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Correlation of Microstructure and Corrosion Behavior of Martensitic Stainless Steel Surgical Grade AISI 420A Exposed to 980-1035°C

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Abstract—Martensitic stainless steels have been extensively used for their good corrosion resistance and better mechanical properties. Heat treatment was suggested as one of the most excellent ways to this regard; hence, it affects the microstructure, mechanical and corrosion properties of the steel. In the current research work the microstructural changes and corrosion behavior in an AISI 420A stainless steel exposed to temperatures in the 980-1035oC range were investigated. The heat treatment is carried out in vacuum furnace within the said temperature range. The quenching of the samples was carried out in oil, brine and water media. The formation and stability of passive film was studied by Open Circuit Potential, Potentiodynamic polarization and Electrochemical Scratch Tests. The Electrochemical Impedance Spectroscopy results simulated with Equivalent Electrical Circuit suggested bilayer structure of outer porous and inner barrier oxide films. The quantitative data showed thick inner barrier oxide film retarded electrochemical reactions. Micrographs of the quenched samples showed sigma and chromium carbide phases which prove the corrosion resistance of steel alloy.

Keywords—Martensitic stainless steel corrosion, microstructure, vacuum furnace.

I. INTRODUCTION

MARTENSITIC Stainless Steels (MSS) are extensively used in mechanical constructions as structural material with reasonable corrosion resistance [1]. Martensitic grades include alloys CA-15, CA-40, CA-15M, and CA-6NM. The CA-15 alloy contains the minimum amount of chromium necessary to make it essentially rustproof. It has good resistance to atmospheric corrosion, as well as to many organic media in relatively mild service. A higher-carbon modification of CA-15, CA-40 can be heat treated to higher strength and hardness levels. Alloy CA-15M is a molybdenum-containing modification of CA-15 that provides improved elevated-temperature strength. Alloy CA- 6NM is an iron-chromium-nickel-molybdenum alloy of low carbon content [2], [3]. As their name implies, martensitic stainless steels are designed to combine the strength of martensite with the corrosion resistance conferred by chromium, while limiting additions of expensive alloying elements. By forming a thin stable surface layer of chromium oxide, chromium protects the underlying metal from further corrosion [4]. The minimum concentration of chromium necessary to obtain an effective passive layer is about 10.5 to 11%, although corrosion resistance increases with chromium content beyond this level [5]. The composition must therefore be adjusted to enable heat treatment within the austenite loop. The most common grades contain between 12 and 15% chromium and 0.1 to 0.5% carbon, although concentrations up to 1% C are sometimes employed [6]. In the present work the correlation of microstructure and corrosion behavior of an AISI 420 MSS sample were measured for different heat treatment conditions. The results are discussed taking into account the physical metallurgy of the steel.

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TABLE I
CHEMICAL COMPOSITION OF ALLOY STEEL 420 GRADE

Elements	%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Mo	%Al
Standard	0.16-0.25	1.00	1.00	0.040	0.030	12.00-14.00	1.00	_	_
Sample	0.209	0.464	0.66	0.014	0.012	12.61	0.121	0.042	0.025
Elements	**%Cu**	**%Co**	**%Ti**	**%Nb**	**%V**	**%W**	**%Pb**	**%B**	**%Sb**
Standard	_	_	_	_	_	_	_	_	_
Sample	0.111	0.023		0.012	0.026	<0.0070	0.0030	0.0015	<0.0020

II. EXPERIMENTAL WORK

The experimental steel was produced in a vacuum induction furnace. Molten steel was cast as cylindrical ingots. The chemical composition of the steel is given in Table I.

The ingot was refined by the electroslag refining process. The refined ingots were hot forged between 900 and 1000 °C, heat treated at 700 °C followed by oil, brine and water quenching. Blocks of suitable size were cut along longitudinal direction for the heat treatment experiments. Samples were austenitized at 980, 1015 and 1050 °C for 30, 60 and 120 min. All samples were tempered at 200 °C for 1 h. After the heat treatment process, corrosion testing was performed in such a way. The electrochemical testing was carried out by using CHI 660 C Electrochemical Workstation with a distinctive three-electrode cell: Pt as the auxiliary electrode, Ag/AgCl as the reference electrode and gold as the working electrode (2 mm diameter), in a NaCl (0.9%) electrolytic solution The Electrochemical impedance spectroscopy results were produced by using a potential perturbation of 30 mV with frequency from 100 kHz to 10 mHz.

III. RESULTS AND DISCUSSION

Steel alloy represents initial spontaneous surface corrosion reactions. Fig. 1 represents the Nyquist plot for steel alloy. The typical Nyquist plots were the representation of passive behavior of both alloy systems. It was observed from higher values of real impedance (Zreal) value of alloy that charge transfer resistance Rct higher. However, in order to predict the level of oxide film protection and to quantify the experimental EIS spectrums these were modeled with an equivalent electrical circuit (EEC) simulated to a physical system. It was determined that passive film capacitance at the surface was non-ideal in nature as evaluated from the coefficient value ‘n’ less than 1. The EEC simulated model suggested the formation of bi-layer oxide film comprising on upper porous layer and inner barrier type film as an intrinsic feature of titanium.

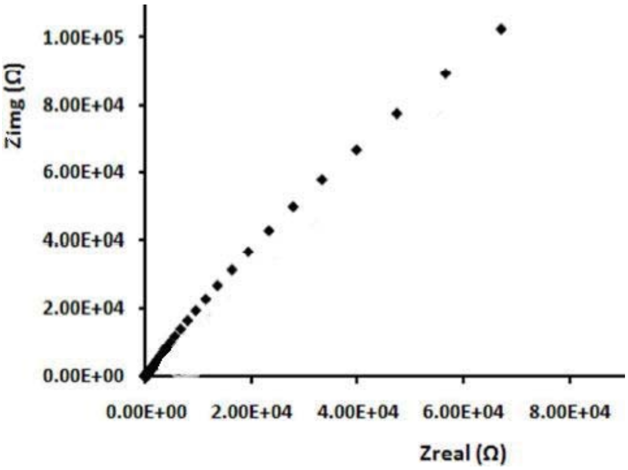

Fig. 1 Electrochemical Impedance Spectroscopy (EIS) plot

The microstructure of steel alloy was composed of single ‘β’ phase and fine intermetallics uniformly dispersed within the solid solution (Fig. 2).

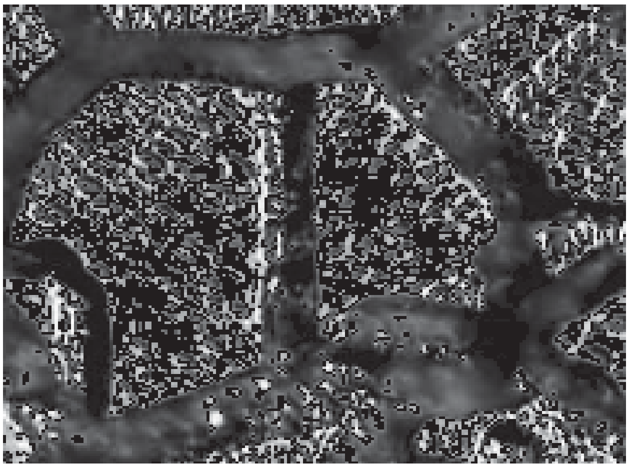

Fig. 2 Microstructures showing carbide phases

The germination of precipitates within ‘β’ solid solution and at grain boundaries was promoted as a function of ‘Cr’ concentration and larger holding time during homogenizing in contrast to the results of corrosion investigation.

IV. CONCLUSION

The microstructure of alloy was Sigma phase precipitation and chromium carbide phase. Chromium carbide and sigma phase precipitation provokes sensitization of the steel, the precipitation was observed within the grains and at the grain boundaries when it was homogenized for 2hours at 1000ºC. The electrochemical characterization of alloys revealed that increase in concentration of Cr resulted in good corrosion solution. EIS plot demonstrated oxide film structure packed of outer oxide layer. Hence this alloy exhibits good electrochemical behavior for real world applications.

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