International Journal of Materials Engineering and Technology
Volume 4, Number 1, 2010, Pages 1-14
Published Online: December 19, 2010
This paper is available online at http://pphmj.com/journals/ijmet.htm

STUDY ON MECHANICAL PROPERTIES AND PENETRATION OF MAG WELD

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Abstract

Metal active gas (MAG) process is an important component in many industrial operations. Due to its higher welding speed, automation and weld bead protection against the atmosphere gases (especially O_2), this process is widely used in different industries. In this research, the effects of various parameters of process, including arc voltage, welding current and welding speed, on mechanical properties and penetration of weld in CK45 steel welded by robotic MAG welding were investigated. Welding currents, arc voltages and welding speeds were chosen as 100, 110, 120 A, 23, 25 and 27 V, 42, 62 and 82 cm/min respectively, for all experiments. Mechanical tests and geometry analysis were performed after the welding operation. Results were clearly illustrated that except impact energy, all of the mechanical properties showed a monotonic relationship to welding parameters. The yield, tensile strength (UTS) and hardness of weld metal increased with increasing welding speed whereas the elongation (%) of weld increased with increasing welding current and arc voltage. It was

Keywords and phrases: welding parameters, heat input, cooling rate.

Communicated by M. Misbahul Amin

Received May 19, 2010

also found that increasing of welding current or arc voltage increased the depth of weld penetration. The deepest penetration in this research was observed in 62 cm/min welding speed.

Introduction

The MAG is a welding process which yields coalescence of metals by heating with a welding arc between a continuous filler metal electrode and the workpiece. The continuous wire electrode which is drawn from a reel by an automatic wire feeder and then is fed through the contact tip inside the welding torch and afterward it is melted by the internal resistive power and heat transferred from the welding arc. Heat is concentrated by the welding arc from the end of the melting electrode to the molten weld pool and by the molten metal which is transferred to the weld pool [1, 2]. The MAG welding parameters are the most important factors affecting the quality, productivity and cost of welding joints [3, 4]. Weld bead size and shape are important considerations for design and manufacturing engineers in the fabrication industry. In fact, weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and mechanical devices [5]. Therefore, these parameters affecting the arc and welding bath should be estimated and their changing conditions during process must be known before in order to obtain optimum results. In fact, a perfect arc can be achieved when all the parameters are in conformity [6]. These are combined in two groups as first order adjustable and second order adjustable parameters defined before welding process. Former are welding current, arc voltage and welding speed, and later are torch angle, free wire length, nozzle distance, welding direction, position and the flow rate of gas [5, 7]. However, wire electrode diameter and its composition, type of protective gas are defined parameters before starting welding and cannot be changed during the process. The enough penetration, high heating rate and right welding profile assure the quality of welding joint. These are affected by welding current, arc voltage, welding speed and protective gas parameters [4, 6-8]. Funderburk [9] studied the effects of heat input on weld mechanical properties for SMA welding. The effects of friction welding parameters on weld mechanical properties were studied by Cavaliere et al. [10]. Also, Choi et al. [11] researched on effects of current and voltage on welding strength of Lap-joint with CO_2 welding process. The aim of present study is investigation on relationship between arc voltage, welding current and welding speed on mechanical properties and penetration of obtained weld bead in CK45 steel, welded by robotic MAG welding.

Material and Methods

In this study, due to high application in industry, welding assemblies were prepared from CK45 steel plates. In addition, ER70S-6 (AWS A5.18 Classification) wire electrode having 1 mm diameter was used as filling metal. The selection of the welding electrode wire was based principally upon matching the mechanical properties and physical characteristics of the base metal, weld size and existing electrode inventory. The chemical composition for weld wire is listed in Table 1.

Table 1. Chemical composition of the filler metal

Elements	P	S	Si	Mn	C	Cu
Wt%	0.035	0.025	0.95	1.63	0.11	0.5

Nozzle opening, the free wire length and wire feeding rate were 10 mm, 15 mm and 10 m/min, respectively. Arc distance was 3 mm, the torch angle was selected 5º. The multipass welds were used to joint the base metals and weld pool was protected by active CO_2 gas. The base materials were supplied in the form of plate with 20 mm thickness for tensile test and 10 mm thickness for bending and impact testing. These plates were cut into $60 \times 350\,\mathrm{mm}$ coupons with a 30° level of each plate to provide 60° groove angle for a single-V-groove butt joint configuration. Experimental test plates were located in the fixture jig for welding operation. MAG welding operations were performed by means of a SOS Model DR Series ARK ROBO 1500 welding robot having a working capacity of 0-600 A and 0-50 V ranges. The welding robot and its apparatus are shown in Figure 1. The chosen welding parameters for this study were arc voltage, welding current, welding speed. These parameters and limits employed are given in Table 1. All other parameters except these parameters under consideration were fixed.

Figure 1. The MAG welding robot and its apparatus.

Having finished the welding processes, tensile, bending, impact and hardness tests, were performed at room temperature in order to evaluate the mechanical properties of the weldments obtained in the different welding conditions. Cylindrical tensile specimens of 12.5 mm in diameter and 62.5 mm gauge length and in accordance with ASTM E8M-05 guidelines were prepared from the weldments and standard charpy V-notch impact specimens were machined in accordance to ASTM E23-96 specification. The charpy specimen contains a 45º V notch, 2 mm deep with a 0.25 mm root radius. Impact tests were performed to assess the impact energy of weld metal. Also, the bending specimens prepared in accordance with ASTM E190 guidelines. Specimens used in the characterization of the bending and impact properties of weld metal were extracted in a direction transverse to the weld and from the both welded coupons. Bend and charpy-V notch (CVN) specimens were $10 \times 15 \times 200\,\text{mm}^3$ and $10 \times 10 \times 55\,\text{mm}^3$, respectively. All notches in impact specimens were located at the centre of the weld deposit. Mechanism of bending test used in this work was free and three points bending test. The tensile and bending tests were carried out in a 20 KN capacity DARTEC testing machine, using a testing rate of 0.25 mm/s for tensile test and 0.1 mm/s for bending test. A Dynatup 8250 Impact Tester was used to carry out all the impact tests. Impact testing of the charpy specimens was performed at an impact velocity of 5.25 m/s in ambient environment using a tup capacity of 44.482 KN. Finally, brinel hardness (HB) indentations were made using a 15.3 kg load on the weldments surfaces in accordance with ASTM E10 guidelines. In order to investigate the relationship between the MAG welding parameters and bead penetration, after the welding processes, the specimens were cut perpendicular to welding direction by using a closed circuit saw in order to measure the penetration depth.

Results and Discussion

Total 27 experiments with different arc voltage, welding current and welding speed combinations were performed and the depth of penetration was measured for all cases. The results are tabulated in Table 2 and Figures 2-4. Also, these experiments were repeated for mechanical tests. The results of mechanical tests are illustrated in Figures 5-20.

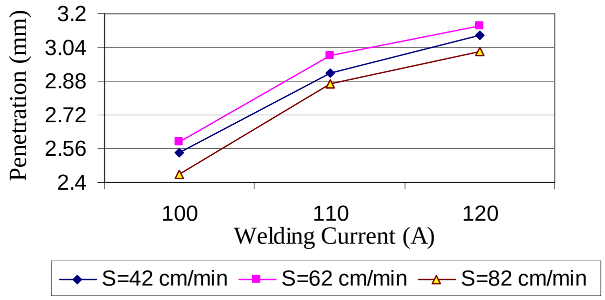

Figure 2. Penetration vs. welding current for 23 V.

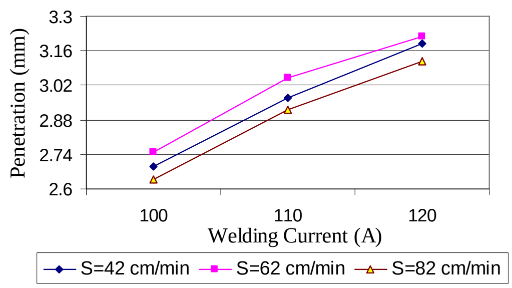

Figure 3. Penetration vs. welding current for 25 V.

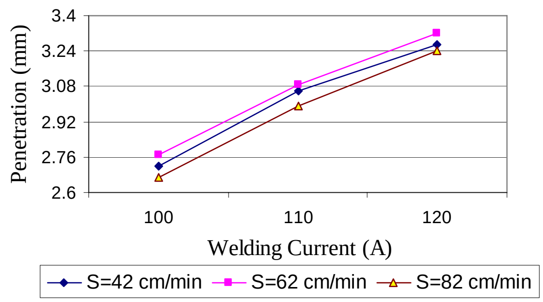

Figure 4. Penetration vs. welding current for 27 V.

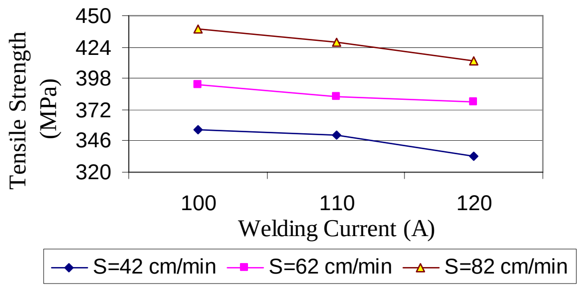

Figure 5. Tensile strength vs. welding current for 23 V.

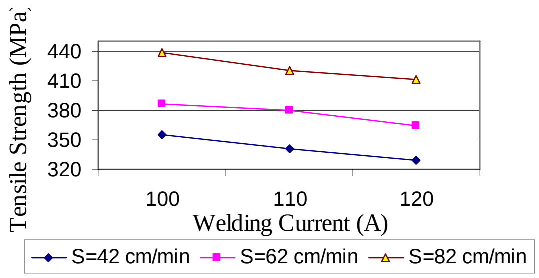

Figure 6. Tensile strength vs. welding current for 25 V.

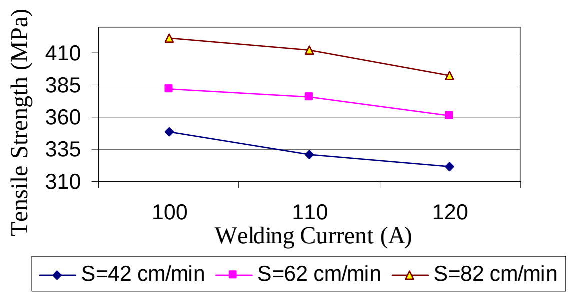

Figure 7. Tensile strength vs. welding current for 27 V.

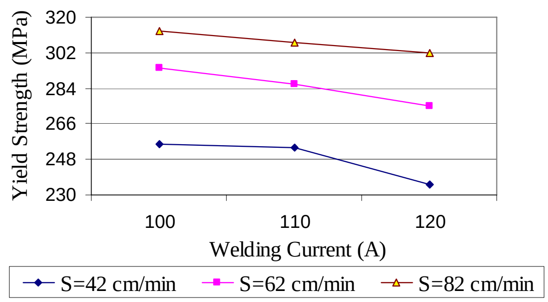

Figure 8. Yield strength vs. welding current for 23 V.

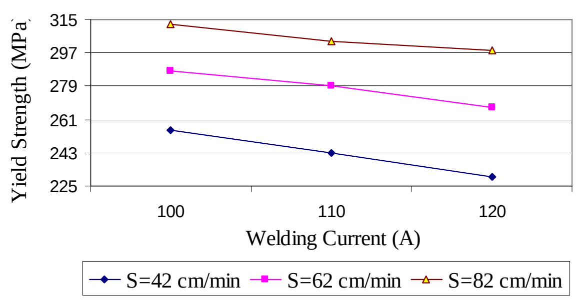

Figure 9. Yield strength vs. welding current for 25 V.

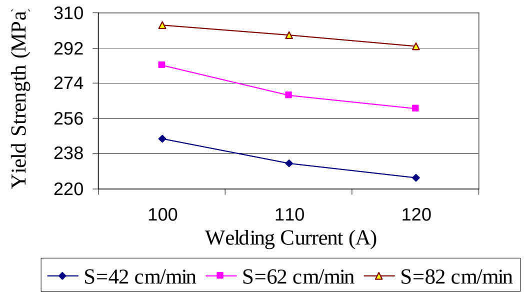

Figure 10. Yield strength vs. welding current for 27 V.

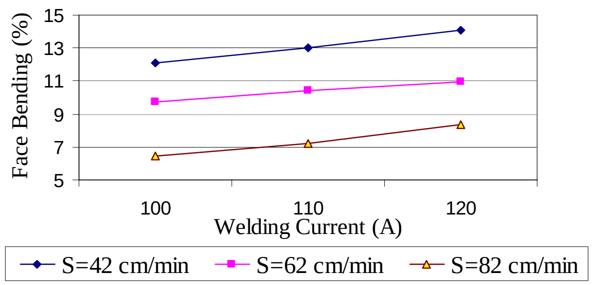

Figure 11. Face bending vs. welding current for 23 V.

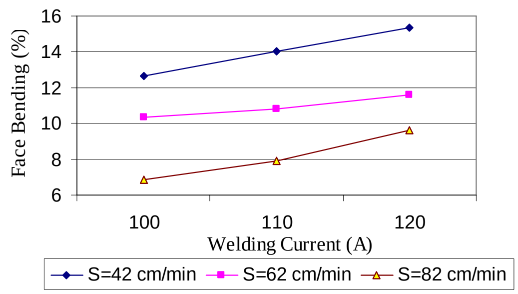

Figure 12. Face bending vs. welding current for 25 V.

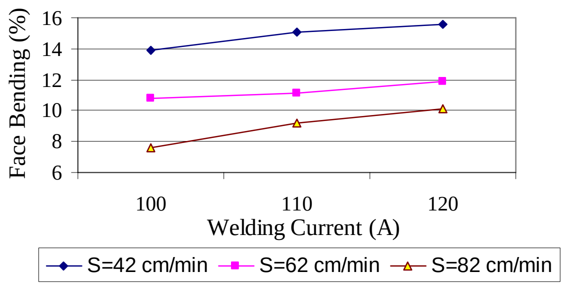

Figure 13. Face bending vs. welding current for 27 V.

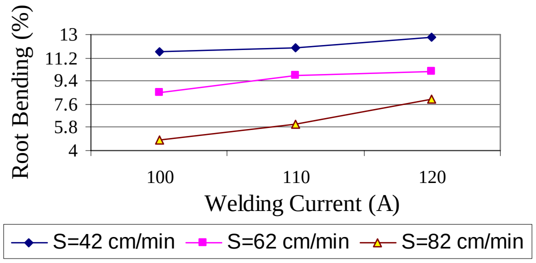

Figure 14. Root bending vs. welding current for 23 V.

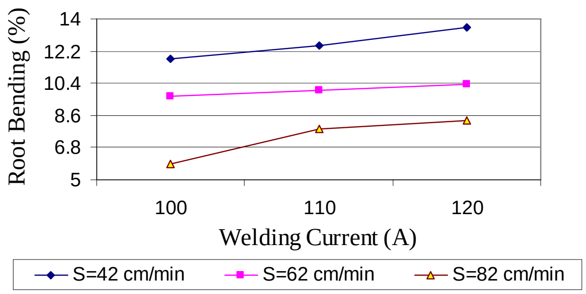

Figure 15. Root bending vs. welding current for 25 V.

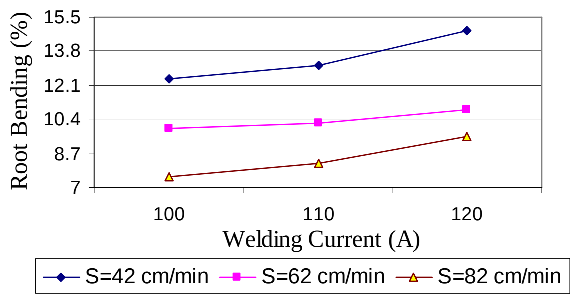

Figure 16. Root bending vs. welding current for 27 V.

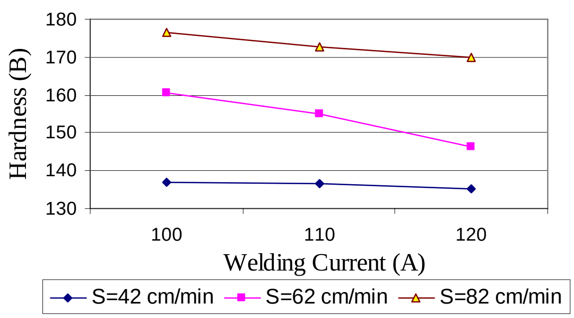

Figure 17. Hardness vs. welding current for 23 V.

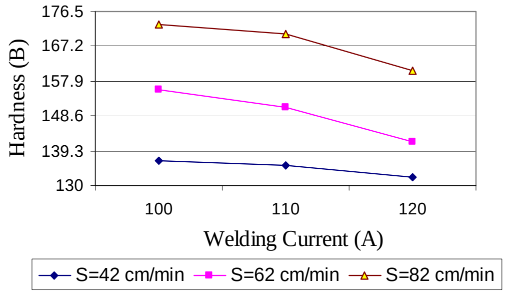

Figure 18. Hardness vs. welding current for 25 V.

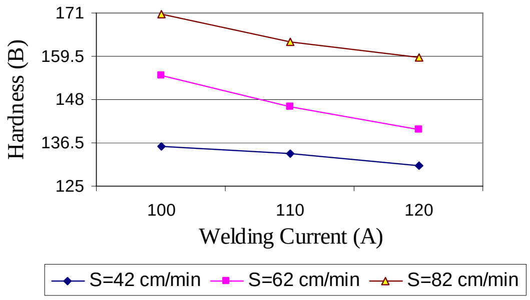

Figure 19. Hardness vs. welding current for 27 V.

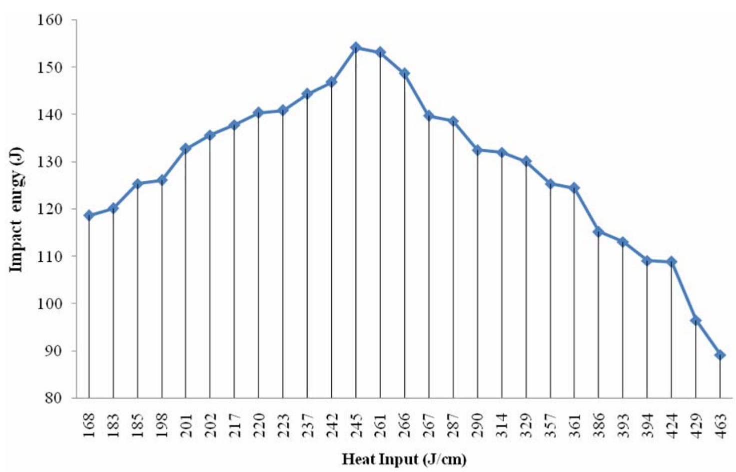

Figure 20. Impact energy of weld vs. heat input.

Table 2. The depth of penetration results of welding operations

Welding current (A)	Arc voltage (V)	Welding speed (cm/min)	Penetration (mm)
100	23	42	2.538
		62	2.592
		82	2.437
	25	42	2.694
		62	2.748
		82	2.635
	27	42	2.723
		62	2.769
		82	2.674
110	23	42	2.920
		62	3.011
		82	2.866
	25	42	2.969
		62	3.051
		82	2.918
	27	42	3.057
		62	3.094
		82	2.989
120	23	42	3.090
		62	3.141
		82	3.019
	25	42	3.188
		62	3.217
		82	3.121
	27	42	3.274
		62	3.320
		82	3.241

(a) Effect of arc voltage on penetration and mechanical properties of weld

According to Table 2 and Figures 2-4, when welding speed was fixed as 42 cm/min, the depth of penetration values were increased with increasing arc voltage for 100, 110 and 120 A and these were 0.185, 0.137 and 0.184 mm in 100, 110 and 120 A, respectively, for a 4 V increment between 23 and 27 V arc voltages. This condition was approximately same for 62 and 82 cm/min welding speed. For 62 cm/min welding speed, a linear penetration increase was observed with increasing arc voltages between 23 and 27 volt range and increase in depth of penetration was 0.177 mm for 100 A, 0.083 mm for 110 A and 0.179 mm for 120 A. For 82 cm/min welding speed, the increased penetration values were 0.237, 0.123 and 0.222 mm in 100, 110 and 120 A, respectively. The depth of penetration increased with increasing arc voltage linearly. Figures 5-10 and 17-19 showed clearly that the increase of arc voltage induces a marked decrease in tensile and yield strength and hardness of the weldments but elongation of weld increased linearly with increasing arc voltage between 23 and 27 V ranges. This increasing in tensile strength, yield strength, hardness and reduction in elongation of weldments, may be associated to the changes in the microstructures observed in the weld zone. According to following function [9] the change in welding parameters results in the variations in welding heat input:

$$H = (60\,EI/1000S), \tag{1}$$

where H = heat input (kJ/mm), E = arc voltage (volts), I = current (amp), S = travel speed (mm/min).

Varying the heat input typically will affect the mechanical properties and metallurgical structure in the weld. The heat input influences cooling rate of the weld. The following proportionality function shows the relationship between preheat temperature, heat input and cooling rate. These two variables (heat input and preheat temperature) interact with others such as material thickness, specific heat, density and thermal conductivity to influence the cooling rate [9],

$$R \propto 1/(T_{\circ}H), \tag{2}$$

where R = cooling rate (°C/sec), $T_{\circ}$ = preheat temperature (°C), H = heat input (kJ/mm).

The cooling rate is a primary factor that determines the final metallurgical structure and mechanical properties of the weld metal. As either the heat input increases, the cooling rate of weld decreases for a given weld metal [9] and decreases the volume fraction of martensite and binate phases and increases the coarsening of the microstructure of weld zone. Also, the results illustrated that other than impact energy of weld, all of the mechanical properties show a monotonic relationship to welding parameters, that is, the mechanical property only increases or decreases with increasing welding parameters. As heat input increases from 168.29 to 244.84 J/cm impact energy increases but with further increasing in heat input from

244.84 to 462.86 J/cm, fracture energy drops significantly. It is shown in Figure 20. It shows that change in impact energy of weldment is not just tied to the heat input, but is also significantly influenced by the weld bead size. As the bead size increases, which corresponds to a higher heat input, the fracture energy tends to decrease. In multiple-pass welds, a portion of the previous weld pass is refined, and the fracture toughness improved, as the heat from each pass tempers the weld metal below it. If the beads are smaller, more grain refinement occurs, resulting in better fracture toughness, all other factors being even [9].

(b) Effect of welding current on penetration and mechanical properties of weld

The effect of welding current on penetration was shown in Table 2 and Figures 2-4. When the welding speed was fixed as 42 cm/min, the highest penetration value was measured as 3.274 mm in 120 A and 27 V condition, while the smallest one as 2.538 mm in 100 A and 23 V and the depth of penetration increased with increasing welding current. This condition was approximately same for 62 and 82 cm/min, welding speed. When the welding speed was fixed as 62 cm/min, the highest penetration value was obtained as 3.320 in 120 A and 27 V, while the smallest one was obtained 2.592 mm in 100 A and 23 V. When the welding speed was fixed as 82 cm/min, the highest and smallest values were 3.241 and 2.437 mm which were obtained in similar conditions to 42 and 62 cm/min welding speed. A linear increase in depth of penetration with increasing welding current was observed commonly in all three different welding speeds. These measured values in penetration for each 1 A current rise in 42, 62 and 82 cm/min were 0.0368, 0.0364 and 0.0402 mm, respectively.

Effects of welding current on mechanical properties of weldment were similar to arc voltage effects but these effects were stronger in compared to arc voltage effects. The results showed that increase of welding current induces a marked decrease in tensile and yield strength and hardness of weld but elongation of weldments increases with welding current.

(c) Effect of welding speed on penetration and mechanical properties of weld

In attention to Table 2 and Figures 2-4 it was seen that the depth of penetration increased with increasing welding speed from 42 to 62 cm/min and reached to maximum value in this point but further increasing in welding speed resulted in decreasing the depth of penetration. The effect of welding speed on mechanical properties was reversed to arc voltage and welding current. When the welding speed increased, weld strength and hardness increases also, but elongation of face, root and side of weld decreased.

Conclusion

(1) The increase in arc voltage or welding current decreases clearly the tensile, yield strength and hardness of weldments but elongation of weld face, root and side increases with arc voltage or welding current. The effect of welding speed on mechanical properties is reversed to other parameters. When welding speed increases, weld strength and brinel hardness also increase but this increasing induces a marked decrease in elongation of weld face, root and side.

(2) The depth of penetration increases linearly with increasing welding current between 100 and 120 A and the average penetration rise was measured as 0.038 mm for each 1 A current increment. In addition to welding current, arc voltage also increases the penetration value however its effect is not as much as welding current. The deepest penetration obtained when the welding speed was 62 cm/min. The optimum configuration seems to be 110 A, 25 V and 82 cm/min to get appropriate penetration and weld joint. The effect of welding current was greater than that of arc voltage and welding speed on penetration.

Acknowledgements

The authors would like to thank Industrial & Manufacturing Company of Oghab Afshan for their financial support and Semnan University for all the facilities.

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