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Review

Manufacturing and characterization of porous titanium components

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A B S T R A C T

A powder-bed 3D printer (3DP) is investigated to fabricate porous titanium components. The titanium material was 3D printed and subsequently post-processed by thermal debinding and sintering. Characterization work was carried out to investigate the effects of sintering temperature on the internal porosity profile and shrinkage of 3D printed titanium components, the effects of different binder content on the overall shape of the pre-designed porous components and the effects of post-processing debinding profiles on the titanium components.

1. Introduction

For implant with load bearing function, it is ideal that the load is shared between the surrounding functional body part and the implant. The stress carried by the implant and the functional body part is directly related to their stiffness [1]. Implants with higher stiffness with that of the surrounding body part may cause issues as the higher stiffness of the implant would take the majority of the loaded stress and thus preventing the functional body part from being loaded properly [2]. For bone implant, this phenomenon is called stress shielding, and could lead to adverse effect of implant loosening in the future [3].

To reduce the high stiffness of metallic implant, it is suggested that implantable devices to be fabricated as porous components. Titanium is the material of choice due to its already favorable

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mechanical and biocompatible properties [4]. As a result, the porous device's mechanical properties could be tailored to better match the yield strength and elastic modulus of the host bone and therefore avoiding stress-shielding effect associated with a mismatch in bone-implant elastic modulus.

Additive manufacturing (AM) technologies, a layer-by-layer manufacturing process which builds 3D objects directly from the objects' computer data models, can aid the fabrication of porous components. Fabrication of porous objects can be done by designing porosity into the objects' computer models. A particular interest is the powder-bed 3-dimensional printer (3DP) to manufacture porous titanium components through an indirect process. 3DP is a relatively low cost AM system, which totals less than US$ 40,000 when combined with a sintering tube furnace [5,6]. This sum is much lower in comparison to direct manufacturing of titanium components using metal-based AM systems, in which the cost starts from US$ 600,000 for powder-bed systems such as selective laser melting [7].

A previous work has shown that the mechanical properties of porous 3D printed titanium can be tailored to be in the range of natural bone [8,9]. This work focuses on the physical characterization of the porous titanium component with respect of porosity and shrinkages profiles, as well as factors affecting the stability of the porous component shape.

2. Methodology

CP titanium powder (Grade 2, ASTM F67, size 45 μm, spherical shape, TLS Technik Spezialpulver) was dry mixed with poly(vinyl alcohol) (PVA) (Nippon Gohsei, Gohsenol, NH-18S) in a ball mill mixer (US Stoneware, 764 AVM Jar Mill) at 100 rpm for 10 h. PVA, as the binder, was mixed with concentration of 5, 10, 15 and 30%. Zirconia balls (diameter 20 mm) were used to facilitate the mixing process, with ball to powder ratio set to be 10:1 by weight. CAD files of the components can be created using any drawing software and subsequently converted to .STL file to feed into a 3DP system (3D Systems, ZPrinter 310 Plus). The layer thickness used is 0.1 mm.

After the printing process completes, the parts were left overnight in the powder-bed to allow the liquid binder to bond to the powder mixture and produce sufficient strength for handling. The parts were subsequently taken out from the building bed and dried in an oven (Townson Mercer) at 50 °C for approximately 1 h to remove the moisture and further strengthen the parts. After depowdering, the parts underwent debinding-cum-sintering process (CM Tube High Temperature Furnace) in Argon environment at the rate of 20 L/min. Sintering temperature was varied at 900, 1000, 1100, 1200, 1250, 1300 and 1350 °C.

Two profiles with a variety in the debinding temperatures (Fig. 1) were used to investigate the effects of thermal post-processing profiles on the titanium components.

For determination of dimensional accuracy and shrinkage a digital calliper with 0.01 mm accuracy. Pore size of the titanium samples were measured by mercury porosimeter (AutoPore IV|Micromeritics). A digital microscopy was used to measure the size of macroscopic pores. Scanning electron microscopy (JEOL) was utilized to examine the pore size.

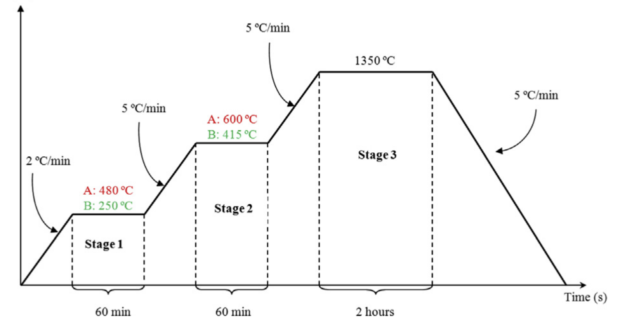

Fig. 1. Thermal post-processing profile with varying debinding temperatures.