Fabrication of a HDPE/BCP Hybrid Bone Plate

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Abstract

A biphasic calcium phosphate (BCP)-reinforced high-density polyethylene (HDPE) hybrid bone plate is a new biomaterial, was made as a copy of a natural bone composition with the aim of a replacement for bone tissues. The HDPE/BCP hybrid bone plates were produced by replacing a mineral component and soft collagen tissue of bone with BCP and HDPE, respectively. HDPE/BCP hybrid bone plate was fabricated by a brander and heat pressings, using commercial granular HDPE and a different volume percentage of synthesized BCP nano-powder (10, 20, 30, 40 and 50 vol%). Density, Vickers hardness, Young’s modulus, bending strength and tensile strength were obtained depending on the volume fractions. The evaluation of the mechanical behavior showed an increase in the Young’s modulus and a resistance at break values attributed to the BCP addition. Elongation at a break decreased considerably. During the bending strength measurement, all the samples did not show a flat fracture surface which is frequently observed in ceramic materials.

Introduction

One of the calcium phosphate systems, biphasic calcium phosphate (BCP) bioceramics consisting of hydroxyapatite (HAp, Ca_{10}(PO_4)_2(OH)_2) and β-tricalcium phosphate (β-TCP, β-Ca_3(PO_4)_2) mixtures are frequently used as bone graft substitutes because their chemical composition is similar to that of bone mineral and controlled interactions with calcified tissue. So the demands for calcium phosphate systems are increasing all over the world. When implanted in bone defects, BCP bioceramics have bioactive and osteoconductivity properties that lead to a bone coalescence. Different bone formation ratios are known between HAp and β-TCP, β-TCP has been shown to be biodegradable more readily than HAp, but in an unpredictable way, so that scaffolding for growing a bone may be lost too early. BCP bioceramics consisting of HAp and β-TCP were therefore developed to achieve a better performance in living tissue than HAp and β-TCP alone. However, there are limitations on the use of BCP due to a brittleness, inadequate mechanical properties, lack of resilience and high Young’s modulus. One of the imaginative approaches for confronting these limitations is the use of bioactive ceramics as a biologically active phase in composites. Such composite materials also, have appropriate mechanical properties which are comparable to those of natural bone. For the last several years, composites of high-density polyethylene (HDPE) reinforced with calcium phosphate systems have been proposed as alternative materials to be used in orthopedic surgery. High-density polyethylene, having bio-inert biological properties, is one of the promising biopolymers that can be used as an implant. Its biological properties have been reinforced and improved by the use of bioceramics such as calcium phosphate systems. The HDPE/BCP hybrid bone plates will
be able to improve their mechanical properties, fracture strength and brittleness while maintaining the main factors of bone plates and a progressive osteointegration. Until quite recently, many researchers have focused on the fabrication of a biodegradable hybrid bone plate. It has been recognized that a biodegradable hybrid bone plate of high mechanical properties can be fabricated with the following approaches.

For this study, the bioresorbable HDPE/BCP hybrid bone plates were fabricated with different HDPE/BCP volume fractions. The basic concept of the microstructure design was to introduce different volume ratios of a bioceramics/biopolymer structure. Furthermore, the relationship between the microstructure and material properties was investigated, depending on the volume ratio of HDPE/BCP, as well as the compressive strength and the elastic modulus, which was compared with that of natural human bone. The bioresorbable HDPE/BCP hybrid plates containing BCP as a reinforcing material were prepared with different mechanical/biological properties.

**Experimental**

Biphasic calcium phosphate (BCP) was synthesized in our research group from calcium hydroxide (Ca(OH)2, SHOWA Chemical Co., Japan, 95.0 %) and phosphoric acid (H3PO4, SHOWA Chemical Co., Japan, 85.0 %) by a microwave irradiation. The pH of the starting solution was adjusted to 7.5 by using a pH meter (HD-2156.2, Delta OHM Co., USA) by the addition of an ammonia solution (NH3, SHOWA Chemical Co., Japan, 28.0 %). The precipitates were washed thoroughly with de-ionized water several times and dried in an oven. Then, the calcinations were carried out at 750° C in an air atmosphere. The matrix polymer was a high-density polyethylene (HDPE, 0.944 g/cm3, Honam Petrochemical Co., Korea). And then, HDPE and BCP mixtures were homogeneously made by using a twin screw mixer (350/350 E, Brabender, Germany) for 1h at a temperature of 150° C depending on the volume ratio of HDPE/BCP.

Secondly, the mixtures of HDPE/BCP were extruded homogeneously as a cylindrical rod shape using a twin screw extruder (DSE 20, Brabender, Germany) at 120–150 rpm for 1h at 150° C, which were about 3 mm in diameter. And to prepare the HDPE/BCP granules, HDPE/BCP fibers were used in the cooling process (Typ.-844500.003, Brabender, Germany) for a morphologic stabilization and a cutting process (Typ.-881207, Brabender, Germany). Finally, the HDPE/BCP hybrid plates were fabricated using the granules of the HDPE/BCP mixtures by a hot pressing method (2697, CARVER, USA) at 135–150° C under a pressure of 3.0 MPa for 30 min. Particularly, the BPC/HDPE hybrid plates were irradiated using γ-ray radiation (MDS Nordion, CA, IR221n wet storage type C-188, ARTI, KAERI, Korea) to total doses of 25 kGy at a dose rate of 10 kGy/h at room temperature in air for a bridged bond and a sterilization.

**Results and Discussion**

A biphasic calcium phosphate (BCP)-reinforced high-density polyethylene (HDPE) hybrid bone plates were made as a copy of a natural bone composition with the aim of
a replacement for natural bone tissues. The HDPE/BCP hybrid bone plates were produced by replacing a mineral component and soft collagen tissue of bone with BCP and HDPE, respectively. HDPE/BCP hybrid bone plate was fabricated by a brander and heat pressings, using commercial granular HDPE and a different volume percentage of synthesized BCP nano-powder (50 to 10 vol%).

<table>
<thead>
<tr>
<th>Code</th>
<th>Composition (vol.%)</th>
<th>HDPE</th>
<th>BCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-0</td>
<td>100</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>90-10</td>
<td>90</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>80-20</td>
<td>80</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>70-30</td>
<td>70</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>60-40</td>
<td>60</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Composition of the HDPE/BCP hybrid bone-plates.

Table 1 shows the typical properties of the constituents used for the experimental procedure. Density, Vickers hardness, Young’s modulus, bending strength and tensile strength were obtained depending on the volume fractions in Table 2. The evaluation of the mechanical behavior showed an increase in the Young’s modulus and a resistance at beak values attributed to the BCP addition. Elongation at a break decreased considerably.

<table>
<thead>
<tr>
<th>Code</th>
<th>Density (g/cm3)</th>
<th>Vickers hardness (Hv)</th>
<th>Young’s modulus (GPa)</th>
<th>Bending strength (MPa)</th>
<th>Tensile strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-0</td>
<td>0.96</td>
<td>6.8 ± 0.2</td>
<td>3.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>90-10</td>
<td>1.13</td>
<td>7.0 ± 0.5</td>
<td>4.1</td>
<td>61.2 ± 2.4</td>
<td>22.9 ± 0.4</td>
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<tr>
<td>80-20</td>
<td>1.36</td>
<td>8.3 ± 0.2</td>
<td>5.6</td>
<td>46.5 ± 1.8</td>
<td>21.7 ± 0.3</td>
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<tr>
<td>70-30</td>
<td>1.57</td>
<td>9.8 ± 0.2</td>
<td>7.9</td>
<td>44.0 ± 0.6</td>
<td>20.4 ± 0.6</td>
</tr>
<tr>
<td>60-40</td>
<td>1.74</td>
<td>11.1 ± 0.4</td>
<td>9.1</td>
<td>32.6 ± 1.2</td>
<td>14.5 ± 0.7</td>
</tr>
</tbody>
</table>

Table 2. Mechanical properties of the hybrid bone-plate depending on volume fractions of HDPE/BCP contents.

During the bending strength measurement, all the samples did not show a flat fracture surface which is frequently observed in ceramic materials. Fig. 1 shows the fracture mode of the HDPE/BCP hybrid bone plate. In the enlarged image and (b) of the 60/40 composite, the crack path was larger than that in the enlarged image and (a) of the 90/10 composite. Although the bending strength for the former increased remarkably, still a crack had a considerable deflection.
Fig. 1. Fracture mode showing crack deflection in the HDPE/BCP hybrid bone-plate: (a) 90/10 and (b) 60/40.

Conclusion
BCP reinforced HDPE composites were fabricated by a brander and heat pressings. Dense microstructure with improved fracture characteristics was observed when the hot pressing method was at 135–150°C under a pressure of 3.0 MPa for 30 min. In the case of the 60–40 mode, a network-type fracture mode was formed, due to a necking of the reinforced-forming agent BCP. The mechanical properties such as the measured bending strength and tensile strength decreased as the volume percentage of the BCP content increased. However, the values of the measured density, Vickers hardness and Young's modulus of the hybrid bone plate containing a 30 vol.% BCP content were about 1.57 g/cm³ and 7.9 GPa, respectively, almost the same as natural human bone.

Acknowledgement
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References
2. I.Ono, T. Tateshita and T.Nakajima, Biomaterials, 21, 143, 2000