Electrochemical Corrosion Properties of 316LSS and Titanium in Various Corrosion Media

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Abstract: ***The work was carried on biomedical implants and the selection of correct methods for corrosion studies and study of the corrosion products, electrochemical methods are used to determine the metal and alloys corrosion rate and to characterize the corrosion damage. Microscopy and spectroscopy studies are used for characterization and determination of thickness and nature of the corrosion products.***

Keywords: Corrosion, Titanium & 316L SS

I. INTRODUCTION

The corrosion of metallic biomaterials in artificial body fluid, and investigated the corrosion behaviour of commercially pure titanium (CP-Ti), Ti-6Al-4V) and 316L stainless steel 316LSS in Hanks solution at 38^0C using the cyclic polarization test. Corrosion behaviour is described in terms of breakdown potential at the rate of corrosion, localized corrosion resistance and breakdown repassivation. It is concluded that CP-Ti used in this study has the lowest corrosion rate and corrosion potential whereas 316LSS showed lower passive current density than CP-Ti and Ti-6Al-4V. Anodized CP-Ti is used in human body due to its lower corrosion rate as higher corrosion potential coupled with the absence of localized corrosion. CP- Ti has low strength than other grades of titanium. Further work can be carried on Titanium grades 2, 3 and 4. Many researchers have conducted on immersion corrosion test, electrochemical corrosion test, fatigue corrosion test and also effects of corrosion on biometals. Pitting corrosion of metals with and without inhibitors was studied. The electrochemical polarization test Nyquist plot showed titanium have more corrosion resistant than other bio-metals.

II. METHODOLOGY

A. Electrochemical Corrosion Test

Electrochemical Corrosion test is conducted on metals. This test is a rapid corrosion test. The test was conducted for 30 minutes electrochemical corrosion apparatus.

The tests are carried out on plate of dimensions 1.0cm x4.0cm x 2 cm Electrochemical measurement on biomaterials is performed at 37^oC in ringer Solution. A conventional three electrode electrochemical cell system is used in Saturated Calomel Electrode (SCE), Platinum mesh is used as reference and Counter electrodes respectively In the experiments, the Open Circuit Potential (OCP) is measured for an hour.

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Electrochemical impedance is usually measured by applying an AC potential to an electrochemical cell and measuring the current through the cell. Electrochemical Impedance is normally measured using a small excitation signal of 10 to 50mV.

III. EXPERIMENTS AND RESULTS

The material is tested for chemical composition and its corrosion resistance.

Table 1: Chemical Composition of 316L SS

Steel 316L					
C	0.021	S	0.002	Ni	14.10
Mn	1.68	P	0.015	Mo	2.51
Si	0.71	Cr	17.20	N	0.060
Fe	Bal				

The 316 LSS chemical composition is given in table: 1 and mechanical properties of 316 LSS are shown in the table: 2

Table 2: Mechanical Properties of 316L SS

Properties	316L SS
Young’s Modulus	210 GPa
Poisson’s ratio	0.3

The tests is conducted on metals and alloys having the following surfaces ground–average roughness R_a = 0.31 µm. To measure the roughness the surfronic 3+ surface analyser is applied. The electrochemical test is conducted on the metal showed pitting of 316L SS metal specimen. The electrochemical corrosion tests are recorded in anodic polarization curve. The CHI Electrochemical workstation with impedance, Model 660A System for electrochemical tests are used in the tests. The metal is immersed into the artificial body solution for 30min and made to open circuit potential (E_{ocp}) stabilized. Then the potentiodynamic polarization is performed. From the polarization study corrosion parameter such as corrosion potential (E_{corr}), Corrosion Current (I_{corr}) and Tafel slopes (anodic ba and cathodic bc) are calculated. All the experiments are repeated for three times. The tests are carried out in various corrosion media used in Implants and fixators.

Table 3: Electrochemical Test Results on 316 LSS

System	Ecorr mv vs SCE	Bc mv/decay	ba mv/decay
Seawater + SS 316L	-430	0.1257	0.2506

Seawater + SS 316L + Creatinine	-228	0.1875	0.0673
Ringer Soln. + 316L SS	-128	0.0672	0.4430
NaOH	-347	.001	0.0058
Hank's Solution	-144	0.7131	0.1773
System	**LPR ohmcm^2**	**Icorr A/cm^2**	
Seawater + SS 316L	7.5565 x10^7	4.8102 x10^{-10}	
Seawater + SS 316L + Creatinine	6.3090 x10^8	3.41 x10^{-11}	
Ringer Soln. + 316L SS	102433 0666	2.4736x10^{-10}	
NaOH	283	8.8660 × 10^{-6}	
Hank's Solution	286384	2.1536 × 10^{-7}	

Table 4 Nyquist plot for 316LSS

System	**Nyquist plot**	
	Rt ohm /cm^2	**CF/cm^2**
Seawater+SS 316L	66.05	1.7938 × 10 $^{-9}$
Seawater+SS 316L+ Creatinine	147.25	1.2203 × 10 $^{-11}$

The table 3 gives the electro chemical tests results on 316 LSS The table 4 gives the Nyquist plot for 316 LSS.

Analysis of Polarization Curve 316L SS

The potentiodynamic polarization curves of 316L stainless steel metal immersed in 5% sodium hydroxide solution, Hank's solution, sea water, Ringer solution these are shown in Figures 1,2, 3, 4. The corrosion parameters are corrosion potential (Ecorr), Tafel slopes (bc= cathodic), (ba = anodic), linear polarization resistance (LPR) and corrosion current (Icorr). The corrosion resistance of a metal in a corrosion medium increases, LPR (Linear Polar Resistance) value increases and the corrosion current decreases. From the corrosion analysis of 316L SS metal specimen in 5% NaOH, the corrosion current is 8.866 × 10^{-6} A cm-^{2} and the LPR value is 283 Ω cm^2. Then 316L SS metal is immersed in Hank's solution, the corrosion current is decreased from 8.866 × 10^{-6} A cm^{-2} to 2.1536 × 10^{-7} A cm^{-2} and the LPR value is increased from 283 Ω cm^2 to 286384 Ω cm^2. The 316L SS metal is immersed in seawater the corrosion current is decreased from 2.1536 × 10^{-7} A cm^{-2} to 4.8102 × 10^{-8} and the LPR value is increased from 286384 Ω cm^2 to 754744 Ω cm^2. The 316L SS metal specimen in Ringer solution the corrosion current was decreased from 4.8102 × 10^{-8} A cm^{-2} to 2.4736 × 10^{10} and the LPR value is increased from 754744 Ω cm^2 to102430666 Ω cm^2. The above results shows that 316L SS is more corrosion resistance in Ringer solution than seawater, Hank's solution and 5% NaOH. The tests also shows formation of protective film on the 316L SS metal surface.

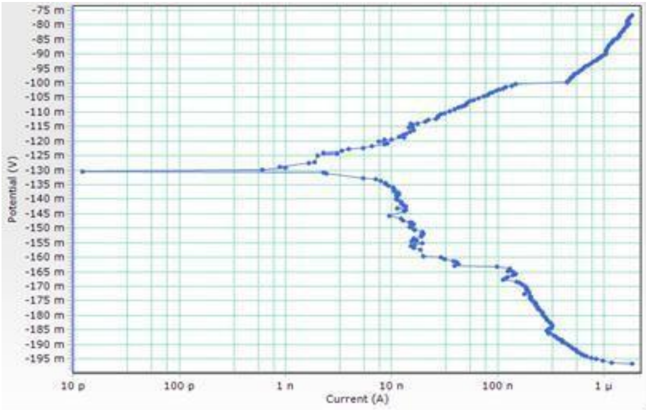

Figure: 1 316L SS 5% NaOH

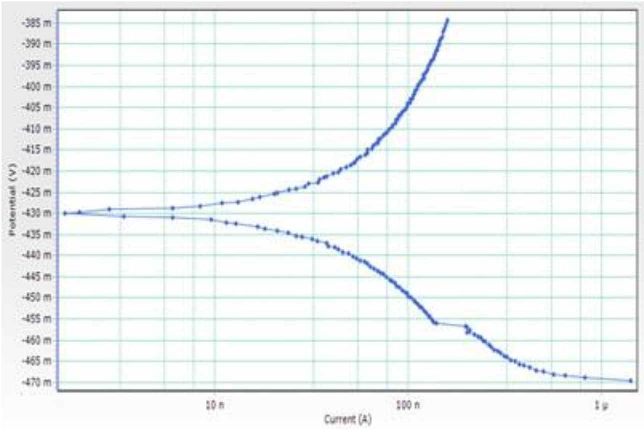

Figure: 2 316L SS + Hanks Solution

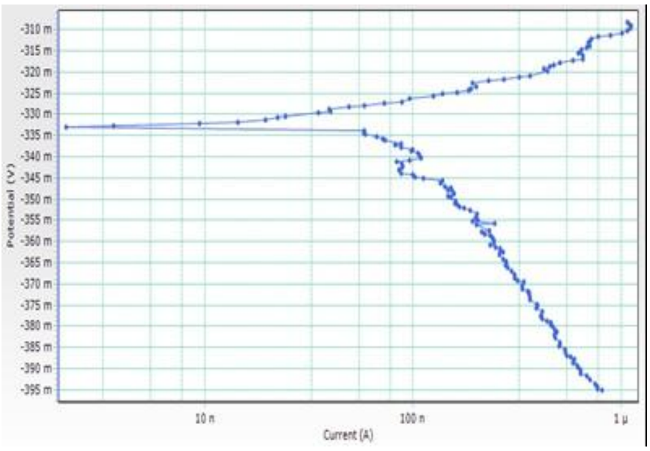

Figure: 3 316L SS + Sea Water

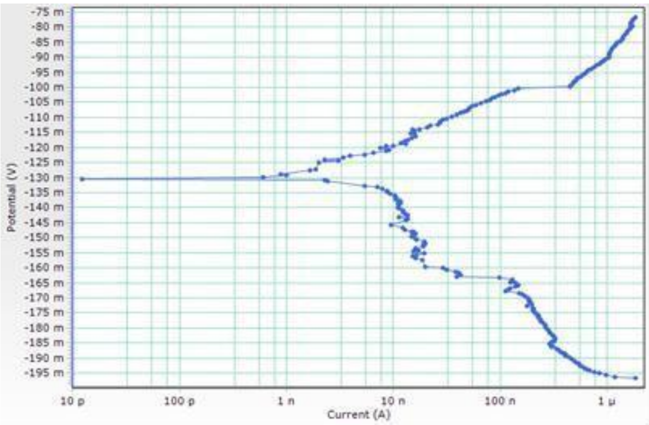

Figure: 4: 316L SS + Ringer Solution

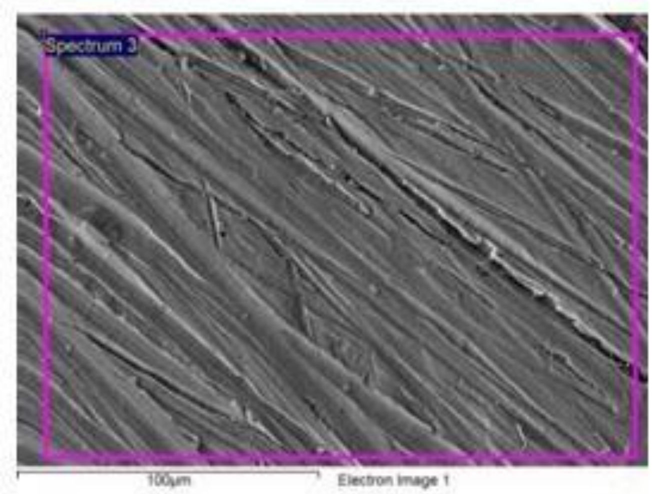

Figure 5: SEM Analysis Electrochemical Corrosion Tests on 316L SS

The above figure:5 results show the SEM Analysis on 316L SS in ringer solution. The surface is seen as thick bands showing the presence of corrosion.

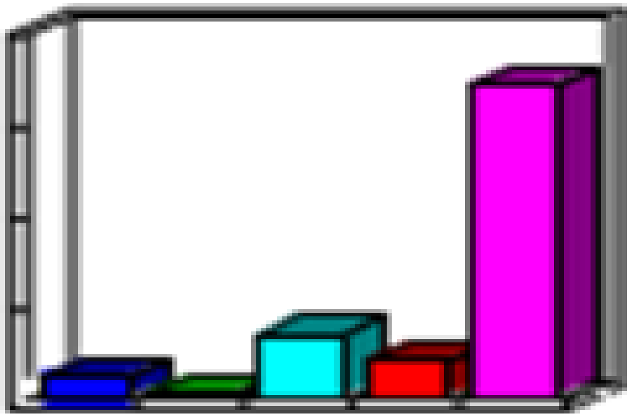

Figure 6: Bar chart Weight % of 316LSS

The Figure 6 shows the bar chart for weight percentage of 316LSS after electrochemical Corrosion Test. The figure 6 bar chart shows the weight % of 316L SS metal immersed in ringer solution. The percentage of oxygen is seen in the figure 6, this indicates the presence. of corrosion..

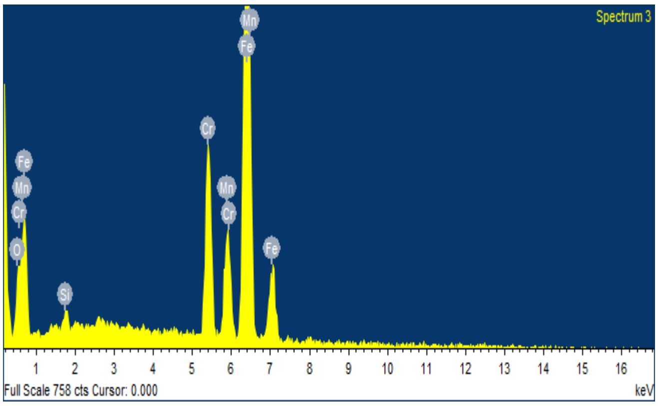

Figure 7: EDAX of 316L SS Eletrochemical Corrosion Test

The figure 7 shows EDAX of 316L SS metal. The 316L SS immersed in ringer solution. The corrosion products chloride is seen as white colour.

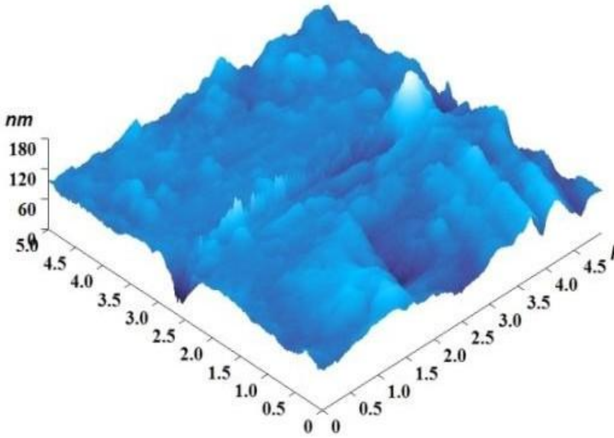

Figure 8: AFM of 316L SS Electrochemical Corrosion Test, Ringer Solution

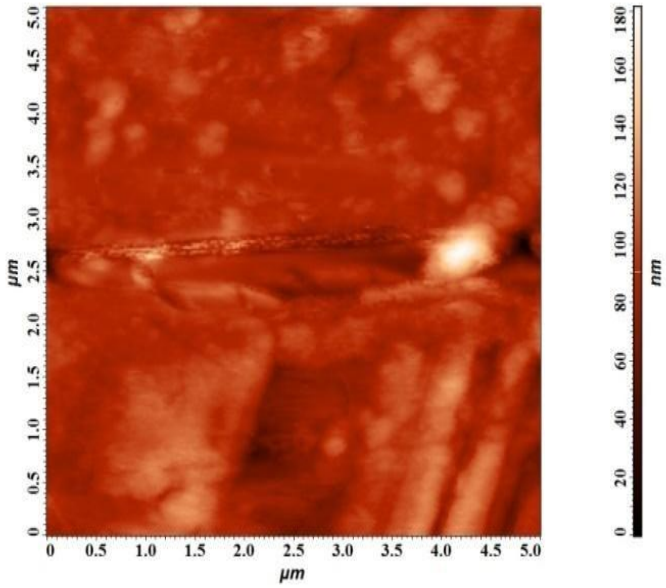

Figure 9: Graph AFM of 316L SS Electrochemical Corrosion Test Ringer Solution

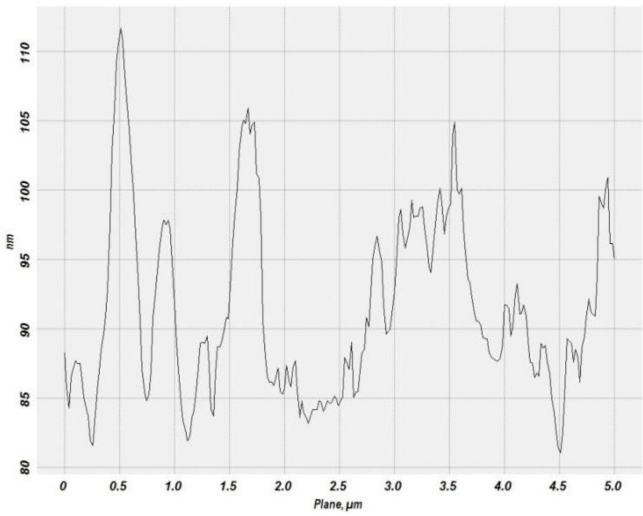

Figure 10: Graph Shows Roughness Analysis Graph for 316L SS immersed in Ringer Solution

Figure 8, 9 shows the 2D and 3D Atomic force microscope Images

Table 5: Surface Analysis for 316L SS

S.No	Surface Analysis	Values
1	Amount of sampling	65536
2	Max	181.374 nm
3	Min	0 nm
4	Peak-to-peak, Sy	181.374 nm
5	Ten point height, Sz	90.9423 nm
6	Average	91.3529 nm
7	Average Roughness, Sa	9.36504 nm
8	Root Mean Square, Sq	13.3928 nm
9	Second moment	8524.72
10	Surface skewness, Ssk	0.511014
11	Coefficient of kurtosis, Ska	4.70375
12	Entropy	8.80241
13	Redundance	-0.174461

The above figure10 shows roughness analysis of 316L SS metal immersed in ringer solution. The peaks and valleys are seen in the graph. The values of surface analysis is given in the table 5. The entropy value 8.80241 indicates corrosion.

IV. CONCLUSION

It is concluded from the above results the polarization curve for the 316L SS is more corrosion resistance in ringer solution than the sea water. From this we infer the 316L SS metal will corrode in blood. We infer that the chemical composition of 316L SS may be altered by adding more chromium in the 316L SS alloy to reduce corrosion when implanted in the human body. The SEM analysis and the AFM results shows that the corrosion as occurred on the 316L SS specimen.

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AUTHOR'S PROFILE

Dr. D. Bubesh Kumar, is working as Associate Professor in the Department of Mechanical Engineering. He has Published more than 15 research papers, He has written a book in the area of Fatigue corrosion of Biomaterials. He has applied for 5 patents out of which three patents are three patents are awaiting for examinations. He has guided more than 90 projects for UG students and 10 projects for PG Students. His Ph.D Scholars are pursuing research in the field of composites, additive manufacturing and Biomechanics.