THE EFFECT OF SURFACE TREATMENTS AND MANUFACTURING TECHNIQUES ON Ti-Ta ALLOY

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DEMANDS/LIMITATIONS OF BIOMATERIALS

- Future demands of biomaterials
  - Good biocompatibility
  - Machinability
  - High performance as the size continues to shrink
  - Minimal maintenance
  - Greener – power source
  - Cost

- Limitations
  - Corrosion
  - Degradation
  - Malfunction of components
## COMPOSITION OF Ti-Ta ALLOYS

<table>
<thead>
<tr>
<th>Manufacturing Process</th>
<th>Ti (wt.%</th>
<th>Ta (wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder Metallurgy</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>ARC Melting</td>
<td>70</td>
<td>30</td>
</tr>
</tbody>
</table>
MANUFACTURING TECHNIQUES

- ARC Melting
- Powder Metallurgy

SURFACE TREATMENTS

- Electropolishing (EP)
- Magnetoelectropolishing (MEP)
VARIABLE PROPERTIES

- Corrosion resistance
- Morphology
- Thickness and nature of the passive oxide layer
- Surface chemistry and speciation
- Surface energy
- Wettability
Corrosion: The destructive attack of a metal by chemical or electrochemical reaction with its environment

\[ \text{X} \leftrightarrow \text{X}^{n+} + \text{n}e^- \] ------ (1)

\[ \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \leftrightarrow 4\text{OH}^- \quad \text{pH}, 7 \] ------ (2)

\[ \text{O}_2 + 4\text{H}^+ + 4\text{e}^- \leftrightarrow 2\text{H}_2\text{O} \quad \text{pH} < 7 \] ------ (3)

Typical types of corrosion on implants:

- Pitting corrosion
- Crevice corrosion
ANODIC DISSOLUTION OF AN ACTIVE-PASSIVE METAL

\[ 2H_2O \rightarrow O_2 + 4H^+ + 4e^- \]

\[ M \leftrightarrow M^{n+} + ne^- \]

Log current density (Amps/Cm^2)
IN-VITRO CORROSION TESTS

- ASTM F2129-08: Potentiodynamic Cyclic Polarization corrosion tests
- GAMRY Potentiostat Series G 750 with Framework Software
- Phosphate Buffered Saline (PBS)
- Temperature: 37 °C
- Scan rate: 1mV/Sec

1- Standard reference calomel electrode  
2 - Working electrode  
3 - Counter electrode (Carbon)  
4 - Lugging capillary  
5 - N₂ gas inlet  
6 - N₂ gas outlet  
7 - Sample holder

Ref: http://www.gamry.com/Products/ProductPhotos/EuroCell%20Kit.jpg
TYPICAL CYCLIC POTENTIODYNAMIC POLARIZATION CURVES

- Clockwise Loop - Positive Hysteresis
- Anti-clockwise Loop - No Hysteresis

- Crevice Corrosion Resistance
- Pitting Corrosion Resistance
- Corrosion Resistance

Potential (V vs. Ref.)

Current
CYCLIC POLARIZATION CURVES:
Ti-30Ta (PM)
## Average Corrosion Parameters for Ti-30Ta (PM) in PBS and Amino Acids

<table>
<thead>
<tr>
<th>Cyclic Potentiodynamic Polarization Measurements</th>
<th>PBS</th>
<th>PBS-BSA</th>
<th>PBS-Glutamine-Histidine-Tryptophan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion Parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_v$ (Volts)</td>
<td>2.367</td>
<td>2.419</td>
<td>2.436</td>
</tr>
<tr>
<td>$E_r$ (Volts)</td>
<td>-0.423</td>
<td>-0.372</td>
<td>-0.355</td>
</tr>
</tbody>
</table>
CYCLIC POLARIZATION CURVES: Ti-30Ta (ARC)

- PBS
- PBS-BSA
- PBS-G-H-T

$E_r = -0.282V$
$E_r = -0.359V$
$E_r = -0.461V$

$E_v = 1.310V$
$E_v = 1.136V$
$E_v = 1.205V$
### Cyclic Potentiodynamic Polarization Measurements.

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<tr>
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<th>PBS-Glutamine-Histidine-Tryptophan</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_b$ (Volts)</td>
<td>1.287</td>
<td>1.207</td>
<td>1.241</td>
</tr>
<tr>
<td>$E_r$ (Volts)</td>
<td>-0.433</td>
<td>-0.324</td>
<td>-0.337</td>
</tr>
<tr>
<td>$E_b-E_r$ (Volts)</td>
<td>1.72</td>
<td>1.531</td>
<td>1.578</td>
</tr>
</tbody>
</table>
CORROSION BEHAVIOR OF Ti-30Ta: ARC VS PM

- Anti clockwise loop
- Report $E_v$
- More resistant to pitting corrosion

- Clockwise loop (hysteresis)
- Report $E_b - E_r$
- Less resistant to pitting corrosion
SURFACE MORPHOLOGY OF Ti-Ta ALLOYS BEFORE (INSET) AND AFTER CORROSION

(a) Ti-Ta PM  (b) Ti-Ta ARC
OSTEOBLAST CELL GROWTH

(a) Ti-Ta ARC

(b) Ti-Ta PM
## COMPOSITION OF ELECTROLYTE AFTER CORROSION

### ICP-MS Analysis:

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Ti-30Ta (PM)</th>
<th>Ti-30Ta (ARC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PBS</td>
<td>PBS - G - H - T</td>
</tr>
<tr>
<td>Ti ppb (µg/L)</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Ta ppb (µg/L)</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>
## Contact Angle Measurement

<table>
<thead>
<tr>
<th>Sample</th>
<th>Contact Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti-30Ta (PM)</td>
<td>68.4</td>
</tr>
<tr>
<td>Ti-30Ta (ARC)</td>
<td>74.5</td>
</tr>
</tbody>
</table>

Kyowa - Contact Angle Meter
### Effect of Surface Treatment on Roughness of Ti-Ta, PM

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean Roughness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>61.9</td>
</tr>
<tr>
<td>EP</td>
<td>126.62</td>
</tr>
<tr>
<td>MEP</td>
<td>86.98</td>
</tr>
</tbody>
</table>

### Images

(a) Ti-30Ta Untreated  
(b) Ti-30Ta, EP  
(c) Ti-30Ta, MEP
EFFECT OF SURFACE TREATMENT ON CORROSION RESISTANCE OF Ti-30Ta

Cyclic Potentiodynamic Polarization Measurements

<table>
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<tr>
<th>Alloys</th>
<th>$E_V$ (Volts)</th>
<th>$E_I$ (Volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti-Ta (Untreated)</td>
<td>2.616</td>
<td>-0.174</td>
</tr>
<tr>
<td>Ti-Ta (EP)</td>
<td>2.680</td>
<td>-0.301</td>
</tr>
<tr>
<td>Ti-Ta (MEP)</td>
<td>2.690</td>
<td>-0.302</td>
</tr>
</tbody>
</table>
CONCLUSION

- The cyclic potentiodynamic corrosion curve for Ti-Ta, PM displayed an anti clockwise loop, whereas the ARC melted alloy displayed a clockwise loop with hysteresis.
- The alloy manufactured by PM was more resistant to localized corrosion as compared with that manufactured by ARC melting.
- The corrosion susceptibility of Ti-30Ta alloys appeared to increase with the addition of amino acids to PBS.
- Growth of human osteoblast cells were observed on both the alloys.
- Both alloys exhibited hydrophilic behavior.
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