Synchrotron X-ray Computed Microtomography of Porous Titanium

N. Davis, D. Dunand
Department of Materials Science and Engineering, Northwestern University, Evanston, IL, U.S.A.

Introduction

Solid-state foaming of titanium and titanium alloys can be achieved by hot isostatic pressing powders with argon gas, followed by high-temperature expansion of the resulting high-pressure argon bubbles. This foaming technique, which was first developed by Kearns et al. [1, 2] and is currently under industrial development at Boeing Corp. for Ti-6Al-4V as the low-density core (LDC) material, is limited in terms of maximum porosity by the low creep rate and ductility of the metal, which lead to slow pore growth and early cell wall fracture.

We address these issues by performing the foaming step under transformation superplastic conditions, where the foam is thermally cycled around the α/β allotropic temperature of titanium [3]. This induces superplasticity because of the complex superposition of internal transformation stresses and the biasing stress from the pore pressure [4]. Variations in processing conditions — such as the initial powder size, backfill pressure, and initial powder aspect ratio — lead to varying pore morphologies. The resulting 3-D pore structures were studied by using synchrotron-based x-ray computed microtomography (CMT) in order to study pore morphology, pore linking, and pore alignment for titanium foam made under various foaming conditions.

Methods and Materials

Powders or wires of commercial-purity titanium (CP-Ti) were packed and encapsulated in evacuated steel canisters that were back-filled with argon. To achieve various initial pore shapes, both sieved powders and wires were used. Powders that were used were sieved to a mesh size of -170/+230 (62-88 μm). Furthermore, a canister was filled with 250-μm-diameter CP-Ti wires from Alfa Aesar (Ward Hill, MA) arranged lengthwise. Canisters were backfilled with 0.33-MPa (powders) or 0.71-MPa (wires) Ar-gas and were subsequently densified by hot isostatic pressuring (i.e., HIPed) by Connaway Technologies and Isostatic Forging (Hilliard, OH) for powders and by Bodycote IMT, Inc. (Andover, MA) for wires. Both were HIPed at 890°C with 100 MPa for 120 min. The result after HIPing was billets of titanium matrix with small, high-pressure Ar bubbles. The pores in the HIPed specimens were expanded either by high-temperature isothermal anneal or by transformation superplasticity, which resulted in porous titanium with a porosity ranging from about 16% to 40% [3-6].

Foamed specimens were sectioned by using a diamond saw into parallelepipeds about $2 \times 2 \times 8$ mm. Specimens were exposed to 30- to 45-keV x-rays with 1200- to 1400-ms exposure times at beamline end station 5-BM-C (DuPont-Northwestern-Dow Collaborative Access Team [DND-CAT], sector 5). A 1300×1300 bit charge-coupled device (CCD) camera was used for image acquisition.

Results

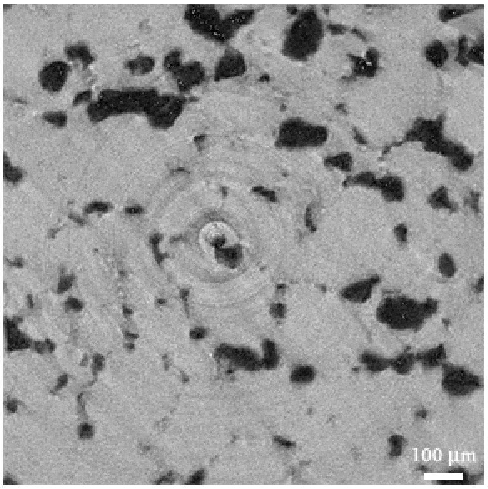
Figures 1(a) and 1(b) show an example of 2-D CMT "slices" for foams made from wires. Figure 1(a) shows the resulting pore structure in the direction perpendicular to the wire length, and Fig. 1(b) shows the resulting pore morphology along the length of the wires. The titanium matrix appears gray, while the pores appear as black regions. For the case of the wires, pores elongated in the direction of the original wire alignment are observed, while equiaxed pores are seen in the perpendicular cross section. Similar images can be constructed for foams made from powders, but no pore alignment or elongation is observed.

Discussion

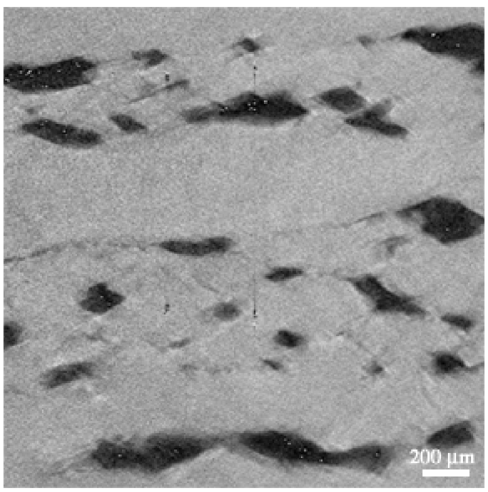
Our preliminary results show that porous titanium can be imaged and that 3-D x-ray CMT can be used to reconstruct the images in order to nondestructively observe pore alignment and morphology. This technique could also be used to monitor pore growth by performing reconstructions during room-temperature interruptions throughout the foaming process. In addition, by successive viewing of 2-D slices or by 3-D reconstruction, pore linkage can be observed.

Acknowledgments

This work was partially supported by the National Science Foundation through Grant Nos. DMR-0108342 and CMS-0074921 to L. C. Brinson, principal investigator. Also, the authors thank E. Spoerke for preparing the wire performs. N. G. Davis acknowledges the support of the U.S. Department of Defense (through a National Defense Science and Engineering Graduate Fellowship), the American Association of University Women (through a Selected Professions Dissertation Year



(a)



(b)

FIG. 1. CMT slices of wire foams that are (a) perpendicular and (b) parallel to the original wire alignment.

Fellowship), and the Zonta International Foundation (through the Amelia Earhart Fellowship). Use of the APS was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

References

[1] M. W. Kearns, P. A. Blenkinsop, A. C. Barber, and T. W. Farthing, Metals and Materials **3**(2), 85 (1987).
[2] M. W. Kearns, *Formation of Porous Bodies*, U.S. Patent No. 4659545 (IMI Titanium Ltd., U.S.A., 1987).
[3] N. G. Davis, J. Teisen, C. Schuh, and D. C. Dunand, J. Mater. Res. **16**(5), 1508 (2001).
[4] D. C. Dunand, "Transformation superplasticity in metals, alloys and composites," in *International Symposium on Superplasticity in Materials THERMEC '97* (The Minerals, Metals, & Materials Society [TMS], 1997).
[5] N. G. Davis and D. C. Dunand, *Enhancement of Solid-State Foaming by Superplasticity* in *Superplasticity and Superplastic Foaming* (The Materials Information Society [ASM], Indianapolis, IN, 2001).
[6] N. G. Davis, D. C. Schuh, and D. C. Dunand (unpublished, 2001).