3D image analysis and µ-synchrotron-tomography for studying multi-component, micro-structured material systems

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Introduction

Micro-structured, multi-component material systems are of high interest due to their broad range of application fields. In this presentation we focus on metallic foams in early stages produced by heating compacted powder precursors as well as biocompatible ceramics implanted in sheep jawbones. Al foams are very interesting for lightweight constructions but there is still a need for basic approaches to control the pore structure [1]. Biodegradable materials are an alternative to autogenous bone grafts for supporting the bone regeneration in defects [2].

Methods and Materials

The use of monochromatic synchrotron-radiation for micro-tomography enables us to distinguish between different phases of materials in the resulting volume images, e.g. the matrix and the blowing agents' particles in metallic foams or ceramic particles and bony tissue. The high spatial resolutions available allow to follow the pore formation in early stages of metallic foams (porosity <10%) and the biodegradatation of bone substitue materials. Subsequent 3D image analysis is performed by separating different phaeses of material within the images into Boolean images which contain only the morphological information [3]. By dilating the pore structure we can determine the dependance of the blowing agent's (TiH_2) density on its distance to the pores. Therefore, we are able to invest spatial correlations between the TiH_2 particles and the pores [4]. By masking the denoised Boolean images of the bony tissue and the ceramics one gets volume images which contain the morphology as well as density information of the different phases of material. Combined volume rendering of these data sets delivers excellent images which can be used for qualitative comparison with histological photos (fig. 2). Samples were prepared as part of an animal study for comparing different bioceramics [2].

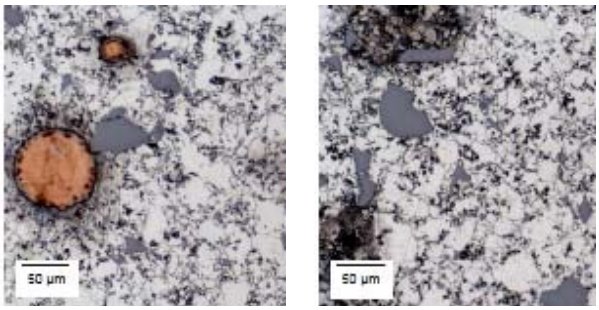

Fig. 1: Metallographical photo of raw precursor AlSi6Cu4 (left) with Cu particles (brewn), Al (light grey), Si (blue) and tempered sample (right, same color code).

Results

For Al foams produced from a pre-alloyed powder Al6061 (Al, Si) it is known that pores and foaming agents' particles are spatial correlated in all foaming stages [1]. In AlSi6Cu10 and AlSi6Cu4 produced from a mixture of pure Al, Cu and Si powders we could prove spatial non-correlations between the TiH_2 particles and the early pores. The control mechanism behind this different behaviour can be understood by examining etched and polished slices of the investigated samples (fig. 1): the raw precursor contains pure Cu, Al and Si, the tempered sample only Al and Si. Cu and part of the Al form an eutectic alloy at already lower temperatures. Here, gas set free from TiH_2 can nucleate most easy and form the first pores. In opposite Al6061 is homogeneous – it has no "weak" positions where pore creation can happen preferred.

For the bioceramics we found a huge difference in the amount of detected bone between the histological and the tomographical investigations (fig. 2). The newly formed bone if not fully evolved has a lower density and therefore is not visible in the CT scans while histology can detect it due to the chemical sensitivity there.

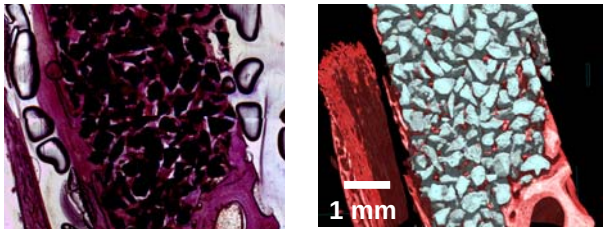

Fig. 2: Left: histological image of bone substitute particles (black) in sheep sinus (bone in pink) and the rendered corresponding section from the segmented 3D data set (right).

Discussion

We could show that heterogeneous precursors are one approach to control the pore structure of metallic foams as first pores start to grow on weak material positions. For the bioceramics we found a novel approach to determine the stage of development of newly formed bony tissue by comparing histological with (synchrotron-)tomographical slices.

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