MICROSTRUCTURE OF WELD METAL IN CK45 CARBON STEEL

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In recent years the gas metal arc welding (GMAW) process has received much attention and has been progressively applied in various industries like automobile manufacturing and shipbuilding. The arc voltage, welding current and welding speed are three important and independent variables for this process. On the other hand, the microstructure of weld metal is an important metallurgical characterization that can strongly influence its physical and mechanical properties. Therefore, the present study focuses on the microstructural evolutions of weld metal in the CK45 carbon steel welded by robotic GMAW process.

Keywords: *gas metal arc welding, welding parameters, microstructure, weld metal.*

Welding is one of the most applicable connection processes in industry [1]. In the early 1900 s a gas metal arc welding process (GMAW) (including two states: metal inert gas (MIG) and metal active gas (MAG) [2]) was introduced and in 1948 the process was commercially accessible [2, 3]. This process is widely used in various industries including gas pipelines, petrochemical plants, automotive and ship buildings. High productivity rate due to the continuous feed of wire electrode, low weld discontinuity, no slag inclusion and low thermal hazard on base metal are the main merits of this process [4]. In the GMAW process the heat is generated by an electric arc and incurporates a continuously feed consumable electrode shielded by an externally supplied gas [1]. The commonly used shielding gases in the GMAW are carbon dioxide (CO_2), argon gas (Ar) and their combinations. The applications of such shielding gases can provide good protection of the molten droplets and weld pool, however they also affect the formation of welding arc, arc stability and metal transfer [5]. The microstructure of the weld metal is one of the most important factors that affect its mechanical and physical properties, and so should be taken into consideration when welding. The arc voltage, welding current, and welding speed are three important parameters for the GMAW with the maximum influence on the welded joint quality [6] that can affect the microstructure of the weld metal. As we know a relatively little information exists on the microstructure of the weld metal in medium-carbon steels. In this paper, an attempt has been made to study the effect of robotic GMAW parameters on the microstructure of the weld metal in CK45 carbon steel.

Materials and methods. The CK45 medium-carbon steel (according to DIN 1.1191 standard) was used as a base material. The GMAW 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 Fig. 1. The 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 and the torch angle was selected 5°. The multipass welds were used to join the bases materials and weld pool was protected by 100% CO_2 shielding gas.

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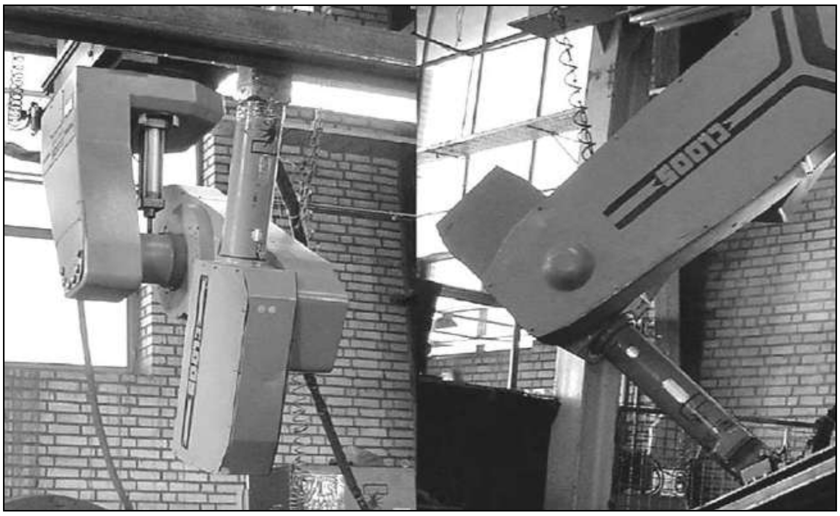

Fig. 1. The welding robot and its apparatus used in this study.

In addition, the ER70S-6 (AWS A5.18 classification) wire electrode with 1 mm diameter was used as a filling metal. The chemical composition of the wire electrode as follows (wt.%): P – 0.035, S – 0.025, Si – 0.95, Mn – 1.63, C – 0.11, Cu – 0.5. The chosen welding variables for this study are: arc voltage, welding current and welding speed, the most influential parameters on the weld metal microstructure, and all other variables are fixed. Having finished the welding processes, the cylindrical samples of 5 mm diameter and 10 mm height were extracted from the weld metals center for metallographic tests. The surface of the extracted samples was ground using SiC-paper and polished mechanically and then etched with 2% Nital. The microstructure observations in this study were conducted using a optical microscope with magnification ×1000.

Results and discussion. The microstructure observations obtained in this study are shown in Figs. 2–4. The influence of GMAW parameters on the microstructural evolutions of the weld metal can be discussed according to Eq. (1) [7]. The changes in the GMAW parameters results in changes in welding heat input. On the other hand Eq. (2) [7] shows the relationship between welding heat input and cooling rate of the weld metal. According to Eq. (2), the heat input is an important factor that affects inversely the weld metal cooling rate. When heat input increases, the cooling rate decreases for the given weld metal. The cooling rate is a primary factor that determines the final metallurgical structure of the weld metal [7]. When the cooling rate increases: the resulting martensite volume fraction in the weld metal increases, the retained austenite volume fraction in the weld metal decreases, the volume fraction of tempered martensite in the weld metal decreases somewhat due to lower heat input (obviously in Figs. 2*a*, *b*; 3*b*, *c* and 4*a*, *b*), and the probability of grain coarsening in the weld zone reduces.

Therefore, varying the heat input typically will affect the metallurgical structures of weld metal [7]:

$$H = 60 \cdot I \cdot V / 1000 \cdot S, \tag{1}$$

$$R = K / (T_0 \cdot H), \tag{2}$$

where H is heat input, kJ/mm; V is arc voltage, V; I is welding current, A; S is welding speed, mm/min; R is cooling rate, °C/s; K is constant; T_0 is preheat temperature, °C.

According to the findings of Dhua et al. [8] the welding heat input can play a significant role in the microstructure of the welding joints, therefore the results of this study agree well with previous investigations.

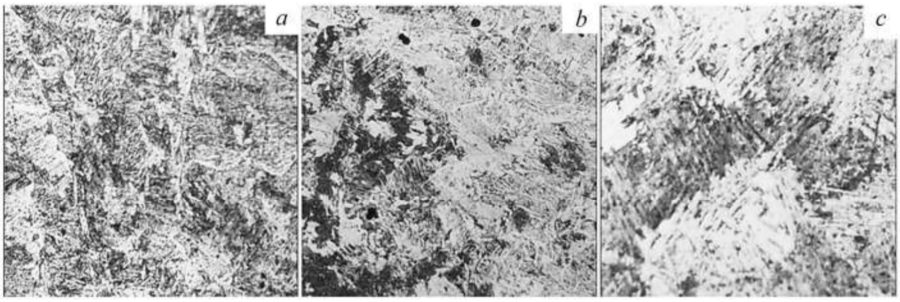

Fig. 2. Microstructure of weld metal in 25 V, 45 cm/min and 100 (*a*), 130 (*b*) and 160 A (*c*); ×1000.

Fig. 3. Microstructure of weld metal in 120 A, 50 cm/min and 20 (*a*), 24 (*b*) and 28 V (*c*); ×1000.

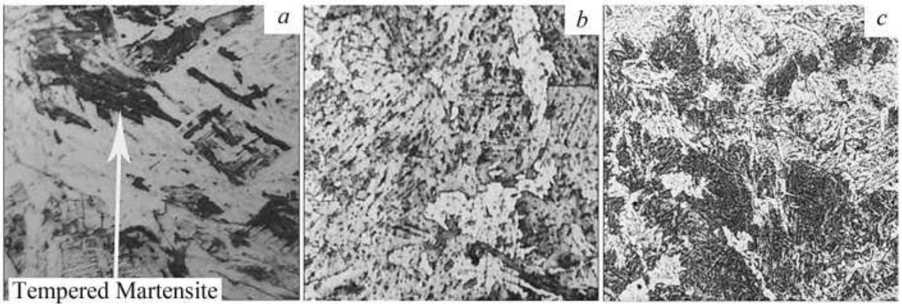

Fig. 4. Microstructure of weld metal in 24 V, 140 A and 30 (*a*), 40 (*b*), and 50 cm/min (*c*); ×1000.

The parameters which affect solidification behavior of fusion zone in fusion welding process are similar to casting process. In fact, a molten weld pool acts just like cast product but in a smaller scale. Hence, researchers in welding field at all times have greatly benefited from theoretical and experimental principles of solidification in casting.

It should be also noted that the microstructure development in the fusion zone depends on the solidification behavior of the weld pool. The principles of solidification control the size and shape of the grains, segregation, and the distribution of inclusions and porosity. During the past 15 years, significant progress has been made in understanding the solidification behavior of the weld pool and the evolution of microstructure in the fusion zone [9] and there is a lot of literature in welding metallurgy (such as [10–13]) in which microstructural aspects of fusion zone have been treated adequately and lack of information about weld metal microstructure in medium carbon steel is compensated by present investigation.

CONCLUSION

A change in the GMAW parameters affects the microstructure of the weld metal. The effect of welding parameters on the weld metal microstrcuture can be described based on the changes in welding heat input and cooling rate of the weld metal. Heat input increases (and subsequently cooling rate of the weld metal inversely decreases) with increasing of arc voltage, welding current or decrease of welding speed. This trend results in decrease in volume fraction of the masrtensite, increasing in retained austenite phase, and also greater fraction of martensite will be tempered in the microstructure.

РЕЗЮМЕ. Останнім часом значну увагу надають електродуговому зварюванню металів у середовищі газу (ЕДЗГ), яке активно застосовується у різних галузях промисловості: виробництво автомобілів і кораблебудування. Напруга, струм та швидкість зварювання є трьома незалежними параметрами процесу. З іншого боку, важливою металургійною характеристикою є мікроструктура металу шва, яка впливає на його фізико-механічні властивості. Тому дане дослідження спрямоване на аналіз мікроструктури зварного шва вуглецевої сталі СК45, виконаного роботом методом ЕДЗГ.

РЕЗЮМЕ. В последнее время значительное внимание уделяют электродуговой сварке металлов в среде газа (ЭДСГ), которое активно применяется в различных отраслях промышленности: производство автомобилей и кораблестроение. Напряжение, ток и скорость сварки являются тремя независимыми параметрами процесса. С другой стороны, важной металлургической характеристикой является микроструктура металла шва, которая влияет на его физико-механические свойства. Поэтому данное исследование направлено на анализ микроструктуры сварного шва углеродистой стали СК45, выполненного роботом методом ЭДСГ.

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