



Experimental Determination of Cooling Rate and its effect on Residual stress development in SAW welded mild steel plate

¹Rahul, ²Harish Arya, ³R. K. Saxena

^{1,2,3}Department of Mechanical Engineering, Sant Longowal Institute of Engineering and Technology
Longowal, Sangrur, Pin-148106 India

Email: ¹arya.iitr@gmail.com, ²erkulwant@yahoo.co.in

Abstract:- Residual stresses in weldment plays major role in failure, crack formation and deformation of welded part. The amount of heat input and rate of cooling responsible for changes in micro hardness, microstructure and development of residual stresses. The efforts has been made to measure/calculate cooling rate and residual stresses and find correlation between them. Full factorial experimental design technique has been used for development of model for prediction of residual stresses in weldment.

I. INTRODUCTION

Mild steel is the most important structural materials for construction because of their high strength and toughness and relatively low cost. Submerged arc welding is the most reliable, efficient and practical metal joining process which is widely used in industries such as Boiler and pressure vessel manufacturing, shipbuilding industry, and off-shore applications. In spite of the many advantages, there are some limitations affecting this process. Welding defects influence the desired properties of welded joints. Cooling rate of weldment significantly affects parameters such as residual stresses, distortions, weld microstructure, HAZ hardness. Because of local heating during welding process, controlling the temperature distribution is critical.[1]Residual stresses will be present in the material after cooling to room temperature. [2] Very limited experimental study regarding relationship between cooling rate and residual stress developed during submerged arc welded plate is available in literature.

II. EXPERIMENTATION

a) Materials and Equipment

The material of plate selected for the present work is mild steel. Typical chemical composition of the plates used in the experiments work is given in the table 1. Plate of size 300*75*12 mm are used with bead on plate welding method. The welding process selected for present experimental work was submerged arc welding (SAW). AB 4001 Data acquisition system (Atomberg Technologies, Mumbai) with AtomVIEW software along with Thermocouples (K- type) were used to

measure the transient temperature distribution during welding. The thermocouples were fixed in the equal distance from the weld center line. The dimensional details of plates and position of thermocouples are shown in Fig. 2. The temperature distributions during experimentation were recorded in real-time. ‘KERC’ Submerged Arc Welding equipment, type ASA-I, has been used with a power source WR-1200-H for welding. 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 electrode wire used for the welding was Auto melt Grade - A of 3.15 mm diameter conforming to AWS SFA 5.17, EL-08. An agglomerate flux is used in this investigation. The specification of flux used for welding is AWS 5.17 OK FLUX 10.71 L, F7AZ - EL 8. During welding, temperature is measured as a function of time. These readings of temperature are useful to draw temperature distribution and calculation of cooling rates. The temperature was measured until the weld reach to the room temperature.

TABLE I- chemical composition of plate

Element	C	Mn	S	P	Si	ferrous
%	0.28	0.53	0.03	0.037	0.17	Rest.

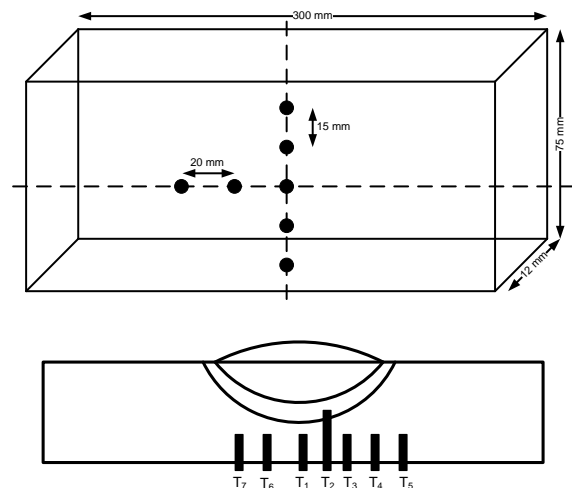


Fig. 1 plate dimension and thermocouple position

b) Methodology

The selected process parameters were wire feed rate (f), open circuit voltage (V), travel speed (S). The Nozzle to plate distance was 20 mm and kept constant Trial runs carried out according to full factorial design. The experiments were performed in random manner to avoid any systematic error. 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. The design matrix is shown in table 3. The working range was decided upon by inspecting the bead for smooth appearance without any visible defects. The upper limit of a factor was coded as +1 and the lower limit as -1. The process variables with their units and notations are given in table 4.

TABLE 2 WELDING PROCESS PARAMETERS

Parameters	Units	Notations	Lower limits	Higher limits
Wire feed rate	m/min	F	0.76	2.40
Open Circuit Voltage	Volts	V	32	42
Welding Speed	m/min	S	0.225	0.425

Table 3: Design matrix

S. No.	Wire feed rate (f) (m/min)	Open circuit Voltage (V)	Welding Speed (S) (m/min)
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

III. RESULT AND DISCUSSION

a) Temperature Profile

Temperature distribution for different set of process parameters as per the design matrix are shown in Figures 2 to 9

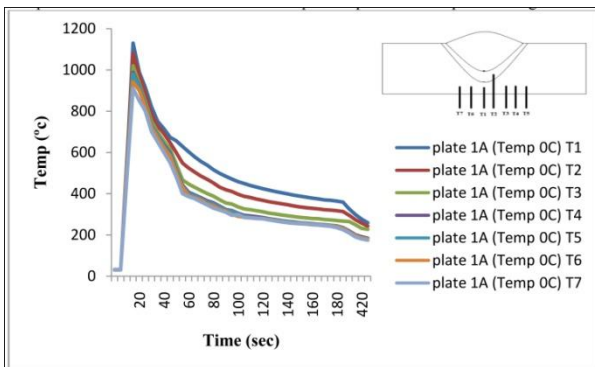


Fig.2 Temperature distributions for plate 1

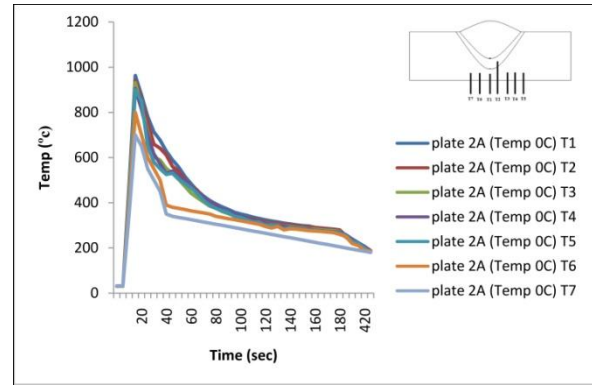


Fig.3 Temperature distributions for plate 2

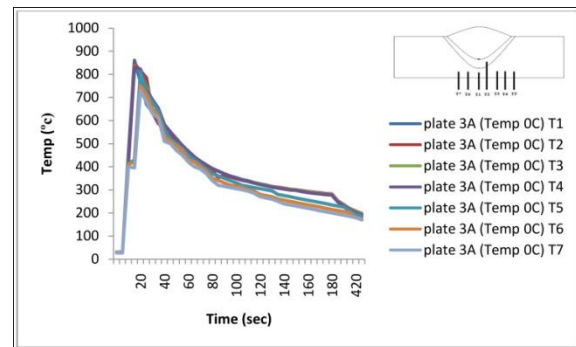


Fig.4 Temperature distributions for plate 3

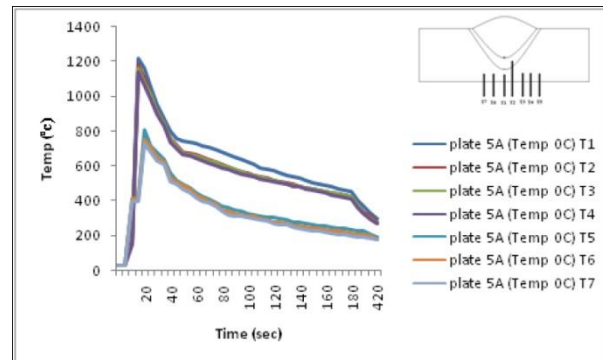


Fig.5 Temperature distributions for plate 4

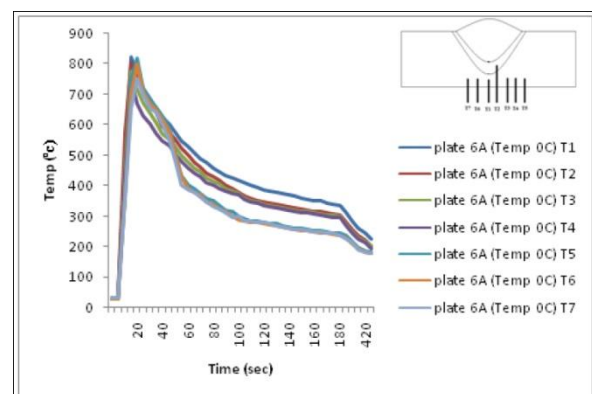


Fig.6 Temperature distributions for plate 5

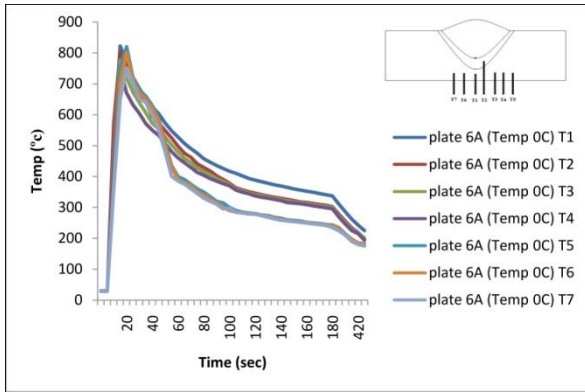


Fig.7 Temperature distribution for plate 6

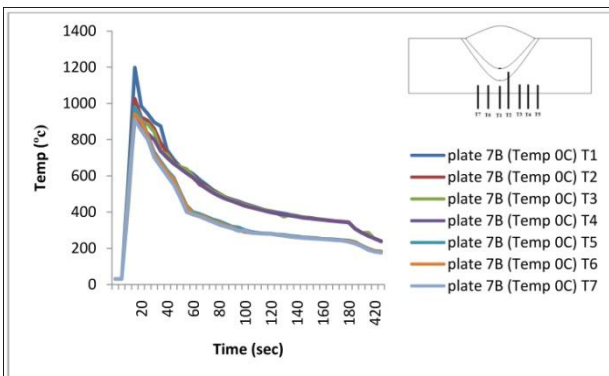


Fig.8 Temperature distribution for plate 7

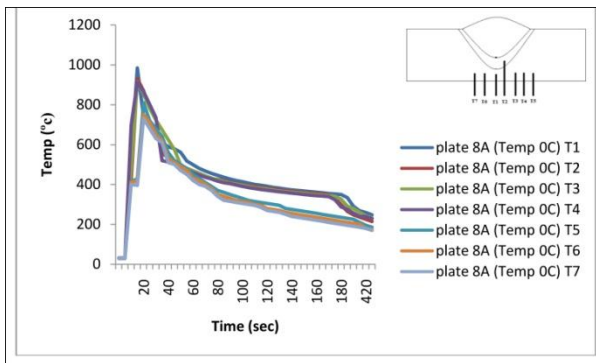


Fig.9 Temperature distributions for plate 8

b) Cooling rate

Cooling rate is calculated from 800⁰C to 500⁰C, 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 5.1 shows the calculated heat input and cooling rate. Heat input is calculated from welding parameters and cooling rate is calculated from thermal histories.

$$\text{Cooling rate} = \frac{\text{Temp range from } 800^{\circ}\text{C to } 500^{\circ}\text{C}}{\text{Time taken from } 800^{\circ}\text{C to } 500^{\circ}\text{C during cooling}} \quad (1)$$

Table.4 Calculated heat input and cooling rate

plate no.	HI in J/m	CR (800-500)
1	1.86	8.42
2	2.94	7.31
3	2.76	8.92
4	4.15	2.65
5	0.80	9.83
6	1.40	4.72
7	1.34	7.13
8	2.01	5.64

Table 4 illustrates the relation between the heat input and cooling rate of weldment. It is observed that the increasing in heat input from 0.80 J/m to 4.15 J/m the cooling rate is reduced from 9.83 ⁰C/sec to 2.65 ⁰C/sec. so with the reduction in heat input the cooling rate is increased.

c) Residual Stress

Residual stress is the stress that exists within a material without application of an external load. The origins of residual stresses in a component may be classified as: mechanical, thermal, and chemical. Mechanically generated residual stresses are often a result of manufacturing processes that produce non-uniform plastic deformation. The X Ray Diffraction method of residual stress determination basically measures the angles at which the maximum diffracted intensity take place when a crystalline sample is subjected to x-rays. From these angles it is possible to obtain the inter-planer spacing of the diffraction planes using Bragg’s law. If the residual stresses exist within the sample, then the d spacing will be different than that of an unstressed state. This difference is proportional to magnitude of the residual stress. The X Ray diffraction machine of National Metallurgical Laboratory Jamshedpur (INDIA) has been used for residual stress measurement the equipment is shown in figure 10 The residual stress are shown in table 5



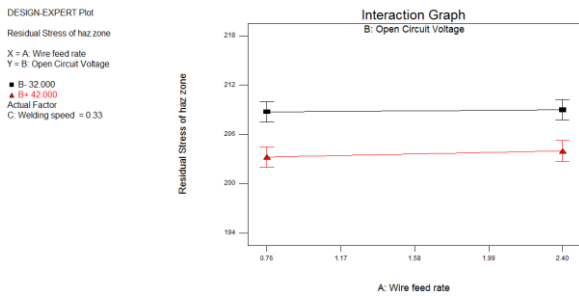
Fig.10 X-RAY Diffraction Machine at NML Jamshedpur

Table.5 Calculated heat input and cooling rate

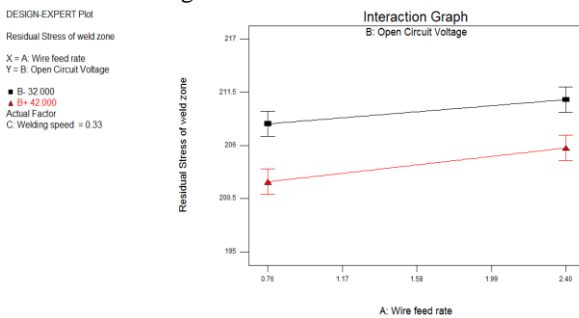
Welding ZONE	Low Cooling Rate	Medium Cooling Rate	High Cooling rate
WELD ZONE	197.6	193.3	239.5
HAZ ZONE	186.9	183	202.3
BASE METAL	148	194	168.1

Residual stress of HAZ zone= $206.25 - 2.63 B - 7.75 C$

Residual stress of weld zone = $206.75 + 1.50A - 2.75 B - 6.38 C$



Interactive effect of wire feed rate & open circuit voltage on residual of HAZ zone



Interactive effect of wire feed rate & open circuit voltage on residual stress of weld zone

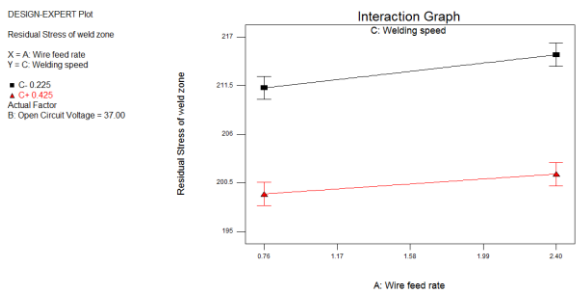


Fig: 5.47 Interactive effect of wire feed rate and welding speed on residual stress of weld zone

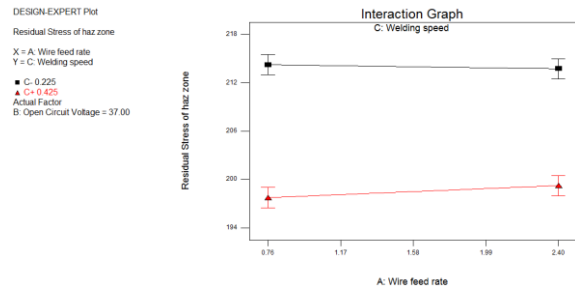


Fig: 5.49 Interactive effect of wire feed rate and welding speed on residual stress of HAZ zone

IV. CONCLUSION

The optimum condition for welding of C 25 as per IS 1570 has been identified through factorial design as shown in result. With the help of temperature distribution graph we got the cooling rates with increase in heat input from low (0.80 J/m) to high (4.15 J/m) the cooling rate reduced from (9.83 °C/sec to 2.65 °C/sec). The residual stresses developed due to increase in heat input in the weldment and amount of stress developed increases with increase in heat input.

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