PARAMETRIC STUDY OF SUBMERGED ARC WELDING ON MILD STEEL

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ABSTRACT

The use of arc welding for fabrication, repair, hard facing and erection has resulted in increase in productivity and quality. Quality of welding largely depends on the bead the characteristics, penetration, mechanical properties, HAZ dimensions and microstructures of weld metal and HAZ. The micro structural sub zones in the heat-affected zone of a weld are spheroidised zone, partially transformed zone, grain refined zone and grain-coarsened zone. Welding parameters has a direct effect on the microstructure and the bead characteristics of a base metal. The typical microstructure formed in the HAZ of mild steel consists of grain boundary ferrite, Widmanstaten ferrite, pearlite, banite, acicular ferrite and martensite depending upon the cooling rate below critical temperature. In submerged arc welding (SAW), selecting appropriate values for process variables is essential in order to control heat-affected zone dimensions and get the required bead size and quality. Also, conditions must be selected that will ensure a predictable and reproducible weld bead, which is critical for obtaining high quality. Present study was conducted to observe the bead geometry and microstructures of weld zone and heat affected zone of submerged arc welding. The experiments were performed on 13 mm thick mild steel plate and single pass submerged arc weld was carried out by varying welding parameters, metallurgical tests where performed using inverted binocular optical metallurgical microscope fitted with digital camera which is connected to a computer. The effects of welding variables on bead geometry and microstructure of weld metal and heat affected zone were experimentally studied using suitable wire flux combination and finally the results were analyzed.

Keywords: Submerged Arc Welding, Heat affected zone, Heat input, Weld penetration, Weld hardness.

List of notations :

I	Current	V	Voltage
F	Wire feed	S	Welding speed
P	Penetration	H	Heat affected zone width
q	Heat input	w	Bead width
h	Bead height		

INTRODUCTION

The normal welding variables of submerged arc welding like current, voltage, travel speed and bead geometry are characterized by bead width, height, penetration, hardness and quality.This study is essential, because of the huge application of this welding in various fields; submerged arc welding is one of the processes having high deposition rate, welding speed, good quality weld and better penetration—fewer operators fatigue because arc is not visible and welder's manipulative skill not needed. From the study, it was found that submerged arc welding bead quality and

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mechanical properties are related to the welding variables. In ideal condition, it is considered that for a same current, voltage and travel speed, weld bead is having same height to width ratio. But practically, it was found that there are always some variations on weld bead height to width ratio, for same welding variables and it have been found that for a same voltage and travel speed, if current increases quality of bead improves; but for further increment in current bead quality diminishes. To maintain the good quality of bead, it is suggested to increase voltage and travel speed for increasing the current. The use of submerged arc welding for fabrication, repair, hardfacing, surfacing and erection for flat position welding has resulted in increase in productivity and quality. When structural members are joined by fusion welding the material of the plates has to be heated to its melting point and then cooled again rapidly under conditions of restraint imposed by the geometry of the joint. As a result of this very severe thermal cycle, the original microstructure and properties of the metal in a region closed to the weld are changed. This volume of metal or zone is usually referred to as the heat affected zone. Further study shows that the welding variables are related to the metallurgy of weld metal and HAZ width, generally the heat flow in the weld is highly directional towards the adjacent cold metal and hence the weld acquires distinctly columnar structure in which grains are long and parallel to the direction of heat flow. As heat input increases both the penetration and HAZ width are increased while hardness of the weld region and HAZ region decreases. The changes in the microstructure of weld metal and heat-affected zone takes place.

Automated submerged arc welding is a versatile process, as it gives best quality, saves time, reduces cost, resurfaces wear surfaces on steel castings, improves repair procedure, process control, increases efficiency and productivity.[1] Kolhe K.P. and Datta C.K. studied the effect of welding variables to control the dimensions and properties of weld bead surface to see the impact of wear on the welded metal surface.[2] Dennis *et al* reported the application of narrow groove submerged arc welding to remove a radical crack in the kiln tyre. As the crack grows from the inside diameter surface, the fatigue crack developed large gouge on the inside surface known to form by complex wear mechanism, and the groove was filled using a constant layer thickness approach where seven to eight beads were typically required per layer, and two 152.4 mmthick mock-ups with weld groove extension[2]. Richard Lafave and Richard Wiegand reported the application of SAW for economical repair of turbo machinery shaft; the repair process has considered three important attributes,

1) The ability to produce ultrasonically clean weld deposit.

2) High deposition rate requires deposition of hundreds kilograms of weld metal for the typical repair.

3) It eases mechanization and operation.

The analytic approach requires unit-operating conditions be understood so that operating stresses, typical component characteristics and failure mechanism can be determined using tools such as finite element modeling[3]. Mallya U.D and Srinivas H.S. revised the literature to show heat input was the sole variable on the variation of bead characteristics. They correlated welding variables with bead characteristics. On increasing current, bead width, height and penetration increased, while increasing voltage, bead width increases but bead height and penetration increased between 24V to 26V and decreased between 26V to 30V and remained constant after 30V. With travel speed bead width and penetration increased; while height decreased[4]. However, in present investigation it is observed that on increasing travel speed, bead width, height and penetration decrease. Kotecki D J and others studied the effects of bead to bead stepover, wire size, wire feed, speed, voltage, flux chromium contents and polarity on dilution and ferrite in single wire submerged arc cladding of ER309L on mild steel plate. It was reported that, dilution found, to be promoted by reduced step-over[5-7]. Kotecki D. J. has clearly demonstrated that the usual choice of type 309L filler metal for joining mild steel to 304 (or other austenitic stainless steels) is not without considerable risk in SAW[8]. Kim J.H and others, conducted experiments on the influence of process parameters, on oxygen transfer in submerged arc, shielded metal arc and gas tungsten arc welding which showed both electrochemical and thermo-chemical reactions are active in direct current arc welding and electrochemical reactions are significant in certain ranges of welding parameters. Welding current and weld travel speed are both important factors in the control of electrochemical oxygen transfer[9] Eroglu M. and Aksoy M. studied effects of nickel content along with varying heat input on the microstructure and mechanical properties of HAZ of low carbon steel. Low heat input gives the highest hardness value in grain coarsened heat affected zone (GCHAZ)[10]. Gunaraj V. and Murugan N. suggested the process variables in SAW, to control HAZ dimensions by developing mathematical models for predicting and controlling the dimensions of different regions of HAZ of a weldment, and investigated the effects of heat input, welding speed, arc voltage, nozzle to plate distance, wire feed rate on heat affected zone to show the few results as, 1) Heat input has a considerable positive effect on almost all HAZ dimension 2) Wire feed rate had positive effect but welding speed had a negative effect on all HAZ dimensions[11]. The metallurgical feature that directly affected by heat input rate is the grain size in the heat-affected zone and in weld metal. Grains in the solidifying weld metal grow coherently with grains in the solid metal at the fusion boundary. Therefore; the longer the time spent above the grain coarsening temperature of the alloy in question, coarser the structure in the heat affected zone and in the weld metal[13-14]. The present paper shows the results of an investigation concerning the effects of welding variables on bead characteristics; mechanical properties penetration, HAZ hardness of the weld made by SAW and the metallurgical changes in the weld metal and HAZ on mild steel.

EXPERIMENTAL PROCEDURE

The experiment has been performed on constant voltage fully automatic SAW equipment, 800 amp current, with 380/440 V/3 phase, 50Hz, rectifier-type power source. Bead-on-plate tests were carried out on 300 X 60 X 13 mm mild steel base metal with 3 mm copper coated mild steel electrode and granular SAW flux as per A WS standard manufactured by Advani-Oerlinkon, the details mechanical properties are as shown in Table 2.

Table 2

Flux	Strength (psi)	Yield strength at 0.2% offset min psi	Elongation % in 2 inch	Digit code% in 2 inch	Indicating
AWS	72,000 to 95,000	60,000	22	2	20 ft/lb at -40°C
				4	
				6	

The metallurgical study was carried out using a metallurgical microscopy of 200 magnifications Experiments were carried out in three stages.

1) In first stage, current (A) and voltage (V) were kept constant while travel speed (S) was changed.

Table 3 shows the experimental results of various bead width, height, penetration and hardness for varying travel speeds. Bead quality was observed after welding and removal of slag.

2) In second stage, voltage (V), and travel speed (S) were kept constant and current was changed. Table 4 shows the experimental results of various bead width, height, penetration and hardness for various current. Bead quality was observed after welding and removal of slag.

3) In third stage, welding variables like current (A), travel speed (S) were kept constant and voltage (V) was changed. Tables 5 show the experimental results of various bead width, height, penetration and hardness for various voltages. Bead quality was also observed after welding and removal of slag.

Table 3

Bead characteristics of SAW, keeping voltage and current constant and varying travel speed

Sr. no.	I amp	V Volt	S Cm/min	w mm	h mm	q J/mm	P mm	H mm	Rockwell Hardness No. Weld bead	HAZ
1	400	25	40	13.70	2.12	0.25	2.94	1.80	82	83
2	400	25	60	11.92	1.75	0.16	2.72	1.74	74	79
3	400	25	80	10.16	1.34	0.12	2.36	1.52	82	84
4	400	25	100	10.01	1.05	0.10	2.20	1.40	80	82

Table 4

Bead characteristics of SAW, keeping voltage and travel speed constant and varying current

Sr. no.	I amp	V Volt	S Cm/min	w mm	h mm	q J/mm	P mm	H mm	Rockwell Hardness No. Weld bead	HAZ
1	400	25	40	13.70	2.12	0.25	2.94	1.80	82	83
2	450	25	40	13.92	2.64	0.28	3.52	2	85.33	86
3	500	25	40	14.94	3.32	0.31	5.09	2.80	81.16	86.66
4	550	25	40	15.10	3.75	0.34	7.8	3	78.16	84
5	600	25	40	15.36	4.81	2.25	9	3.76	74	82

Table 5

Bead characteristics of SAW, keeping travel speed and current constant and varying voltage

Sr. no.	A amp	V Volt	S Cm/min	w mm	h mm	q J/mm	P mm	H mm	Rockwell Hardness No. Weld bead	HAZ
1	400	25	40	13.70	2.12	0.25	2.94	1.80	82	83
2	400	30	40	14.03	1.57	0.16	2.92	2	89.16	85.66
3	400	35	40	13.03	1.02	0.12	2.70	2.74	98.33	89
4	400	41	40	14.9	1.06	0.10	3.12	3.80	88.5	83.33

From the experimental results various graph have been plotted, for stage 1, 2, 3 then for various welding parameters, samples have been prepared for various current, voltage and travel speed. The various samples have been prepared by dry polishing the surface of specimens on various grades of emery papers followed by wet polishing. Finally the specimens are dipped in Nital etchant and then washed in water and dried by air blower. Then for various current, voltage and travel speed the penetration and HAZ width has been recorded. From this experimental results, welding variable like current, voltage and travel speed, were plotted against penetration and HAZ width. The specimens were then tested under Rockwell hardness testing machine to find the hardness at various regions of base metal, weld metals and heat-affected zone. From these experimental results various graphs of welding variables against hardness were plotted. The experimental results were finally analyzed.

RESULTS AND DISCUSSION

From fig. 1, it is observed that welding speed (S) has a linear relationship with bead width and height. As travel speed increases with current and voltage constant, fewer amount of metal deposits on the base metal, hence bead width decreases gradually up to 80 cm/min, after which it almost remains same, while bead height gradually decreases successively. From figure 2 it has been seen that current (A) is having a linear relationship with bead height; while bead width increases slightly up to 450 amp, followed by sharp increase up to 500 amp. After that it slightly increases with increase in current. As the current increases, melting rate of electrode also increases. But since the voltage and travel speed are constant, hence bead width and height increase in differcnt fashion and bead quality is good up to 550 amp but after that it is seen very poor with porosities on the bead. As the current increases from 550 amps to 600 amps the heat input increases from 2.06 KJ/mm to 2.25 KJ/mm but percentage of heat input decreases w.r.t. previous values, resulting in poor shielding of flux from the atmosphere causing porosity. But from figure 3 it is seen that the increases in voltage keeping current and travel speed constant has a completely different effect on the bead width, as voltage (V) increases, bead width increases up to 32V (21 to 25 V sharp increase and 25 to 32 V gradual increase), then decreases up to 35V and after that increases slightly. While bead height decreases up to 35V, after that it increases slightly. It has also been observed that before 23V, with constant current and travel speed bead quality was very poor with less bead width and height, as voltage further increases up to 25V, bead quality with smooth improvement has been observed. Since the arc is diverging type, increases in the arc length, increases width of contacting base metal surface, hence bead width increases while bead height decreases. It is also observed that before 23 V, Bead quality from 23V and beyond was very poor since w/h<l up to 24V but w/h>l beyond 24V. As voltage further increases up to 25 V (from 23V and beyond), the bead quality is smooth. Since the arc is diverging type, increase in the arc length the arc gap increases hence bead width increases while bead height decreases.

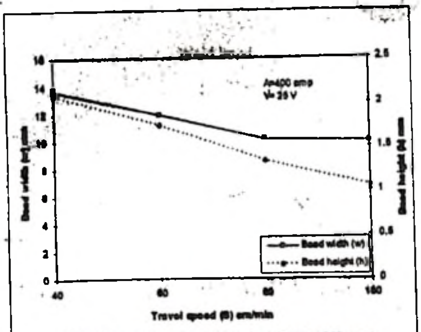

Fig. 1 Influence of Travel speed on Bead width and height

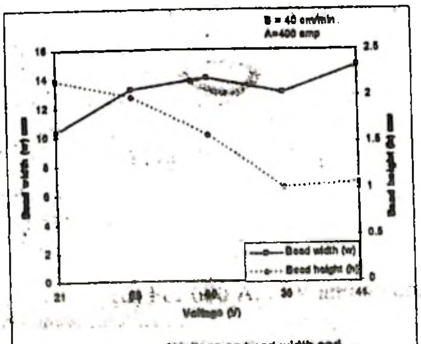

Fig.3 Influence of Voltage on bead width and height

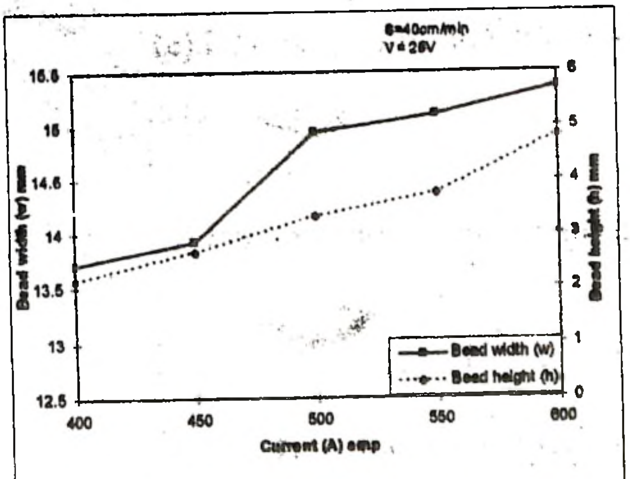

Fig. 2 Influence of Current on bead width and height

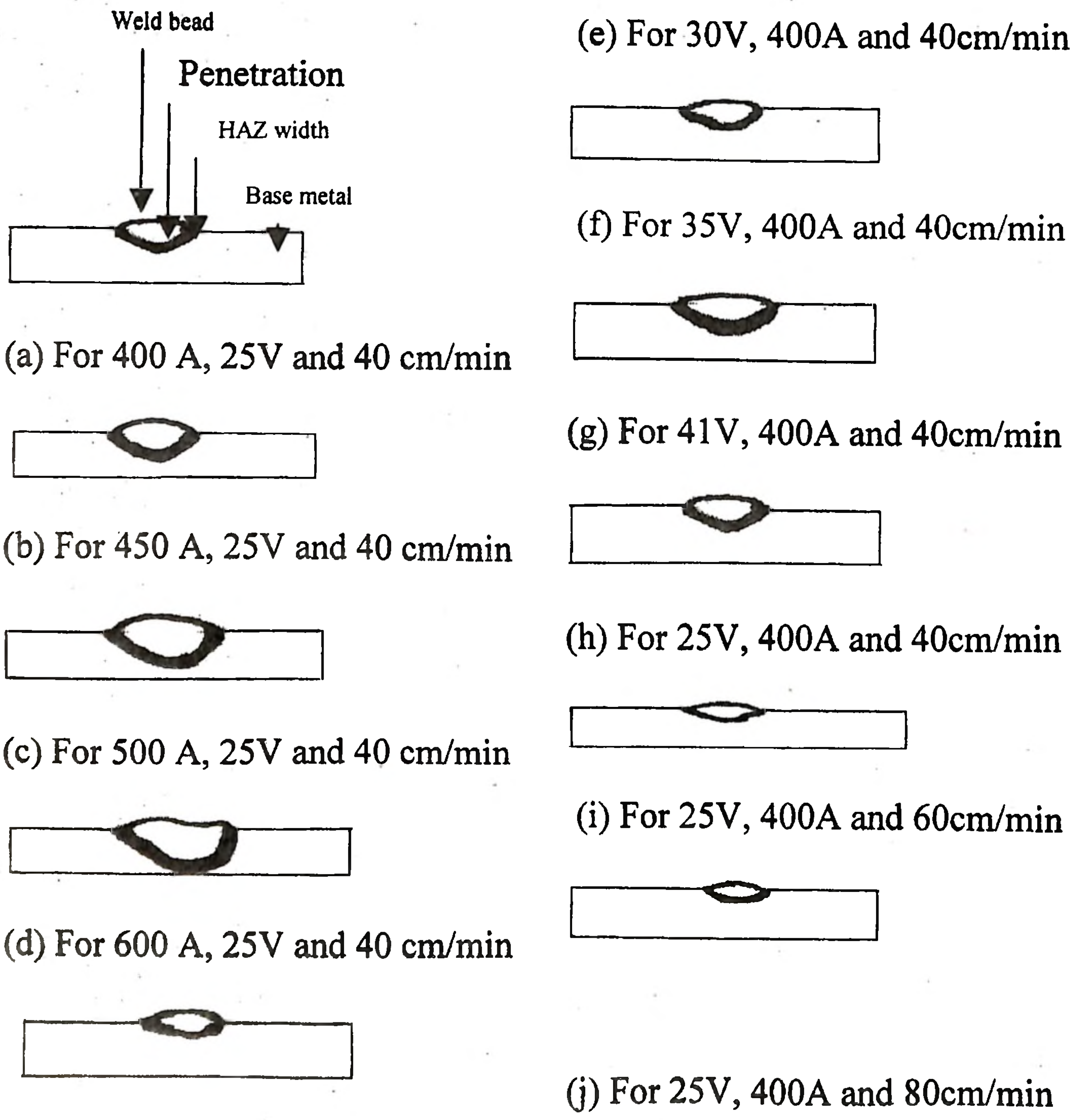

Fig.4 Penetration Patterns of SAW Bead, for various Current, Voltage and Travel Speed

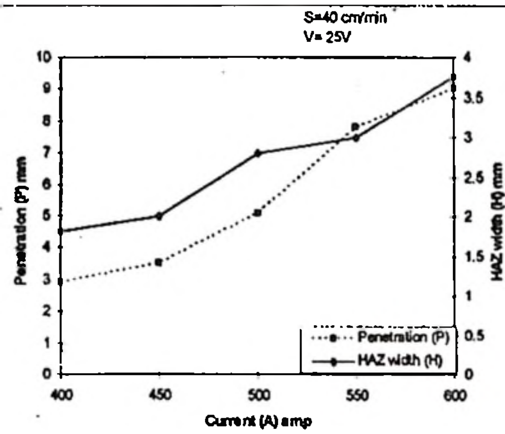

Fig. 5 Influence of Current on penetration and HAZ width

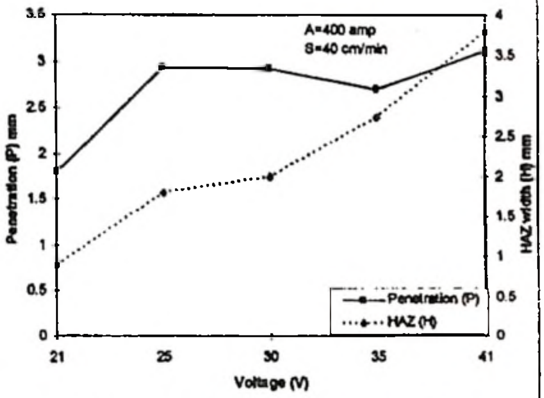

Fig 6 Influence of Voltage on Penetration and HAZ width

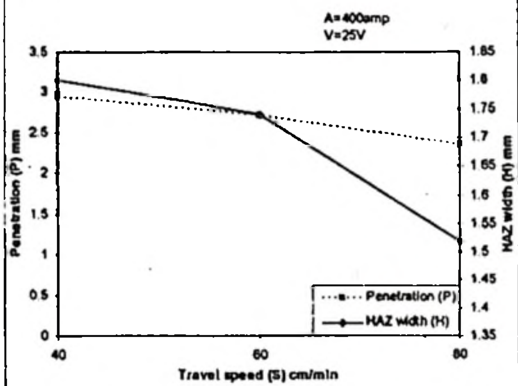

Fig.7 Influence of Travel Speed on Penetration and HAZ width

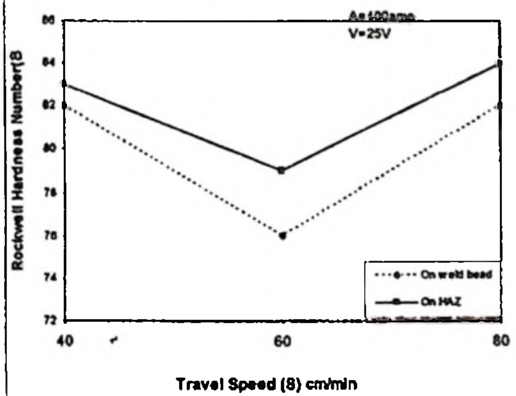

Fig 8 Influence of Travel speed on Rockwell Hardness Number

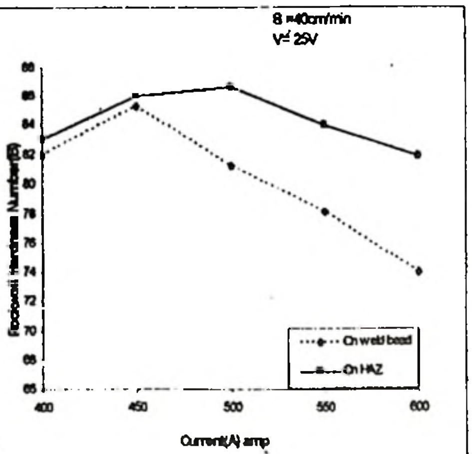

Fig 9 Influence of Current on Rockwell Hardness Number

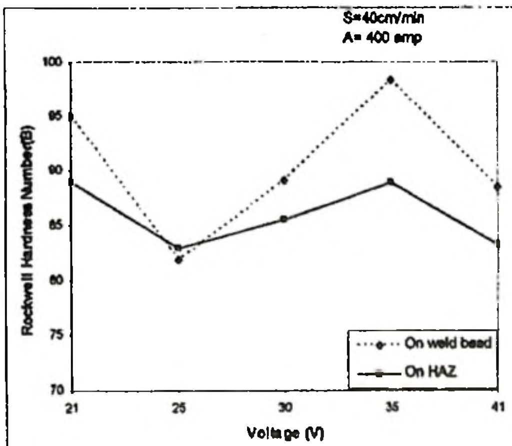

Fig. 10 Influence of voltage on Rockwell Hardness Number

PENETRATION AND HAZ

Penetration and HAZ are very important bead characteristics as the dilution largely depends upon penetration. The various patterns of penetration and HAZ are shown in figure 4. From the figure it is observed that for a fixed voltage and travel speed, if current increases, the heat input also increase. This melts the parent metal deep due to which penetration and HAZ increase, which also changes the penetration pattern figure 4 (a, b, c, d). For high current with low travel speed, if current increases further it may melt the whole base metal, so for higher current low travel speed should be avoided. While for constant current and travel speed, if voltage increases weld penetration and HAZ increase, and there is a slightly change in penetration pattern figure [4] (e f, g). Due to increase of voltage, the arc length increases and as a result, the arc plasma constricts into a concentrated heat source, hence construction of the arc increases digging action on the base plate and so penetration increases4. For constant current and voltage with increasing travel speed, heat input decreases due to which less amount of heat transfer in parent metal takes place, which almost takes the penetration pattern same as shown in figure 4 (h, i, j). For low current if travel speed increases, it gives very less penetration due to which strength of joint decreases. So for maintaining good strength of welded joint it is also suggested to avoid higher travel speed for lower current. From figure 5 it is clear that in general penetration increases with current but not in a uniform pattern. From the graph, it is seen that with increasing current for constant voltage and travel speed, penetration increases (from 400 amp to 450 amp gradual and 450 amp to 500 amp sharp) up to 500 amp, followed by gradual increase up to 550 amp. After that it sharply increases with increase in current, while HAZ width gradually increases up to 500 amp with varying fashion followed by sharp increase up to 550 amp further it gradually increases. Figure 6 shows the variation of penetration and HAZ width with voltage for constant current and travel speed. From the figure, it is observed that increase in voltage; penetration and HAZ sharply increase up to 25V, after that penetration decreases slightly up to 35V and again increases. But HAZ slightly increases up to 30V and then it increases sharply with changing fashion. From figure 7, the variation of penetration and HAZ with travel speed is shown. It is clearly seen that as travel speed increases with current and voltage remaining constant, penetration decreases slightly successively. While HAZ width decreases, slightly up to 60 cm/min followed by sharp decrease in this with increase in travel speed.

HARDNESS

From figure 8, it is observed that as travel speed increases with constant current and voltage, hardness of weld bead and HAZ sharply decrease up to 60 cm/min, then it increase sharply. But for same travel speed hardness of HAZ is more than weld bead, this may be due to difference in structures of both the zones. Normally weld metal is having a cast structure, with columnar grains and HAZ is having region of grain growth near fusion boundary and other zones like recrystallized zone, transition zone etc., as we move away from the weld metal. Whereas if current increased for voltage and travel speed constant, hardness of HAZ first increases up to 500 amp with changing fashion followed by gradual decrease, with increase in current. But for weld bead, hardness increases slightly up to 450 amp, after which it sharply decreases (Figure 9). As the current is increased to a high value heat input also increases substantially causing changes in the metallurgical structures. From figure 10, it is observed that with increased of voltage for current and travel speed constant, hardness of weld bead and HAZ decrease (weld bead sharply and HAZ gradually) followed by sharp increase in weld hardness and gradual increase in bead hardness up to 35V. After which both decrease with different with further increase in voltage, which also increases the arc gap.

MICROSTRUCTURE

For less heat input, accular ferrite which shown in figure 11(a) by white region and the dark region indicates pearlite region on the weld metal, while for the same parameters on HAZ shows the coarse grain structure of ferrite and pearlite as shown in fig 11 (b). From fig. 11(c) with increasing heat input the ferrite area changes to polygonal ferrite and pearlite region changes to the granules, the region closer to the weld zone is fusion zone which is also known as grain growth region in which very fine precipitate of pro eutectoid ferrite characteristics of HAZ transformation in which for increasing heat input ferrite and pearlite grains are elongated as shown in fig 11 (d). This part has received heat approximately about AC_3 temperature followed by cooling. In heat affected zone ferrite and pearlite grains are elongated, which changes the mechanical properties of the metal. The microscopic examination of weld in mild steel is shows few comets, mild steel even those with a medium carbon equivalent, rarely shows intermediate microstructures of banite type; the structures are usually either of pearlite type (fine pearlite, troosite). The heat affected zone has very fine precipitates of pro-eutectoid ferrite characteristics of HAZ transformation, as shown in fig. 11(f).

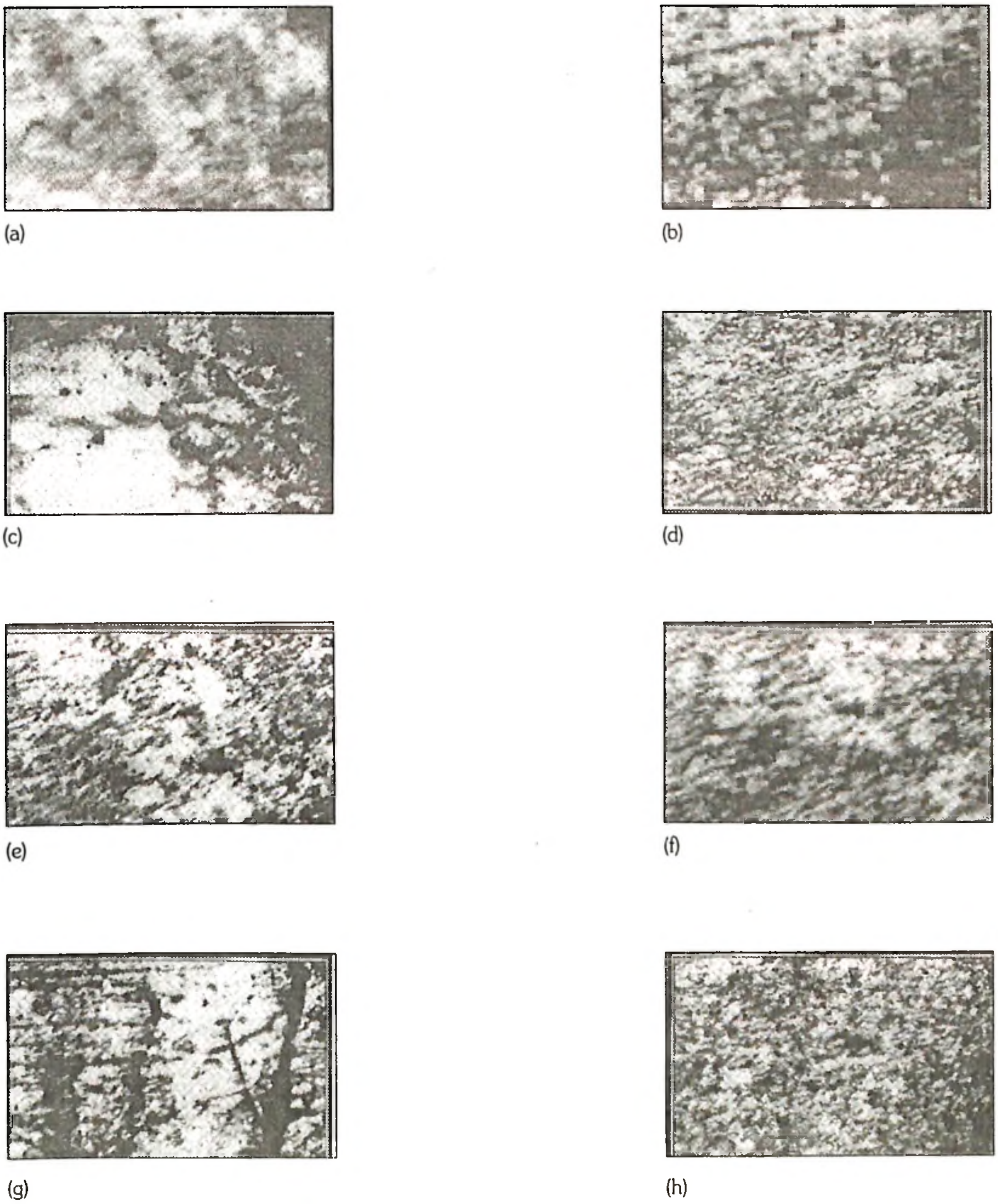

Fig 11. Microstructure of submerged arc weld bead on mild steel showing varying percentage of ferrite and pearliie region on weld (a,c,e,g) and HAZ (b,d,f,h) region at various current (Voltage and speed remains constant at 200 magnifications).

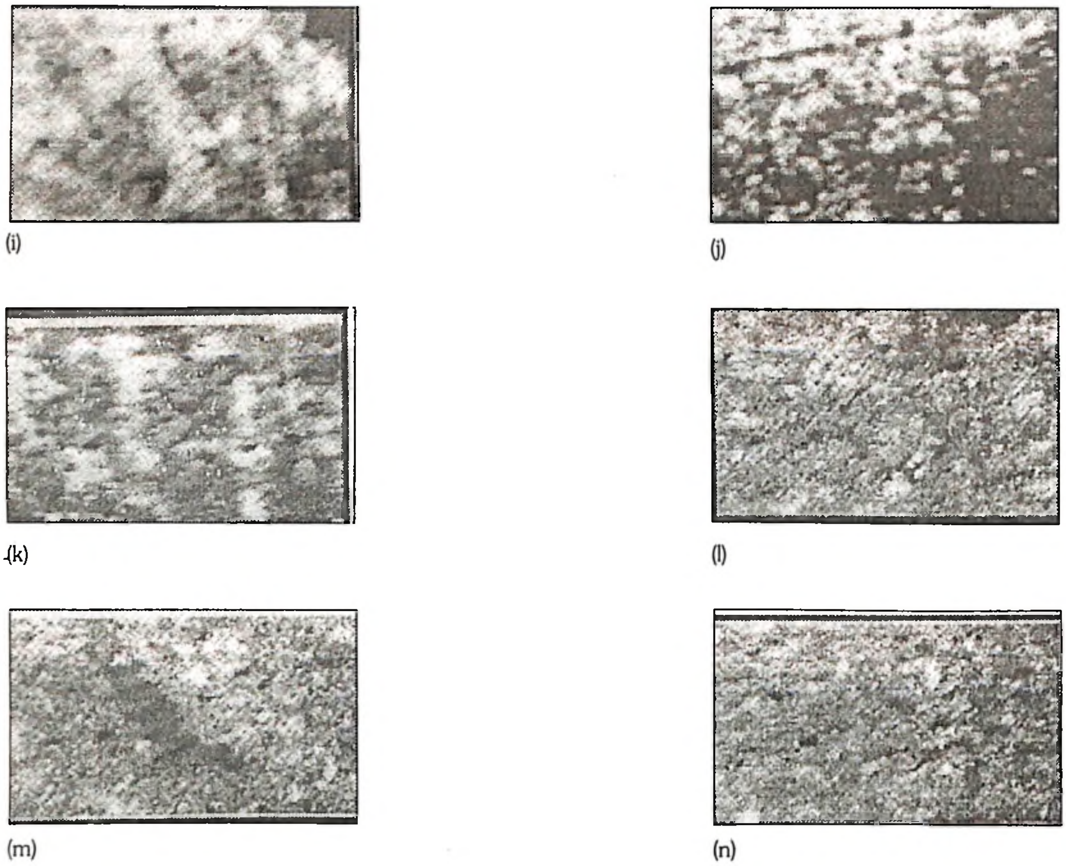

Fig. 12 Microstructure of submerged arc weld bead on mild steel showing varying percentage of ferrite and pearlite region on weld (i,k,m) and HAZ (j,l,n) region at various travel speed (Current and voltage remains constant at 200 magnifications).

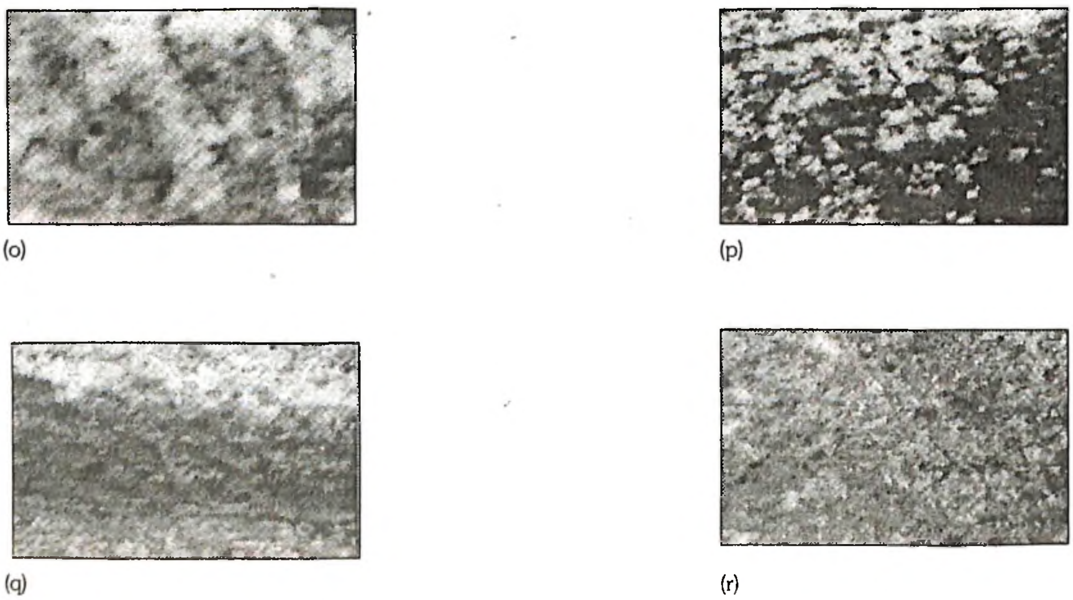

Fig. 13. Microstructure of submerged arc weld bead on mild steel showing varying percentage of ferrite (and pearlite region on weld (o,q) and HAZ (p,r) region at various travel speed (Current and voltage remains constant at 200 magnifications).

From fig. 11 (g) with high heat input, ferrite is converted to cementite and the structure becomes brittle with poor mechanical properties, results in the formation of weld cracks in the microstructure. The microstructure in the weld metal is fine acicular ferrite formed at upper banite temperature. The changes in the microstructure observed with increment in current, also affects on the quality of weld bead, due to increase in heat input for same travel speed the melting rate of the electrode increases for constant travel speed, which result increase in martensite content in weld metal. The microstructures in heat-affected zone of the parent metal are similar only the weld metal and structure zone shows the structural difference. This structure consists of granular banite with a coarser ferrite network; a mixture of proeutectoid ferrite and lower banite marks the junction zone. From fig. 12 (i, k,m), the heat input and welding speed can affects the solidification of weld metal. As welding speed increases for fixed voltage and current the heat input reduces, that will affects the variation in temperature gradient and grain growth rate along the fusion zone and heat affected zone, which will also affects the quality of weld metal. For reducing heat input results increase in ferrite area of the weld metal on weld zone but reduction in ferrite area on the heat affected zone was observed fig. j,l,n). From figure 13 (o,q,p,r), with increase in voltage at constant current and travel speed, heat input increases, due to increase in voltage arc region of the weld surface also increases that will concentrated more heat on the weld region, which results increase in pearlite region weld zone, while reduction in pearlite region on HAZ zone.

CONCLUSION

Based on the experimental results it has been conclude that,

1) Travel speed has an almost negative effect on bead width, height, penetration and HAZ width; variations in weld bead and HAZ width hardness were also found in an increased with travel speed.

2) Current has an almost positive effect on bead, width, height, penetration and HAZ width; there is a considerable increment in bead width, height, penetration and HAZ width with increase in current, penetration increases in a non uniform fashion but HAZ increases in a uniform fashion. Where as there is an overall negative effect on weld bead and HAZ hardness.

3) Voltage has an overall positive effect on bead width, penetration and HAZ width, while negative effect on bead height. Variations in HAZ and weld hardness were also found in an increased with voltage.

4) The effect of increasing heat input on the microstructure and mechanical properties has been studied by performing micro structural examination that results the transformation in coarse and fine grain sizes. The high heat input diminishes the quality of weld metal that produces the cracks in the microstructure of weld metal. A high heat input rate posses will in general, give a longer thermal cycle and tends to generate a coarse structure, cracks some times appear in the parent metal close to the weld boundary immediately after welding while low heat input brought the changes in the ferrite and pearlite content in fusion zone and heat affected zone microstructure.

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