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ELECTROCHEMICAL INVESTIGATION OF CORROSION BEHAVIOR OF BORON DOPED POWDER METALLURGY 316L STAINLESS STEELS IN ACIDIC MEDIA

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Abstract

Corrosion behavior of PIM 316L, PIM 316L with 1.5wt% NiB and casting 316L stainless steels were investigated using electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization methods in acidic solutions such as 1M HCl and 1M H_2SO_4 under room temperature (25±1 °C). The corrosion performances of PIM 316L with 1.5wt% NiB were compared with the PIM 316L and casting 316L stainless steels processed at similar conditions. All measurements show that the addition of 1.5wt% NiB to 316L stainless steels under study improve corrosion behavior of PIM 316L stainless steel. The results of corrosion experiment of stainless steels obtained from all the methods employed are in agreement.

Keywords: corrosion, electrochemical impedance spectroscopy, potentiodynamic polarization

1. Introduction

The corrosion of metals is a very important problem for all industries. The cost due to corrosion in many countries is as high as 5% of the GNP. In practice, corrosion can never be stopped but hindered to a reasonable level [1-3].

Stainless steels are iron base alloys that contain a minimum of approximately 11 % Cr. Stainless steels are used in a wide variety application [4]. Type 316L stainless steel is a low-carbon version of the AISI 316 stainless steel used extensively in many purposes [5, 6]. The type 316L stainless steel has good corrosion resistance and has been used increasingly for cooling water service in the chemical, petrochemical and power utility industries. However, stainless steel is susceptible to localized corrosion by chloride ions and reduced sulfur compounds [7].

Powder metallurgy (PM) technique is one of the best methods to produce complex shapes with appreciable tolerance and high productivity. However, the applications are limited due to the relatively poor mechanical and corrosion properties of PM components when compared to casting products [8]. Therefore, it is thought that adding some elements to PM stainless steels improves the mechanical and corrosion properties of these stainless steels.

The aim of this study is to investigate the corrosion behavior of boron added powder metallurgy 316L stainless steel (PIM 316L+NiB) by comparing with PIM 316L and casting 316L stainless steels in acidic media at room temperature (25±1 °C) using electrochemical techniques such as potentiodynamic polarization and electrochemical impedance spectroscopy (EIS).

2. Experimental

Three typer of 316L stainless steel electrode were used for the electrochemical tests:
(a) Casting 316L stainless steel,
(b) PIM 316L,
(c) PIM 316L+NiB (1,5wt% NiB)

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Polarization and impedance measurements were performed using rod structure specimens. Electrodes were prepared by embedding the rod in epoxy resin, exposing a geometrical surface area to the electrolyte. All these electrodes were prepared by H. Ozkan GULSOY from Marmara University Technology Faculty.

Prior to each experiment, the electrodes were ground up 1000 and 2500 SiC abrasive papers and then polished with 1 μm alumina slurry to obtain mirror-like exposure surface and triple distilled water before introduction into the working cell.

All solutions as working environment were prepared from analytical reagent grade and triple distilled water. All tests were performed at room temperature (25 ± 1 °C).

Measurements were carried out in a conventional three electrodes Pyrex cell with a platinum wire counter electrode and silver/silver chloride (Ag/AgCl (sat. KCl)) electrode as the reference electrode. All the reported potentials are referred to this electrode. All measurements were carried out using a PC controlled VoltaLab 80 PGZ 402 system with VoltaLab 4 software and were performed three times to assure reproducibility.

Prior to the polarization test, each sample was stabilized for about 1 hour in the solution to get a stable open circuit potential (OCP). All solutions were de-aerated with nitrogen and mixed vigorously with a magnetic stirrer for this time in the working cell. The potentials were recorded at a scan rate of 1 mV/s starting from more cathodic potential than E_{OCP} to anodic direction, $E = E_{OCP} \pm 200$mV.

Impedance spectra were obtained in the frequency range 100 kHz to 10 mHz with 10 points per decade at the corrosion potential, E_{corr}, after a stabilization period of 1 hour. Sine wave amplitude of 10 mV was used as the perturbation signal. The same cell and system was used as in the polarization method.

3. Results and Discussion

3.1. Polarization measurements

Fig. 1 and 2 represent the Tafel curves of casting 316L, PIM 316L and PIM 316L+NiB stainless steels in different solutions such as 1M HCl and 1M H_2SO_4. On the other hand, Table 1 provides some of the electrochemical corrosion parameters, i.e., the corrosion potential (E_{corr}), corrosion current density (i_{corr}), corrosion resistance (R_p), anodic and cathodic Tafel slopes (β_a and β_c). Values of corrosion potential (E_{corr}), corrosion current density (i_{corr}), anodic and cathodic Tafel slopes (β_a and β_c) obtained from Tafel curves and then values of corrosion resistance (R_p) were obtained using the following Stern Geary equation:

$$i_{corr} = \frac{1}{2.303 R_p} \times \frac{\beta_a \beta_c}{\beta_a + \beta_c} \quad (1)$$

The Tafel curves and some of the electrochemical corrosion parameters of casting 316L, PIM 316L and PIM 316L+NiB stainless steels in 1M HCl solution are shown in Fig. 1 and Table 1, respectively.

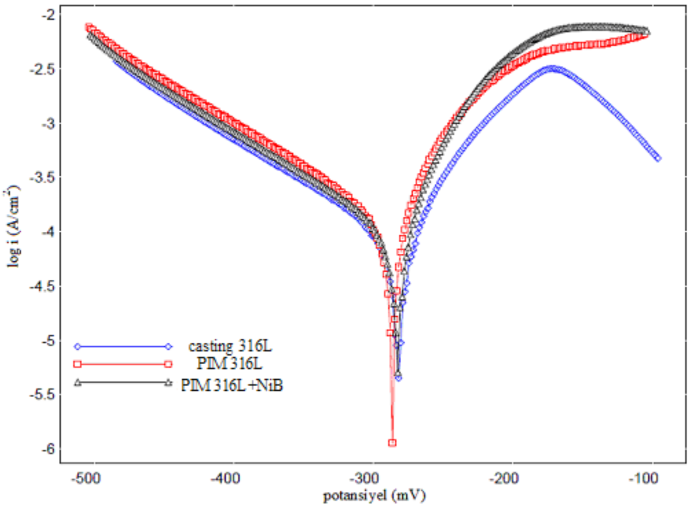

Figure 1. Tafel curves for casting 316L, PIM 316L and PIM 316L+NiB stainless steels in 1M HCl

According to Tafel curves in 1M HCl solution (Fig. 1) and Table 1, corrosion current density of casting 316L electrode is less than PIM 316L and PIM 316L+NiB electrodes. At the same time, PIM 316L+NiB electrode has less corrosion current density value compared to PIM 316L electrode. Similarly, casting 316L electrode has the highest corrosion resistance than other electrodes and also corrosion resistance of PIM 316L+NiB electrode is more than PIM 316L electrode. These results show that 1.5wt% NiB additions on PIM 316L stainless steel improve corrosion resistance in 1M HCl solution medium.

Table 1. Corrosion parameters for casting 316L, PIM 316L and PIM 316L+NiB stainless steels in 1M HCl and 1M H_2SO_4

		- E_{corr} (mV)	i_{corr} ($\mu A/cm^2$)	R_p ($\Omega.cm^2$)	β_a (mV)	- β_c (mV)
1M HCl	casting 316L	284	98.1	181.5	59.9	130.0
	PIM 316L	289	144.6	113.2	53.6	127.3
	PIM 316L+NiB	285	106.2	134.6	44.4	127.4
1M H_2SO_4	casting 316L	268	35.9	977.3	274.6	114.5
	PIM 316L	300	150.3	253.8	282.2	127.6
	PIM 316L+NiB	290	138.3	263.2	278.0	120.0

The Tafel curves and some of the electrochemical corrosion parameters of casting 316L, PIM 316L and 316L+NiB stainless steels in the 1M H_2SO_4 solution are shown in Fig. 2 and Table 1, respectively.

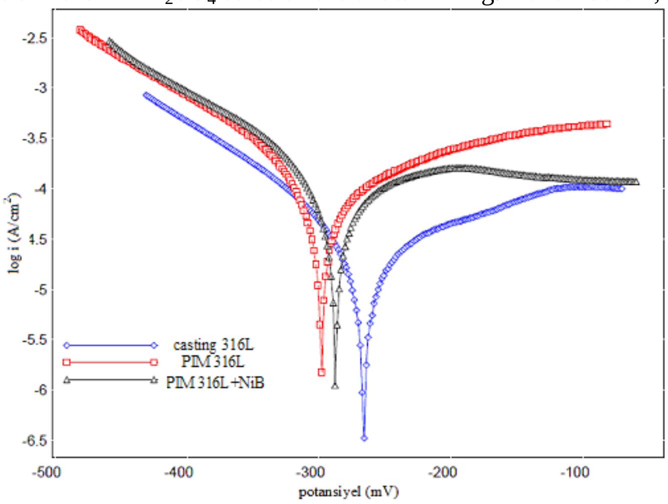

Figure 2. Tafel curves for casting 316L, PIM 316L and PIM 316L+NiB stainless steels in 1M H_2SO_4

According to Tafel curves in 1M H_2SO_4 solution (Fig. 2) and Table 1, corrosion current density of casting 316L electrode is lower than PIM 316L and PIM 316L+NiB electrodes. At the same time, PIM 316L+NiB electrode has lower corrosion current density than PIM 316L electrode. These results show that 1.5wt% NiB additions on PIM 316L decrease corrosion rate in 1M H_2SO_4 solution medium.

3.2. Electrochemical impedance spectroscopy measurements

Fig. 4 and 5 represent the electrochemical impedance diagrams (Nyquist curves) of casting 316L, PIM 316L and 316L+NiB stainless steels in different solutions such as 1M HCl and 1M H_2SO_4.

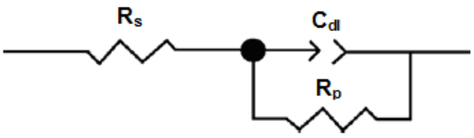

Figure 3. Equivalent circuit

The equivalent electrical circuit used to represent these diagrams is presented in Fig. 3. Various parameters such as polarization resistance (R_p), pseudo capacitance (C_{dl}) have been calculated and listed in Table 2. The polarization resistance (R_p) values have been calculated from the difference in impedance at higher and lower frequencies. The values of C_{dl} were obtained at maximum frequency (f_{max}), using the following equation:

$$C_{dl} = \frac{1}{2\pi f_{max}} \frac{1}{R_p} \quad (2)$$

The Nyquist curves of casting 316L, PIM 316L and 316L+NiB stainless steels in the 1M HCl solution are shown in Fig. 4 and also various parameters, obtained from Nyquist curves, such as polarization resistance (Rp), pseudo capacitance C_{dl} are presented in Table 2.

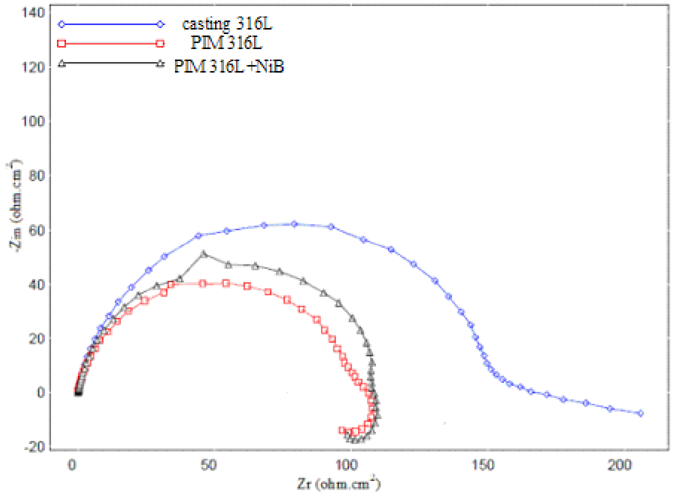

Figure 4. Nyquist curves for casting 316L, PIM 316L and PIM 316L+NiB stainless steels in 1M HCl

According to Nyquist curves in 1M HCl solution (Fig. 4) and Table 2, corrosion resistance of casting 316L electrode is higher than PIM 316L and PIM 316L+NiB electrodes. At the same time, PIM 316L+NiB electrode has higher corrosion resistance than PIM 316L electrode. Similarly, casting 316L electrode has the least pseudo capacitance (C_{dl}) than other electrodes and also pseudo capacitance (C_{dl}) of PIM 316L+NiB electrode is lower than PIM 316L electrode. These results show that 1.5wt% NiB additions on PIM 316L increase corrosion resistance in 1M HCl solution medium. These results are in agreement with the results obtained from the Tafel curves.

Table 2. Corrosion parameters for casting 316L, PIM 316L and PIM 316L+NiB stainless steels in 1M HCl and 1M H_2SO_4

		Rp ($\Omega.cm^2$)	**C_{dl} ($\mu F/cm^2$)**
1M HCl	**casting 316L**	153.8	517.0
	PIM 316L	102.9	618.0
	PIM 316L+NiB	112.0	568.0
1M H_2SO_4	**casting 316L**	433.5	183.0
	PIM 316L	106.7	235.0
	PIM 316L+NiB	131.8	191.0

The Nyquist curves of casting 316L stainless steel, PIM 316L and 316L+NiB in the 1M H_2SO_4 solution are shown in Fig. 5 and also various parameters, obtained from Nyquist curves, such as polarization resistance (R_p), pseudo capacitance (C_{dl}) are presented in Table 2.

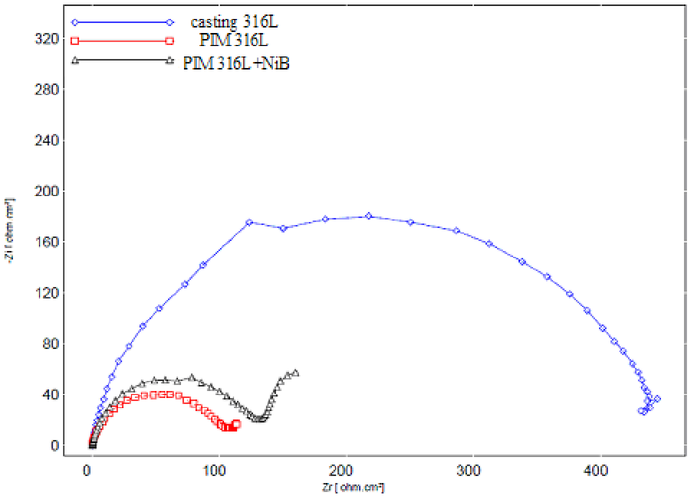

Figure 5. Nyquist curves for casting 316L, PIM 316L and PIM 316L+NiB stainless steels in 1M H_2SO_4

According to Nyquist curves in 1M H_2SO_4 solution (Figure 5) and Table 2, corrosion resistance of casting 316L electrode is higher than PIM 316L and PIM 316L+NiB electrodes. At the same time, PIM 316L+NiB electrode has higher corrosion resistance value compared to PIM 316L electrode. These results show that 1.5wt% NiB additions on PIM 316L improve corrosion resistance in 1M H_2SO_4 solution medium. These results are in agreement with the results obtained from the Tafel curves.

4. Conclusion

Corrosion current density for casting 316L electrode were found to be lower than that of the PIM 316L and PIM 316L+NiB electrodes in 1M HCl and 1M H_2SO_4 solution media. Similarly, 316L+NiB electrode was found to show lower corrosion current density with respect to the 316L electrode. Therefore, casting 316L electrode was found to have the highest corrosion resistance. In contrast, PIM 316L electrode was found to have the smallest corrosion resistance. Thus, the corrosion resistances for the electrodes were as following: casting 316L > PIM 316L+NiB > PIM 316L in 1M HCl and 1M H_2SO_4 solutions media.

Acknowledgements

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