very fine grains pearlitic/ferritic structure. And in Weld zone is self cooled pearlitic ferritic structure

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