Microstructural parameters for modelling of superconducting foams

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***Abstract*—Modelling the mechanical and superconducting properties of superconducting, open-cell foam samples requires a proper description of their specific microstructure. For this purpose, foam samples are investigated using optical microscopy, SEM and x-ray tomography, enabling to identify the parameters important for modelling.**

***Keywords*—superconducting foams, porous structure, microstructure, YBCO**

I. INTRODUCTION

Superconducting $YBa_2Cu_3O_y$ (YBCO) open-cell foam samples [1], [2] were originally prepared starting with polyurethane foams covered with a slurry of Y_2BaCuO_5 (Y-211), which is then converted into the YBCO superconductor using the infiltration growth process. In the required heat treatments, the polyurethane is completely burnt out, and the superconducting material is quasi replicating the original polyurethane foam. Thus, we may use the already existing modelling approaches for polyurethane foams [3]–[6]. However, it is an essential task to properly evaluate the microstructure of the superconducting foams (Fig. 1) in the view of modelling the superconducting parameters, as the infiltration growth process created an unique microstructure which is not seen in bulk superconductors [7]. Thus, we performed a thorough analysis of the foam microstructure, applying optical microscopy, SEM (EBSD) and x-ray tomography to identify the structural parameters important for modelling.

II. RESULTS AND DISCUSSION

The previous modelling of polyurethane foams clearly revealed that it is important to model the real microstructure in order to achieve proper results for the mechanical properties of such foams. The Kelvin cell geometry has been used by many researchers to represent foam structures. This geometry consists out of six square and eight hexagonal faces (Fig. 1) and is capable to partition the space into identical equal-volume units with minimal surface energy. However, we see that in this model all foam struts are identical, and the nodes, where the struts interconnect, are quite simplified. Although such Kelvin cell models have proven to be efficient and useful to model the mechanical response of cellular materials, the geometry of the Kelvin cell does not comply with a real foam topology. The cells of real foams are irregular polyhedra with anywhere from 9 to 17 faces in nearly monodisperse foams. The material is concentrated in the nearly straight ligaments and in the nodes where they intersect. Thus, the mechanical properties of foams depend strongly on the microstructure realized, and on the basic properties of the base material. The

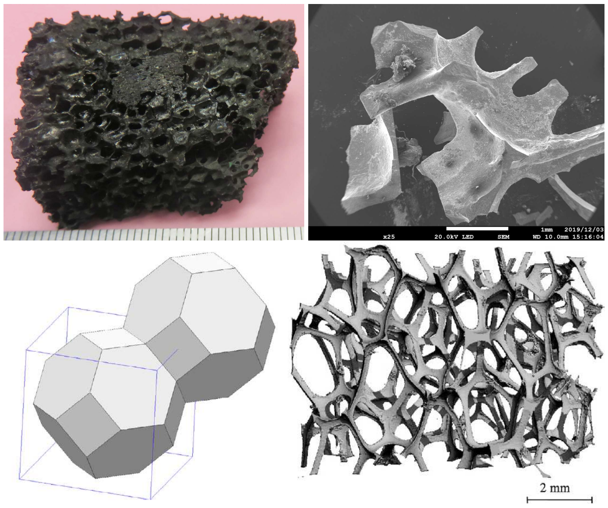

Fig. 1. A superconducting 40-ppi foam, its struts, two typical Kelvin cells for modeling (drawn using Surface Evolver software, and a reconstructed model of a 20 ppi polyurethane foam.

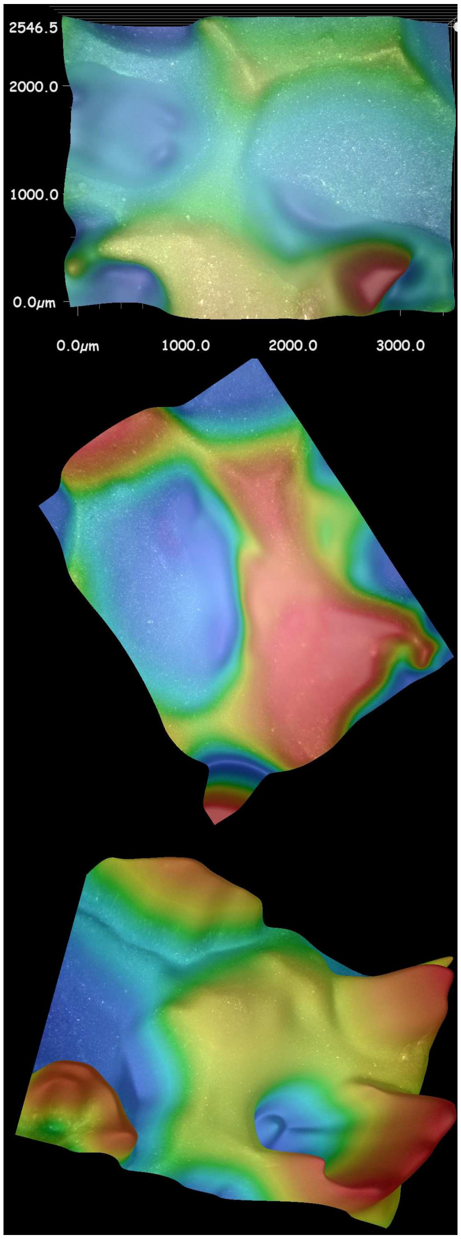

Fig. 2. Optical analysis (optical digital microscope Keyence X-5000) of several foam nodes.

specific part of the microstructure, which is relevant for the mechanical properties of the foam, is the shape and geomtery of the various nodes [4]. Thus, it is essential to determine the relevant parameters (cell size, cell anisotropy, ligament length) of the superconducting foam samples (Fig. 2). The flow of the superconducting currents in a foam sample is manifold: (i) There is a current flow in the entire sample perimeter, which can be visualized by trapped field measurements [8], [9]. (ii) Currents can flow in small circles around a given pore. This current flow gives rise to the sharp peaks seen in the trapped field measurements. (iii) Currents can branch up at the nodes in the structure. (iv) Currents flowing within the foam struts face the variation of orientation of the superconducting material (Fig. 3), depending on the location within the foam sample.

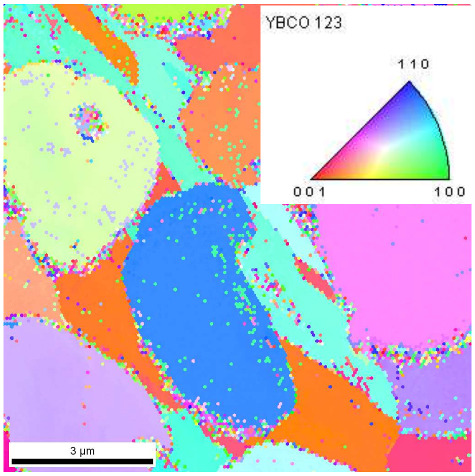

Fig. 3. EBSD inverse pole figure map in ND direction (normal) of a foam strut. The color code for the orientations is given in the stereographic triangle.

Furthermore, we have to note that there is a specific structure of the foam struts: The tiny Y-211 particles are located mostly in groove-like channels within the YBCO matrix [7], and the strut surface exhibits the presence of $Ba_3Cu_5O_8$-particles stemming form the liquid source in the IG-processing at the strut surfaces, which also contribute to the flux pinning. Such additional particles at the sample surface are not seen in the commonly prepared bulk samples. All these details do not play a role for the mechanical properties, but are essential for the superconducting performance. Thus, the final model must consider all these specific details of the foam microstructure.

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