EFFECT OF THE ROBOTIC GMAW PARAMETERS ON THE HAZ WIDTH IN HQ130 STEEL JOINTS

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Gas-metal arc welding (GMAW) has received much attention over the last several years and has numerous wide and beneficial applications in different industries. The heat-affected zone (HAZ) is the region between the base and weld metal characterized by the lowest toughness in a welding joint. Hence, this zone is always a matter of interest for many researchers. Our study is focused on the effects of GMAW parameters, including the electrode-to-work angle (φ), filler metal diameter (d), and shielding gas type (SGT) on the average HAZ width (AHW) in HQ130 steel. With this aim, different welding samples were produced by employing electrode-to-work angles of 65°, 75° and 85°; filler metal diameters of 0.8 mm, 1 mm, and 1.2 mm, and argon, helium, and carbon dioxide as shielding gases. After termination of the welding process, the average HAZ width was experimentally measured and discussed for all samples. The results of this study indicate that the variations of robotic GMAW parameters have significant effects upon the average HAZ width.

Keywords: gas-metal arc welding, welding parameters, HQ130 steel, heat-affected zone, average width of the heat-affected zone.

Introduction

Welding is an important process commonly used to join different materials [1]. The process of gas-metal arc welding (GMAW) {including two states: "metal–inert gas" (MIG) and "metal-active gas" (MAG) [2]} was introduced in the early 1900s. In 1948, the process became commercially accessible [2, 3]. This process is widely used in various branches of industry, including gas pipelines, petrochemical plants, and automotive and ship building. As the main merits of this process, we can mention its high productivity rate (caused by the continuous feed of the wire electrode), low discontinuity of the weld, absence of slag inclusions, and low thermal hazard on the base metal [4].

The robotic welding process has more advantages than the conventional manual process because the quality of the weld is more consistent, the process speed is higher as compared with the manual process; moreover, the process has less wastes and reduced cost [5]. The term heat-affected zone (HAZ) refers to a nonmelted area adjacent to the weld metal in fusion welding processes, which undergoes numerous microstructural changes as compared with the base metal. In several studies [6–11], it was indicated that the HAZ may have the lowest toughness in the welded joint and, hence, the importance of HAZ was emphasized. With intensification of the use of welded steel structures, it becomes clear that the HAZ shows susceptibility to various types of cracking, especially cold cracking, which was attributed to the formation of very susceptible HAZ microstructures [12]. Therefore, in the analysis of all these problems, it seems likely that the minimization of HAZ width should be

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Table 1

Various Combinations of Parameters for the Present Study

Test No.	φ, deg	d, mm	SGT
a_1	65	1.6	CO_2
a_2	75	1.6	CO_2
a_3	85	1.6	CO_2
b_1	80	1.2	CO_2
b_2	80	1	CO_2
b_3	80	0.8	CO_2
c_1	80	1.6	Argon
c_2	80	1.6	Helium
c_3	80	1.6	CO_2

quite helpful. The HQ130 steel is a high-strength steel and its tensile strength exceeds 1300 MPa [13]. Moreover, this is newly developed low-carbon quenched-and-tempered steel used for engineering machinery [14]. As far as we know, there is relatively little information regarding the HAZ width in steels. Therefore, in the present work, we make an attempt to investigate the effects of robotic GMAW parameters on the HAZ width in HQ130 steel.

Materials and Methods

Due to their high industrial importance, HQ130 steel plates 5 mm in thickness were chosen as base material in our study. They have the following chemical composition of the base material (wt.%): 0.176 C, 0.275 Si, 1.221 Mn, 0.284 Mo, 0.55 Cr, 0.03 Ni, 0.0013 B, 0.0058 S, and 0.027 P.

As in our previous studies (see [15–17]), the GMAW process was performed by means of a SOS Model DR Series ARK ROBO-1500 welding robot with a capacity of 0–600 A and 0–50 V ranges. Single-pass butt welds were used to join the base materials and ER70S-6 (AWS A5.18 classification) wire electrodes with a composition of 0.11C–1.63Mn–0.95Si–0.5Cu (wt.%) used as the filler metal. To prevent welding distortion, tested plates were placed in a fixture jig prior to welding operations.

For this study, we have chosen the following parameters: the electrode-to-work angle (φ), the diameter of the filler metal (d), and the type of shielding gas (SGT). Different combinations of parameters for the present study are tabulated in Table 1. In addition, fixed values of the parameters during welding operations are given in Table 2. After termination of the welding process, welded specimens were cut perpendicularly to the direction of welding by using a power hacksaw. Then the cross sections of the specimens were machined, removed from any combination, polished, and etched with a 2.5% Nital solution in order to measure the average HAZ width (AHW).

**Table 2**
Fixed Parameters During Welding Operations

| Parameter	Limit / Type
Cylinder pressure	135 bar
Cylinder outlet pressure	14 l/min
Nozzle opening	10 mm
Electrode stick out	15 mm
Arc length	3 mm
Nozzle-to-work distance	18 mm
Contact-tip-to-work distance	18 mm
Arc voltage	23 V
Welding current	140 A
Welding speed	60 cm/min
Wire feeding rate	8 m/min
Polarity	DCEP

Results and Discussion

The effects of the parameters of robotic GMAW process on the weld geometry in HQ130 steel joints were studied in the available literature [18]. Hence, in this study, we focus our attention specifically on the HAZ width. In total, we performed nine experiments with different electrode-to-work angles, filler metal diameters, and shielding gases. Moreover, the AHW value was measured in all experiments. The experimental results obtained in the presented study are illustrated in Figs. 1 and 2.

For the investigation of the influence of electrode-to-work angle on the AHW value, we chose a diameter of 1.6 mm for the filler metal, carbon dioxide was chosen as the shielding gas, and the electrode-to-work angle was increased from 65° to 85°. As shown in Figs. 1 and 2, the AHW value increases from 1.32 mm to 2.93 mm as the electrode-to-work angle increases from 65° to 85°, whereas the average increase in the AHW value was equal to 0.081 mm per 1° increment of the electrode-to-work angle. The AHW value increased by 0.53 mm and by 1.08 mm as the electrode-to-work angle increased from 65° to 75° and from 75° to 85°, respectively. This means that the increase in the electrode-to-work angle within the range 75–85° causes an increase in the AHW value, which is twice higher than within range 65–75°.

In order to study the effect of the diameter of filler metal on the value of AHW, the electrode-to-work angle was fixed at 80°, carbon dioxide was chosen as the shielding gas, and the diameter of filler metal was elevated from 0.8 mm to 1.2 mm. The AHW value decreased from 2.87 mm to 1.48 mm as the filler metal diameter increased from 0.8 mm to 1.2 mm. Moreover, the average decrease in the AHW value was 0.35 mm per 0.1 mm
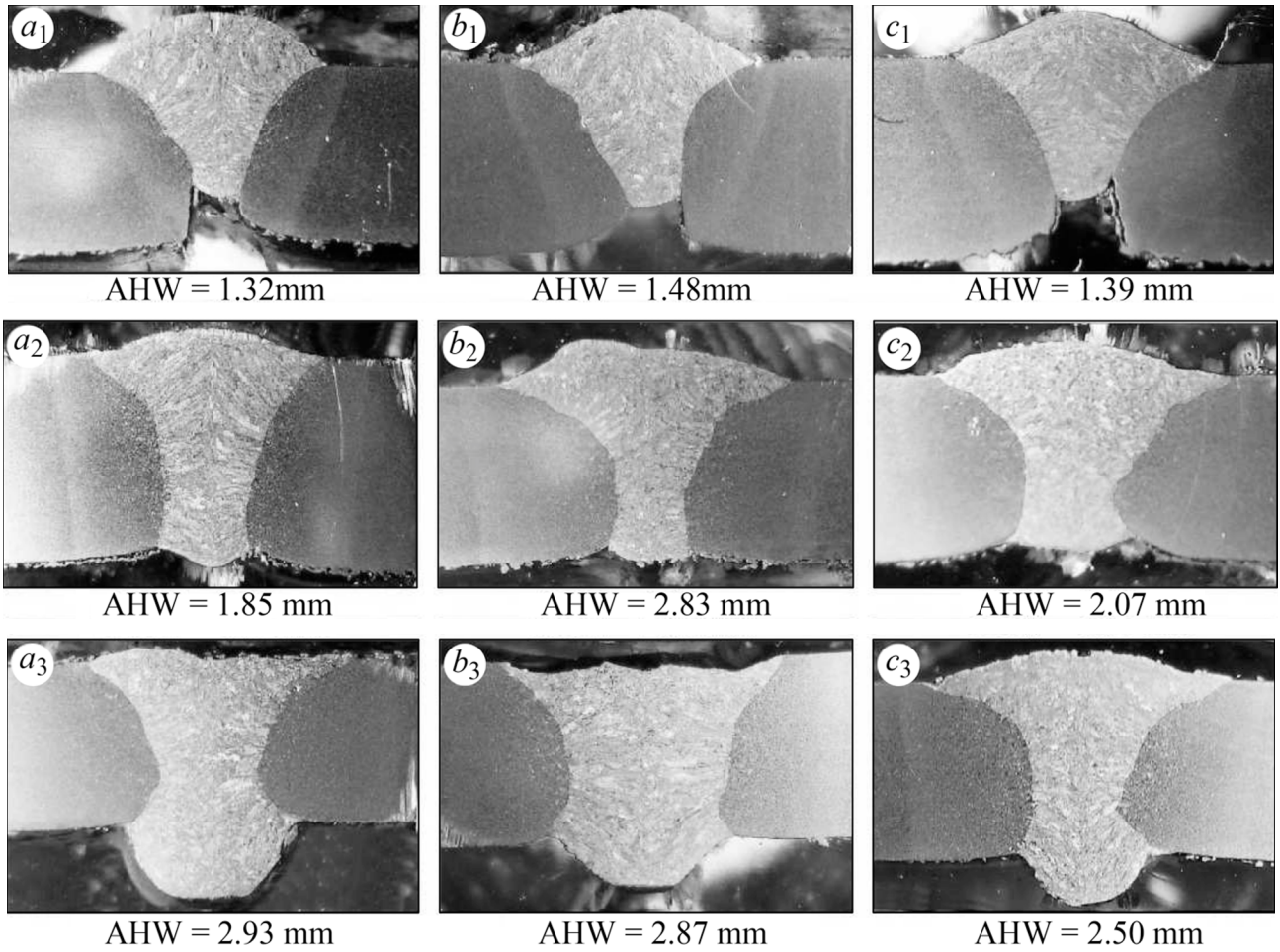
Fig. 1. Measured experimental values of AHW.
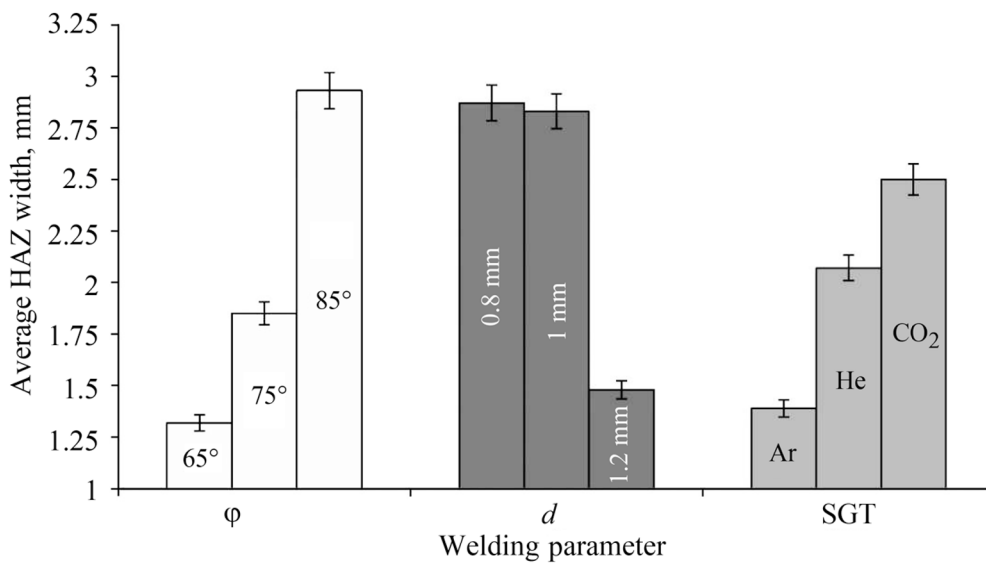
Fig. 2. The effects of welding parameters on the AHW.

increment of the diameter of filler metal (Figs. 1, 2). The AHW value decreased by 0.04 mm and 1.35 mm as the filler metal diameter was increased from 0.8 mm to 1 mm and from 1 mm to 1.2 mm, respectively. This means that the decrease in the AHW value caused by the increment of the filler-metal diameter within the range 1–1.2 mm is much more pronounced than within the range 0.8–1 mm. These observations can be based on the focus of the electric arc and its efficiency. The focus of the electric arc and its heat on the base materials and the joint area increases with an increase in the electrode-to-work angle and/or decrease in the filler-metal diameter. Moreover, the efficiency of the electric arc increases in this case. Thus, the heat produced by the electric-arc and received by the base materials and the joint area increases, which leads to the elevation of the AHW value.

In order to understand the effect of the type of shielding gas on the AHW value, the electrode-to-work angle was set equal to 80°, a diameter of 1.6 mm was chosen for the filler metal, and welding processes were carried out by using (separately) argon, helium, and carbon dioxide as shielding gases. Carbon dioxide (as the active shielding gas) and argon and helium (as inert shielding gases) are commonly used in the GMAW process. According to Figs. 1 and 2, the highest AHW value equal to 2.5 mm was obtained by using carbon dioxide as a shielding gas. At the same time, the AHW value obtained when using argon as shielding gas (1.39 mm) was the lowest under the indicated conditions. The carbon-dioxide-shielded arc leads to the formation of a weld bead of excellent penetration with rougher surface profile. Helium has a higher thermal conductivity than argon and also produces arc plasma in which the arc energy is more uniformly dispersed. The argon-arc plasma is characterized by a very high energy of the inner core and the outer mantle with lower heat energy. The helium arc produces a deep broad parabolic weld bead [19]. These phenomena and the characteristics of shielding gases may strongly affect the value of AHW.

CONCLUSIONS

According to the obtained data, as a result of the robotic GMAW process applied to HQ130 steel with a thickness of 5 mm, the AHW value increased from 1.32 mm to 2.93 mm as the electrode-to-work angle increased from 65° to 85°, whereas the average increase in the AHW value was equal to 0.081 mm per 1° increment of the electrode-to-work angle. Moreover, the AHW value decreased from 2.87 mm to 1.48 mm as the diameter of the filler metal increased from 0.8 mm to 1.2 mm. In this case, the average decrement of the AHW value was equal to 0.35 mm per 0.1 mm increment of the diameter of filler metal. The use of an active shielding gas leads to higher AHW values than for the inert shielding gas. The highest AHW value equal to 2.5 mm was obtained when using carbon dioxide as a shielding gas, while the AHW value obtained by using argon as a shielding gas (1.39 mm) proved to be the lowest under the analyzed conditions.

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