INDUSTRIAL PILOT PROJECT

In situ X-ray imaging of bone-biomaterial composite to understand the mechanical interactions

THE INDUSTRIAL CHALLENGE

BoneSupport is developing injectable biomaterials to be used as bone substitutes in patients. However, understanding how the bone-biomaterial interact during mechanical loading is challenging and there is a need to clarify how the bone response to loading is altered when injected with a biomaterial.

WHY USING A LARGE SCALE FACILITY

To understand relationships between loading, strain localization, damage initiation and crack propagation in bone injected with biomaterial, high resolution tomography with *in situ* mechanical loading is required. Synchrotron facilities are the only viable option, since it provides substantially higher resolution, better signal to noise and faster imaging, than laboratory-based sources.

HOW THE WORK WAS DONE

Imaging and *in situ* loading were carried out with x-ray tomography at the TOMCAT beamline of the Swiss Light Source (PSI) Switzerland (30 keV; scanning speed: ~2 min/scan; voxel size: 2.75 µm).

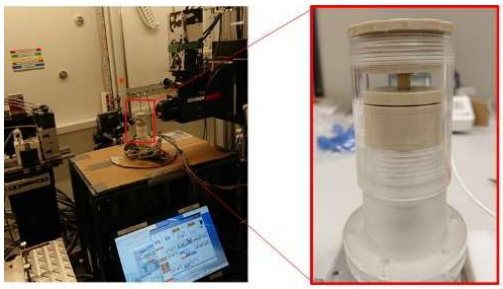

Figure 1: Study setup at TOMCAT beamline.

Cylindrical plugs (Ø 6 mm, H 7.5 mm) were drilled from human femoral heads. The bone marrow was removed and biomaterial was injected in half the plugs. Images were obtained at each 0.15 mm displacement until failure. From the load curves, peak stress, stiffness and work were determined. For image analysis, a region of interest where damage occurred were selected. At each load step the cracks were segmented. For composite samples (bone + biomaterial) a distinction was made between cracks within biomaterial, cracks in bone and cracks separating the bone-biomaterial interface.

THE RESULTS AND EXPECTED IMPACT

The bone-only sample showed large deformations before failing at a relatively low peak force. The composite sample showed the most plastic behavior (Fig. 2, red). During early loading small cracks formed in the biomaterial and it started to separate from the bone at the interface. However at the last load step the bone was still mostly intact (Fig 2, green, load step 2). The biomaterial-only sample had the highest mechanical properties, and a brittle fracture (Fig. 2, blue). Reinforcing bone with the biomaterial increased the peak force, stiffness and absorbed energy (Fig 2, red, load step 4). Most interesting, the new information explains that the increase in absorbed energy were caused by micro-cracks in the biomaterial (not the bone tissue) before composite failure.

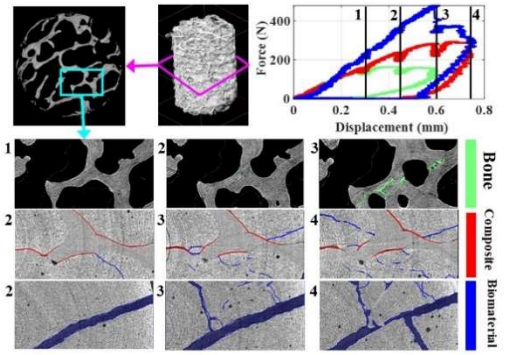

Figure 2. Force-displacement curves of three samples where the crack evolution is exemplified for the last three load steps (numbered 1-4). The numbers correspond to where image acquisition were performed. Cracks are colored blue (biomaterial), yellow (bone), and red (bone-biomaterial separation.

The findings helped understanding the industrial challenge of how the biomaterial responds to loading inside human bone. It extended earlier collaboration between the partners to a new area of biomaterial characterization.

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