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CORROSION PROPERTIES OF LOW-CARBON STEEL WELDED JOINT IN SYNTHETIC SEA WATER ENVIRONMENT

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Abstract: *In this study corrosion properties of welded joint of low carbon steel were tested. The welded joint was made using S355JR steel by the metal inert gas technique (MIG welding process). Corrosion properties of used base metal (BM) and welded joint were investigated by the electrochemical techniques including open circuit potential, electrochemical impedance spectroscopy and potentiodynamic polarization. All tests were conducted in 3.5 wt.% NaCl solution. The obtained results show that the lowest corrosion rate is present on the welded joint surface. This interesting result may be explained by the difference in the chemical composition of welded joint and base metals. Namely, the carbon content is the lowest in the welded joint, and consequently, the density of cathodic sites is the lowest in this area, as compared to the base metal parts.*

Keywords: *welded joints; corrosion behavior; polarization; EIS*

1. INTRODUCTION

Low-carbon steels, containing less than 0.25% C, are widely used in structural applications due to their excellent mechanical properties, good formability and weldability. Their vast application is recognized in various industries such as automotive, civil engineering, and oil industry, for structural parts (beams, turbine blades, pipes, etc). [1,2]. Their strength and ductility make it suitable for the demanding conditions of semi-trailer structures, providing durability and reliability in transport applications [3,4]. Generally, carbon steel has been the popular choice of structural material as it is abundantly available, inexpensive with the adequate mechanical properties, but it has a good general corrosion rate [5].

When a welded structure is exposed to water containing corrosion-aggressive ions such as chloride ions, corrosion becomes severe, even in a short period of exposure [5]. Corrosion of low-carbon MIG-welded joint can be influenced by several factors, including chemical composition of the base metal, the quality of the welded joint and environmental conditions. The weld metal may exhibit different corrosion resistance compared to the base metal due to change in microstructure and chemical composition. Differences in carbon content, as well as welding parameters lead to different microstructural morphologies formed in weld metal compared to base metal. With increase of carbon content, the corrosion rate increases too. Content of the ferrite phase decreases as carbon content increases, which leads to the increase of the cathode – anode area ratio of a galvanic couple. This is because corrosion forms on ferrite phase (anode) prior to cementite (cathode). Consequently, the corrosion is accelerated with the increase of carbon content [6]. The corrosion rate is the rate at which each metal deteriorates in a particular environment [7].

In this research, corrosion behavior of the MIG welded low-carbon steel joint was monitored trough the change of electrochemical parameters of the weld metal and the base metal. Corrosion test was performed by electrochemical methods for all specimens in environment of 3.5% NaCl solution.

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2. EXPERIMENTAL WORK

2.1 Materials

Low carbon steel was used for fabrication of the welded joint using MIG welding method.

Corrosion tests were carried out on a sample taken from cross section of the welded joint. Sample, for further electrochemical testing, was prepared by using grinding and polishing techniques. Revealing the macroscopic appearance of welded joint was done by etching in 3% Nital reagent and recording on stereomicroscope „Leica".

2.2 The chemical composition of the samples

The chemical composition of the base materials (BM) and the weld metal (WM) was determined by optical emission spectrometry on BELEC Compact Port HLC device. The determination of steel quality was carried out in accordance with the SRPS EN 10025-2 standard [8].

2.3 Electrochemical Methods

The instrument Gamry Interface 1010E Potentiostat/Galvanostat/ZRA was used for electrochemical measurements. The 3.5 wt.% aqueous NaCl solution, open to the air at room temperature, was regarded as electrochemical corrosion medium simulating sea environment. The corrosion tests were performed in an electrochemical cell with three electrodes: saturated calomel (SCE) as a reference, platinum as a counter electrode, and the steel part as the working electrode. The base metal and the weld metal were working electrodes with an exposed area of 1.0 cm^2. To establish a stationary state, i.e., a stable open circuit potential, the steel plate was immersed in the test solution for 1h prior to all electrochemical measurements. Impedance measurements were performed at open circuit potential in the frequency range from 0.01 Hz to 100 kHz with 10 points per decade using a 10 mV amplitude of sinusoidal voltage, and polarization measurements were performed in the potential range from -250 mV to +250 mV vs. E_{corr}. All electrochemical tests were performed at 298 K. The obtained data were analyzed using the Gamry E-Chem Analyst software package.

3. RESULTS AND DISCUSSION

3.1 Material

Macroscopic appearance of the cross section of the welded joint is shown in Figure 1.

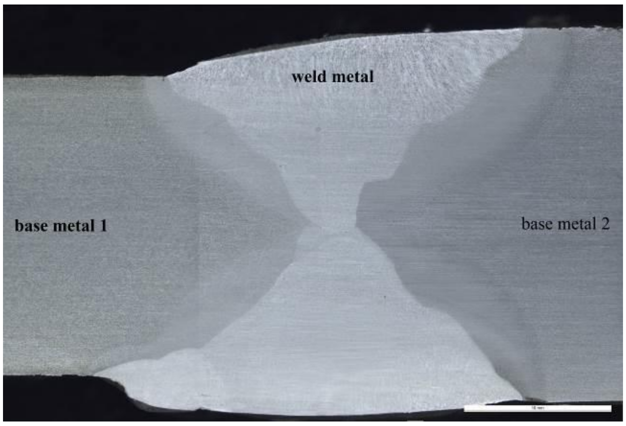

Figure 1. Macroscopic appearance of welded joint.

3.2 Chemical composition

The chemical composition of the base metal and welded metal are given in Table 1.

Table 1. Chemical composition, wt.%

	C	Si	Mn	P	S	N	Cu	Fe
BM 1	0.135	0.212	1.315	0.024	0.017	0,005	0.367	Bal.
BM 2	0.224	0.458	1.222	0.016	0.012	0,005	0.178	Bal.
WM	0.099	0.714	1.294	0.012	0.014	0,004	0.105	Bal.

The results of chemical analysis show that both base metals of weldment were made of a low-carbon steel grade S355JR. The carbon content of the three samples differs significantly. The lowest C content is observed at the surface of the weld joint. Although BM1 and BM2 are made of the same metal, their C content differs because the chemical composition analysis at the BM1 has been performed at the spot closer to the welding zone, as compared to the BM2. To conclude, the carbon content in the base metal increases with the distance from the welding zone.

3.3 Electrochemical Impedance Spectroscopy Test

Impedance spectra were recorded 1 hour after the application of the corrosion agent, following the establishment of a stable open circuit potential. Experimental data shown in Figure 2 were fitted using the equivalent electrical circuit (Figure 3). The values of polarization resistance of BM1 and BM2, as well as the WM are 1393, 727.7 and 1737 ohm, respectively.

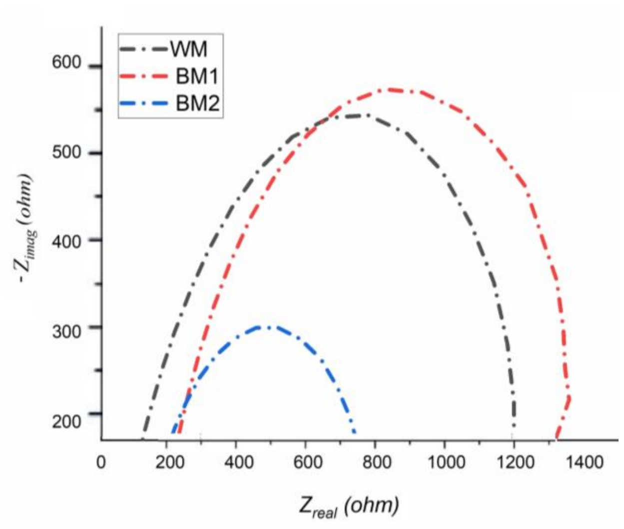

Figure 2. Nyquist diagram of BM1, BM2 and WM in 3.5 wt% NaCl solution.

The elements of the equivalent circuit are the electrolyte resistance (R_s), the resistance of the charge transfer (R_p), and an element with a constant phase angle (*CPE*). The *CPE* directly depends on frequency and is often used instead of the capacitance of the passive layer for non-homogeneous surfaces [9,10]. The base metal 1 and welded joint show significantly higher semicircle of the Nyquist loop, in comparison to the base metal 2, showing their increased corrosion resistance. This difference may be explained by the difference in the carbon content. As Table 1 depicts, BM2 possesses the highest carbon content, which produces more cathodic sites on the metal surface.

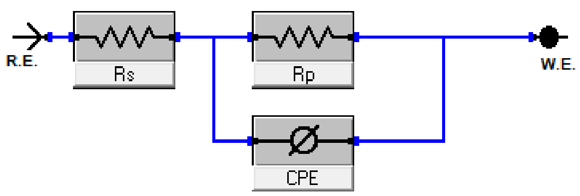

Figure 3. Model of the electrical equivalent circuit used to fit EIS data.

3.4 Potentiodynamic Polarization Test

The polarization curves for all samples have typical characteristics of active dissolution in 3.5% NaCl aqueous solution [11].

The welded joint shows the most negative corrosion potential in chloride solution. Base materials have more positive corrosion potentials, which differ slightly and are -691 mV and -684 mV, respectively. The test results showed that the WM has the lowest corrosion current density, and therefore the lowest corrosion rate, which means that WM is more corrosion resistant compared to the base material [9]. As mentioned in the impedance analysis, the lowest corrosion rate of the weldment is probably the result of the lowest carbon content, i.e., the lowest number of cathodic sites on the corroding surface.

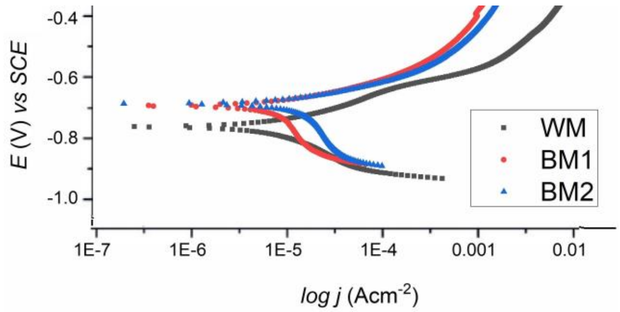

Figure 4. Polarization Tafel curves of BM1, BM2 and WM samples.

Table 2. Electrochemical parameters of BM1, BM2 and WM obtained from polarization curves in 3.5 wt% NaCl solution.

Sample	$-E_{corr}$/mV	j_{corr}/μA cm^{-2}	Corrosion rate / mm y^{-1}
BM1	691	49	563 x10^{-3}
BM2	684	70	805 x10^{-3}
WM	761	11	129 x10^{-3}

5. CONCLUSION

The results obtained from the chemical analysis showed that both base metals and the welded joint are made of a low-carbon steel quality S355JR and that the weldment has the lowest carbon content. Electrochemical methods have shown that the weld metal has the lowest corrosion current density, and therefore the lowest corrosion rate. The lowest corrosion rate of the weldment is probably the result of the lowest carbon content, i.e., the lowest number of cathodic sites on the corroding surface.

Acknowledgement

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