EFFECTS OF WELDING CURRENT AND ARC VOLTAGE ON FCAW WELD BEAD GEOMETRY

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Abstract

Flux cored arc welding(FCAW) process is characterized with its high deposition rate and productivity. Control of the operating parameters in FCAW is essential to obtain high production rates and good quality welds. Bead on plate welds were carried out on mild steel plates to study the influence of welding current and arc voltage on weld bead geometry parameters. The weld bead coss-sections were metallographically investigated. The effects of these welding parameters were evaluated by measuring penetration depth, reinforcement height, bead width, wetting angle, electrod deposit area and plate fusion area. The bead cross-section area and the weld shape factor were calculated from the measured results. The effects of welding parameters on weld bead geometry have been presented by histograms.

Key Words: Flux cored arc welding, arc welding parameters, weld bead geometry, weld shape factor

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1. INTRODUCTION

Flux cored arc welding (FCAW) is a fusion welding achieved by an electric arc produced between a continuous filler metal electrode and the weld pool [1]. In this method the filler metal of tubular shape is continuously fed and has a fluxed core which provides shielding capabilities to the welding process with or without additional shielding from an externally supplied protection gas. The core is mainly formed by slag formers, deoxidizers, arc stabilizers, and alloying elements. FCAW method have received great attention from welders and contractors because flux cored wire have a lot of advantages such as outstanding productivity, high quality welds, deep penetration, spatter reduced welding behavior, higher deposition rates, high welding speed and cost advantages [2]. FCAW may be applied semi automatically or automatically. The FCAW process has become a very popular semiautomatic process for structural steel fabrication [3], shipyard Works [4] and repairs [5-7]. FCAW is also readily accepted for weld cladding [8,9].

The profile of a weld bead geometry and its geometry parameters are schematically shown in Figure 1[10]. Weld geometry parameters are represented by bead width (W), height of reinforcement (H), depth of penetration (D), wetting angle (θ), electrode deposit area (A_d) and plate fusion area (A_m). These parameters are measured on images of weld beads. The weld bead cross-section area (A_t) is calculated by adding the electrode deposit area to the plate fusion area. Many researchers accepted the ratio of weld penetration depth to the weld width (D/W) is an important parameter to describe the weld profile [11-13]. This parameter is named as weld shape factor [14]. The weld bead geometry is directly dependent on welding parameters [15]. The cross-sectional area of the bead detemines the cooling rate of the weldment [16]. Bead cross-sectional area [17] and the ratio of penetration depth to weld width [10] determine the residual stresses and cracking of the weldment. Due to the above reasons, the quality and mechanical properties of weldments are dependent on size and shape of the weld bead [18,19]. Welding parameters must be optimized in order to obtain a good weld joint with the required bead geometry and weld quality [20]. There are also several publications about optimizations of the FCAW process by weld bead geometry analysis [21-35]. In these studies especially the effects of FCAW welding current, welding speed, arc voltage, electrod angle and nozzle to plate distance were investigated. The effects of these welding parameters on weld penetration depth, weld width and weld cross-sectional area were determined.



Fig-1: Geometry parameters of a bead on plate weld 10).
A_d: Electrode deposit area, A_m: Plate fusion area, D:
Penetration depth, H: Reinforcement height, W: Bead width, θ: Wetting angle

In this study the influence of the welding current and the arc voltage on weld bead geometry were investigated. These two welding parameters are very importanat in arc welding processes. In electric arc welding operations the heat input per unit length of the weld bead is calculated by equation 1 [36]:

$$H = \frac{I \cdot E}{S} f \qquad (1)$$

where I = welding current (Amperes), E = arc voltage (volts), S = welding speed (mm/s) and f = arc efficiency percentage.

2. EXPERIMENTS

In this investigation, 10 mm thick SAE 1015 steel plates were used. The plates were sawed into 350x100 mm stripes. Prior to the welding operations, the surface of stripes were cleaned with an abrasive wheel. Bead on plate welds were carried out using a semi automatic Askaynak Magtronik 500 W FCAW welding machine. The speed of the torch was controlled with a mechanized system and during each welding operation the welding speed was kept costant at 4 mm/s speed. The welding torch was kept at an inclination of 80° to the pull direction. AWS E71T-5 basic filler wire of diameter 1.2 mm was used in welding. In all the welding operations the distance between the work piece and the contact tip was fixed at 19.5 mm. Preheating was not used in welding operations. CO₂ shielding gas flow was kept at 12 lt/min. A 300 mm long weld was produced on each stripe. Three welds were produced at flat positions. The welding parameters and calculated heat input energy of the welds are shown in Table 1. The arc efficiency factor was accepted as %86 [37] for calculating the heat input.

 Table-1: The welding parameters and calculated heat input energy of the welds.

	Welding p	arameters	Welding heat input energy, J/mm	
Test number	Welding current, Amper	Arc voltage, Volt		
1	200	26,5	1140	
2	255	26,5	1453	
3	255	32,0	1754	

After finishing the welding processes, the welds were cut perpendicular to the welding direction by using a power hacksaw. A 30 mm long piece from the beginning and the end of the weld were cut out. The remaining of the weld was cut into 6 equal specimens. The cut surfaces of the specimens were polished using 600, 800, 1000 and 1200 grade SiC abrasive papers. Then the specimens were etched using 8% nital solution to reveal the weld bead size and shape. The etched sections were scanned to 1000% of the original size in a scanner and each weld bead was photographed. The weld bead geometry parameters were measured by using a planimeter, a ruler and a protactor on the macrostructure image photograph. We obtained 12 different results for each welding condition. Simple averages of the results were calculated to determine each weld bead geometry parameter and the weld shape factor.

3. RESULTS AND DISCUSSIONS

The objective of this study is to find out relationships between main two FCAW welding parameters (welding current and arc voltage) and weld bead geometry parameters. The effects of welding parameters on the weld bead geometry were obtained from the measurements made on the weld bead photographs and calculations of some measured results. Figure 2 shows a typical macroscopic cross-section of a weld bead. 12 photographs were obtained Simple averages of the measured for each weld bead. results were calculated. These results are shown in Table 2. The bead cross-sectional area and the ratio of penetration depth to weld width for each weld were also calculated. The obtained results are given in Table 2. The experimental results were given in terms of figures for better explainations of the welding parameter effects. In each figure there are three results. The first result belongs to the first weld. The aim of the first weld was to form the basis of the following comparisons: The second weld represents the effect of the weld current. The heat input energy difference between the first weld and the second weld was created by raising the weld current from 200 Amperes to 255 Amperes as indicated in Table 1. The third weld represents the effect of the arc voltage. The heat input energy difference between the second weld and the third weld was created by raising the arc voltage from 26.5 volts to 32 volts as indicated in Table 1. Thus, comparing the three results of a figure will reveal the welding parameter effect on the weld bead geometry parameter. For example Chart-1 shows the relationships between the welding parameters and the weld penetration depth.

Table-2: Weld geometry parameters of the weld beads.

Test	D	W	D/	Н	At	Am	Ad	Angle,
num	m	mm	W	mm	mm	mm ²	mm ²	degrees
ber	m				2			
1	2,1	12,5	0,1	3,58	42,	15,7	26,8	41
	7	5	7		60	8	2	
2	3,1	12,5	0,2	4,88	64,	20,2	43,7	64
	5	7	5		06	6	9	
3	3,1	16,3	0,1	3,54	65,	26,8	38,3	37
	5	9	9		20	7	3	



Fig-2: Typical macrography of a weld bead.

Penetration depth(D), weld width(W) and weld penetration depth to the weld width (D/W) ratio of the three welds are shown in Chart-1,2 and 3 respectively. Chart-1 shows that there is a 45% difference between the first and the second weld. Raising the weld current resulted with a pronounced

penetration depth increase. There is 313 J/mm heat input difference between the second weld and the first weld as shown in Table 1. This energy difference was obtained by increasing the welding current. This energy difference produced the distinguished penetration depth difference between the welds. There is 301 J/mm heat input difference between the third weld and the second weld as shown in This extra welding energy didn't cause a Table 1. penetration depth increase in the third weld. The results of Chart-1 indicate that the weld penetration depth is depended on the welding current and independent of the arc voltage. The effects of welding parameters on the weld width are shown in Chart-2. The second weld is a faintly wider than the first weld. There is a big difference between the third weld and the second one. The third weld is 30% wider than the second one. These results point out the important effect of the arc voltage on the weld width. Chart-3 shows how the welding parameters affect the weld shape factor (D/W ratio). The results of Chart-3 were directly produced from Chart-1 and 2 results. Chart 3 indicates that deep welds are obtained with high welding current and shallow welds are produced with high arc voltage.



Chart-1: The effect of the welding heat input on the weld depth of penetration (D).



Chart-2: The effect of the welding heat input on the weld bead width (W).



Chart-3: The effect of the welding heat input on the weld shape factor (D/W ratio).



Chart-4: The effect of the welding heat input on the weld plate fusion area (A_m).

Chart-4,5 and 6 inform how the welding parameters affect the weld bead area. Chart-4 shows that the plate fusion area (A_m) is direct proportion to the welding heat input energy. Welding current and arc voltage have similar effects on A_m . Chart-5 instructs us how the welding parameters affect the electrode deposit area (A_d) . The electrode deposit area of the second weld is very big. The electrode deposit area increased with the current. Raising the welding current resulted with a high melted electrode volume and a big A_d .



Chart-5: The effect of the welding heat input on the weld electrode deposit $area(A_d)$.



Chart-6: Figure 8. The effect of the welding heat input on the weld bead cross-section area (A_t) .

The electrode deposit area of the third weld is smaller than the second one. This result informs that less electrode is melted with the high arc voltage. It is evident that melting rate of the electrode decreases with increasing the arc voltage. Bead cross-section area (A_t) of the welds are shown in Chart-6. There is a big increase with the welding current and a small increase with the arc voltage.

Chart-7 shows the effects of the welding parameters on height of reinforcement (H). The second weld had a big H because, the electrode deposit area (A_d) of this weld was very big as shown in Chart-5 and its weld width didn't change a lot with the welding current as shown in Chart-2. In the third weld the bead width grew 30% (Chart-2) but the electrode deposit area showed an exiguous growth(Chart-5). Therefore the height of reinforcement (H) of the third weld was very small than the second weld. It was even smaller than the first weld. The size of the weld width and the reinforcement height determine the wetting angle (θ) of the weld. The wetting angle increases with the height of reinforcement and decreases with the weld width. Therefore, the wetting angle of the second weld was big and the wetting angle of the third was small as shown in Chart-8. The welding current density of an electrode increases with the welding current [2]. In arc welding the heating and the melting rate of the electrode increases with the welding current density [38,39]. Melting of an electrode becomes easier if it is over heated. More electrode metal enters the liquid weld pool as the electrode melting rate increases [25].



Chart-7: The effect of the welding heat input on the weld height of reinforcement (H).

The electrode deposit area enlarges with increasing the welding current [40] as shown in Chart-5. The temperature of the droplets which are formed at the tip of the electrode rises with the welding current [41]. The size of the droplets decreases and their formation frequency increases with the droplet temperature [10]. The falling velocity of the droplets also increases with the temperature [42]. The momentum of the droplets increases with the welding current which affects the penetration depth. A deeper weld bead was obtained with the high welding current [10,41]. The second weld which had a higher welding current than the first one gave a deeper bead as shown in Chart-1. The electrode deposit area of the second weld was very big (Chart-5) because, more electrode was melted and more metal was trasferred to the weld pool. High amount of metal and hotter metal transfer to the welding pool caused a high heat input in the workpiece [41]. A higher energy input enlarged the melting volume of the workpiece. As a result the plate fusion area (A_m) increased as shown in Chart-4. Although both the electrode deposit area and the plate fusion area enlarged with the welding current, their growing rates weren't equal. Their growing rates could be be calculated by the results given in Chart-4 and 5. The growth rate of A_m was not as big as the A_d growth rate. The weld current had a negligible effect on the weld width (Chart-3). The weld width grew slightly. This slight weld width grow affected D/W ratio, height of reinforcement (H) and the wetting angle (θ). D/W ratio of the second weld was the biggest (Chart-3) [26] because, in this weld the weld depth increased but the width showed a very small increase. The big electrode deposit area growth of the second weld caused a high height of reinforcement (H) (Chart-8) [43,44] and a high wetting angle (Chart-8) [27].

A raising in the arc voltage increases the heat input of the weld according to the Equation 1[36]. This increased heat input has a small effect on the electrode melting rate[10]. There are conflicting results about the effect of the arc voltage on the electrode melting rate. Gunaraj [45] identified a minor increase in electrode melting rate but, Ostsemin [39] stated a decreased melting rate. The electrode deposite area of the third weld was smaller than the second weld as shown in Chart-5. This resultant supported Ostsemin's results. The arc voltage mainly controls weld arc geometry [2]. The bottom diameter of the arc enlarges with the arc voltage [41].



Chart-8: The effect of the welding heat input on the weld wetting angle (θ) .

The enlargement of the arc bottom causes more heating and melting at the surface of the workpiece [42,46]. Thus, a wider weld bead was obtained with a high arc voltage [27]. The third weld which has the highest arc voltage gave the widest weld bead (Chart-2). More heating at the surface of the workpiece causes more workpiece melting and a big plate fusion area [10]. The third weld which has the highest arc voltage gave the biggest plate fusion area as shown in Chart-4. The increased arc voltage doesn't change the droplet formation frequency at the tip of the electrode [41]. droplet temperature [39], droplet falling velocity [41] and momentum of droplets [41]. Therefore, the penetration depth of the the third weld didn't increase with the heat input (Chart-1). In the third weld the height of reinforcement(H) was small (Chart-7) because, the bead width increased and the electrode deposit area decreased with the arc voltage. The wetting angle was also decreased (Chart-8) according to the profile of the weld bead [42].

4. CONCLUSIONS

In this article, an experimental study was conducted to investigate the influence of welding parameters in FCAW process particularly welding current and arc voltage on weld bead dimensions. From the above investigations following conclusions have been drawn:

- Melting rate of a FCAW electrode increases with the welding current and it decreases with the arc voltage.
- The plate fusion area depends on the heat input of the weld.
- The height of reinforcement(H), the depth of penetration(D) and the wetting angle(θ) increase with the welding current.
- The arc voltage increases the weld width.

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