Corrosion performance and electrochemical stability of 316L in body fluid

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Abstract—Metal implants are the best choice for the long-term replacement of hard tissue, such as hip and knee joints, because of their excellent mechanical properties. 316L stainless steel is widely accepted as biocompatible metal implants. The aim of this work is to study the biocompatibility of 316L stainless steel, for the manufacture of screw plates having high chromium and low carbon contents; in a simulated blood medium (Ringer's solution). The specimen having a cylindrical shape, has been characterized by a spectral analysis for the identification of the chemical composition, a mechanical characterization (hardness Rockwell), physicochemical (X-ray diffraction), and finally electrochemical measurements (monitoring the free potential evolution, plots of polarization curves and electrochemical impedance spectroscopy (EIS) techniques). Polarization experiments were conducted after 4h, 6h, 24h, 48h, 168h, 215h, 10 days and 15 days of immersion in Ringer's solution. The influence of parameters such as electrolytic medium, pH, agitation of the medical device (screw plates used in orthopedics) has studied. Very low current densities were obtained, indicating the formation of a passive layer. Impedance spectra, represented in the Nyquist plan, exhibited a single constant system suggesting the formation of one layer.

Keywords—Implants; stainless steel; biocompatibility; Ringer's solution; X-ray diffraction.

I. INTRODUCTION

Stainless steel high resistance to corrosion derives from a dense film of chromium oxide (passive film) that naturally forms on the iron surface. Generally first requirement of any material serving in biological system is that it should be inert and not causing any undesirable reaction with its surrounding. When stainless steel is placed inside a tissue, the interaction between the implant and tissue determines the degree of biocompatibility. It implies to the ability of the material to perform effectively with an appropriate host response for the desired applications.(1) Common medical devices include hip replacements, prosthetic heart valves, neurological prostheses and drug delivery systems. (2) Corrosion as an electrochemical process commences on the surface of stainless steel implants and subsequently affects the body response. This is undesirably followed by release of ions such as chromium and nickel in surrounding tissue which can negatively affect the response of host body to biomaterial. The literature has proven that nature concentration of ions Cr\textsuperscript{3+}, Fe\textsuperscript{2+}, Ni\textsuperscript{2+} inside the body may severely prevent the tissue functionality and can ultimately lead to severe health related consequences, therefore corrosion of material is the first issue to be considered when the material is designed as a bio implant. It is also necessary to establish an understanding of biological factors effecting corrosion. There are various in vivo and in vitro studies on corrosion of metal implants which employed simulated body fluids. (3)

II. EXPERIMENTAL

The corrosion behavior of orthopedic implant stainless steel 316L has been studied in a simulated body fluid (Ringer's solution), using potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques. Polarization experiments were conducted after 4h, 6h, 24h, 48h, 168h, 215h, 10 days and 15 days, of immersion in Ringer's solution..

A stainless steel 316L sample of the following chemical composition (as percentage) was served as working electrode:

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Ni</th>
<th>Cr</th>
<th>Cu</th>
<th>Mo</th>
<th>V</th>
<th>Ti</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>1.56</td>
<td>0.71</td>
<td>14.15</td>
<td>17.02</td>
<td>0.12</td>
<td>3.19</td>
<td>0.092</td>
<td>0.049</td>
<td>0.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>W</th>
<th>Sn</th>
<th>Co</th>
<th>B</th>
<th>Ta</th>
<th>Mg</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.023</td>
<td>0.037</td>
<td>0.009</td>
<td>0.041</td>
<td>0.021</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The working electrode was polished with different grades of SiC papers (500, 600, 800, 1200, 2000) and a finishing with diamond paste of 1 µm to obtain a mirror surface, degreased with acetone and rinsed with distilled water, before its

TABLE I. CHEMICAL COMPOSITION OF STAINLESS STEEL 316L.
immersion in a simulated blood medium (Ringer’s solution). Potentiostatic polarization studies were carried out using Potentiostat/Galvanostat PGZ-301.

**TABLE II. CHEMICAL COMPOSITION OF RINGER’S SOLUTION.**

<table>
<thead>
<tr>
<th>Composition</th>
<th>Concentrations (g/L)</th>
<th>Concentrations (mole/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>2.25</td>
<td>0.0384</td>
</tr>
<tr>
<td>KCl</td>
<td>0.105</td>
<td>0.0014</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>0.12</td>
<td>0.0010</td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>0.05</td>
<td>0.0005</td>
</tr>
<tr>
<td>H₂O</td>
<td>Graduated flasks 1000 ml</td>
<td>Graduated flasks 1000 ml</td>
</tr>
</tbody>
</table>

**III. RESULTS AND DISCUSSION**

**A. Absence of agitation**

![Logarithmic graph](image)

Fig. 1. Polarization curves obtained for the stainless steel 316 L immersed in Ringer’s solution without agitation (T=37°C).

**B. Presence of agitation**

![Logarithmic graph](image)

Fig. 2. Polarization curves obtained for the stainless steel 316 L immersed in Ringer’s solution with agitation (T=37°C).

**TABLE III. ELECTROCHEMICAL PARAMETERS OF STAINLESS STEEL 316L IN RINGER’S SOLUTION IN THE ABSENCE AND PRESENCE OF AGITATION.**

<table>
<thead>
<tr>
<th></th>
<th>Ecorr (mV/SCE)</th>
<th>icorr (µA/cm²)</th>
<th>Veat (mm/an)</th>
<th>Rp (KΩ.cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without agitation</td>
<td>-43.9</td>
<td>0.5693</td>
<td>6.658 .10⁻³</td>
<td>170.79</td>
</tr>
<tr>
<td>With agitation</td>
<td>15.5</td>
<td>0.0974</td>
<td>1.139 .10⁻³</td>
<td>310.59</td>
</tr>
</tbody>
</table>

In this work we followed the agitation action of orthopedic implant of stainless steel 316L in Ringer’s solution (physiological solution blood simulated) at T=37°C.

According to polarization curves (Figure 1 and figure 2) we can be said that:

Stainless steel 316L in presence of agitation has a noble potential than unagitated solution and the polarization resistance of SS 316L in presence of agitation is twofold the resistance in solution of agitation.

**C. Impedance characteristics stainless steel 316L**

![Impedance graph](image)

Fig.1. Impedance spectroscopy analysis of 316L stainless steel in Ringer's solution for various immersion times at 37 °C.

The existence of two capacitive arcs:

- The first capacitive arc (high -frequencies) correspond to transfer of charge metal / solution interface.
- The second capacitive arc (low- frequencies) corresponds to the formation and growth of oxide and hydroxide film.

**TABLE IV.** The equivalent circuit parameter obtained by adjusting electrochemical of impedance data for stainless steel 316L in Ringer's solution for various immersion times with a total error <4%.
At the beginning of immersion the resistance transfer of charge is increased within 4h, 6h, 24h, 48h while the capacitance values of $Q_{dc}$ decreased slightly during the immersion time, due to construction of passive layer enriched with chrome; after 48 hours of immersion, $R_{tc}$ is decreased indicating deterioration of the passive layer.

CONCLUSION

Stainless steel surgical quality (316L stainless steel) is one of the materials that are widely used as implants in orthopedic surgery. The aim of this work is to study the biocompatibility of 316L stainless steel, for the manufacture of screw plates having high chromium and low carbon contents, in a simulated blood medium.

The electrochemical study reveals the best corrosion resistance of 316L stainless steel in Ringer's solution.

REFERENCES

