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Effect of pulse current on mechanical properties and dendritic morphology of modified medium manganese steel welds metal

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ABSTRACT

Modified medium manganese steel (MMMS) samples were joined using gas metal arc welding (GMAW) and pulse-GMAW (P-GMAW) techniques. The joints were examined using optical microscope, scanning electron microscope, hardness tests, tensile tests and side bend tests. The use of P-GMAW was found to be superior to the GMAW process, resulting in a noteworthy enhancement of the plastic deformation capacity of the weld joint while maintaining comparable tensile properties. Microstructural study and measurement of primary and secondary dendrite arm spacing were also performed to better understand the important aspects of weld metal solidification, i.e., pulse current. The treatment with pulse current restrained the dendrite growth in the welds, resulting in finer dendritic grains, which improved the ductility of the weld joint. The refinement of the microstructure can be attributed to the application of the pulse current, which intensified the effective vibration of the molten pool, facilitated the diffusion of the alloy and reduced the microsegregation.

1. Introduction

High manganese austenitic steel and its excellent work-hardening properties during high-impact use have been a major area of study in the field of wear resistance over the past century ever since the English metallurgist Sir Robert Hadfield invented Hadfield's steel in 1882 [1], and studies on welding this type of steel have been progressively emerging since that time [2–5]. In 1963, to meet the requirements of low-impact applications, the American Metal Climax company introduced modified medium manganese wear-resistant steel (MMMS) [6], which also had an austenitic structure but with lower stability, and this property leads to better wear resistance performance under low stress abrasive wear conditions via the formation of numerous strain-induced martensites and twins [7].

The emergence of new types of steel is often accompanied with corresponding weldability problems. Usually, certain issues, such as hot cracking and coarse columnar grains, which appear in the welds of austenitic steel, will also arise in the welds of MMMS because of the similar austenitic structure [8]. To obtain a weld deposit with better crack resistance, the electrodes or wires used for welding austenitic manganese steel should be austenitic with high nickel or molybdenum contents when necessary [2,5]. In addition, typical issues, such as intergranular brittleness due to the carbide precipitation in heat-affected zone (HAZ) during welding of austenitic manganese steel, will also occur [2].

Unfortunately, there are few works that have reported the welding of MMMS despite the fact that this type of steel is widely used; jointing MMMS is extremely urgent. In general, gas metal arc welding (GMAW) can obtain a low heat input if a large current, fine wire, and high-speed welding can be used, and thus, a smaller HAZ width and carbide precipitation tendency could be achieved. Most importantly, this technique improves productivity. To obtain grain refinement of the solidification structure of a weld and a better HAZ performance, different dynamic grain refining techniques, including arc oscillation and weaving, ultrasonic vibration and weld stirring using magnetic force, have been applied to fusion welding [9–11].

Pulse welding can effectively control the heat input, leading to less distortion and improved quality, which is especially important for welding highly heat-sensitive alloy materials [12–15]. However, the pulse applied to the welds of MMMS is provided

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less. Two different GMAW processes were presented to study the role of current pulsation on the weld solidification structure of MMMS and its corresponding mechanical properties. This paper reports and discusses the results of this experimental investigation, and sound welds and improvements are expected with pulse welding.

2. Experimental details

The chemical compositions of the MMMS and weld metal are listed in Table 1. The base metal and filler metal have different elements and elemental contents, and the *P* and *S* contents are very low. The microstructure of MMMS, which is shown in Fig. 1, is austenitic at room temperature. The test plates used in this investigation are divided into two groups, with dimensions of 500 mm in length, 220 mm in width and 30 mm in thickness. The details of the weld joint are given in Fig. 2. Both are welded using G18–8 Mn wire, which is 1.2 mm in diameter, according to BS EN 12072–2000 [16].

A shielding gas of 80% Ar + 20% CO_2 was used, and the gas flow rate was 15–20 $L \cdot min^{-1}$. Weld deposition was performed at a 60 $cm \cdot min^{-1}$ travel speed and without any preheating or post-weld heat treatment. The feed speed was 5 $m \cdot min^{-1}$. The group without adding pulse was designated GMAW, while the other group, which had applied pulse current, was labeled P-GMAW. After early attempts, an appropriate set of square wave pulse parameters was used to obtain good bead appearance. During the welding process, the welding current and voltage were collected using a data acquisition card PCI8622. The average voltage and current in the GMAW process, which were calculated using the collected data, were 25 V and 224 A, respectively. Fig. 3 is a pulse current waveform collected from the actual welding process in 100 ms. The peak current was approximately 300 A, and the background current was approximately 70 A. The main parameters of the rectangular current pulse are given in Fig. 4. The joint distortion was kept to a minimum by alternating the successive weld passes between the two sides of the double-V-groove weld. The number of GMAW weld passes was 19, and for P-GMAW, this number was 26.

Metallographic samples were truncated from the two welds for microstructure observation. Standard metallographic techniques were applied to prepare the samples. The welds were subjected to microscopic examination using an optical microscope and a scanning electron microscope (SEM) equipped with an energy dispersive X-ray detector (EDX) spectrometer. This analysis was performed at 20 kV. Then, the alloy contents were measured to study the intergranular and intragranular microsegregation. The mechanical tests for the welding of specimens were performed according to the ISO standards [17–19]. The microhardness tests were performed under a 10 kg load.

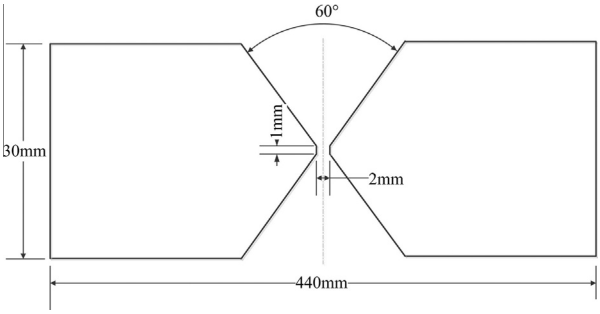

Fig. 2. Details of the double-V-groove butt joint.

Table 1
Chemical composition of the base metal and weld metal (wt.%).

Element	Base metal	Weld metal
C	0.98	0.18
Mn	6.5	6.3
Cr	1.2	16.8
Ni	–	7.2
Si	0.19	0.58
Mo	2.9	0.11
V	0.2	–
Nb	0.006	–
P	0.003	0.006
S	0.002	0.002

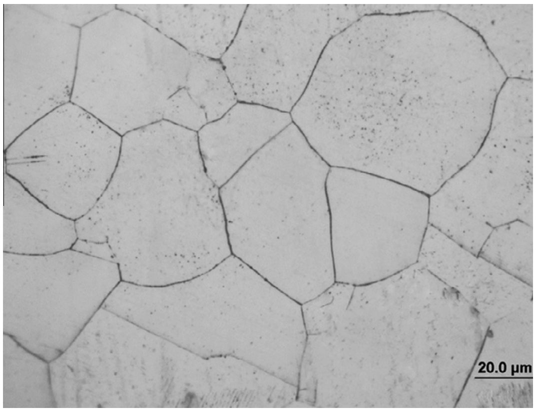

Fig. 1. Microstructure of the base metal.

3. Results and analysis

3.1. Assessment of parameters related to solidification

The HAZ of austenitic manganese steel will become brittle when subjected to extensive heating due to the temperature dependent carbide precipitation and perlite formation in the austenitic structure [20]. Therefore, the suggested maximum heat input per unit length of the weld, *q*, should be less than 19.2–23.0 $kJ\ cm^{-1}$, considering the arc efficiency of gas metal arc welding, and the heat input can be calculated using the following equation [21]:

$$q = \frac{\eta IU}{v} = \frac{\eta}{v} \times \frac{\sum_{i=1}^{n} I_i U_i}{n} \tag{1}$$

where q is the heat input in $kJ \cdot cm^{-1}$, I is the welding current in A; U is the welding voltage in V; v is the welding speed in $cm \cdot s^{-1}$; η is the arc efficiency, for gas metal arc welding, $\eta = 0.75–0.9$ [10], n is the total counts, and $\sum_{i=1}^{n} I_i U_i$ is the total power during the counting period.

In this investigation, the heat input values calculated using the resulting voltage and current data corresponding to GMAW and P-GMAW were 4.19–5.03 $kJ \cdot cm^{-1}$ and 4.38–5.27 $kJ \cdot cm^{-1}$, respectively, which are far less than 19.2–23.0 $kJ \cdot cm^{-1}$, and acceptable.

3.2. Optical microscopy

Welds with good bead appearance and macroscopic morphologies were obtained, and no solidification cracking was found because the amount of sulfur and phosphorus was very low and the manganese content was adequate; thus, the segregation of a low melting eutectic phase could be suppressed [8]. The austenitic