Customized Additively Manufactured Bio-ceramics for Bone Tissue Engineering

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Customized bio-ceramic implants

Additive manufacturing by stereolithography (SL) is a promising fabrication process for production of complex ceramic parts with high surface quality and resolution. This makes the technique suitable for individualized parts such as patient specific implants where the external geometrical shape can be defined from CT-data. In addition to external shape, fine features such as macro-porosity with a defined size and shape can also be introduced in the implant.

The biological response to the implant will mainly depend on the chemical composition, surface and the microstructure of the implant material. It is thus of interest to have the tools required in order to produce not only the shape but also chose the material and control the microstructure depending on the purpose.

Additive manufacturing of ceramics by SL

Process steps

1. Ball milling
2. Freeze granulation
3. Suspension preparation
4. Shaping by SL
5. Debinding and sintering

- Ball milled powder was freeze granulated: spraying into liquid nitrogen and subsequently removing solvent by freeze-drying.
- High solids loading of powder was dispersed in a mixture of multifunctional acrylates and non-reactive diluents.
- The composition of the suspensions was adjusted depending on the powder used to obtain suitable rheological properties, cure depth and lateral resolution to allow shaping by SL.
- Ceramic green bodies were manufactured by SL. Finally the parts went trough thermal debinding and sintering to form the final ceramic components.

Manufactured parts and materials

<table>
<thead>
<tr>
<th>Alumina</th>
<th>Zirconia</th>
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<tbody>
<tr>
<td>Photograph of additively manufactured alumina component.</td>
<td>Photograph of additively manufactured zirconia component.</td>
</tr>
<tr>
<td>Alumina (CT 3000SG, Almatis) suspension with a solids loading of 50 vol% and a viscosity of 1.22 Pa·s at 25 s⁻¹ was used to produce parts with a density &gt;99 % T.D and pores &lt;5 µm in size.</td>
<td>Zirconia (TZ-3YS-E, Tosoh) suspension with a solids loading of 46 vol% and a viscosity of 10.41 Pa·s at 25 s⁻¹ was used to manufacture parts with a density &gt;99 % T.D.</td>
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<th>Silicon nitride</th>
<th>Hydroxyapatite</th>
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<tbody>
<tr>
<td>Photograph of additively manufactured silicon nitride parts.</td>
<td>Photograph of additively manufactured hydroxyapatite parts.</td>
</tr>
<tr>
<td>Suspension of silicon nitride (SN-E05, UBE Industries) and 8 wt% sintering additives with a solids loading of 40 vol% was used to manufacture complex components.</td>
<td>Hydroxyapatite (supplied by Riga Technical University) suspension with a solids loading of 45 vol% was used to manufacture complex components.</td>
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Defects

- Layer defects visible in fracture surface of sintered zirconia specimen.
- Inclusion of previously cured layer sheet in sintered zirconia specimen.

Defects in produced parts remain a major obstacle for the process reliability. These can include layer inclusions, large pores and surface defects which limits the mechanical properties.

Defect resistant ceramics for the future

Ceramic composites with higher toughness and reduced sensitivity to defects, such as Ce-TZP with 8wt% of Al₂O₃ and 8wt% of SrAl₂O₄, developed within the European project LONGLIFE, can be used to improve the reliability of AM ceramics.