An Advanced Structural Design for Bone Plate

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Introduction

Metallic bone plates have being used commonly in the healing of long bone fractures. Rigid metal plates can cause local bone atrophy due to stress shielding and the weakened the bone can be refractured again after plate removal (Ferguson et al., 1996). Composite bone plates which are made of carbon fiber/epoxy have been considered to be alternatives (Ali et al,1990, Baixauli et al., 1995, Zimmerman et al., 1987)

Materials and Method

A new design containing carbon fiber as load carrying component has either epoxy or hydroxyapatite(HA) as matrix material. Especially carbon fiber/hydroxyapatite composite bone plate is considered a new approach since hydroxyapatite has good record of biocompatibility beside the excellent mechanical properties of carbon fiber (Maistrelli et al., 1992, Boeree et al., 1993). Composite bone plates are compared numerically, according to their effects on the bone and the fracture area, and their behaviours under the condition of compression, which occurs while standing up.

The finite element method is utilised to analyse bone plate-bone assembly (Figure 1) and the results of the analyses are obtained for Strain Energy Density (SED), deformations and stresses. Analyses have been carried out for different plate materials, such as stainless steel, titanium alloy, and carbon fiber/epoxy and carbon fiber/hydroxyapatite composites. Graphite/epoxy is selected as carbon/epoxy composite (Barbero, 1989). During the calculation of material properties, carbon fiber and hydroxyapatit composite plate is

Figure 1: The Finite Element Model
modelled as 20% fiber and 80% matrix. The long intact bone included in the model is treated as an anisotropic material having properties similar to the composite bone plates. Mechanical properties of materials used in analyses are given in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>$E_x$[MPa]</th>
<th>$E_y$[MPa]</th>
<th>$E_z$[MPa]</th>
<th>$\nu_{xy}$</th>
<th>$\nu_{yz}$</th>
<th>$\nu_{xz}$</th>
<th>$G_{xy}$[MPa]</th>
<th>$G_{yz}$[MPa]</th>
<th>$G_{xz}$[MPa]</th>
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</thead>
<tbody>
<tr>
<td>Stainless Steel</td>
<td>200000</td>
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<td>200000</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>77000</td>
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<tr>
<td>Ti6Al4V</td>
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<td>117240</td>
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<td>0.3</td>
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<td>45090</td>
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<tr>
<td>Carbon/Epoxy</td>
<td>132400</td>
<td>10800</td>
<td>10800</td>
<td>0.24</td>
<td>0.49</td>
<td>0.24</td>
<td>5600</td>
<td>3600</td>
<td>5600</td>
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<tr>
<td>Carbon/HA</td>
<td>78000</td>
<td>47900</td>
<td>47900</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>5800</td>
<td>5800</td>
<td>5800</td>
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<tr>
<td>Bone (Intact)</td>
<td>18400</td>
<td>7000</td>
<td>8500</td>
<td>0.12</td>
<td>0.37</td>
<td>0.14</td>
<td>3600</td>
<td>2400</td>
<td>5000</td>
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<tr>
<td>Bone (Fractured)</td>
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<td>700</td>
<td>850</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Material Properties

Results and Discussion

Finite element analyses of bone plate-long bone assembly have been conducted for above mentioned implant materials. The results are implemented in three important categories: SED, peak stresses, and deformations. The comparison of results showed that in the fracture area the load in the bone is distributed evenly for composite bone plates with proper fiber orientation ($[\pm 45]_8$) and there are decreases in the local peak stress values (Figure 2). Changing the ply orientation of the composite bone plates could alter deformations positively in the plate (Figure 3). Additionally, Figure 4 shows that SED values of carbon/HA increase in the critical region of the fractured bone where the SED values are low. Therefore it is expected that the adverse bone remodelling will slow down. Thus, the bone growth, in other words, fracture healing could be faster with the composite bone plates.
References


Figure 4: SED in Fracture Section (J/mm$^3$)