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Highly Porous titanium foam through powder metallurgy by using the space holder method

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Abstract
This study presents a novel technique for fabricating porous titanium with a regulated net-like pore structure, making it suitable for biomedical applications. This technique relies on urea particles acting as "space bearers" to generate mechanically stable and easily machined compacts. Using urea and titanium powder, we could compress a material with a transverse rupture strength (85 MPa) high enough for machining, and then remove urea particles from the net-shape compact to make a titanium scaffold with intricate geometry. The (200-400) m-sized pores were evenly dispersed and linked to one another. Because of anisotropy and pore alignment, the compressive strength changed according on the direction of compression.

Keywords: *porous titanium, powder metallurgy, space holder, urea*

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I. INTRODUCTION

The last ten years have seen a significant increase in the importance of developing novel lightweight materials. In every industrial sector, lightweight materials are highly desired for various structural and functional uses. They are closely connected to the decrease in energy and natural resource usage. By using lighter alloys, increasing their porosity without significantly reducing their properties, adding lighter reinforcing phases, increasing their porosity without significantly reducing their strength, and applying new or improved processing techniques, it is possible to create metallic materials that are both lighter and stronger. The materials science and engineering advances are astonishing [1–3].

Various combinations are often used in processing to yield the final porous material. Heat-accelerated chemical processes and/or phase changes are the causes of materials with pores. One typical concoction ingredient, the "space holder," is responsible for the final structure's voids. Filler materials might be solids or gases. To the best of our knowledge, no reports exist of the use of liquid substances, but we can assume that they are likewise applicable. The porosity of porous materials can be open, closed, or hybrid and can be generated in vitro or in situ. Titanium and its alloy foams are a special group of these materials because they combine unique properties, such as a high strength-to-weight ratio, excellent corrosion resistance, and biocompatibility, that offer potential use in biomedical applications [4]. In addition to extraordinary mechanical behavior specific to cellular metals, these materials also exhibit extraordinary mechanical behavior.

Additionally, property profile, titanium foams are promising materials in the fields of aerospace, chemical engineering, and sports equipment with an optimum design, necessitating a thorough examination of tailoring-induced mechanical property changes. The strain-rate sensitivity of titanium and its alloys is also well known [5], and titanium foams have been found to react differentially to static and dynamic loading [6]. However, the impact of cell shape has never been brought up.

II. METHODOLOGY

The production of titanium (Ti) foams was carried out using the space holder technique, employing commercially pure (cp) Ti powder with a purity level of 99.5% and particle sizes ranging from 40 μm to 80 μm. The titanium powder exhibited variable morphology. The titanium powder and urea particles were thoroughly blended in a mortar to ensure a homogeneous mixture. The urea particles were combined with a titanium powder, constituting roughly 30% of the total volume in the mixture; for the powder binding, a 2% wt polyvinyl alcohol (PVC) solution was added.

The powder mixture was subjected to homogeneous mixing and then cold compacted using a pellet press afterward. The compaction process was carried out in a cylindrical die with a diameter of 60 mm, at a pressure of 200 MPa. The compacted samples underwent pre-heating in an argon environment at a temperature of 200 °C for a duration of 2 hours. This process was carried out using a high-temperature furnace. This pre-heating aimed to ensure the total elimination of urea from the samples, which was subsequently confirmed by reweighing the compacts after the pre-heating process. The powder compacts, which had been pre-heated, were subsequently sintered in a vacuum furnace. The sintering process took place at a temperature of 1100 °C for a duration of 60 minutes.

Figure 1 depicts the procedural steps involved in the fabrication of porous titanium via the space holder method. The pore parameters, including pore form, size, and porosity, were analyzed using scanning electron microscopy (SEM) manufactured by JEOL Technique. The identification of phases in obtaining compacts, green bodies, and sintered samples was conducted using an X-ray diffractometer.

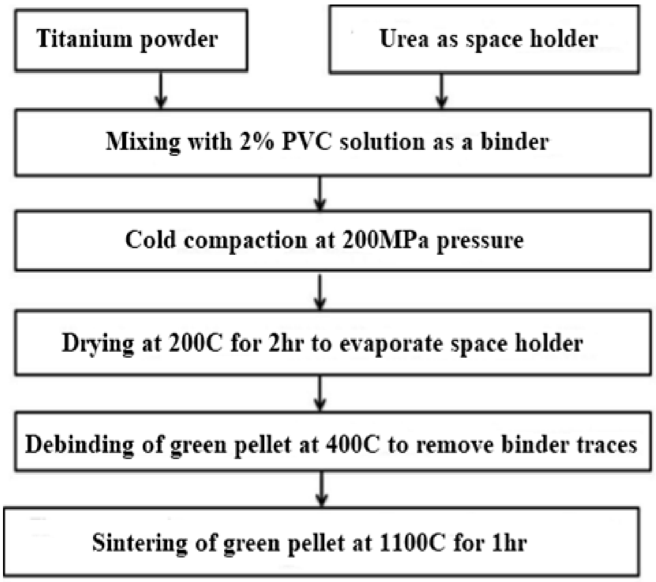

Figure 1: Preparation process flow chart for making titanium foam by powder metallurgy process.

III. RESULT AND DISCUSSION

The urea particles serve as space-holding particles, effectively determining the pore size throughout the compaction process of the Ti/urea mixture. The employed mixing technique results in a homogeneous dispersion of urea particles, without any degradation or reduction in particle size. The small quantity of PVC facilitates the cohesive interaction between the powders during compaction. The compacts exhibit favorable mechanical strength, which is advantageous for facilitating the subsequent consolidation phase. The urea particles dissolved while removing the space holder, which was conducted in a mixed water solution, creating voids inside the Ti scaffold. The compact demonstrated sufficient strength to maintain mechanical integration during the process of being held by tweezers, dried, and afterward placed into the furnace for sintering.

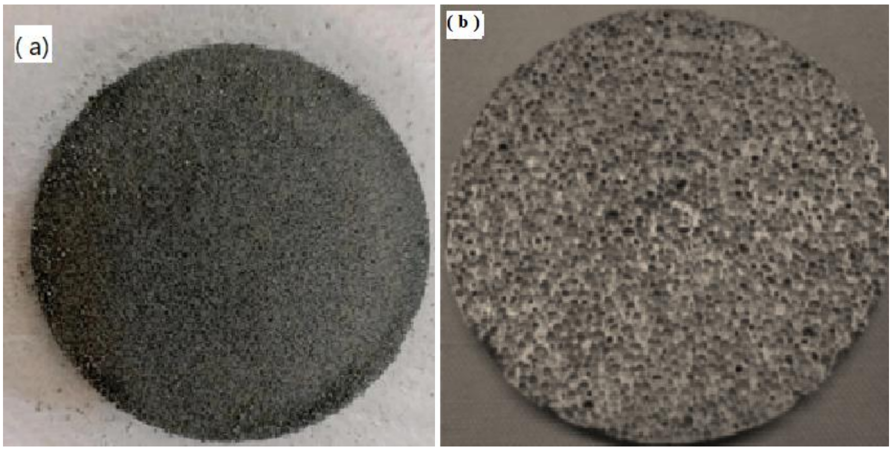

Figure 2: Green pellets a) before sintering and b) after sintering.

Titanium foams exhibiting varying degrees of porosity were effectively manufactured by incorporating variable proportions of space holders. Three samples within a similar range of porosity were manufactured for each ratio of starch to titanium, and all these samples were subsequently utilized for analysis.

Figure 3 displays a scanning electron microscope (SEM) image that illustrates the presence of urea particles, identifiable by the white areas, dispersed throughout the compacted mass matrix. Nevertheless, a disparity in the volume fraction was noted in the vicinity of the margins of the cross-section, which may be ascribed to the fluctuation of the compaction pressure across the cross-section. Consequently, the region subjected to the highest load exhibited a greater volume proportion of urea. Acicular holes become evident after the elimination of urea. The matrix exhibited the presence of pores with dimensions on the micron scale. The presence of linked macropores can be attributed to the process of starch breakdown. The diameters of these holes vary between 200 µm and 400 µm. Nevertheless, the structure also contains micropores. The entities mentioned above are formed through the process of partial sintering of titanium particles.

The formation of these pores results from applying low pressure during the compaction process of the powder mixture. Additionally, the pore size exhibited dimensions exceeding the urea particles. This phenomenon may be attributed to the evaporation of urea particles, resulting in the disruption of mechanical linkages within the matrix and the subsequent formation of bigger spaces. The compacts exhibited the maximum degree of porosity in the pre-heated state, reaching approximately 79%. In contrast, the vacuum-sintered samples had the lowest porosity level, measuring around 55%. The porosity level in the green compact was approximately 55%, which closely resembled that of the sintered mass.

The increased porosity observed in the final foam sample may be related to the partial sintering and compaction of the titanium matrix. This phenomenon arises from the uneven degree of compaction caused by changing pressure across different regions. The porous patches observed in pre-heated compacts had an acicular morphology. The presence of porous regions can be attributed to the significant driving force that promotes pore shrinking in areas where the pores exhibit severe curvature during the sintering process. The presence of a larger pore within an acicular porous zone is indicative of an unhealed section.

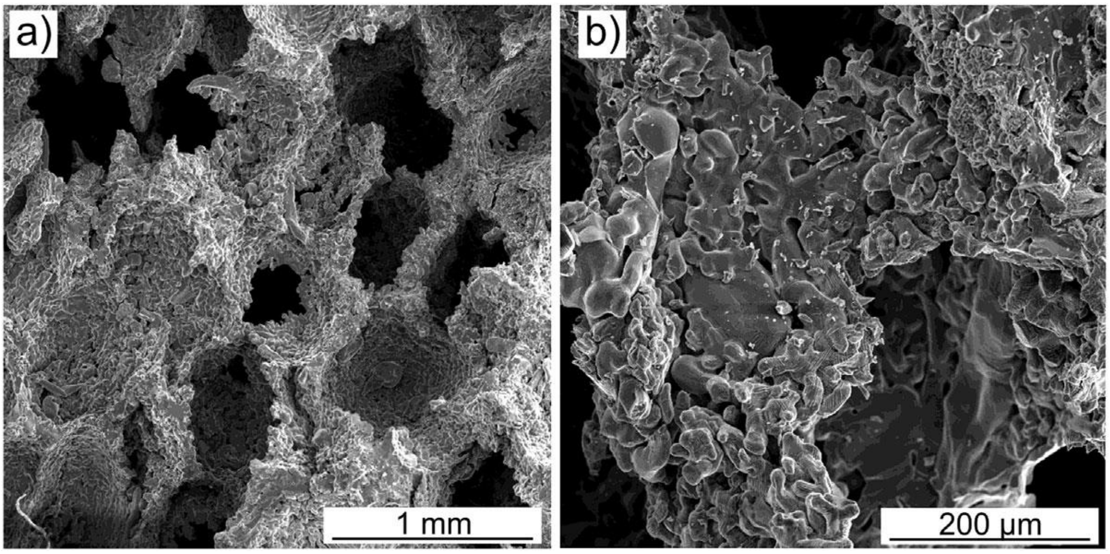

Figure 3. SEM of titanium foam achieved a) microporosity at 1mm and b) microscopy of wall substructure at 200µm.

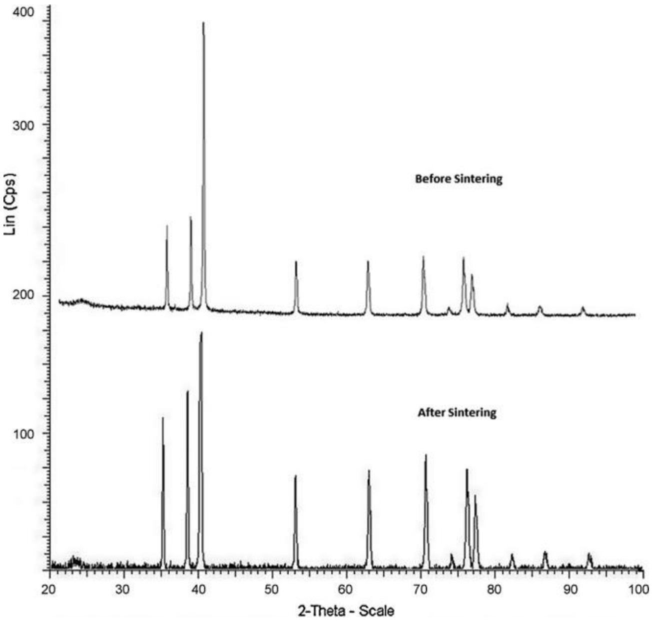

Figure 4: XRD results of the sample before and after sintering.

According to the XRD analysis, partially oxidized foams containing residues of saccharose were formed in Figure 4. The XRD spectra of a sugar and a titanium (a and b, respectively) are displayed for comparison. Due to the sensitivity of Ti to oxidation, titanium oxide was found on the surface of the initial Ti powder (even when stored in a protective atmosphere). Ti oxide is formed during the subsequent processing steps (air pressing, water dissolving, and argon sintering). In light of this, it appears that the biological uses of these foams are quite promising. The titanium powders underwent a contaminant assessment prior to the processing stage. The primary objective of X-ray diffraction (XRD) is to ascertain the degree of similarity between the compound utilized before sintering and the compound obtained after the sintering process. The peaks observed in the uppermost section of Figure 4 correspond to the titanium peaks associated with the samples prior to the sintering process. In contrast to the pre-sintering pattern, the peaks observed at the bottom of Figure 4 remained unchanged, suggesting the absence of any alterations or contamination following the sintering process.

IV. CONCLUSION

Titanium metallic foams can be effectively manufactured utilizing the powder metallurgy method, employing urea particles as a space holder. The study examined the impact of the space holder content on the porosity and the relationship between the porosity of the sample. The foam that was created exhibited acicular porous patches containing micro-pores and sporadic larger pores that can be considered as sections of the initial pore. The optimization of sintering time and temperature can lead to the reduction or elimination of bigger pores. The present work effectively produced titanium foam using a sintering and dissolving process (SDP) employing urea as the space holder. This study's findings prove that Urea is a highly effective space holder for producing titanium foam, enabling precise control over its porosity and pore morphology.

REFERENCES

[1]. Ashby, M. F., Evans, A. G., Fleck, N. A., Gibson, L. J., Hutchinson, J. W., and Wadley, H. N. G., 2000, Metal Foams: A Design Guide, Butterworth-Heinemann, Boston, MA.
[2]. Banhart, J., 2001, "Manufacture, Characterisation, and Application of Cellular Metals and Metal Foams," Prog. Mater. Sci., 46(6), pp.559–632.
[3]. Aerogel.org, 2008, "Silica Aerogel," Aerogel.org.
[4]. M. Geetha, A.K. Singh, R. Asokamani, A.K. Gogia, Prog Mater. Sci. 54 (2009) 397.
[5]. S. Nemat-Nasser, W.G. Guo, J.Y. Cheng, Acta Mater. 47 (13) (1999) 3705–3720.
[6]. P. Siegkas, V.L. Tagarielli, N. Petrinic, J. Mater. Sci. 46 (2011) 2741–2747.