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Investigation on Effect of Heat Input on Cooling Rate and Mechanical Property (Hardness) Of Mild Steel Weld Joint by MMAW Process

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ABSTRACT: *The effect of heat input in MMAW arc welding on cooling rate and hardness of weld joint is investigated in this paper. The parameter affects the heat input are welding current, arc voltage and welding speed. Mild steel weldments were welded under varying current 80, 90 and 100 ampere and keeping arc voltage and travel speed constant. Other mild steel specimens were welded under varying arc voltage 21V, 23V and 25V and keeping welding current and welding speed constant. Other mild steel specimens were welded by varying welding travel speed 1.52 mm/sec, 1.67 mm/sec and 1.82 mm/sec and keeping arc voltage and welding current constant. Heat input was calculated for each weldment. Rockwell hardness testing of all specimens was done. It was observed that with increase in arc current hardness of mild steel weld joint was increased up to optimum level and then decreased. Cooling rate was decreased with increased in arc current. With increase in welding arc voltage hardness of weld joint decreased and cooling rate was decreased also. With increase in welding travel speed hardness of weld joint increased and cooling rate was increased also.*
Keywords - *MMAW, welding current, arc voltage, welding speed, cooling rate*

I. Introduction

Welding is most common metal joining process. MMAW welding process was used from early 1930's.[1]. In MMAW process metal is joined by application of heat. This heat is produced by establishing an electric arc between flux coated electrode and base metal. Welding arc is a sustained electrical discharge through an ionized gas. The electric discharge through ionized gas produces high amount of heat which is sufficient for melting the metal.[2]. The process is shown in fig-1[3]. Mild steel is widely used for fabrication of process equipment, structure, ships, pipes etc. Welding of mild steel is very much sensitive to heal flow. Mechanical properties like tensile strength, impact strength and hardness are changed during welding due to change in microstructure. Generally mild steel is having ferrite microstructure but after welding it changes to pearlite, bainite or martensite. Hardness of weld joint increases from alteration of microstructure from ferrite to martensite. This change depends on heat input and cooling rate in welding. Fig-2 shows effect of heat input on cooling rate[4]. The factors affecting on heat input are welding current, arc voltage, welding speed and thermal efficiency of mild steel. Factors affecting cooling rate are thickness of metal, heat input, welding speed, preheating temperature, post weld heat treatment. Among these variables welding current, welding voltage and welding speed are primary variable which controls the fusion, depth of penetration, shape of weld puddle, reinforcement and heat input. Electrode polarity, inclination angle and welding technique are secondary variable which affect on energy absorbed, melting rate of base metal and weld metal.

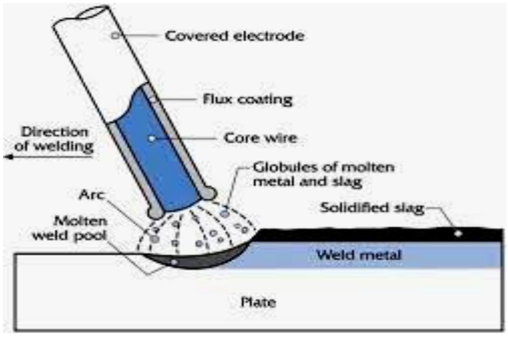


Fig.-1 MMAW welding process

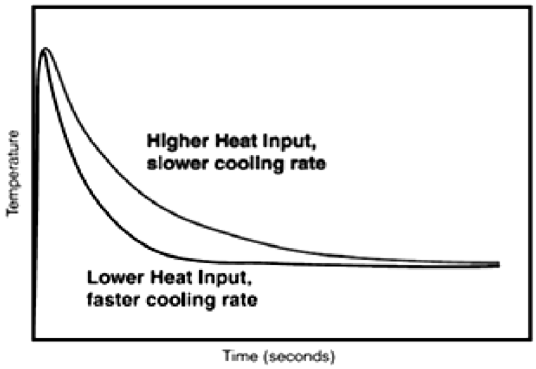


Fig. 2 Effect of Heat input on cooling rate

1.1 Heat input

Heat input rate or energy of arc was an important parameter in welding which can be calculated by following formula[5][6]

$$\text{Heat input } \frac{J}{min} = \frac{V \times A \times 60}{S}$$

Where V = arc voltage
A = welding current
S = welding speed or arc travel speed (mm/min)

But for MMAW process the heat transfer efficiency is 0.65 to 0.85 [2]. So we have to multiply this equation by heat transfer efficiency then we will get actual heat input during welding.

1.2 Cooling rate

Cooling rate was another important parameter during welding. The microstructure obtained in weld joint depends on cooling rate. As welding current increased the heat input also increased. Hence cooling rate also decreased. As welding speed increased heat input will decreased due to less arcing time on specific region hence cooling rate will also increased. So hardness of weld joint was also increased. Cooling rate can be calculated from following formulas [6][7].

Step-1 first we have to calculate the relative plate thickness t1

$$t1 = \sqrt{\frac{\rho \times C \times (Tc - To)}{Hnet}}$$

Where t = plate thickness
ρ = density of material g/mm^3
C = specific heat of solid material J/g°C
ρC = volumetric specific heat J/ mm^3 °C
Tc = temperature near the pearlite nose on TTT diagram
Hnet = Heat input J/min

Step-2 If t1 > 0.75 then

$$\text{Cooling Rate R} = \frac{2 \times \pi \times k \times (Tc - To)^2}{Hnet}$$

Where R= cooling rate °C/sec
K = thermal conductivity J/mm,s°C
To = Initial temperature of plate to be welded °C

Step-3 If t1<0.75 then

$$Cooling\ Rate\ R = 2 \times \pi \times k \times \rho C \times \left({}^{t}/_{Hnet}\right)^2 \times (Tc - to)^3$$

1.3 Various zones of weld joint

The steel weld joint mainly divided in three zones i.e. Weld metal zone, Heat affected zone (HAZ) and base metal zone. The HAZ was further classified in three region i.e. grain growth region, grain refined region and transition region [7]. The hardness during weld joint is not uniform. The steel is sensitive for thermal cycle and the metal of weld joint was having highest temperature i.e. above melting point and the parent metal was having temperature very less below the lower critical line. Due to high temperature difference between these two regions the cooling rate was very fast and the solidification of weld metal was under non equilibrium conditions. Due to this from austenite to pearlite micro constituents transformation was not occurred and austenite to martensite or binatic lathe micro constituents transformation was occurred. So hardness of this region was very high and HAZ was become more susceptible to cracking. [1][2][8]. Types of microstructure obtained and its hardness is depend on cooling rate which is shown in fig.-3[9].

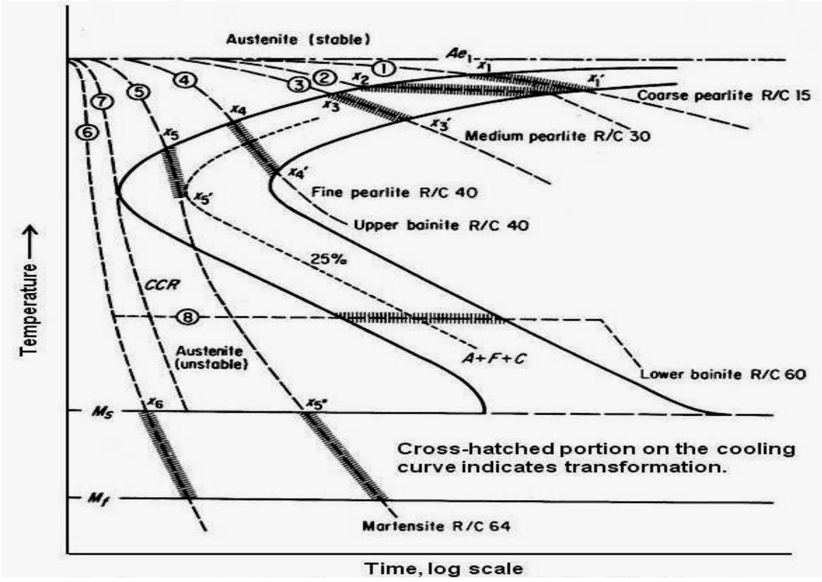


Fig-3 TTT diagram

II. Literature Review

DR.Evance had concluded in his study that with increase in heat input the number of beads per layer varied and the nugget and recrystallised area increased. The hardness of as-deposited weld metal decreased. the average width of columnar grains increased. Yield strength and tensile strength decreased. optimum charpy-v impact properties achieved at 2 KJ/mm. grain size increased and proeutectoid ferrite in weld metal increased at the cost of acicular ferrite.[5].

Sindo kuo As the heat input and welding speed both increase, the weld pool becomes more elongated, shifting from elliptical to teardrop shaped. The higher the welding speed, the greater the length–width ratio becomes and the more the geometric center of the pool lags behind the electrode tip. The cooling rate decreases with increasing heat input and preheating[10].

As per AWS the thermal condition in welding affect metallurgical structure of weldment, mechanical properties, thermal stresses and distortion. The major factors are (1) the solidification rate of weld metal (2) the distribution of maximum temperature in weld heat affected zone (3) the cooling rate in weld metal and HAZ (4) the distribution of heat in weldmetal and HAZ[6].

Bhaskar vishvakarma, Manish verma & Tribhuwasn kishor Mishra had concluded in their research that with increased in welding current impact strength of weldmetal increased while hardness decreased[11].

Rakesh kumar, Satish kumar had invstigated on mechanical properties of mild steel 1018 during MIG welding. They concluded welding current was the most significant parameter affecting the mechanical properties and hardness of weld joint. They found that no matrensite formation during MIG welding[12].

Prof. Rohit Jha, Dr. A.K.Jha had concluded in their research with increase in welding current the UTS will increase until an optimum value, increase in further welding current optimum value will result in decreasing UTS[13].

Ajay N. Boob and Prof. G.K.Gattani, have investigated on MMAW welding process parameter of heat affected zone (HAZ) for mild steel 1005. They found that during welding austenite microstructure was refined and converted into bainite so strength and impact toughness of base metal was improved. Heat input rate was most significant parameter for controlling width of HAZ and with increase in welding speed width of HAZ was decreased, proper control on welding speed was became the important parameter for controlling the HAZ[14].

Riyad Mohammed Ali Hamza, Abdulkareem Aloraier, Emad Abdulradh Al-Faraj had investigated effect of welding polarity in joint bead geometry and mechanical properties of MMAW process. They concluded that highest hardness measurement was recorded when welding was performed using DC-polarity. Hardness value was dropped down as the metal moving through the HAZ to the parent metal. The lowest hardness recorded when welding was performed using the AC polarity [15].

III. Experimental Methodology

3.1 Experiment procedure – Specimen of 100 mm long x 50 mm width x 10 mm thick cut from mild steel flat bar. Chemical composition of base metal was as shown in table-1. 30° single V edge preparation was made on these specimens as shown in Fig.-4. Set-up was made by tack welding. Root gap and root face kept 2 mm each. Welding of different specimens was performed using 1G welding position as shown in Fig-5. Flux coated electrode used for welding was AWS/SFA 5.1 E-6013 of 3.15 mm diameter and 350 mm long. Chemical composition of electrode used was shown in table-2. The Welding ampere were 80, 90, 100 by keeping welding speed 1.52 mm/sec and arc voltage 21 volts constant. Technical specification of welding power source used was mentioned in table-3 and photograph of welding power source used was shown in fig-6. Welding polarity was kept DCEP. Then Welding of different specimens was performed using 1G welding position as shown in Fig-5. The observations were recorded in table-5. Welding voltage 21, 23, 25 by keeping welding current 90 amp and speed 1.52 mm/sec constant. Welding polarity was DCEP. Arc voltage was measured as shown in fig.-7 by using multimeter. Welding of different specimens was performed using 1G welding position as shown in Fig-5. The observations were recorded in table-6.Welding travel speed 1.52 mm/sec, 1.67 mm/sec and 1.82 mm/sec by keeping welding current 90 amp and voltage 21 volts constant. Welding polarity was DCEP. The observations were recorded in table-7. After welding, weld reinforcement was ground and weld joint face made flat. All the specimens were tested on Rockwell hardness testing machine and hardness was measured at three points i.e. at base metal (before and after welding at 50 mm distance from weld center line), HAZ at near to fusion boundary and weld metal center line as shown in fig-8. The readings were noted in observation table-5,6 & 7. Technical specification of Rockwell hardness tester used was as per table-4.

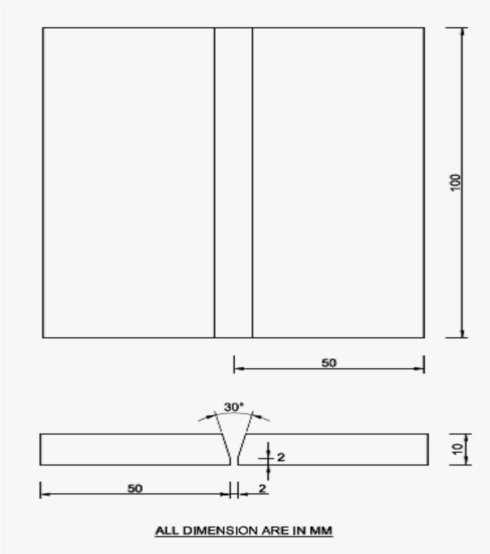


Fig-4 Dimensional sketch of weld joint

Fig-5 Experimental setup

TABLE -1 Chemical Composition Of Base Metal

Element	C	Mn	Si	S	P
percent	0.16-0.18	0.70-0.90	0.40 max	0.40 max	0.40 max

TABLE -2 Chemical Composition of E-6013 Electrode

Element	C	Mn	Si	S	P
percent	0.07	0.44	0.22	0.02	0.02

TABLE – 3 Technical Specification of welding machine

Model	G-200
Range	0 – 200 Amp
KVA	5
Duty Cycle	50 %
Primary Voltage	230 V
Primary current	25 Amp

Fig-6 Welding Machine

Fig- 7 Measurement of arc voltage using multimeter

Fig-8 Hardness Testing

TABLE – 4 Technical specification of hardness testing machine

Model	TRS
Type	Rockwell Hardness Tester
Max. Test Height	216 mm
Throat depth	133 mm
Make	MCS
Capacity	2500 N
Height	630 mm
Net Weight	77 Kgs

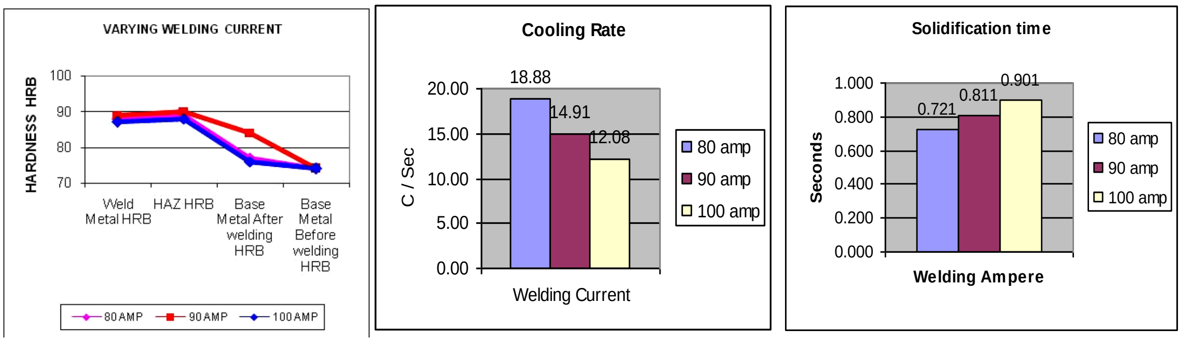
IV. Result & Discussion

4.1 Effect of changing welding current:

Heat input is increased with increase from 942 J/mm to 1178 J/mm with increase in welding current from 80 amp to 100 amp. Hardness of base metal was increased after welding in all specimens. The maximum hardness observed at 90 amp. Hardness of weld metal, HAZ and base metal increased upto 90 amp then it was decreased. This shows that increased in welding current up to optimum level, hardness of weld joint increased than it was decreased. In weld joint hardness of HAZ was greater than weld joint and base metal in all specimens as shown in Fig-8(A). With increase in welding current cooling rate decrease in parabolic curve pattern as shown in Fig.-8(B) and solidification time increased in straight line pattern as shown in Fig-8(C). Due to this increase in welding current up to 90 amp weld joint remains more time between temperature zone of 800 °C to 500 °C. So more binatic lathe formation instead of pearlite hence hardness increased. But then after further increased in welding current increased more heat input rate and these results in extra normalizing effect on weld joint which results in decrease in hardness.

TABLE – 5 Effect of heat input controlled by change in welding current

Specimen No.	Current Amp	Voltage	Welding Time sec.	Welding Speed mm/sec	Hnet J/mm	Cooling Rate C/sec	solidification time sec	Weld Metal HRB	HAZ HRB	Base Metal After welding HRB	Base Metal Before welding HRB
1	80	21	66	1.52	942	18.88	0.721	88	89	77	74
2	90	21	66	1.52	1060	14.91	0.811	89	90	84	74
3	100	21	66	1.52	1178	12.08	0.901	87	88	76	74



(A) (B) (C)

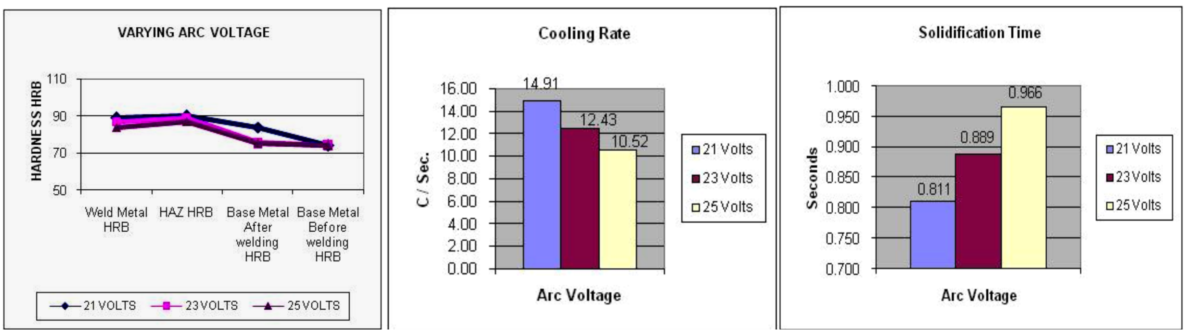
Fig-8 (A) change in hardness zone wise in weld joint (B) change in cooling rate (C) change in solidification time

4.2 Effect of changing welding arc voltage:

Heat input was increased from 1060 J/mm to 1262 J/mm with increased in arc voltage from 21 to 25 volts. Arc voltage was having more influence on heat input than arc current. Hardness of base metal was increased after welding in all specimens. Maximum difference in base metal hardness change observed at 21 volts. Hardness of HAZ was greater than base metal and weld metal in all specimens as shown in Fig.9(A). With increase in arc voltage hardness of weld joint was decrease in all three regions. Cooling rate decreased in parabolic pattern with increased in welding arc voltage as shown in fig.9(B). Weld solidification time increased with increase in welding arc voltage in straight line pattern as shown in fig. 9(C). With increase in welding arc voltage width of weld joint increased and its penetration decreased. More spatters were observed on the weld surface.

TABLE – 6 Effect of heat input controlled by change in welding arc voltage

Specimen No.	current Amp	voltage	welding time sec.	welding speed mm/sec	Hnet J/mm	Cooling Rate C/sec	solidification time St. sec	Weld Metal HRB	HAZ HRB	Base Metal After welding HRB	Base Metal Before welding HRB
1	90	21	66	1.52	1060	14.91	0.811	89	90	84	74
2	90	23	66	1.52	1161	12.43	0.889	87	89	76	74
3	90	25	66	1.52	1262	10.52	0.966	84	87	75	74



(A) (B) (C)

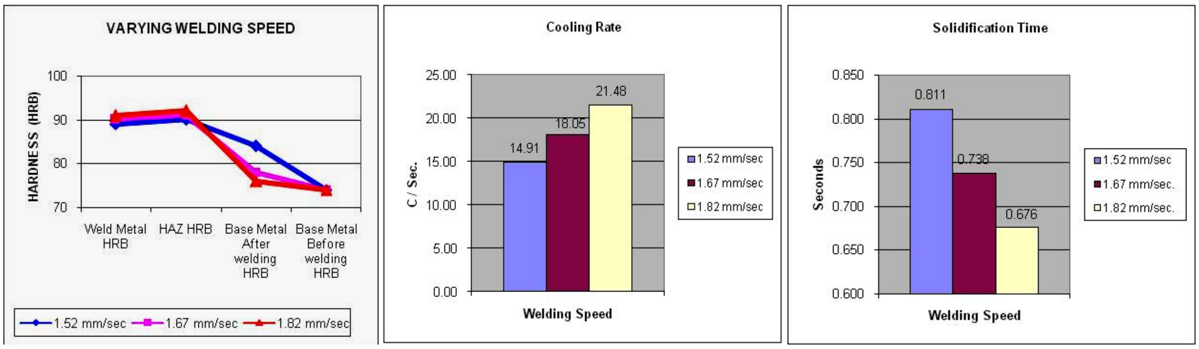
Fig-9 (A) change in hardness zone wise in weld joint (B) change in cooling rate (C) change in solidification time

4.3 Effect of changing welding speed:

With increase in welding speed heat input was decreased due to less arcing time. With increase in welding speed hardness of HAZ and weld metal was increased but hardness of base metal after welding was decreased as shown in fig. 10(A). The reason for decrease in hardness of base metal after welding was less time of base metal between 800 °C to 500 °C. With increase in welding speed cooling rate increase as shown in fig. 10(B). With increase welding speed weld solidification time reduce very rapidly so more chances of martensite formation in HAZ and weld metal hence hardness of this region increases with increase in welding speed. Width of weld joint decrease with increase in welding speed. Penetration of weld increase up to optimum welding speed and then it decreased.

TABLE – 7 Effect of heat input controlled by change in welding speed

Specimen No.	current Amp	voltage	welding time sec.	welding speed mm/sec	Hnet J/mm	Cooling Rate C/sec	solidification time St. sec	Weld Metal HRB	HAZ HRB	Base Metal After welding HRB	Base Metal Before welding HRB
1	90	21	66	1.52	1060	14.91	0.811	89	90	84	74
2	90	21	60	1.67	964	18.05	0.738	90	91	78	74
3	90	21	55	1.82	884	21.48	0.676	91	92	76	74



(A) (B) (C)

Fig-10 (A) change in hardness zone wise in weld joint (B) change in cooling rate (C) change in solidification time

V. Conclusion

Following conclusions can be obtained from this investigation:

1. Heat input is one of the primary factor affects the hardness of weld joint.
2. Welding current, arc voltage and welding speed are major factors affects the heat input in welding.
3. Heat input affects the cooling rate and solidification time of weld joint.
4. Hardness of all three regions i.e. weld metal, HAZ and base metal alters due to heat input and cooling rate.

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