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The effect of microstructure on hardness and toughness of low carbon welded steel using inert gas welding

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ABSTRACT

The heat affected zone (HAZ), has a great influence on the properties of welded joints since it can alter the microstructure and residual stresses. In this paper, the effect of welding parameters and heat input on the HAZ and grain growth has been investigated. The role of grain size on hardness and toughness of low carbon steel has also been studied.

It was observed that, at high heat input, coarse grains appear in the HAZ which results in lower hardness values in this zone. For example raising the voltage from 20 to 30 V decreased the grain size number from 12.4 to 9.8 and hardness decreased from 160 to 148 HBN. High heat input and low cooling rates produced fine austenite grains, resulting in the formation of fine grained polygonal ferrites at ambient temperature.

1. Introduction

Welded joints are heterogeneous by nature and present a gradient of properties in the base metal and the HAZ. The welded joints can be classified on the basis of coherency between the welded zone and the base metal [1]. The control of microstructure is of prime importance in such area.

One of the major factors affecting the toughness of the welded metal is the formation of local brittle zone (LBZ). The degree of brittleness in this zone varies with material chemistry and welding conditions [2]. It has been reported that the formation of more than 77% needle ferrite phase, led to a reduction in toughness in steel [3]. Furthermore, the grains close to the fusion line, behave as the origins of nucleation. Since the weld pool easily wets the substrate, crystals nucleate upon the substrate grains. Epitaxial nucleation and growth proceed without altering the crystallographic orientations. As solidification proceeds, grains tend to have columnar growth, perpendicular to the pool boundary since maximum temperature gradient exists there [4–5]. However, the elevation of heat input and welding speed, can lead to the formation of equiaxed grains [6–9]. Balasubramanian and coworkers [10] studied the properties of welded AA 6061 Aluminum and reported that the tensile strength is directly proportional to the existence of equiaxed grains in the microstructure. This phenomenon has been attributed to the reduced sensitivity of finer grains to solidification cracks. Secondly they contribute to enhanced fracture toughness and ductility. Generally, high heat input and low cooling rate accelerate nucleation and recrystallisation and hence grain growth in the HAZ. Several grain refining techniques have emerged to counteract this effect, namely weld pool stirring, arc oscillation and arc pulsation [11].

This paper deals with the effect of welding parameters on grain size and phase conditions in low carbon steel.

2. Experimental procedure

The chemical composition and mechanical properties of the test specimens are shown in Table 1, and that of the welding electrode are given in Table 2.

The dimensions of Charpy impact test specimens were $10 \times 10 \times 55$ mm and had a V-notch of 1.6 mm wide and 5 mm deep. All impact tests were carried out according to ASTM E23 standard [12]. A ParsMIG-SP501 welding machine with a shielding gas of CO_2 and the electrode was a standard AWS-ER 70S-6 having a diameter of 1 mm. The welding parameters are given in Table 3.

The specimens were polished and etched in 2% Nital to reveal the microstructure [13,14]. The microstructure photos were taken

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Table 1
Chemical composition and mechanical properties of base metal.

% Si	% S	% P	% Mn	Yield strength (MPa)	Ultimate strength (MPa)	Elongation (%)
0.1	0.016	0.009	0.508	436	477	29

Table 2
Chemical composition and mechanical properties of filler metal.

% C	% Si	% S	% P	% Mn	Yield strength (MPa)	Ultimate strength (MPa)	Impact of energy (j)	Elongation (%)
0.06	0.84	0.008	0.009	1.38	489	578	105	7

Table 3
Welding parameters.

Filler wire diameter (mm)	1
Voltage (V)	20, 25, 30
Amperage (A)	130, 180
Welding speed (cm/min)	40
Gas flow rate (l/min)	12–17
Shielding gas	CO_2

from these etched surfaces by means of Nikon Stereo Zoom optical microscope. A Philips XL30 scanning electron microscope (SEM) was used for examination of fracture surfaces of weld metal. Clemex image software was employed for microstructural analyses and Brinell hardness tests were performed at a load of 125 kg on polished surfaces [15].

3. Results and discussion

3.1. Microstructure

The microstructure of the HAZ depends on chemical composition and the peak welding temperature and welding voltage [16]. Fig. 1 illustrates the microstructure of the specimens welded at 20 and 30 V, showing larger grains at high voltage conditions.

The energy transfer per unit length of weld is a function of heat input, which in turn can alter the mechanical properties of the welded zone. The heat input can be calculated as follows [17]:

$$H = \frac{60 \cdot E \cdot I}{1000 \cdot S} \quad (1)$$

where H is the heat input (kJ/mm); E the voltage (V); I the current (A); and S is the travel speed (mm/min).

The effects of welding parameters on the properties are shown in Fig. 2. It demonstrates that high heat input and low cooling rates widen the HAZ and increase the grain size. The cooling rate is of prime importance. Low cooling rate entails an increase in the size of austenite grains. The mutual dependency of voltage and heat input is shown in Eq. (1). Grain boundary migration and mean grain diameter ($\overline{D}$) enlargement occur following a high heat input. On the other hand, grain boundary migration energy (γ) and grain size are related by Eq. (2). It is expected that at low welding speeds the grain boundary energy increases leading to grain growth [18].

$$\frac{d\overline{D}}{dt} \cong \frac{2\gamma}{\overline{D}} \quad (2)$$

Fig. 3 illustrates the microstructure and grain size both in the welded metal and also in the heat affected zone.

The interrelationship of voltage and retention time of temperature above the recrystallisation temperature can be justified.

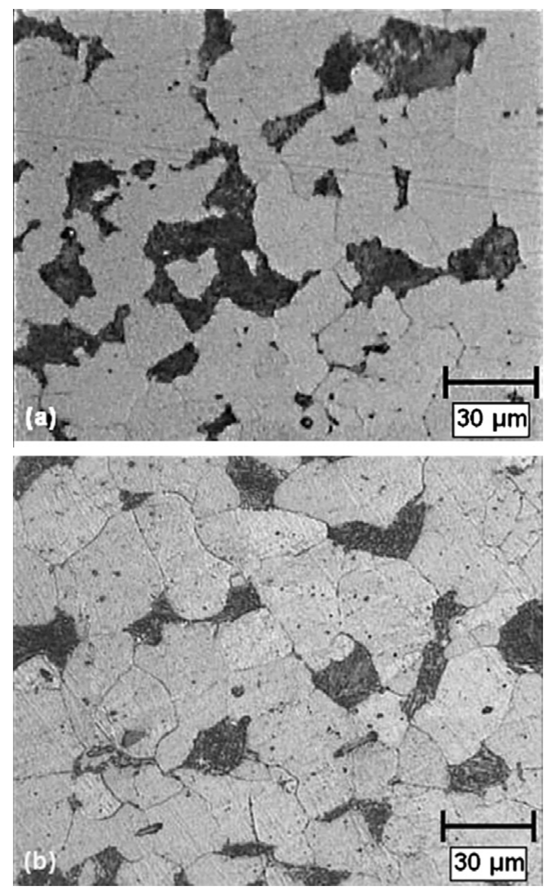

Fig. 1. Optical micrographs: (a) microstructure of welded specimen with 20 V and (b) microstructure of welded specimen with 30 V.

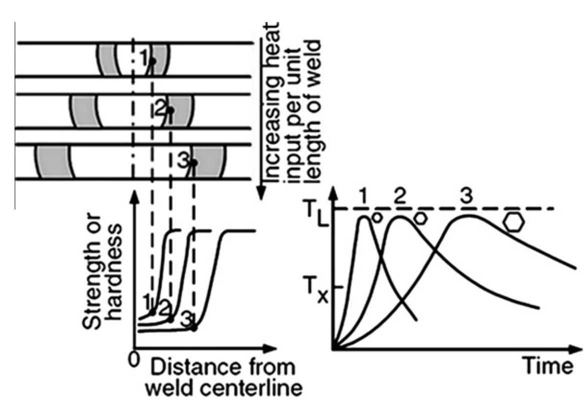

Fig. 2. Effect of heat input per unit length of weld on: (a) width of HAZ (shaded), (b) thermal cycles near fusion boundary, and (c) strength or hardness profiles.