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

H. R. GHAZVINLOO, A. HONARBAKHSH-RAOUF

Department of Materials Engineering, Semnan University, Semnan, Iran

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

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

Останнім часом електродуговому зварюванню металів у газі (GMAW) приділяють особливу увагу через його ефективне застосування у різних галузях промисловості. Зона термічного впливу (HAZ) відзначається найнижчою в'язкістю у зварному з'єднанні і тому викликає особливу зацікавленість багатьох дослідників. Розглянуто вплив параметрів GMAW, зокрема, кута робочого електрода (φ), діаметра металевого наповнювача (*d*) і типу захисного газу (SGT) на середню ширину HAZ (AHW) в сталі HQ130. Для цього використано різні зварювальні зразки з кутами 65°, 75° та 85°; діаметрами 0,8 mm, 1 mm та 1,2 mm, а також аргон, гелій і діоксид вуглецю як SGT. Визначено та проаналізовано ширину HAZ. Показано, що відмінності у параметрах роботизованого GMAW суттєво впливають на AHW.

Ключові слова: *електродугове зварювання металів у газі, робочі параметри, сталь HQ130, зона термічного впливу, середня ширина зони термічного впливу.*

Introduction. Welding is an important process commonly used to join different materials together [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 1900 s. 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, no slag inclusions, and low thermal hazard on the base metal [4]. The robotic welding process has more advantages than the conventional manual process, since the quality of the weld is more consistent, the process speed is higher compared with manual, there is less waste and a reduced cost [5]. The HAZ refers to a non-melted area adjacent to weld metal in the fusion welding processes

Corresponding authors: H. R. GHAZVINLOO, e-mail: Hamid.Ghazvinloo@gmail.com

which undergoes a lot of microstructural changes compared to base metal. Several studies [6–11] have indicated that HAZ can have the lowest toughness in a welded joint and hence emphasize the importance of the HAZ. With increasing use of welded steel constructions, it becomes apparent that the HAZ shows susceptibility to various types of cracking, especially cold cracking which has been attributed to the formation of a very susceptible HAZ microstructure [12]. So with considering all these problems, it makes sense that the minimizing of HAZ width will only help. Steel HQ130 is one of the high-strength steels and its tensile strength is more than 1300 MPa [13] and is newly developed low carbon quenched-and-tempered steel used for engineering machinery [14]. From what we know, there is relatively little information regarding the HAZ width in steels. Therefore, an attempt has been made in the present work to investigate the effects of robotic GMAW parameters on HAZ width in HQ130 steel.

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

Table 1. The different combinations of parameters for present study

Test No.	φ, degree	*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

Table 2. The 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

Similar to our previous studies [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. The single-pass butt welds were used to join the base materials and the ER70S-6 (AWS A5.18 classification) wire electrode with composition of 0.11C–1.63Mn–0.95Si–0.5Cu (wt.%) was used as filler metal. To prevent welding distortion, test plates were located in the fixture jig before welding operations.

The chosen parameters for this study were: electrode to work angle (φ), filler metal diameter (*d*), and shielding gas type (SGT). The different combinations of parameters for present study are tabulated in Table 1 and also the fixed parameters during welding operations are given in Table 2. Having finished the welding process, the welding specimens were cut perpendicular to the direction of welding by using a power hacksaw. Then the cross-sections were machined, removed from any combination, polished, and etched with 2.5% nital solution in order to measure the average HAZ width (AHW).

Results and discuttion. The effects of the robotic GMAW process parameters on weld geometry in HQ130 steel joints were studied in previous literature [18]. So in this study, we focus specifically on HAZ width. Totally, nine experiments with different electrode to work angles, filler metal diameters, and shielding gases were performed and the AHW value was measured for all experiments. The experimental results obtained in this study are illustrated in Figs. 1 and 2.

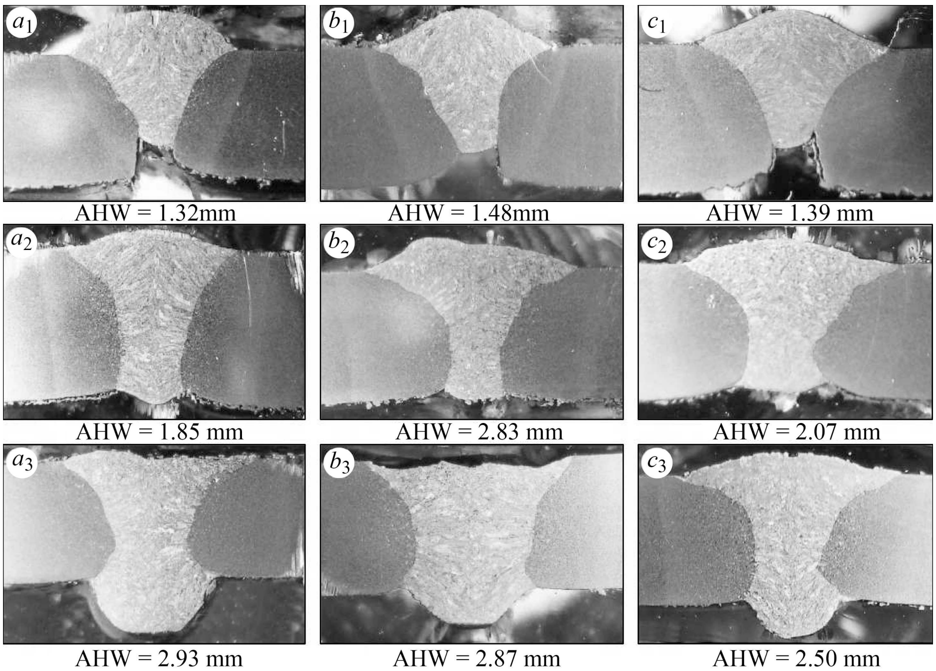

Fig. 1. The measured value for AHW in experiments.

For the investigation of the effect of the electrode to work angle on AHW value, a diameter of 1.6 mm was chosen for filler metal, the 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 increased from 1.32 mm to 2.93 mm with increase in the electrode to work angle from 65° to 85°, and the average increase in the AHW value was 0.081 mm per 1° increase in the electrode to the work angle. The AHW value increased by 0.53 mm and 1.08 mm when the electrode to work angle was increased from 65° to 75° and from 75° to 85°, respectively. This means that increasing the electrode to work angle in range of the 75...85° increases twice the AHW value compared to range of the 65...75°. In order to study the effect of filler metal diameter on AHW value, the electrode to work angle was fixed on 80°, carbon dioxide was chosen as the shielding gas, and diameter of filler metal was increased from 0.8 mm to 1.2 mm. The AHW value decreased from 2.87 mm to 1.48 mm with increase in the filler metal diameter from 0.8 mm to 1.2 mm, and the average decrease in the AHW value was 0.35 mm per 0.1 mm increase in the filler metal diameter (Figs. 1, 2). The AHW value decreased by 0.04 mm and 1.35 mm when 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 AHW value due to the filler metal diameter increase in range of 1...1.2 mm is much more than that in the range of 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 joint area increases with an increase in the electrode to work angle and/or decrease in the filler metal diameter, and the efficiency of the electric arc increases in this condition. Thus, the heat resulting from electric arc which is received by the base materials and joint area increases and this leads to an increase in AHW value. In order to understand the effect of the shielding gas type on AHW value, the electrode to work angle was set 80°, a diameter of 1.6 mm was selected for the filler metal, and welding processes were performed using argon, helium, and carbon dioxide as shielding gas, separately. Carbon dioxide as an active shielding gas and argon and helium as inert shielding gases are commonly used in GMAW process. According to Figs. 1 and 2, the greatest AHW value of 2.5 mm was obtained when using carbon dioxide as shielding gas while the AHW value obtained when using argon shielding gas (1.39 mm) was the lowest in this condition. The carbon dioxide-shielded arc produces a weld bead of excellent penetration with a rougher surface profile. Helium possesses 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 inner core and an outer mantle of lower heat energy. The helium arc produces a deep, broad, parabolic weld bead [19]. These phenomena and characteristics of shielding gases can strongly affect the AHW value.

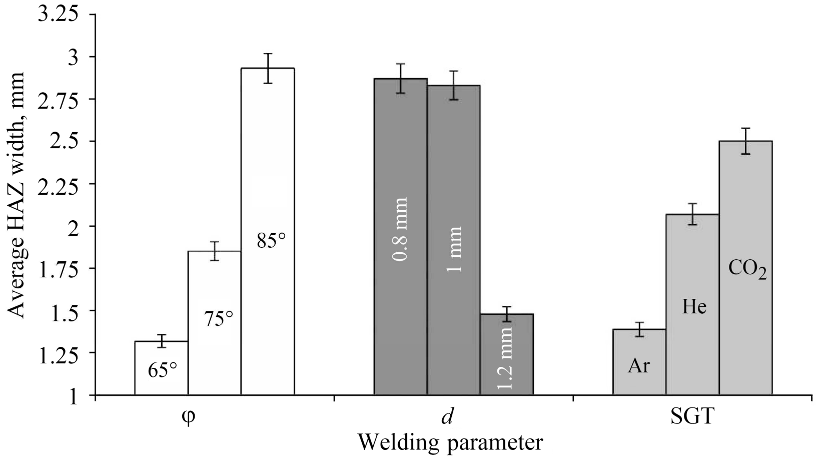

Fig. 2. The effect of welding parameters on AHW.

CONCLUSIONS

According to the obtained results from robotic GMAW process applied to HQ130 steel with 5 mm thickness: the AHW value increased from 1.32 mm to 2.93 mm with increase in the electrode to work angle from 65° to 85°, and the average increase in the AHW value was 0.081 mm per 1° increase in the electrode to work angle; the AHW value decreased from 2.87 mm to 1.48 mm with increase in the filler metal diameter from 0.8 mm to 1.2 mm, and the average decrease in the AHW value was 0.35 mm per 0.1 mm increase in the filler metal diameter; the active shielding gas led to a greater AHW value than the inert shielding gas; The greatest AHW value of 2.5 mm was obtained when using carbon dioxide as a shielding gas while the AHW value obtained when using argon as a shielding gas (1.39 mm) was the lowest in this condition.

1. *HasanA. S., Ali O. M., and Alsaffawi A. M.* Effect of welding current on weldments properties in MIG and TIG welding // Int. J. of Eng. and Techn. – 2018. – **7**. – P. 192–197.
2. *Microstructural* analysis of the anode in gas metal arc welding (GMAW) / S. Zielinska, F. Valensi, N. Pellerin, S. Pellerin, K. Musioł, Ch. de Izarra, and F. Briand // J. of Mat. Proc. Techn. – 2009. – **209**. – P. 3581–3591.
3. *O'Brien R.* Welding Handbook: Welding Processes. Ed. 8th. – Miami: American Welding Society, 1991. – P. 786–798.
4. *Anzehaee M. M. and Haeri M.* A new method to control heat and mass transfer to work piece in a GMAW process // J. of Process Control. – 2012. – **22**. – P. 1087–1102.
5. *Nuraini A. A., Zainal A. S., and Azmah Hanim M. A.* The effects of welding parameters on butt joints using robotic gas metal arc welding // J. of Mech. Eng. Sci. – 2014. – **6**. – P. 988–994.
6. *Dolby R. E.* // Metal Construction and British Welding Journal. – 1971. – **3**. – 99 p.
7. *Harrison J. D.* Why Does Low Toughness in the HAZ Matter? The Welding Institute Seminar. – England: Coventry, 1983.
8. *Fairchild D. P.* / Ed.: J. Y. Koo // in Welding Metallurgy of Structural Steels, TMS. – Denver, CO, 1987. – P. 303–318.
9. *Haze T., and Aihara S.* // in Proc. 7th Conf. on Offshore Mechanics and Arabic Engineering (OMAE). – Houston, 1988.
10. *Harisson P. L. and Hant P. H. M.* // In Proc. Int. Conf. on Weld Failures. – London: the Welding Institute, 1988.
11. *Denys R. M.* // In Proc. Int. Conf. on Weld Failures. – London: the Welding Institute, 1988.
12. *Boniszewski T. and Watkinson F.* Effect of weld microstructure on hydrogen-induced cracking in transformable steels // Metals and Materials. – 1973. – **7**. – P. 91–96/145–151.
13. *Ashby M. F. and Easterling K. E.* A first report of microstructure and hardness for heat-affected zones // Acta Metallurgica. – 1982. – **30**. – P. 1969–1978.
14. *Juan W., Yajiang L., and Peng L.* Effect of weld heat input on toughness and structure of HAZ of a new super-high strength steel // Bulletin of Mat. Sci. – 2003. – **26**. – P. 301–305.
15. *Ghazvinloo H. R. and Honarbakhsh-Raouf A.* Ductility of welded joints in CK45 carbon steel // Materials Science. – 2020. – **56**, № 3. – P. 359–362.

    (*Ghazvinloo H. R., Honarbakhsh-Raouf A.* Пластичність зварного з'єднання вуглецевої сталі CK45 // Фіз.-хім. механіка матеріалів. – 2020. – **56**, № 3. – P. 66–69.)
16. *Ghazvinloo H. R. and Honarbakhsh-Raouf A.* Mechanical strength of the weld metal in CK45 carbon steel // Materials Science. – 2020. – **56**, № 2. – P. 210–213.

    (*Ghazvinloo H. R. and Honarbakhsh-Raouf A.* В'язкість зварних з'єднань вуглецевої сталі CK45 // Фіз.-хім. механіка матеріалів. – 2020. – **56**, № 2. – P. 67–70.)
17. *Ghazvinloo H. R. and Honarbakhsh-Raouf A.* Microstructure of the weld metal in CK45 carbon steel // Materials Science. – 2019. – **54**, № 5. – P. 748–752.

    (*Ghazvinloo H. R., Honarbakhsh-Raouf A.* Мікроструктура металу шва на вуглецевій сталі CK45 // Фіз.-хім. механіка матеріалів. – 2018. – **54**, № 5. – P. 126–129.)
18. *Ghazvinloo H. R., Honarbakhsh-Raouf A., and Shadfar N.* Effect of the electrode to work angle, filler diameter and shielding gas type on weld geometry of HQ130 steel joints produced by robotic GMAW // Indian J. of Sci. and Techn. – 2010. – **3**. – P. 26–30.
19. *American* Welding Society. MIG/MAG Welding Guide. Ed., 3rd. – Lincoln Electric CO, 1997.

Received 07.06.2021