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Corrosion behavior of the high strength low alloy steel joined by vertical electro-gas welding and submerged arc welding methods

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ABSTRACT

The high strength low alloy (HSLA) steel used as a large crude oil storage tank (LCOST) was often welded by vertical electro-gas welding (VEGW) and submerged arc welding (SAW). The VEGW specimen was produced by single-pass weld with high heat input (about 100 KJ/cm), and the SAW specimen was manufactured by mutil-pass weld with low heat input (about 30 KJ/cm). The corrosion behaviors of both samples were studied by electrochemical techniques and surface methods. The research results achieved in this investigation disclosed that the welding process played an important role in obtaining satisfactory corrosion property. In comparison with the SAW joint, the VEGW joint showed uniform microstructure and coarse micro-phase. The scanning vibrating electrode technique (SVET) results demonstrated that the corrosion of the VEGW joint majorly took in the heat effect zone (HAZ) and the attack for the SAW joint mainly occurred in the fusion zone (FZ). In addition, the scanning electron microscopy (SEM) results exhibited that the VEGW joint exhibited a light local attack and the SAW joint demonstrated a heavy uniform corrosion. The electrochemical results showed that the VEGW joint showed lower corrosion rate than the SAW joint. In summary, it can be discovered that the corrosion rates of welded specimens were associated with the welding-pass and the corrosion forms of welded specimens were related to the heat input energy.

1. Introduction

The high strength low alloy (HSLA) steel has been widely used to build a large crude oil storage tank (LCOST) [1]. During build process, The horizontal welding seam is produced by submerged arc welding(SAW) and the vertical welding seam is joined by vertical electro-gas welding (VEGW) [2]. The LCOST steel has been produced in the major steel enterprise Baosteel, WISCO, Ansteel and Shougang. The Welded joints of the LCOST steel exhibit good mechanical property and excellent welding ability, however, the corrosion problems caused by chloride have been paid more and more attention on the LCOST by now. This is due to that the domestic crude oil comes from the ocean and makes the seawater as pressure water during exploitation. In addition, the import crude oil mostly comes from the Middle East and contains many chlorides [3]. As a result, the corrosion of crude oil becomes more and more serious, which takes serious corrosion to the LCOST and shortens its service life. Therefore great economic losses are caused by the corrosion of the LCOST. On the other hand, seawater is seemed to substitute to freshwater in hydraulic experiment during the LCOST building, which can save lots of freshwater resources and construction costs. However, seawater can lead to serious corrosion for the LCOST by the chloride. Therefore, it is necessary to study corrosion problems for the LCOST in chloride solution, especially to the welding joint site for the most sensitive corrosion in the LCOST.

It was proposed that the welding would increase the corrosion activity of the HSLA steel due to metallurgical changes and residual stresses introduce a series of phase transformations taking place in the fusion zone (FZ) and heat effect zone (HAZ), In recent years, there have been many researches on the mechanical property and welding ability for the welded joint of the LCOST steel [4–6], however, there were few researches on its corrosion behaviors [7]. As a result, it is necessary to study the corrosion behaviors of welded joints of the LCOST steel in 3.5% NaCl solution.

In this work, scanning vibrating electrode technique (SVET) combined with scanning electron microscopy (SEM) observation as well as electrochemical impedance spectroscopy (EIS) measurement, was used to investigate the corrosion behaviors of welding joints of the LCOST steel in 3.5% NaCl solution.

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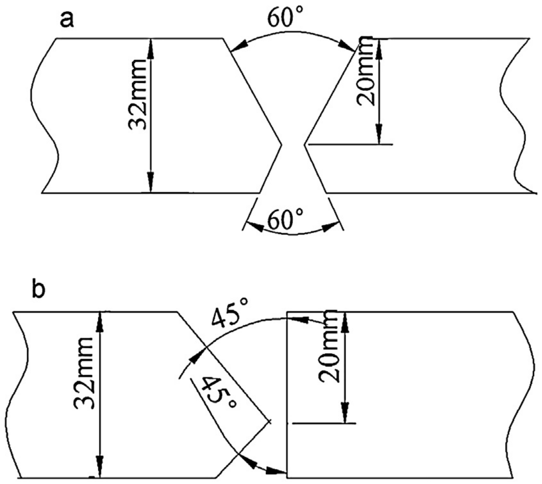

Fig. 1. Schematic illustration of welded groove (a) VEGW joint (b) SAW joint.

2. Experimental procedures

2.1. Sample preparation

Test specimens were cut from the longitudinally welded LCOST steel containing welded metal (WM), HAZ and base metal (BM). The chemical compositions of the LCOST steel and filler metal were shown in Table 1.

Butt welds were made on plates of 250 mm × 200 mm × 32 mm using VEGW and SAW. The size of welding groove was shown in Fig. 1. The VEGW joint was made using by single-pass welding and established suitably welding parameters (i.e., 450 A welding current, 45 V welding voltage, 12 cm/min welding speed, 100KJ/cm heat input). The SAW joint was produced by multi-pass welding and optimally welding parameters (produced using welding current of 500 A, welding voltage of 30 V, welding speed of 40 cm/min, heat input of 30 KJ/cm and argon shielding flow rate of 15 L/min welding parameters). Radiographic (RT) examined all welded joints showed that they were full penetration and acceptable bead profile with no welding defects such as porosity, undercut, cracks, or lack of fusion. Cross-section micro-images of both welding technology were shown in Fig. 2, which exhibited that both of these joints had good welded quality. Welded samples were machined by electrochemical sample with 10 mm × 10 mm × 10 mm. All sides of the specimen were embedded in an epoxy resin except the exposure surface, which was ground sequentially with 400, 600, and 800 grit emery papers. The specimen was cleaned by distilled water and degreased in acetone. Finally, a specimen was subjected for 5 min to ultrasonic washing with acetone and dried in warm flowing air prior to every experiment. EIS began after a 2 h immersion for samples to reach a steady state condition.

2.2. Experimental device description

Both electrochemical measurements were performed in a standard three-electrochemical cell, with a saturated calomel electrode (SCE) as the reference electrode, a platinum sheet as the auxiliary electrode (AE), and the samples as the working electrode (WE). Polarization curve and EIS were carried out in a VMP3 electrochemical corrosion testing apparatus at room temperature in 3.5% NaCl solution. For the potentiodyanmic curve, the sweeping potential was from −0.25 V to 0.25 V with a scanning rate of 0.1667 mV/s. EIS measurements were performed at the open circuit potential with AC amplitude of 5 mV, and the applied frequencies ranged from 0.01 Hz to 10 KHz. At least three tests were conducted under each condition to confirm the validity of the experiment measurements.

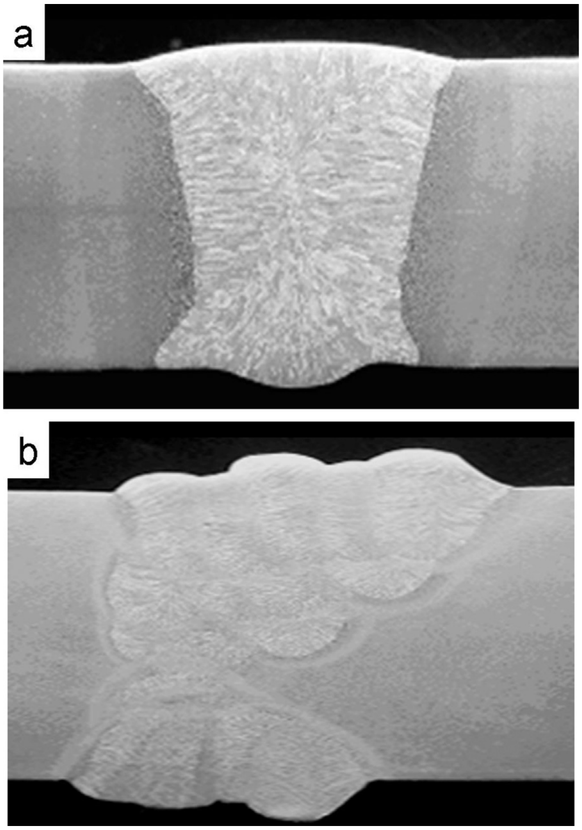

Fig. 2. Cross-section macro-images of both the welding technology (a) VEGW joint (b) SAW joint.

The SVET measurements were conducted through a PAR370 Scanning Electrochemical Workstation. The detailed setup was described as previous works [8]. A video camera was used for imaging and controlling the distance between the Pt-Ir micro-probe and the work electrode surface, which was set at 100 μm. The vibrating amplitude of the micro-electrode was 25 μm and the vibrating frequency was 400 Hz in the direction to the surface. The potential of the microelectrode was proportional to its position in the vibrating plane. The difference of the potentials when the microelectrode was located at the vibrating peak and valley, respectively, $\triangle E$, was measured by an electrometer incorporated in M370. The solution resistance between the vibrating peak and valley, R is determined by $R = d/k$, where d is the vibrating amplitude of the microelectrode (35 μm) and k is the solution conductivity. The SVET current I was then obtained by $I = \triangle E/R$ polishing with diamond paste, and etched by a mixture of 5% nitric acid and ethanol.

Micro-hardness test was conducted through a nano-indentation measuring device (TI900 Tribo-Indenter, Hysteron). In a force-controlled mode, the indenter tip (Berovich type triangular pyramid) was loaded with a peak force of 3000 μN at a rate of 50 μN/s.

Scanning electrode microscopy (SEM) was utilized to investigate the corrosion morphologies of removed corrosion scales for the SAW joint and the VEGW joint after 144 h of immersion in 3.5% NaCl solution.

3. Result and discussion

3.1. Microstructure of SAW and VEGW welds

Fig. 3 shows the micrographs for the VEGW samples of WM, HAZ and BM, respectively. Various micro-phases are observed in different zones. The BM is character to bainite and acicular ferrite.