Electrochemical behavior of various implantation biomaterials in the presence of various simulated body fluids–an overview

ABSTRACT

In Modern medicine, metals and alloys are being used as implants. The Corrosion behaviour of various biomaterials under artificial body fluids are being studied. Artificial biomaterials are being implanted inside the human body to replace bone, teeth, etc. Even organs are being medically substituted with different types of metals such as mild steel, carbon steel, Ni-Cr alloy, Fe-Cr alloy, 22 carat Gold, 24 carat Gold Tin, etc. due to their biocompatibility. This is achieved by connecting these metals directly with body tissues. The metals tend to corrode when it gets in contact with human body fluids. The body fluids thereby come in direct contact with tissues and the tissues are in contact with the metal thus causing the metal to corrode. And hence the corrosion resistance studies such as polarisation, AC impedance, cyclic voltammetric studies, etc, are being conducted in a medium like artificial blood plasma, artificial urine, artificial salvia, artificial sweat, Hank solution, Ringer solution, etc. The different body fluids are examined in the presence of different implantation metals by electrochemical methods and protective films are formed which are analyzed by various surface analysis techniques such as AFM, FTIR-UV, SEM, etc. The research findings will thereby be very helpful to the medical field.

Keywords: Corrosion, Hank solution, Alloy, Artificial body fluids.

1. INTRODUCTION

Metallic biomaterials are often employed in orthopedic and dental surgery, operative cardiology, and urological repair. Mechanical strength and biocompatibility, corrosion resistance, safety, ductility, and wear resistance are all desirable qualities in implant alloys[1-39]. Biomaterials such as mild steel, carbon steel, Ni-Cr alloys, 22 carat Gold, 24 carat Gold, tin, etc, are being used in the human body for various medical purposes. These metals when comes in contact with the body fluids such as blood plasma, sweat, Hank solution, etc, may tend to corrode. So the corrosion resistance of these metals in artificial body fluids is being studied in the presence and absence of inhibitors (additives) and results are being concluded with the Corrosion Resistance factors. Methods like SEM, TEM, AFM are commonly used to examine metals after their corrosion process. The detailed overview of various biomaterials and their recorded results are being summarised below [1-39].

Advance medical science uses metals and alloys as implants in human body. These metals may tend to corrode with time when they interact with body fluids. Thus the corrosion resistance of these metals are being studied in artificial body medium using various inhibitors (additives) and the corrosion resistance of these metals and alloys with suitable inhibitor is concluded.
Table 1. The corrosion behavior of various metal and its alloys

<table>
<thead>
<tr>
<th>S. No</th>
<th>METAL</th>
<th>MEDIUM</th>
<th>Additive</th>
<th>METHOD</th>
<th>FINDINGS (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mild Steel Galvanised Steel SS 316L</td>
<td>Artificial Sweat</td>
<td>-</td>
<td>Potentiodynamic Polarization</td>
<td>Corrosion Resistance: GS &gt; SS 316 &gt; MS Material Resistance: SS 316 &gt; MS &gt; GS Compactness of the film: SS316 &gt; MS &gt; GS¹</td>
</tr>
<tr>
<td>2.</td>
<td>Mild steel Ni-Ti super elastic alloy</td>
<td>Artificial Urine</td>
<td>Urea</td>
<td>Potentiodynamic polarisation Surface examination Study Scanning Electron Microscopic Studies</td>
<td>Ni-Ti has more Corrosion resistance in absence of urea than in presence Mild steel has less corrosion resistance in presence of urea than in absence²</td>
</tr>
<tr>
<td>3.</td>
<td>Ni-Ti alloy Thermoactive alloy SS 316L</td>
<td>Artificial saliva</td>
<td>Coffee</td>
<td>Potentiodynamic Polarisation study AC Impedance spectra</td>
<td>Corrosion Resistance of alloys: SS 316L &gt; Thermoactive alloy &gt; Ni-Ti alloy³</td>
</tr>
<tr>
<td>4.</td>
<td>Mild steel Mild steel coated with Zn SS 316L</td>
<td>Artificial saliva</td>
<td>D-Glucose</td>
<td>Potentiodynamic Polarisation AC impedancespectra</td>
<td>Corrosion Resistance the absence and presence of D-Glucose SS 316L &gt; MS-Zn &gt; MS⁴</td>
</tr>
<tr>
<td>5.</td>
<td>Zr₆₀Cu₁₇.₅Ni₁₀Al₁₇.₅ (Zr₆₀Nb₃)Cu₁₇.₅Ni₁₀Al₁₇.₅ (Zr₆₀Nb₃)Cu₁₇.₅(Ni₅Pd₅Al₁₇.₅)</td>
<td>Artificial Saliva Phosphate buffered solution Artificial Blood plasma</td>
<td>-</td>
<td>Electrochemical polarisation Galvanostatic-step measurement</td>
<td>Addition of Nb enhanced the corrosion resistance among the Zr-based Bulk Metallic Glasses (BGM)⁵</td>
</tr>
<tr>
<td>6.</td>
<td>Copper</td>
<td>Artificial Blood Plasma</td>
<td>Adenine and 2,6-diaminopurine potassium sorbate</td>
<td>Potentiodynamic polarisation Electrochemical Impedance spectroscopy Cyclic voltammetry measurements</td>
<td>Efficiency up till 90% was provided with both compounds⁶</td>
</tr>
<tr>
<td>7.</td>
<td>AISI 420 Custom 630 Custom 455</td>
<td>Artificial Blood Plasma</td>
<td>-</td>
<td>Potentiodynamic polarisation Electrochemical Impedance analysis Magnetic behaviour</td>
<td>Custom 630 was the better corrosion resistive material⁷</td>
</tr>
<tr>
<td>8.</td>
<td>La added 316L stainless steel</td>
<td>Simulated Blood plasma Hank’s solution</td>
<td>-</td>
<td>Potentiodynamic polarisation</td>
<td>Corrosion Resistance of La added 316L stainless steel in both solution is improved due to the effect of La in the purification of steel⁸</td>
</tr>
<tr>
<td>9.</td>
<td>Zr-Ti Zr-Hf</td>
<td>Hank’s Solution</td>
<td>-</td>
<td>Potentiodynamic polarisation Homogenization Heat treatment</td>
<td>Addition of Ti to Zr over 5% increases pitting corrosion resistance. Addition of Hf to Zrdecreased the corrosion resistance⁹</td>
</tr>
</tbody>
</table>
| 10 | Ti5Al4V  
|    | Ti6Al4V | Ringer solution  
|    |        | Phosphate Buffer solution | H₂O₂ | Potentiodynamic polarisation  
|    |        |                           |      | Heat treatment fabrication method | The alloy was found to have better corrosion resistance in test solutions ¹⁹ |
| 11 | Co-Cr  
|    | Ni-Cr  
|    | Cu-Ni-Al | Commercially pure Ti (cpTi) | Artificial Saliva | - | Electrochemical impedance spectroscopy  
|    |        |                           |      | Tafel & cyclic polarisation. | Corrosion Rates  
|    |        |                           |      | Cu-Ni-Al > cpTi > Co-Cr > Ni-Cr | ¹¹ |
| 12 | SS 316L | Artificial Blood Plasma | Amoxicillin | Potentiodynamic Polarization  
|    |        |                           |      | Electrochemical impedance Method | Corrosion Resistance of SS 316L in ABp is of the order:  
|    |        |                           |      |                           | SS316 + ABp + 10ppm Amoxicillin > SS316 + 50ppm + ABp > SS 316 L + ABp ¹² |
| 13 | Mild Steel  
|    | Mild Steel coated with Zinc  
|    | SS 316L | Artificial saliva | Spirulina | Potentiodynamic Polarization  
|    |        |                           |      | Electrochemical impedance Method | SS 316L and MS-Zn has more Corrosion resistance in the absence of Spirulina than in their presence  
|    |        |                           |      |                           | MS has more Corrosion Resistance in the presence of Spirulina than in their absence ¹³ |
| 14 | Ni-Cr Alloy | Artificial Saliva | Metformin Hydrochloride (250 mg) | Potentiodynamic Polarization  
|    |        |                           |      | AC Impedance Method | In the presence of Metformin Hydrochloride the corrosion resistance of NiCr alloy increases. ¹⁴ |
| 15 | Fe-17Cr-8Ni alloy  
|    | Fe-7Cr-10Ni alloy  
|    | Fe-17 Cr-14Ni alloy | Stimulated body fluid | H₂O₂ and albumin | Potentiodynamic Polarization  
|    |        |                           |      | Electrochemical impedance Method | Fe-Cr-14Ni alloy contains smallest rate of corrosion than Fe-17Cr-8Ni and Fe-17Cr-10Ni alloys.  
|    |        |                           |      |                           | Fe-17Cr-14Ni obtained the smallest corrosion rate due to the protective oxide film  
|    |        |                           |      |                           | Fe-17Cr-8 Ni < Fe-7 Cr-10Ni < Fe-17 Cr-14Ni ¹⁵ |
| 16 | Mild Steel  
|    | Ni-Ti super elastic alloy | Artificial Urine | NaCl | Potentiodynamic Polarisation study | Ni-Ti has more Corrosion resistance in presence of NaCl than in absence  
|    |        |                           |      |                           | Mild steel has less corrosion resistance in presence of NaCl than in absence. ¹⁶ |
| 17 | Mild steel  
|    | 22-carat gold  
|    | 18-carat gold  
|    | Ni-Cr alloy  
|    | SS316L | Ringer’s solution | - | Electrochemical impedance Method | Corrosion Resistance :  
|    |        |                           |      |                           | Ni-Cr > Gold 22 > SS 316L > Gold 18 > mild steel ¹⁷ |
| 18 | Austenitic stainless steel Cr- 
|    | Ni-Mo | Artificial Urine Tyrode’s physiological solution  
<p>|    |        | Artifical plasma | - | Potentiodynamic Polarization | Cr-Ni-Mo steel shows better corrosion resistance in Tyrode’s physiological solution ¹⁹ |</p>
<table>
<thead>
<tr>
<th>No.</th>
<th>Biomaterial/Alloy Description</th>
<th>Solution/Environment</th>
<th>Characterization Method</th>
<th>Corrosion Resistance Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Ti-6Al-4V Alloy with Nitride coating</td>
<td>Tyrode’s solution 0.9% NaCl</td>
<td>Chemical – Thermal Treatment X-ray phase analysis SEM Electro Chemical Test</td>
<td>Ti-6Al-4V alloy has higher corrosion resistance in Tyrode’s solution&lt;sup&gt;19&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>Austenitic 304 Stainless Steel</td>
<td>Tyrode’s physiological solution</td>
<td>Potentiodynamic Polarization AC Impedance Method SEM</td>
<td>It was seen that electro polishing increases the uniform pitting corrosion in The Austenitic 304 Stainless Steel&lt;sup&gt;20&lt;/sup&gt;</td>
</tr>
<tr>
<td>21</td>
<td>Ni-Ti Ni-Ti-Cu Pure Ti Ti-6-Al-4V 316L</td>
<td>Hank’s solution</td>
<td>Potentiometric polarization Method Re Passivation Test</td>
<td>The susceptibility to corrosion of the order : cpTi≈Ti6Al4V&lt;&lt;316L &lt;NiTiCu&gt;NiTi Cp Ti and Ti6Al4V are resistant to the initiation of crevice corrosion in Hank’s solution Cu addition to NiTi improves the repassivation capability by EDS analysis&lt;sup&gt;21&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>Co-Cr-W-Ni alloy</td>
<td>Artificial blood plasma Artificial urine Tyrode solution</td>
<td>Electrochemical impedance Method</td>
<td>Co-Cr-W-Ni showed good corrosion resistance&lt;sup&gt;22&lt;/sup&gt;</td>
</tr>
<tr>
<td>23</td>
<td>Ti Co-Cr Alloy</td>
<td>Artificial saliva</td>
<td>Electrochemical impedance Method</td>
<td>Titanium was found to have high Corrosion Resistance&lt;sup&gt;23&lt;/sup&gt;</td>
</tr>
<tr>
<td>24</td>
<td>AZ91D Ti-6Al-4V</td>
<td>Stimulated blood fluids at 37°C</td>
<td>Potentiometric polarization Method Electrochemical impedance Method</td>
<td>The corrosion resistance of Titanium alloy was high compared to Magnesium alloy&lt;sup&gt;24&lt;/sup&gt;</td>
</tr>
<tr>
<td>25</td>
<td>Co-Cr Ni-Cr alloy</td>
<td>Artificial saliva Streptococcus mutans</td>
<td>Potentiodynamic Polarisation Impedance spectroscopy Open circuit potential measurement</td>
<td>The presence of Streptococcus mutans reduced corrosion rate of both alloys. &lt;sup&gt;25&lt;/sup&gt;</td>
</tr>
<tr>
<td>26</td>
<td>Mild steel Ni-Cr SS-316 Cu-Ni-Ti 22-carat gold 24-carat gold Super elastic Ni-Ti</td>
<td>Artificial Plasma Glucose</td>
<td>Tafel electrochemical impedance spectroscopic experiments</td>
<td>Ni-Cr and SS_316 showed good corrosion resistance both in the absence and in the presence of 0.05g of glucose The rest 5 metals showed good corrosion resistance in small amounts of glucose. &lt;sup&gt;26&lt;/sup&gt;</td>
</tr>
<tr>
<td>27</td>
<td>Ni-Ti based alloys (Super Elastics)</td>
<td>Artificial Saliva Sulfa drugs like Phexin</td>
<td>Polarisation study</td>
<td>0.1g of phexin has more corrosion resistance than 0.05g of phexin when added. &lt;sup&gt;27&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
### 2. CONCLUSION

The artificial biomaterials implanted inside the human body in the place of bone, teeth, and even organs are being medically substituted with different types of metals such as mild steel, carbon steel, Ni-Cr alloy, Fe-Cr alloy, 22 carat Gold, 24 carat Gold, Tin, etc. and the studies were summarized. Corrosion resistance studies such as polarisation, AC impedance, cyclic voltammetric studies conducted in mediums like artificial blood plasma, artificial urine, artificial salvia, artificial sweat, Hank solution, Ringer solution, etc. were determined. Future Research on the field of Corrosion Resistance of various biomaterials can be analysed and studied for the betterment of implantation in the field of medicine.

### 3. REFERENCES


IZVOD

ELEKTROHEMIJSKO PONAŠANJE RAZLIČITIH METALA ZA IMPLANTACIJU U PRISUSTVU RAZLIČITIH SIMULIRANIH TELESNIH TEČNOSTI – PREGLED

U savremenoj medicini metali i legure se koriste kao implantati. Proučava se ponašanje korozije različitih biomaterijala u veštačkim telesnim tečnostima. U ljudsko telo se ugrađuju veštački biomaterijali koji zamenjuju kosti, zube itd. Čak se i organi medicinski zamjenjuju različitim vrstama metala, poput mekog čelika, ugljeničnog čelika, legure Ni-Cr, legure Fe-Cr, 22-karatnog zlata, 24-karatnog zlatnog kalaja itd., zbog njihove biokompatibilnosti. To se postiže povezivanjem ovih metala direktno sa tkivima tela. Metali imaju tendenciju korozije kada dođu u kontakt sa tečnostima ljudskog tela. Telesne tečnosti na taj način dolaze u direktan kontakt sa tkivima, a tkiva su u kontaktu sa metalom i na taj način izazivaju koroziju metala. Stoga se studije otpornosti na koroziju, poput polarizacije, impedanse naizmenične struje, cikličnih voltametrijskih studija itd., sprovode u medijumu poput veštačke krvne plazme, veštačkog urina, veštačke salvije, veštačkog znoja, Henkovog rastvora, Ringerovog rastvora itd. Tečnosti se ispituju u prisustvu različitih implantacionih metala elektrohemijskim metodama i formiraju se zaštitni filmovi koji se analiziraju različitim tehnikama površinske analize kao što su AFM, FTIR-UV, SEM itd. Nalazi istraživanja će time biti od velike pomoći medicinskom polju.

Ključne reči: Korozija, Henkov rastvor, legura, veštačke telesne tečnosti.

Pregledni rad
Rad priljben: 01. 07. 2021.
Rad je dostupan na sajtu: www.idk.org.rs/casopis

© 2021 Authors. Published by Engineering Society for Corrosion. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution 4.0 International license (https://creativecommons.org/licenses/by/4.0/)