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Comparison of Corrosion Behavior of 316 and Duplex Stainless Steels in 7% NaCl Solution

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Desalination can be defined as the process of extracting salts from seawater or brackish water to obtain drinking water through desalination plants. The development of desalination plants to desalinate seawater is proving to be an effective solution to meet the planet's need for water suitable for consumption, with these seawater desalination plants producing water for both public supply and irrigation. The desalination process and its technology have evolved considerably over the past five decades, becoming increasingly cost-effective and efficient. Initially, the water desalination process was a thermal process; however, it has evolved in response to technological and scientific advances, leading to the predominance of reverse osmosis in the current market. Seawater is highly corrosive, necessitating the use of materials with high corrosion resistance for the reverse osmosis seawater desalination process. Initially, 316 stainless steel was utilized, and subsequently, duplex steels were employed to enhance this effect. Additionally, the reverse osmosis process results in the production of drinking water and brine, which possesses an even higher salinity and is thus significantly more corrosive. This underscores the necessity to employ the highest quality stainless steels to ensure optimal performance and durability in this application.

Stainless steel is an essential material in a variety of industries because of its corrosion resistance and mechanical properties. 316 austenitic steel and 2205 duplex stainless steel are among the most prominent alloys, whose unique chemical compositions and microstructures determine their behavior in specific applications [1]. 316 stainless steel, composed of 16-18% Cr, 10-14% Ni and 2-3% molybdenum [2], offers excellent corrosion resistance and high-temperature durability [3], making it ideal for applications in chemical processing, marine environments, and medical devices [4]. Conversely, 2205 duplex stainless steel, comprising 22% chromium, 5-6% nickel and 3% molybdenum, along with a high nitrogen content [5], provides enhanced resistance to pitting, mechanical strength and stress corrosion cracking in comparison to conventional austenitic steels [6].

The present study focuses on the metallographic characterization, corrosion resistance evaluation and microhardness measurement of 316 and duplex 2205 stainless steel samples. By comparatively analyzing these properties, we seek to provide a deeper understanding of the advantages and limitations of each alloy, providing a solid basis for their optimal application in various industrial sectors.

The samples of SS 316 and Duplex stainless steel used in this research has the composition (in wt%) presented in Table 1. Each composition was measured applying X-ray fluorescence technique with X MET7000 eXpress handheld XRF analyzer from Oxford Instruments.

Microhardness and electrochemical testing, on both samples were performed. In accordance with ISO 14577-1:2015, ten measurements were performed applying the Future Tech FM-810 hardness tester. Each measurement lasted 15 seconds, with a load of 50 gf applied to obtain the Vickers hardness values. The BioLogic Essential SP-150 potentiostat and Sodium chloride solution (7% NaCl), were utilized for electrochemical tests in continuous and alternate current to obtain the corrosion potential and corrosion rate and perform the electrochemical impedance spectroscopy.

As demonstrated in Fig. 1, the Vickers hardness values of the Duplex steel (508 HV) are significantly higher than those of the SS 316 (185 HV), although the duplex steel has a higher standard deviation (SD).

Electrochemical tests were performed in order to ascertain the corrosion potentials of the two samples during the 24-hour immersion in Ringer's solution. The results demonstrated a tendency towards surface passivation, with more positive values recorded for the Duplex steel (see Fig. 2.a).

Furthermore, the Duplex exhibited a lower corrosion rate value of 7.10-10^{-4} mpy, while the SS 316 demonstrated a value of 3.69 -10^{-3} mpy, as illustrated in the linear polarization curves of Fig. 2.b. The Nyquist diagrams depicted in Fig. 3a. demonstrate higher impedance values for the SS316 sample, indicating its capacitive behavior. Conversely, the Bode-impedance and Bode-phase diagrams demonstrate a higher maximum impedance value for SS316 at low frequencies (0.1 mHz), although both samples exhibited comparable maximum phase angle values, with the Duplex displaying a marginally higher value of 75°.

The equivalent circuit that most closely matched the impedance results obtained for both samples was $R_1(Q_2(R_2(C_3R_3)))$, where: R_1 denotes the resistance of the solution, R_2 and Q_2 constitute the resistance and phase constant element of the external porous passive layer of the surface, while R_3 and C_3 belong to the resistance and capacitor of the internal compact passive layer of the sample surface (see Fig. 3).

The Duplex sample had harder steel structures as well as better corrosion resistance as compared to SS 316 because of a lower corrosion rate and more positive potentials. Despite higher capacitive SS 316 exhibited more passive behavior, both steels had some tendency to passivate in extreme saline environments. Notable passive layers were revealed in the impedance analysis, which accounted for the differences in their electrochemical behavior.

Table 1. Composition (in wt%) of the alloys under study according to XRF.

Elements	Composition (in wt%)	
	SS316	Duplex 2205
Fe	68.82 ± 0.125	65.93 ± 0.242
Cr	16.60 ± 0.061	21.58 ± 0.135
Ni	10.65 ± 0.055	7.29 ± 0.087
Mo	2.07 ± 0.011	3.92 ± 0.027
Mn	1.33 ± 0.045	0.63 ± 0.080
Co	0.35 ± 0.020	0.17 ± 0.037
Ti	-	0.22 ± 0.036
Cu	0.04 ± 0.004	0.17 ± 0.019
Zn	-	0.09 ± 0.012
V	0.11 ± 0.09	-
W	0.03 ± 0.007	-

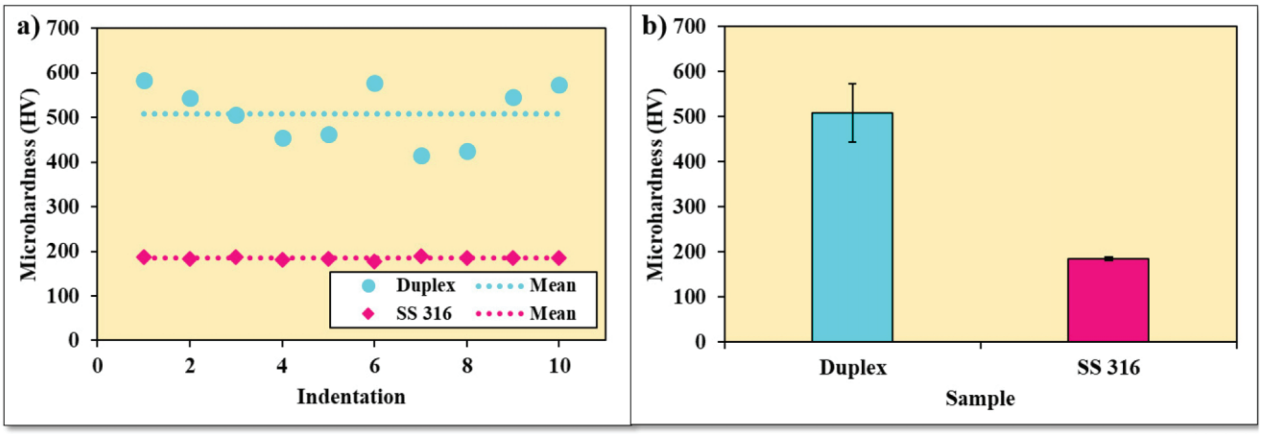

Fig. 1. a) Vickers microhardness values for each indentation with their respective mean; b) Mean Vickers microhardness values with SD for each sample.

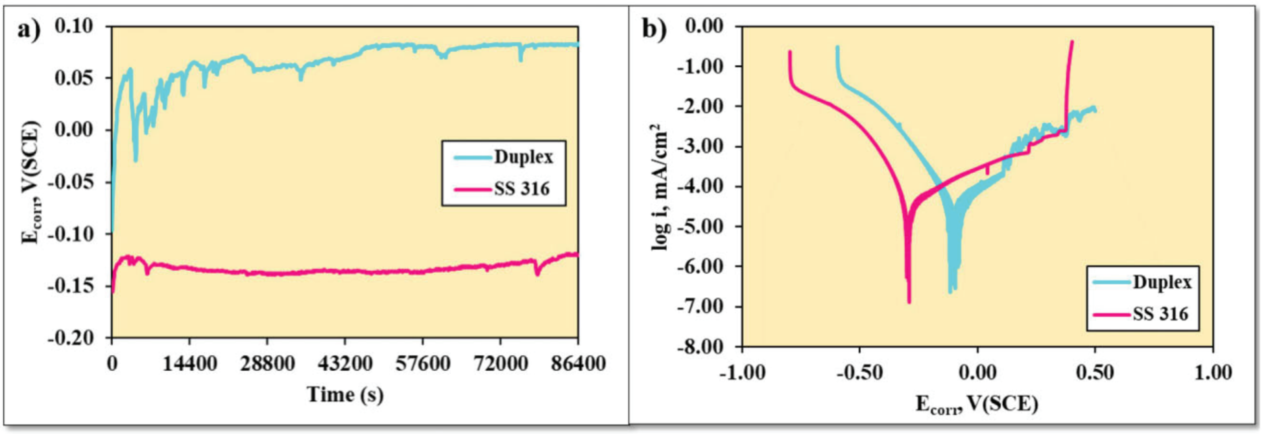

Fig. 2. a) Corrosion potential during the 24-hour immersion test; b) linear polarization curves of both samples.

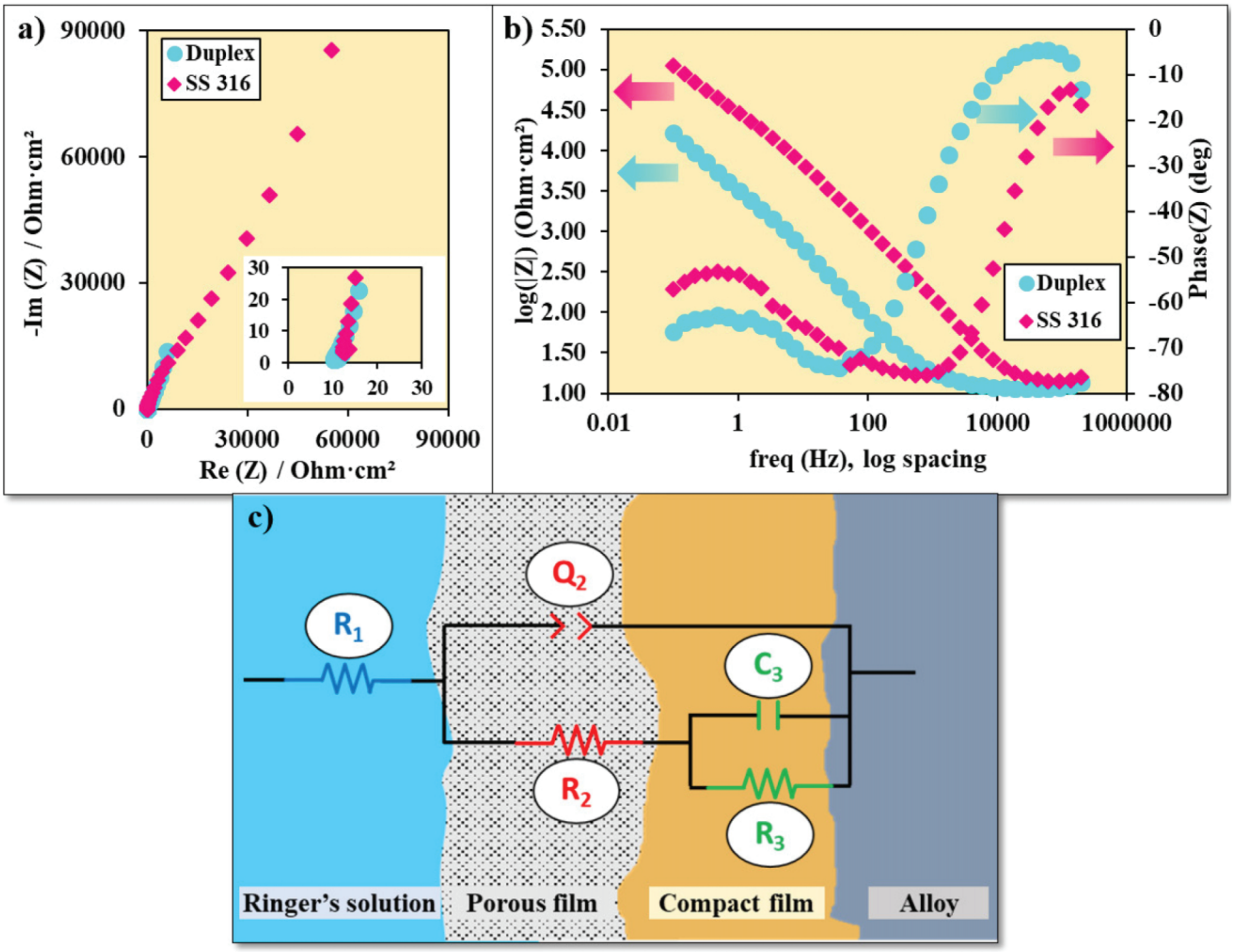

Fig. 3. Nyquist plots (a)), Bode-impedance and Bode-phase plots (b)) and electrical equivalent circuit $R_1(Q_2(R_2(C_3R_3))$ of the samples.

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