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Report:

Biomimetics is a newly emerging interdisciplinary field in materials science, chemistry and biology in which basic architectural principles taken from nature form the basis for novel technological materials. In a very novel approach, trying a reverse engineering of a material similar to bone, we were able to produce a long-fiber reinforced metal foam using a powder-metallurgical route [1]. Since the reinforcing fibers are "hard" alumina fibers, and the matrix consists of "soft" (i.e. plastically deformable) aluminum, we could hope to reproduce some of the extraordinary mechanical properties of bone. For the presently used production route, foaming was successful only for fiber volume fractions up to 5%, even when short fibers were used instead of long fibers. This volume fraction is probably too low to significantly enhance the mechanical properties, a fact, which was also verified by mechanical tests on the present foams [1]. Nonetheless, for future improvements of the production route (permitting, e.g. higher volume fractions), it appears important to investigate the microstructure of the foam walls in some detail. In the present experiment, some crucial questions concerning the composite character of the material were addressed by micro tomography on single foam walls:

- Orientation distribution of the fibers: do the fibers follow the traces of the cell-walls, as required for an optimum fiber reinforcement similar to bone?
- Homogeneity of the fiber distribution?
- Fiber fracture: do the very brittle fibers break into pieces during the foaming process?

Samples for micro-tomography were prepared by embedding the foams into resin and cutting out specimens containing single foam walls (see e.g. Fig. 1a). In total, seven samples were investigated: three long-fiber (LF) reinforced foam samples, and additionally four samples from test materials to improve the mechanical properties by changing the fiber type and/or the production route (one short-fiber (SF) reinforced foam, one (SF) reinforced- and one un-reinforced pressing, and one particle reinforced foam produced by a formgrip process). For the (LF) foam samples, at least two sets of projections at different positions along the specimens were measured.

First, some fast (i.e., low resolution) sets of projections were collected and reconstructed on-site in order to optimize the experimental parameters. Similar to an earlier experiment [2], phase-contrast turned out to be essential due to the very similar absorption coefficient of the matrix (aluminum) and the fibers (alumina). An energy of 15 keV, a sample to detector distance of 64 mm, and a 12 μm thick Eu:YAG scintilator (PSF ≈ 1 μm) were finally found to be the best compromise with respect to resolution, contrast and measurement time. Projections were measured using a Frelon-CCD, coupled via an optical microscope to the scintilator, with acquisition times between 1 - 5 s per single projection, and either 1250 or 2500 projections, corresponding to final voxel sizes of $(1.4\ \mu m)^3$ or $(0.7\ \mu m)^3$, respectively. In total, 12 “good” sets of projections were collected and partly (about 50%) reconstructed at the ESRF using the “HST”-software (and corresponding hardware). The rest of the data is currently being reconstructed in the home laboratory using an “IDL”-based software (provided by T. Weitkamp, ESRF). In the following we refer only to the results from the long-fiber reinforced foams, since the other data are currently still being evaluated.

Careful inspection of five tomography sets from two samples of the long-fiber reinforced foam yield the following preliminary results:

1) The fibers are preferentially oriented parallel to the traces of the foam walls. This is clearly demonstrated in Fig. 1b, and was consistently found for all datasets.
2) The fiber distribution is strongly heterogeneous. There are large areas (sometimes up to the order of mm) without fibers, and areas with a very high density of fibers. This agglomeration of the fibers is expected to occur already at the stage of mixing the fibers with the metal powder.
3) Almost all of the fibers are broken into several pieces (typically less than 100μm, see Fig.1b). Fiber fracture is probably happening already during production of the pre-material, i.e. due to the high stresses during pressing the powder-fiber mixture. It is expected that a different processing route such as the formgrip process could avoid fiber fracture.
4) Generally, the foam walls are not very dense, but strongly porous, and there seems to be a rather weak bonding of the fibers to the matrix.

Despite of point 1) – which is indeed encouraging in proceeding with our attempt to produce a bio-inspired material with similar structure as bone – these results are rather sobering, confirming the weak mechanical properties of this type of materials [1]. It is expected, however, that together with the level of awareness of the present investigation, new production ways can be found to optimize the structure – and thus, the mechanical properties – of these promising materials.

[1] A. Wöss, *Diploma-thesis*, University of Leoben (2000).
[2] O. Paris, H. Peterlik, D. Loidl, C. Rau and T. Weitkamp, *Mat. Res. Soc. Symp. Proc.* **678** (2001) EE3.8.1.

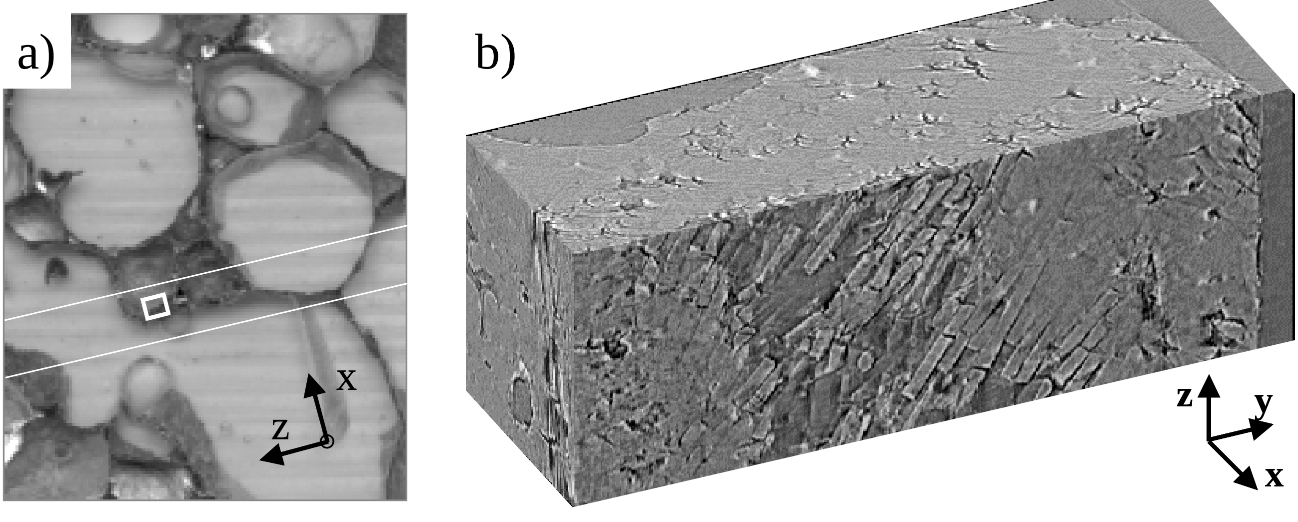

Fig. 1: a) Light microscopic image of a long-fiber reinforced foam, embedded into resin and cut to a plate with thickness of ≈ 0.7 mm. The white lines indicate the cut to obtain a ≈ $(0.7 \times 0.7 \times 10)\ mm^3$ specimen for micro-tomography at ID22. b) 3D representation of part of a reconstructed volume (indicated by the white box in a)), obtained by micro-tomography at ID22. The (right handed) coordinate system for a) is drawn within the image, the one for b) at the lower right corner. The size of the reconstructed volume in b) is $(240 \times 725 \times 267)\ \mu m^3$, the voxel size was $(1.4)\ \mu m^3$.