Highly aligned porous biomaterials by reverse freeze casting

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Statement of Purpose: Various porous materials have been developed for tissue engineering of bone or cartilage [1]. The structure of these materials must be highly porous with interconnected open pores in the size range of 100–500 µm, which allow bone cells to penetrate and grow[2]. However, highly porous materials generally show poor mechanical properties which can cause a fracture of implant during the healing stage even for metallic material. So far, a variety of manufacturing methods to fabricate strong porous materials have been reported, including rapid prototyping method, and unidirectional freeze casting. Those methods generally produce highly aligned pores, but there are some limits in controlling the pore structure such as pore size, degree of alignment. In this study, reverse freeze casting (RFC) method was applied to fabricate various materials. Representatively, pore structures and mechanical properties of porous titanium were demonstrated.

Methods: Liquid camphene was poured into Teflon cylinder with a diameter of 5 cm attached to a copper plate. The copper plate was then immersed in a cold water bath. The unidirectional freezing was conducted for 20 min in an oven to keep a constant surrounding temperature of 45 °C. Titanium powder (or other materials) / camphene slurries with adequate powder contents (15~20 vol.%) were prepared by ball-milling at 60 °C for 12 h. Prepared slurries were poured onto solidified camphene and kept at 45.5 °C for various periods of time (1~3 days), in order to allow sufficient migration of raw powders. After de-molding, the green bodies were then freeze dried and sintered. The porous structures and migration process were analyzed using µ-CT and SEM. . In order to evaluate their mechanical properties, their compressive stress–strain behaviors were monitored.

Results and Discussion:
Fig. 1 shows the schematic representation of reverse freeze casting. After pouring the slurry onto frozen camphene, powders in the slurry were migrated downward along the boundary of camphene solid at 45.5 °C. Migration path was almost linear and same with initial camphene structure. Optical and µ-CT images of finished green body (24 h casting) are shown in Fig. 2. All of the fabricated samples showed a highly porous structure with large interconnected pores. Pore structure (pore size and porosity) was controlled by adjusting temperature or casting time (data not shown here). Fig. 3 shows various porous materials fabricated by reverse freeze casting. Regardless of the raw material, every sample shows similar structure. It should be noted that all metallic/ceramic powders can be used as raw materials for porous bodies. Compressive strength of porous scaffolds with aligned pores was larger than other porous materials with same porosity and with random pores [4].

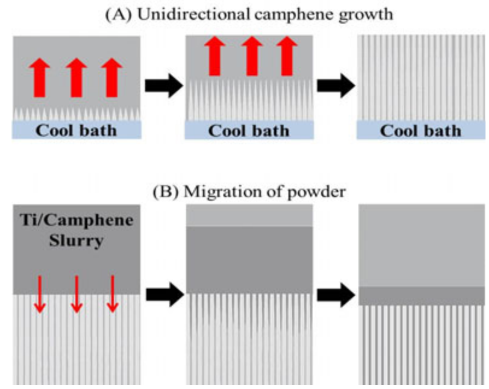

Fig 1. Schematic representation of reverse freeze casting

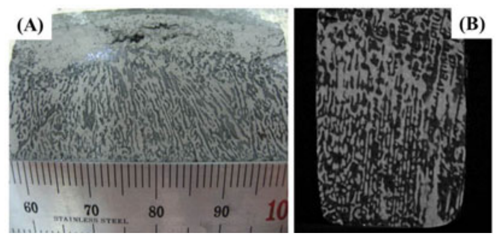

Fig 2. Aligned pores of green body after casting.
(A) Optical image (B) µ-CT image

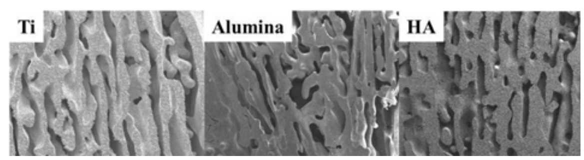

Fig 3. SEM images of various porous materials fabricated by reverse freeze casting.

Conclusions: Highly porous materials with large, aligned, and interconnected pores were fabricated by reverse freeze casting. Migration of various metallic/ceramic powders was occurred along the boundary of camphene solid by keeping at specific temperature. The porous scaffolds with aligned pores were stronger than other porous materials with same porosity. Reverse freeze casting method can be widely applied to producing porous scaffolds for bone tissue engineering.

References:

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