

The Evaluation of Corrosion Behavior of AISI 347 Stainless Steel to ASTM A335 Low Alloy Steel Dissimilar Welds

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Abstract

In the present study, the corrosion behavior of AISI 347 austenitic stainless steel to ASTM A335 low alloy steel dissimilar joint was investigated. For this purpose, two filler metals, ER309L and ERNiCr-3, were selected to be used during the gas tungsten arc welding process. To investigate the corrosion behavior of the joints after welding, the specimens were tested in 3.5% sodium chloride solution using Tafel and cyclic polarization tests. Also, the microstructures of base and weld metals were evaluated using optical microscopy. The microstructural evaluations showed that a two-phase structure consisting of dendritic and inter-dendritic regions with primary austenite solidification was observed in ERNiCr-3 filler metal and a primary skeleton-shaped ferrite in austenitic matrix was observed in 309L filler metal. The results of electrochemical tests also showed that 347 austenitic stainless steel base metal had more resistance to corrosion in comparison to A335 low alloy steel base metal, due to more amounts of chromium and nickel in its structure. Also, ERNiCr-3 filler metal displayed better resistance to pitting corrosion.

Keywords: Corrosion, Dissimilar Welding, Austenitic Stainless Steel, Low Alloy Steels, Microstructure.

1. Introduction

Stainless steels are ferrous alloys containing at least 10 to 12 percent chromium. 347 austenitic stainless steel is one of the most common types of steel used in industries, especially in oil and gas industry, refineries and electric power stations because of its corrosion resistance to water environments and high temperatures¹. This alloy has good resistance to intergranular corrosion in many corrosive environments^{2,3}. Chromium-molybdenum low alloy steels are other types of steel resistant to erosion and corrosion. These steels are mostly used in producing gearwheels, steam utilities, and petroleum and power stations. Dissimilar joints of 347 austenitic stainless steel and A335 low alloy steel pipes have been widely employed in oil and gas industry, especially in heat exchangers. In dissimilar welding, one of the most important concerns is the selection of a proper filler material⁴. In recent years, some studies have been conducted on the evaluation of dissimilar welding of stainless steels and low alloy steels. Arivazhagan et

al.⁵ investigated different methods for welding 304 stainless steel to 4140 low alloy steel and obtained the best corrosion properties using electron beam welding. Their results showed that a high heat input enhanced the micro-segregation of alloy elements and created a non-chromium zone in the grain boundaries; therefore, due to the high cooling rate in this method, the amount of Cr-rich carbides was decreased in the grain boundaries. However, no systematic work has been conducted on the corrosion behavior of the joints between 347 austenitic stainless steel and A335 low alloy steel pipes. The aim of this study was to investigate the microstructure and corrosion behavior of different welding zones in order to find the best filler metal with the proper engineering properties for these dissimilar joints.

2. Experimental procedure

The base metals used in this study were A335 low alloy steel and 347 austenitic stainless steel pipes which were under rolled and solution annealed conditions, respectively. The pipes were 8 mm thick, 400 mm long and 200 mm in outer diameter. The two filler metals, ER309L and ERNiCr-3, were used to join the base metals. The nominal chemical compositions of the base and filler metals are given in Table 1.

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Table 1. The Chemical composition of used materials (wt. %)

Element	C	Cr	Ni	Mo	Mn	Si	Ti	Cu	Nb	Fe
A335	0.1	1.12	–	0.5	.03	1.0	–	0.08	–	Bal.
AISI 347	0.08	17.36	10.65	0.37	2.0	1.0	0.01	0.35	0.55	Bal.
ER309L	0.02	23.7	13.9	0.04	1.8	0.51	–	0.05	–	Bal.
ERNiCr-3	0.1	16	Bal.	3	0.5	0.75	.05	0.12	3	3

Wires 2.4 mm in diameter were used for root pass and hot and cover passes. Before welding, the pipes were prepared to make a single V groove butt configuration. The welding was done by gas tungsten arc welding process with Direct-Current Electrode Negative (GTAW-DCEN) and argon gas of 99.99% purity and 30 flow rate and shield. In order to minimize the tension of the weld metal solidification, the inter-pass temperature was selected to be 150°C.

The heat input was calculated by the following equation and the minimum length of arc was considered to be about 2mm⁴⁾:

$$H.I = \frac{\eta \cdot I \cdot V}{S}$$

The current was about 140 amperes in each pass, the voltage (v) was about 11 volts, the welding speed was about 1- 1.1 mm/s, and arc Efficiency (η) was considered to be 0.6. For both weld metals, the heat input was calculated to be about 0.882. Metallography procedure was used to study the microstructure of base metals, weld metals, and microstructure changes²⁾; therefore, for each joint, two specimens with the proper size were prepared by grinding using 80 to 2000 grits silicon carbide paper, which was followed by final polishing with 0.3 μ m alumina powders. The specimens were etched for 15 seconds using Nital solution (2% nitrate acid in alcohol) to show the structure of low alloy steel; also, they were etched by Marbel solution (10 gr of CuSO₄ + 50cc HCl + 50cc H₂O) to find the microstructure of austenitic stainless steel weld metal. The specimens were electroetched by a solution (60 ml water and 40 ml nitrate acid), with 5 volts for 10 seconds; as a result, the microstructure of nickel-based weld metal was found.

In order to investigate the corrosion behavior of the weld cross-sections, first, specimens were cut in proper dimensions and they were made smooth by grinding. Afterwards, to make electric connection, coated copper wires were soldered on the back of the specimens. Then the specimens were coated with a special wax so that finally, just a specific part was touching the electrolyte solution. To make sure that the surface of the specimens was smooth for different corrosion tests, the mounted specimens were sandpapered using 100 to 1200 grits silicon carbide paper. They were washed several times using acetone and dried with a current of warm air. In each test,

attempts were made to prepare the specimens before the tests and without any delay; then they were put into the solution for two hours so that the system could reach a balance. After that, the cyclic polarization and Tafel extrapolation tests were done based on the ASTM-G61 standard, in 3.5% NaCl, using a Parstat 2273 Potanso Stat machine. The tests included intracellular corrosion three electrodes with reference electrode, saturated calomel electrode, platinum plate auxiliary electrode and sample working electrode. The scanning rate was the same for all specimens (1mv/s) and all tests were conducted at room temperature and initiated at a potential of about 250 mV below the corrosion potential.

3. Results and discussion

Figure 1(a) shows the microstructure of A335 chromium-molybdenum low alloy steel in which ferrite grains with dark pearlite grains can be observed. The microstructure of 347 austenitic stainless steel contained an austenitic field with equiaxed grains as shown in Figure 1(b).

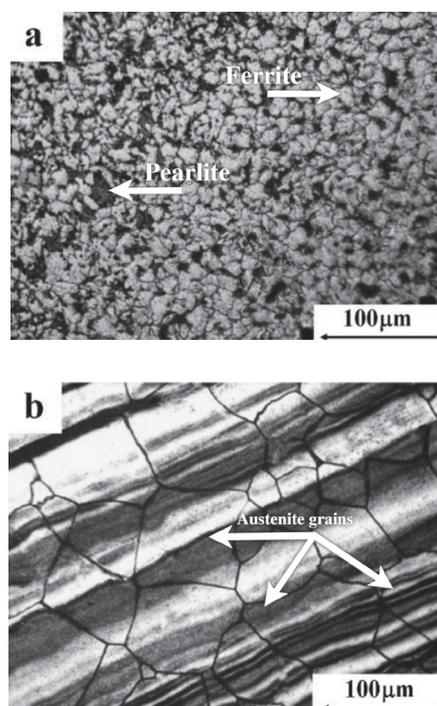


Fig. 1. optical micrographs of (a) A335 low alloy steel and (b) 347 austenitic stainless steel.

The microstructure of 309L austenitic stainless steel weld metal is shown in Figure 2. The solidification of 309L as a primary ferrite exhibited a skeletal ferrite morphology and solidification of FA type.

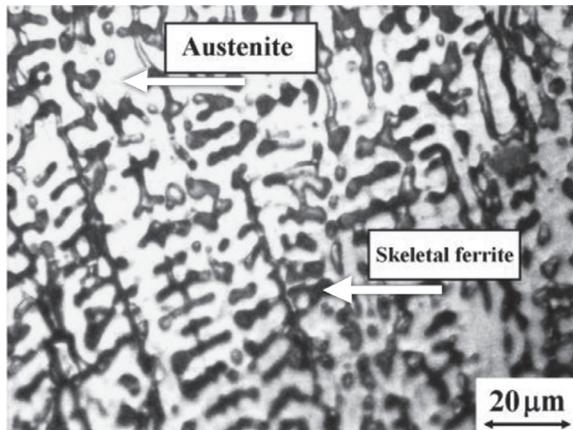


Fig. 2. Microstructure of ER309L weld metal.

The granular structure of ERNiCr-3 weld metal is shown in Figure 3. The solidification of ERNiCr-3 weld metal was fully austenitic; also a two-phase structure which contained dendrite and interdendrite zones could be observed¹⁾.

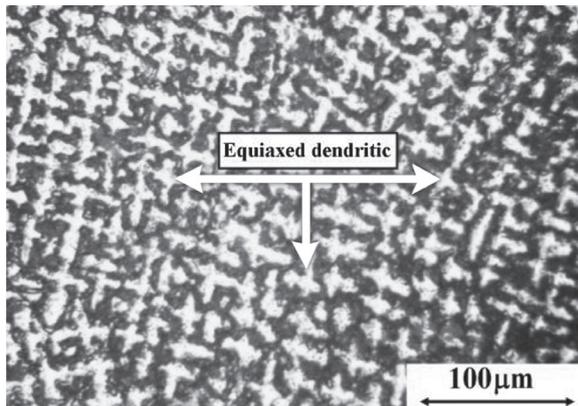


Fig. 3. Microstructure of ERNiCr-3 weld metal.

As it is obvious, with regard to the type of the filler metal (nickel-based and iron-based), the difference in the austenite percentage of the weld metal and the type of chemical composition can be seen by evaluating the effect of microstructure on corrosion behavior. In order to study the corrosion behavior, two different tests of electrochemical Tafel extrapolation and cyclic polarization were used. The results are presented below.

After floating the specimens in the solution, they reached a stable condition in about 2 hours and the open circuit potential was transferred to higher (nobler) potentials, which could be attributed to the

formation of the passive layer⁶⁾. Table 2 shows open circuit potential in the tested base metals and weld metals. With regard to the chemical composition of the base metals, according to studies conducted by researchers such as Shimada and Amini, it has been specified that chromium is an active metal; however, chromium itself and its alloys are passive and show high resistance to corrosion in many environments^{5,7)}. The presence of chromium element in these specimens and the formation of an outer layer containing Cr_2O_3 , cause the deactivation of the surface and resistance to corrosion. Some sources have only considered the single layer Cr_2O_3 ⁶⁾, which is divided into two sub-layers in stainless steels. The inner layer provides the deactivating effect and contains Cr_2O_3 and the outer layer contains iron oxides and hydroxides and is mostly influenced by external conditions⁷⁾.

Table 2. Evaluation of open circuit potential of the base metals and the weld metals

Element	347	A335	ERNiCr-3	ER309L
Eocp (V_{SCE})	-0.361	-0.611	-0.123	-0.260

As presented, the 347 specimen contained more chromium and a higher free potential of corrosion. The other difference was the amount of copper in each base metal. According to Table 1, the amount of copper in 347 stainless steel base metal was 5 times more than in A335 low alloy steel. Ogazi⁶⁾ investigated the effect of adding copper on corrosion behavior. The results showed that adding copper led to the improvement of resistance to pitting corrosion. For weld metals, the free potential of ERNiCr-3 was higher than 309L, which could be related to more nickel in the form of nickel oxide (NiO). The electron and ion conductivity in the passive layer formed on the surface of nickel-based alloys and Cr-Ni alloys were more than that formed on the surface of pure chromium. Nickel is a proper metal for producing the alloys that need resistance to high temperatures⁸⁾. In addition, most serious corrosion problems in alkaline materials and solutions are solved with nickel. In fact, alloys corrosion resistance, for instance in sodium hydroxide, is proportional to their nickel content. The Tafel extrapolation curve, which is related to the base metals in 3.5% sodium chloride solution, is displayed in Figure 4. According to the curves obtained from the test of Tafel extrapolation in Figure 4(a), it is shown that the curve which is related to 347 austenitic stainless steel base metal has moved upwards and left in comparison to A335 low alloy steel base metal.

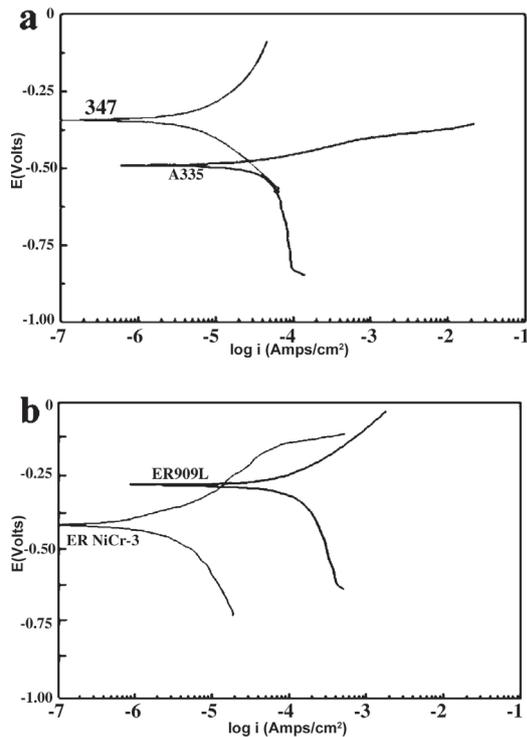


Fig. 4. Tafel extrapolation plots of (a) base metals and (b) weld metals.

Table 3 gives the concentration on the free corrosion potential and corrosion current density in different specimens. As it is observed, the amount of corrosion current density in austenitic stainless steel has been less, showing that 347 austenitic stainless steel base metal has higher (nobler) corrosion potential and lower corrosion current density. This means that 347 austenitic stainless steel base metal has better resistance to corrosion in the chemical composition of both base metals. 347 austenitic stainless steel base metal contains 20 times more chromium than A335 low alloy steel base metal, showing that along with the present nickel, it leads to the general improvement of resistance to corrosion in this metal.

Table 3. Free corrosion potential and corrosion current density in difference specimens

Element	347	A335	ERNiCr-3	ER309L
E_{CORR} (mV _{SCE})	-462	-625	-411	-274
i_{CORR} (μA/cm ²)	89	240	7	80

Figure 4(b) shows the curve of Tafel extrapolation which is related to the weld metals used in this test and in the fourth pass. It can be conducted that both weld metals have good resistance to corrosion although the difference in the chemical composition leads to different behaviors in the test environments. But, generally ERNiCr-3 filler metal shows less corrosion current density by moving to the left of the graph.

In this test, the starting potential relative to EOCp is considered to be -0.2500V and the ending potential relative to EOCp is 0.2500 V. In Figure 5(a), the cyclic polarization curve which is related to the base metals can be seen. Both base metals have formed positive hysteresis loop after the return potential and during the reverse scanning, showing the pitting corrosion in the two base metals. In other words, both base metals are sensitive to pitting corrosion, but the intensity of the occurrence of pitting corrosion, which depends on the area of the hysteresis loop, is different. By paying close attention to the figure, it is obvious that 347 austenitic stainless steel base metal has much better resistance to pitting corrosion in comparison to A335 low alloy steel, due to its chemical composition, especially more nickel and chromium content. Figure 5(b) shows the cyclic polarization curve for the weld metals. As it is observed in this figure, it can be concluded that the intensity of pitting corrosion in 309L weld metal is more than ERNiCr-3 weld metal. ERNiCr-3 filler metal has a lot of molybdenum which contributes to deactivation of the surface and increases the resistance of the outer layer, which, in turn, increases the resistance to pitting corrosion in this alloy⁸). ERNiCr-3 filler metal was selected using AWS A5.14 standard and studying the references. After obtaining the results from the corrosion test and noting that generally, chromium, molybdenum and nickel increase the resistance to pitting corrosion, and also, by bearing in mind that ERNiCr-3 filler metal contains high amounts of these elements, it can be concluded that the function of this metal against corrosion is better than 309 filler metal.

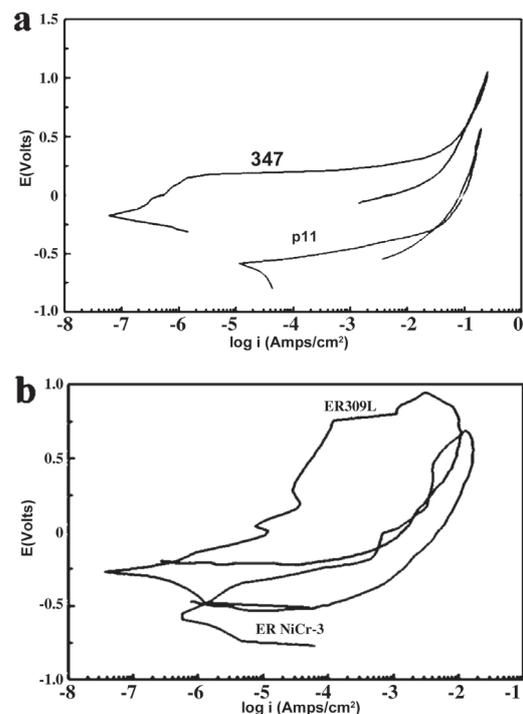


Fig. 5. Cyclic polarization plots of (a) base metals and (b) weld metals.

4. Conclusions

1. The solidification of ERNiCr-3 weld metal was similar to the primary austenite, and there was a two-phase structure which contained dendritic and interdendritic zones. The microstructure of the ER309L weld metal included primary ferrite with some austenite at the end of solidification which contained skeleton ferrite.
2. 347 austenitic stainless steel base metal had a higher (nobler) corrosion potential and lower corrosion current density in comparison to A335 steel in 3.5% sodium chloride solution using corrosion tests of Tafel extrapolation and cyclic polarization at room temperature. In all specimens, the base and filler metals were sensitive to pitting corrosion, However, 347 austenitic stainless steel base metal had much better resistance to pitting corrosion in comparison to A335 low alloy steel.
3. The ERNiCr-3 filler metal displayed better resistance to pitting corrosion than 309L filler metal in 3.5% sodium chloride solution using corrosion tests of Tafel and cyclic polarization at room temperature.

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