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# Influence of Welding Current, Arc Voltage and Welding Speed on Hardness and Microstructure Behavior of Weld in AISI 4140 Steel Joint Produced by FCAW

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**Abstract:** In this study, the effect of various welding parameters on weld hardness and microstructure feature in AISI 4140 steel having 6 mm thickness welded by robotic FCAW-G were investigated. The welding current, arc voltage and welding speed were chosen as variable parameters. The brinel and metallography tests ware performed for each specimen after the welding operations and the effects of these parameters on hardness and microstructure evolution of weld were researched. The welding currents were chosen as 100, 140 and 180A, arc voltages were chosen as 20, 25 and 30V and welding speeds were chosen as 30, 45 and 60 cm/min for all experiments. As a result of this study, it was obvious that arc voltage and welding current have similar effects on hardness, grain size and phases transformation in weld metal while the effect of welding speed on weld properties was reversed to others parameters.

**Key words:** FCAW · AISI 4140 steel · Welding parameters · Hardness · Microstructure · Heat input

## INTRODUCTION

FCAW-G process used in the experimental stage is a fully automated process, in which the welding electrode is a tubular wire that is continuously fed to the weld area. The flux materials are in the core of the tube. The outer shell of the tube conducts the electricity that forms the arc and then becomes the filler metal as it is consumed [1]. Recent studies indicate [2-4] that FCAW has a number of advantages over the common welding techniques available that use solid wires such as manual metal arc welding (MMAW) and gas metal arc welding (GMAW). During the past 20 years significant progress has been made in understanding the solidification behavior of welds and the evolution of microstructure [5,6]. Muthupandi *et al.* [7] researched on Effect of weld metal chemistry and heat input on the structure of duplex stainless steel welds. Relationship between friction stir welding parameters and microstructure properties of AA6056 joints was studied by Cavaliere *et al.* [8] also effects of heat input on the microstructure of the 8 MnMoNi 5 5 shape-welded nuclear steel was predicted by Million *et al.* [9]. The present work is aimed to the evaluation of the welding current, arc voltage and welding speed effect on hardness and microstructure behavior of welded joints produced of AISI 4140 steel.

## MATERIALS AND METHODS

In this study, welds were produced in coupon plates of AISI 4140 steel with 6mm thickness, using a FCAW process. The chemical composition of base metal was listed in Table 1.

100% $CO_2$ was used as shielding gas to protect weld pool. In addition, flux cored wire of 1.6 mm diameter (AWS classification E70T5) as filling metal employed on FCAW machine. 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. Robotic FCAW operations were performed by means of a WOD-E 1595 Model DK Series ARK ROBO 1350 welding robot having a working capacity of 0-600A and 0-50V ranges. The chosen welding parameters for this study were arc voltage, welding current and welding speed. These parameters and limits employed were given in Table 2.

After welding process, brinel hardness indentations were made using a 15.63 kg load on the weldments cross surface and for characterizing of weld microstructure, weld surface was removed from each combination and grounded through 200-1000 mesh using grinding papers and then polished. The samples were etched in 2% Nital solution in methanol for 4 s. In the present work, optical

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Table 1: Chemical composition of base metal

| Element | C | Si | Mn | P | S | Cr | Mo | Ni | Cu | Ti | V | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| wt(%) | 0.417 | 0.26 | 0.772 | 0.008 | 0.005 | 0.923 | 0.157 | 0.051 | 0.05 | 0.002 | 0.003 | 0.029 |

Table 2: Process parameters and limits

| Parameter | Symbol | Unit | Limits |
|---|---|---|---|
| Welding current | I | Amp | 100, 140 and 180 |
| Arc voltage | V | Volt | 20, 25 and 30 |
| Welding speed | S | cm/min | 30, 45 and 60 |

examination of samples was carried out using a Nikon DIC microscope. All experiments were performed at Semnan University in Iran during 2009.

## RESULTS AND DESCUSION

Totally 27 experiments with different welding currents, arc voltages and welding speeds combinations were performed and the hardness values were measured for all cases. The results were tabulated as in Table 3 and were shown in Figs. 1-3.

Figs. 1-3 showed clearly that the increase of welding current between 100 and 180 A and arc voltage between 20 and 30 V induces a marked decrease in hardness of the weldments but increasing in welding speed between 30 to 60 cm/min increases weld hardness. This behavior can be associated to the changes in microstructures observed in the weld zone. According to Eq. 1, the change in FCA welding parameters results in the variations in welding heat input:

$$H = \eta(UI/S) \quad (1)$$

Where,

H = heat input (kJ/mm)

$\eta$ = arc efficiency factor

U = arc voltage (V)

I = current intensity (A)

S = welding speed (mm/min)

Varying the heat input typically will affect the mechanical properties and microstructure of weld. The heat input influences on cooling rate of the weld. The Eq.2 shows this relationship between preheat temperature, heat input and cooling rate for FCA welding process.

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 [10].

Table 3: Different condition for welding process

| Welding current (A) | Arc voltage (v) | Welding speed (cm/min) | Weld Hardness (HB) |
|---|---|---|---|
| 100 | 20 | 30 | 141.95 |
| | | 45 | 165.71 |
| | | 60 | 181.56 |
| | 25 | 30 | 141.78 |
| | | 45 | 160.68 |
| | | 60 | 178.14 |
| | 30 | 30 | 140.61 |
| | | 45 | 159.48 |
| | | 60 | 175.65 |
| 140 | 20 | 30 | 141.48 |
| | | 45 | 160.13 |
| | | 60 | 177.85 |
| | 25 | 30 | 140.29 |
| | | 45 | 156.01 |
| | | 60 | 175.48 |
| | 30 | 30 | 138.64 |
| | | 45 | 151.09 |
| | | 60 | 168.19 |
| 180 | 20 | 30 | 140.12 |
| | | 45 | 151.44 |
| | | 60 | 175.08 |
| | 25 | 30 | 137.18 |
| | | 45 | 146.58 |
| | | 60 | 165.84 |
| | 30 | 30 | 135.59 |
| | | 45 | 145.07 |
| | | 60 | 164.25 |

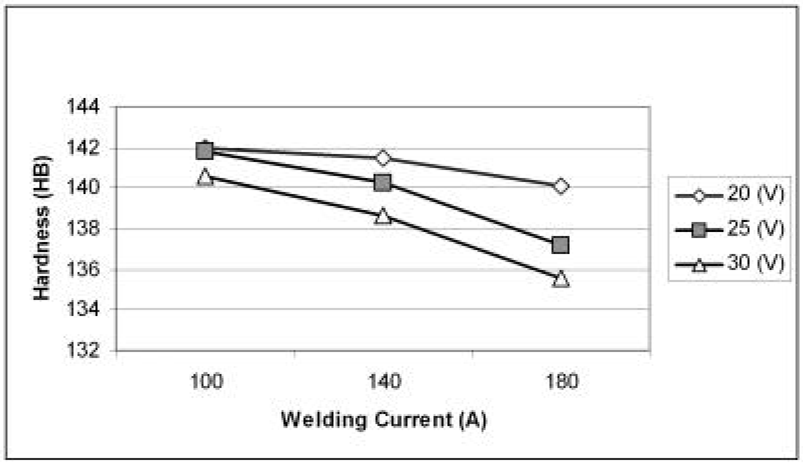


Fig. 1: Weld hardness vs. welding current in S=30 cm/min

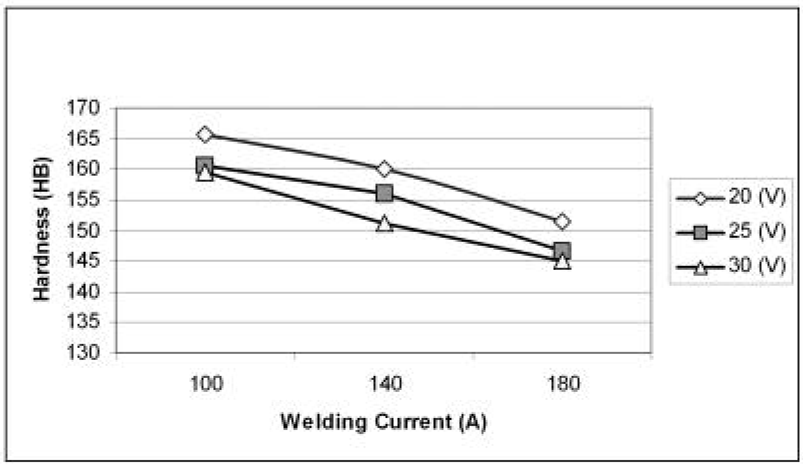


Fig. 2: Weld hardness vs. welding current in S=45 cm/min

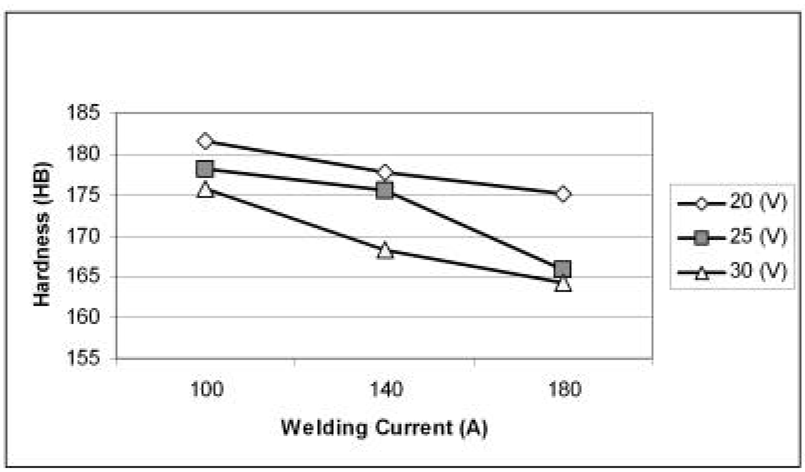


Fig. 3: Weld hardness vs. welding current in S=60 cm/min

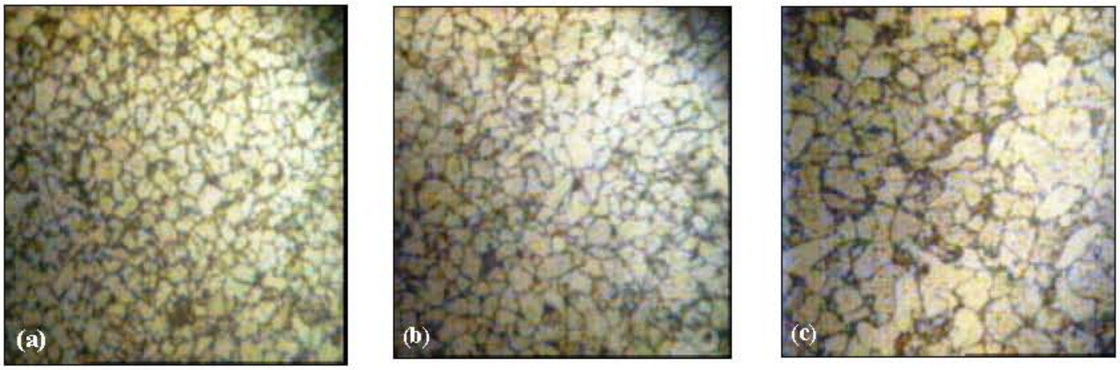


Fig. 4: Microstructure of weld metal for V=25V, S=45cm/min and (a) 100, (b) 140 and (c) 180 A, 1000×.

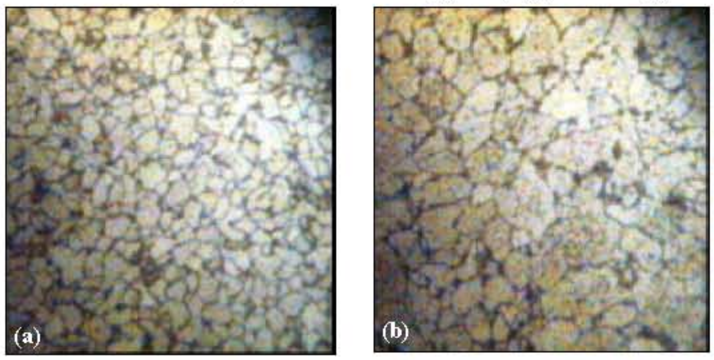


Fig. 5: Microstructure of weld metal for I=140A, S=45cm/min and (a) 20 and (b) 30 V, 1000×.

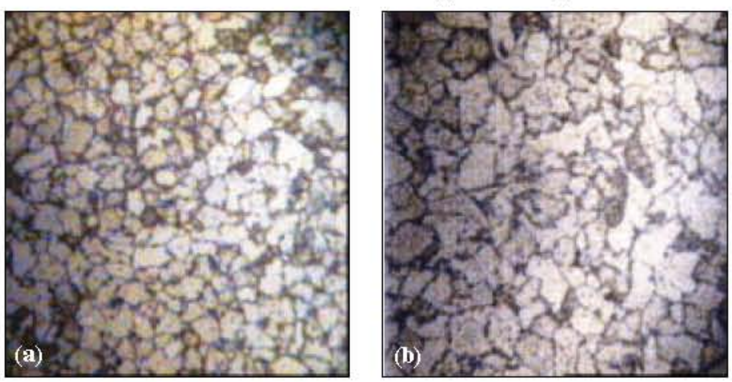


Fig. 6: Microstructure of weld metal for V=25V, I=140A and (a) 60 and (b) 45 cm/min,1000×.

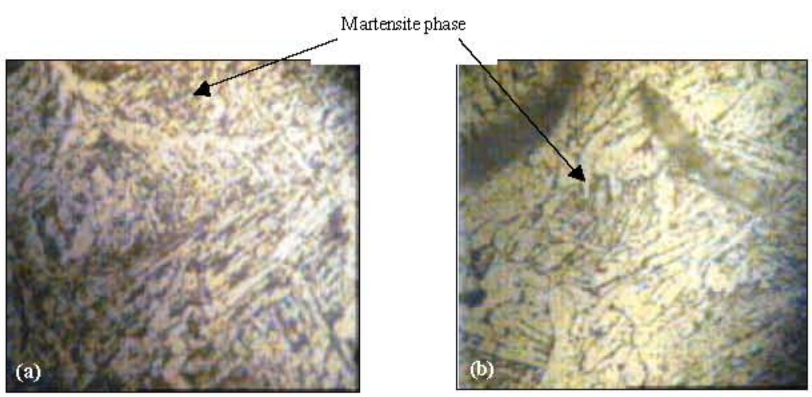


Fig. 7: Microstructure of weld metal for heat input (a) 130 J/mm and (b) 160 J/mm, 1000×.

$$R \propto 1/(T_o H) \quad (2)$$

Where,
R = cooling rate (°C/sec)
$T_o$ = preheat temperature (°C)
H = heat input (kJ/mm)

The cooling rate is a primary factor which determines the final metallurgical structure and mechanical properties of the weld metal. As either the heat input increases, the cooling rate decreases for a given weld metal [10] and decreases the volume fraction of martensite and increases the coarsening of the microstructure of weld zone. Hardness of weld increases with increasing the volume fraction of martensite but increasing grain size results in decreasing the hardness. The metallographic test results were illustrated in Figs. 4-7.

## CONCLUSION

According to the results obtained from robotic FCA welding applied to AISI 4140 steel:

- Brinel hardness of weldments decreased clearly with increasing in arc voltage and welding current while effect of welding speed on hardness was reversed to other parameters. When welding speed was increased, weld hardness also increased.
- Heat input increases with increasing arc voltage and welding current while increasing in welding speed results in decreasing in welding heat input. As either the heat input increases, the cooling rate decreases for a given weld metal and decreases the volume fraction of martensite and increases the coarsening of the microstructure of weld zone.
- Maximum value for weld hardness was measured as 181.56 HB in 100A, 20V and 60 cm/min and seems it be the optimum state while the minimum value was 135.59 HB in 180A, 30V and 30 cm/min conditions.

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