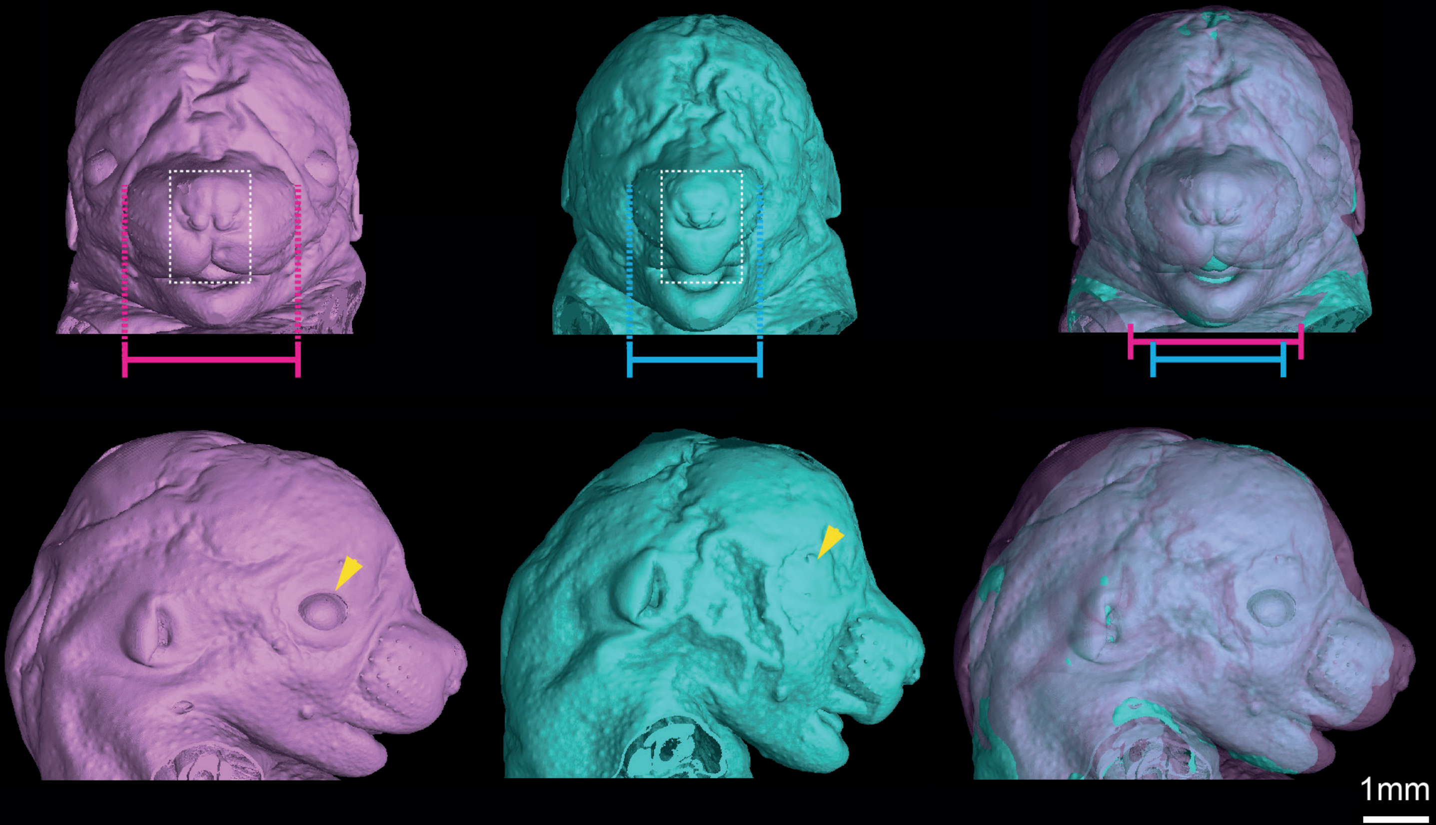
CTLAB X-ray Computed Tomography

BRNO UNIVERSITY OF TECHNOLOGY



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NEWSLETTER AUTUMN 2018

FOREWORD

Dear Readers,

It is a great pleasure for me to introduce you a new issue of our laboratory newsletter. In our Laboratory of X-ray micro and nano computed tomography CEITEC BUT, the most important thing to mention recently is a microtomograph HeliScan. This unique microCT system has been provided to our laboratory in the scope of a long-term collaboration with Thermo Fisher Scientific. In this issue, we would like to introduce you this device in more detail. You can also read about interesting microCT application in dentistry. Moreover, in the section Education we will describe the Fiber Orientation module in VGStudio MAX.

Enjoy the reading!

Tomáš Zikmund
Head of the laboratory

NEW POSSIBILITIES OF A CT ANALYSIS

Utilization of microCT imaging in autotransplantation in dentistry

The autotransplantation of tooth is a very appropriate modern technique that allows to restore a patient's smile. In this procedure, a patient's own healthy tooth is transplanted into the missing place in mouth. Even though this method is not well known and widespread amongst dentists, it can be advantageous when dealing with some challenging and complex cases such as multiple agenesis of the teeth, large clefts and loss of the leading teeth in childhood. The method uses the patients' own teeth, most commonly it is an unnecessary tooth from the back of the oral cavity (e.g. wisdom tooth). The procedure can also be used in situations where a tooth loss occurs due to an injury or sport and the tooth itself is not damaged. In this case, the patient's own tooth is more permanent and more resistant in comparison with the implant, and a negative immune response of the patient's body is excluded.

However, in some cases, resorptions of the transplanted teeth might appear after this surgical procedure. Resorptions are a little bit of a mystery for dentists because of the resorptions' unpredictable behavior. Thanks to the application of microCT, it is possible to reconstruct the enlargement of the resorptive process by tooth tissue and to observe if some dental tissues are more resistant to these unwanted events (Figure 1). The microCT results are consequently compared to the clinical information such as a course of surgery, a subsequent orthodontic treatment with the dental braces or an overload of the transplant. This information helps to eliminate the risk of the resorption developing and progressing in autotransplanted teeth.

Fig. 1: 3D render of tooth (left), highlighted resorption (red) in transparent (center) and longitudinal tomographic slice of human tooth (right).

Application of microCT for analysis of ultrasonic probe

Ultrasonic probes belong to non-destructive testing tools and they are designed to detect material defects, material thickness checks or, for example, to check the quality of welds and cracks. In principle, an ultrasound wave reflects at the material transition of metal and air. If there are no defects in the tested material, the ultrasound wave is reflected at the end of the material wall and its thickness is measured. In the case of a defect such as an air pore, the wave is reflected earlier at the defect interface. Based on this information, it is possible to determine both the deflection distance from the ultrasonic probe and the size of the defect.

The probes are developed and manufactured according to strict standards and specifications. By utilizing X-ray computed tomography, it is possible to observe nondestructively any sensor for an inspection of the standard position of individual components. It is also possible to detect the defects in the structure of the piezoelectric transducer by this way.

Here, an analysis of dual ultrasound probe is shown. The probe consists of a steel body and two piezoelectric ceramic converters embedded in the epoxy. The damping part is created with a mixture of epoxide and ferrite powder. The inner parts of the probe were visualised in detail by microCT (Figure 2 a-c). There are two piezoelectric transducers with a thickness of approximately 1 mm or thin wire feeds to the individual piezoelectric members that lead into the tuning coils. One piezoelectric transducer works here as an ultrasonic wave transmitter and the other one as a receiver.

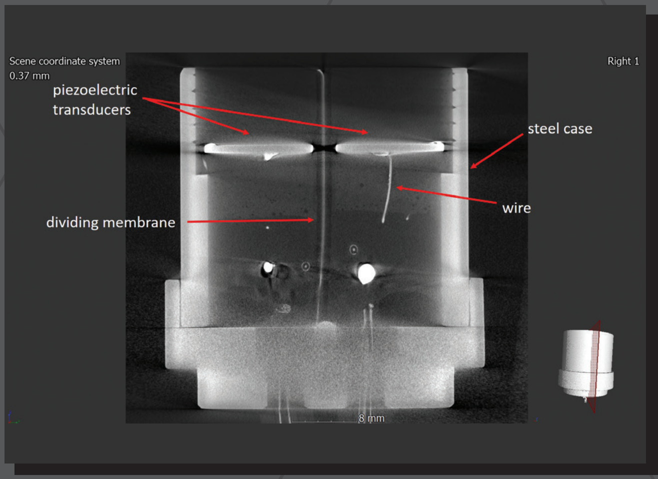

Fig. 2a: Longitudinal tomographic slice of the ultrasonic probe.

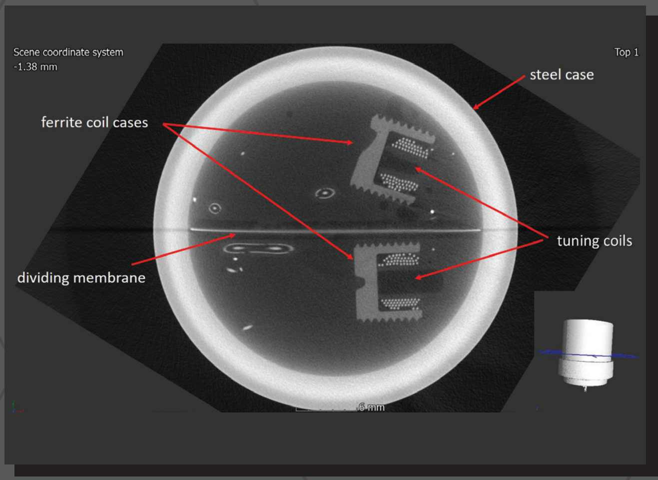

Fig. 2b: Transverse tomographic slice of ultrasonic probe.

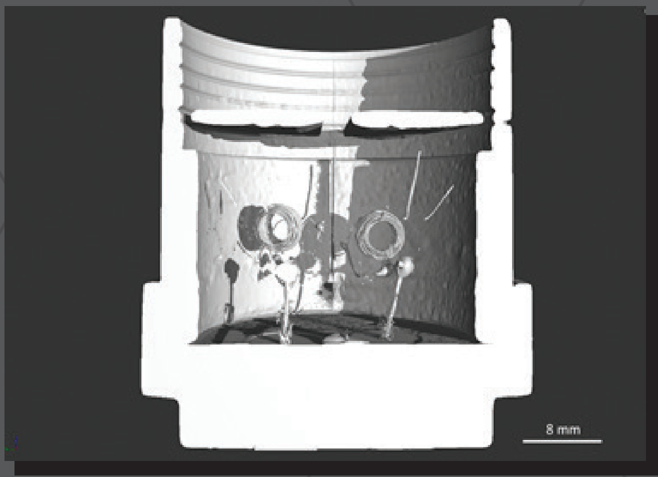

Fig. 2c: 3D view into ultrasonic dual probe showing two piezoelectric transducers, contacting them and two tuning coils.

The use of microCT in restoration: investigation of a scapular amulet

In cooperation with the Regional Museum in Olomouc we investigated a scapular amulet, a small textile case with Christian-pagan content inside. Due to the refusal to unlock the amulet's textile case, it was necessary to apply nondestructive X-ray computed microtomography in our laboratory.

The aim of this observation was to study the amulet content in detail, to identify the objects and to specify them further. We used some already opened amulets from the same period of time as an analogy in order to investigate the amulet to more details. After a microCT analysis and a CT data evaluation, the composition of the amulet was described (Figure 3). The amulet contained both metallic and non-metallic objects which were segmented and color-coded. The large white cross (at the front of the picture) was a part of the dracoun embroidery of the silk case. The cross is situated on both sides of the amulet. The dracoun embroidery is easily visualized by microCT because the embroidering is done with a thread around which a very thin metal wire was twined. The thread can be made of silk, linen or cotton. The objects identified inside the amulet were some metallic parts, a small patriarchal cross and a Benedictine medallion. The amulet also contained non-metallic parts: an earthen plate, several plant seeds, a piece of conifer and lichen, herbal mixture and Marian statue (shown in detail). The results of the microCT analysis and the identification of the individual parts helped to provide a more detailed description of the amulet content without its destruction. The results were presented at the Conservator-Restorers Conference in Litomyšl (Czech Republic) last year [1].

[1] JANUSOVÁ, Lucie, Lukáš KUČERA, Veronika SMÉKALOVÁ, Tomáš ZIKMUND a Jozef KAISER. Průzkum škapulířového amuletu a jeho analogií ze sbírky Vlastivědného muzea v Olomouci. In: Fórum pro konzervátory-restaurátory. Brno: GRAFICOON, 2017, s. 9. ISBN 978-80-87896-44-0. ISSN 1805-0050.

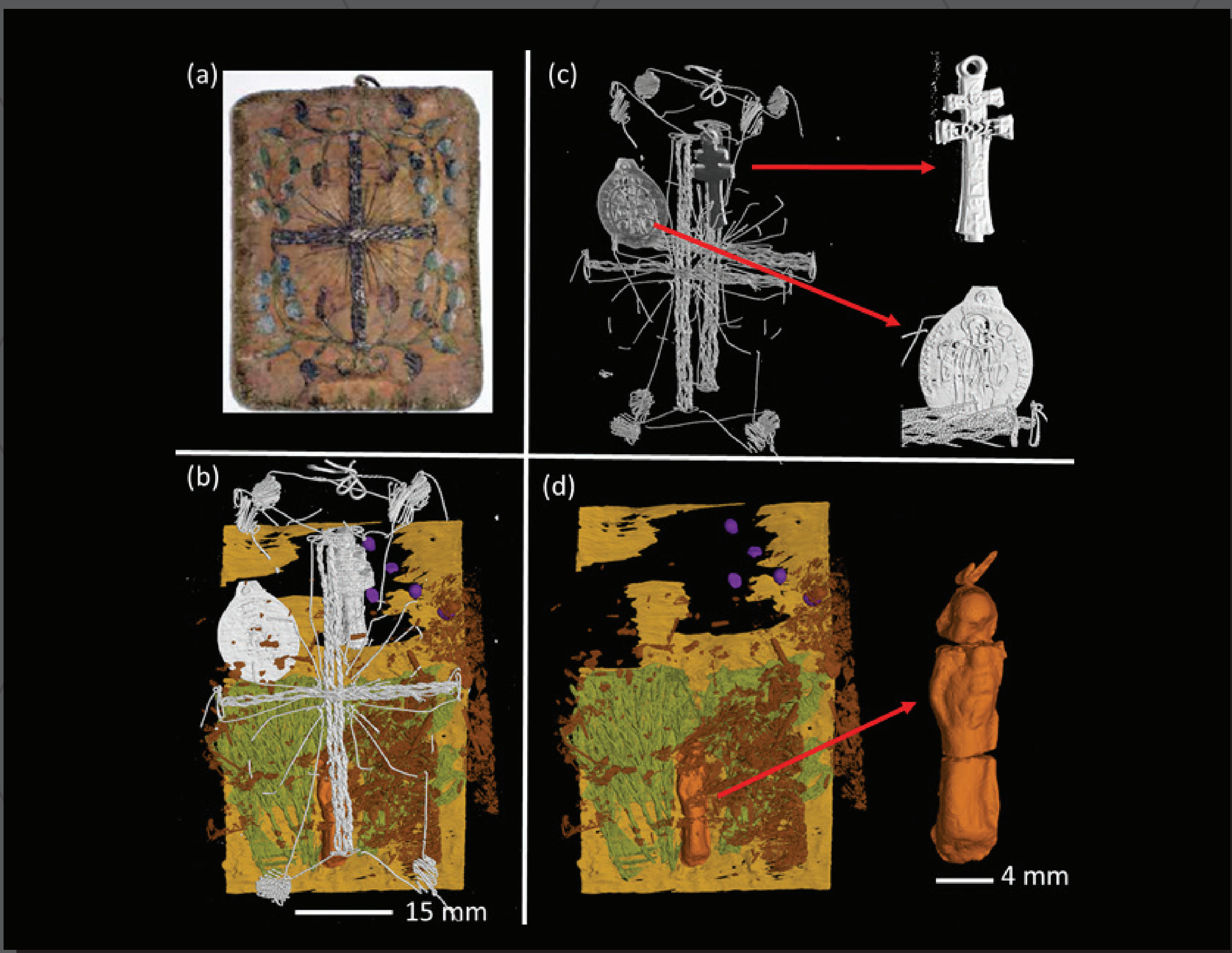

Fig. 3: A photo of the scapular amulet (a), CT image (b), where white color represents the metal parts of the amulet: metallic embroidery in the shape of a cross on the case of the amulet and a small patriarchal cross and a Benedictine medallion inside (c). The inner contents of the amulet (d) were furthermore composed by a clay plate (yellow), several plant seeds (purple), a piece of coniferous twigs (green on the right) and a piece of a lichen branch (green on the left), herbal mixture (brown) and an important part was also the Marian statue (orange, in detail).

Fiber Composite Material Analysis Module (Analysis FIBER ORIENTATION)

A fiber orientation analysis can be done by using VGStudio MAX software. The outcome of this analysis is detail information about fibers creating a sample's structure. This analysis enables a calculation of fiber orientations and other relevant parameters in composite materials. Its utilization is especially to characterize polymer composites toughened with glass/carbon/kevlar fibers or steel wires in concrete. It is possible to apply various approaches of the analysis: Fiber orientation, Fibre volume fraction or tensors determination.

Fiber orientation

In this case, the fibers are color distributed in accordance to their deviation angle (Figure 4). The angle of deviation of the fibers can be either related to an arbitrary reference plane or determined in 3D according to the coordinate system. Another advantageous outcome of this analysis is that the frequency of individual fiber orientations is recorded in histogram.

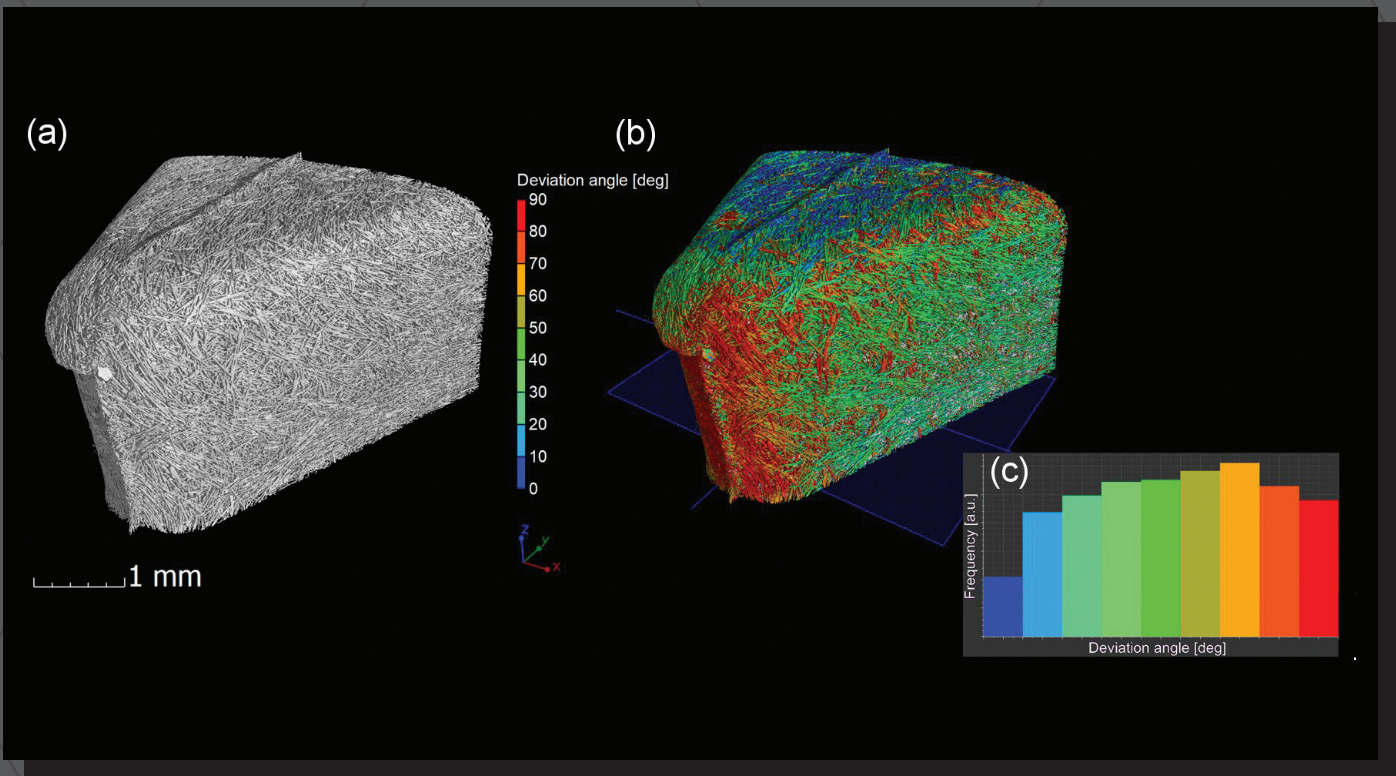

Fig. 4: MicroCT data of glass reinforced material; a) 3D visualization; b) Fibers orientation; c) Histogram.

Fiber volume fraction

The concentration of fibers in a sample is determined by using an artificially created grid. This grid divides the sample into individual cells in the form of cubes. A percentage of fibers is calculated for each cell and the cells are colored individually depending on the calculated percentage of fibers (Figure 5). It is possible to calculate a fiber volume fraction for the whole sample or for a specific region of interest.

Determination of tensor

Tensor can be calculated for each individual cell of the artificially created grid. The data are presented by plotting the graphically displayed tensor (Figure 6). This tensor is shown for both color and shape. Another possible output is represented by the numerical values of individual tensors or by the global tensors in a form of matrix writing.

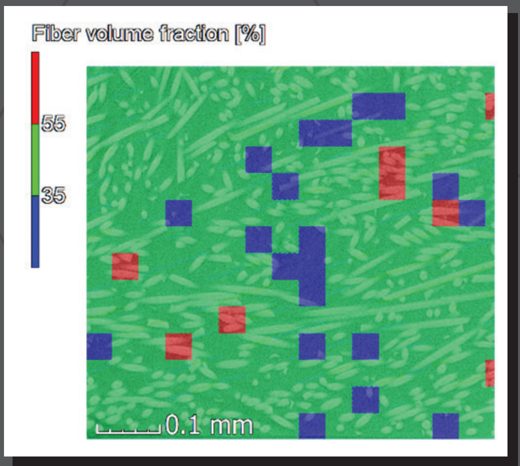

Fig. 5: NanoCT data of the glass reinforced material; fiber volume fraction.

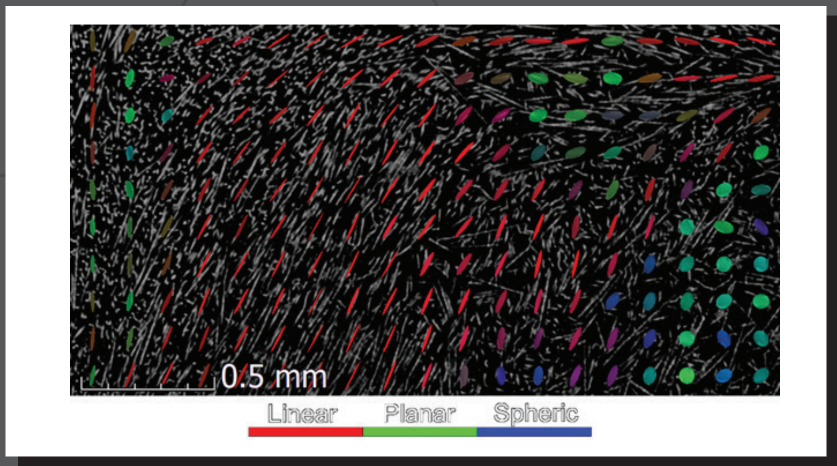

Fig. 6: MicroCT data of the glass reinforced material; tensors.

PARTICIPATION

XRM 2018 conference, Saskatoon (Canada)

One of our PhD students attended the 14th International Conference on X-ray Microscopy (XRM2018) held in Saskatoon, Canada August 19-24, 2018. The title of the contribution that she presented was „Correlation of X-ray Computed Nanotomography and Scanning Electron Microscopy Imaging of Collagen Scaffolds". The abstract from this conference was published as a Supplementary Material in the journal Microscopy and Microanalysis. For the participants of the conference, it was possible to visit the Canadian Light Source, the only synchrotron facility in Canada.

XTOP 2018 conference, Bari (Italy)

The XTOP 2018 (14th Biennial Conference on High-Resolution X-Ray Diffraction and Imaging) was held in the Southern Italian city of Bari in September, 3-7. Since as far back as in 1992, this international conference has been attended by scientists using X-rays in different fields of interest. This year, our laboratory was also participating in Bari with the contribution: X-RAY COMPUTED TOMOGRAPHY FOR QUANTITATIVE ANALYSIS OF 3D CELLS DISTRIBUTION IN CARTILAGE FOR STUDY DEVELOPMENT IN VERTEBRATES. The conference hosted approximately 200 delegates from various countries and the most discussed topics were following: the reconstruction of images, use of synchrotron radiation, combination of multiple methods during one experiment (e.g. in situ observation of X-ray diffraction coupled with X-ray computed tomography).

New publications

1. Characterization of inner structure of limestone by X-ray computed sub-micron tomography

X-ray computed tomography (CT) was used for a characterization of the inner structure of limestone, an important industrial and building material. In cooperation with AdMaS centre of Faculty of civil engineering, Brno University of Technology, and Tescan Brno company, the CT measurement of limestone sample was supplemented with other petrographic methods such as light microscopy (LM), mineralogical and chemical analysis, microthermometry, and serial-sectioning 3D analysis with X-ray energy dispersive spectroscopic analysis (3D EDS). A scanning electron microscope equipped with a focused ion beam (FIB-SEM) was used. A correlation between CT, LM and 3D EDS FIB-SEM helped to determine volumes and a 3D distribution of air cavities and Mg rich regions (Figure 7). All results explain behaviour of investigated limestone during industrial processing. Determining the number of inclusions and their visualization allows to predict the behavior of limestone in the firing process.

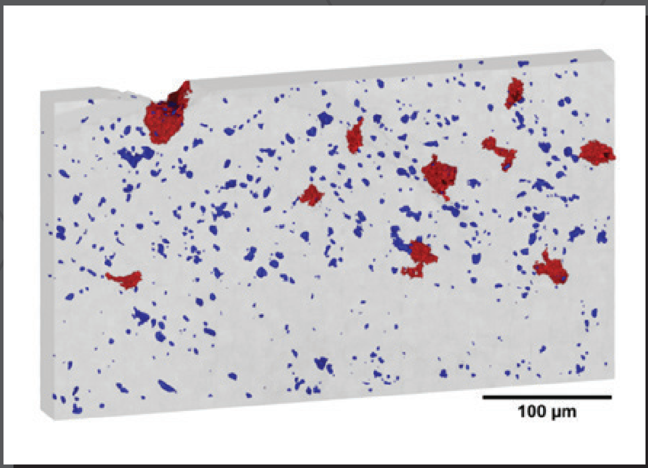

Fig. 7: 3D transparent render of CT data. Cavities are labelled by blue colour, magnesium rich regions are labelled by red colour.

Read more: https://doi.org/10.1016/j.conbuildmat.2018.04.142

2. Epoxy-Based Gelcasting of Machinable Hydroxyapatite Foams for Medical Applications

This study describes a usage of machinable hydroxyapatite foams for the subtractive manufacturing of customized bone scaffolds. In those structures, it is generally desirable to avoid an occurence of pores since they reduce mechanical properties. X-ray computed tomography was used here to characterize interconnected pores in the foams. The porosity/inclusion analysis module in VGStudio MAX was used to divide the pore space into individual pores and to calculate their volumes and also surfaces between them called pore windows (Figure 8).

Read more: https://doi.org/10.1111/jace.15523

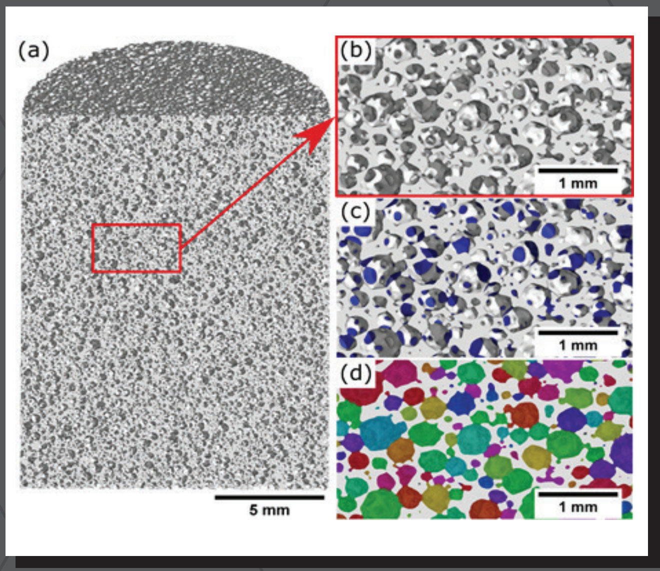

Fig. 8: CT images and pore structure analysis of sintered foam; (a) cross section of the tested foam, (b) detail of the foam structure, (c) pore windows analysis, (d) pore size analysis.

3. Our new publication in eLife: Signals from the brain and olfactory epithelium control shaping of the mammalian nasal capsule cartilage

Our laboratory has been collaborating with a Swedish group of developmental biologists since 2012. The research on which we collaborate is focused on an explanation of the facial formation mechanism in vertebrates. A part of the results was published last year (read more: https://www.ceitec.eu/scientists-from-ceitec-but-in-collaboration-with-karolinska-institutet-contributed-to-the-explanation-of-the-mechanisms-responsible-for-face-formation-in-vertebrates/t3005). Further results have recently been published in the prestigious eLife journal. There is a new incredible discovery i.e. a description of the signaling pathways which are directly responsible for building various anatomical structures in the facial area.

The entire team collaborated on a series of genetic experiments done on mouse embryos where mutations of different genes and different stages of development were observed. Our CT team was responsible for the 3D visualization and evaluation of digitized 3D models (Figure 9). We also managed to exactly calculate which parts of the cartilage are most affected and how they differ from each other. Thanks to the X-ray computed tomography technique, we were able to visualize other soft tissues such as cerebral cortex or olfactory epithelium. Finally, these two structures have proved to be a key in creating the signals shaping a future face. An article about this research was published in the eLife (IF 8.5) and it was already the second article published in this prestigious journal in last two years. „Having a strong multidisciplinary research team is the key to be successfull in the internationational scientific field. "Currently, doing a significant research is impossible without the strong technical background that we offer to developmental biologists," said Professor Jozef Kaiser, the leader of our research group.

Read more: https://elifesciences.org/articles/34465

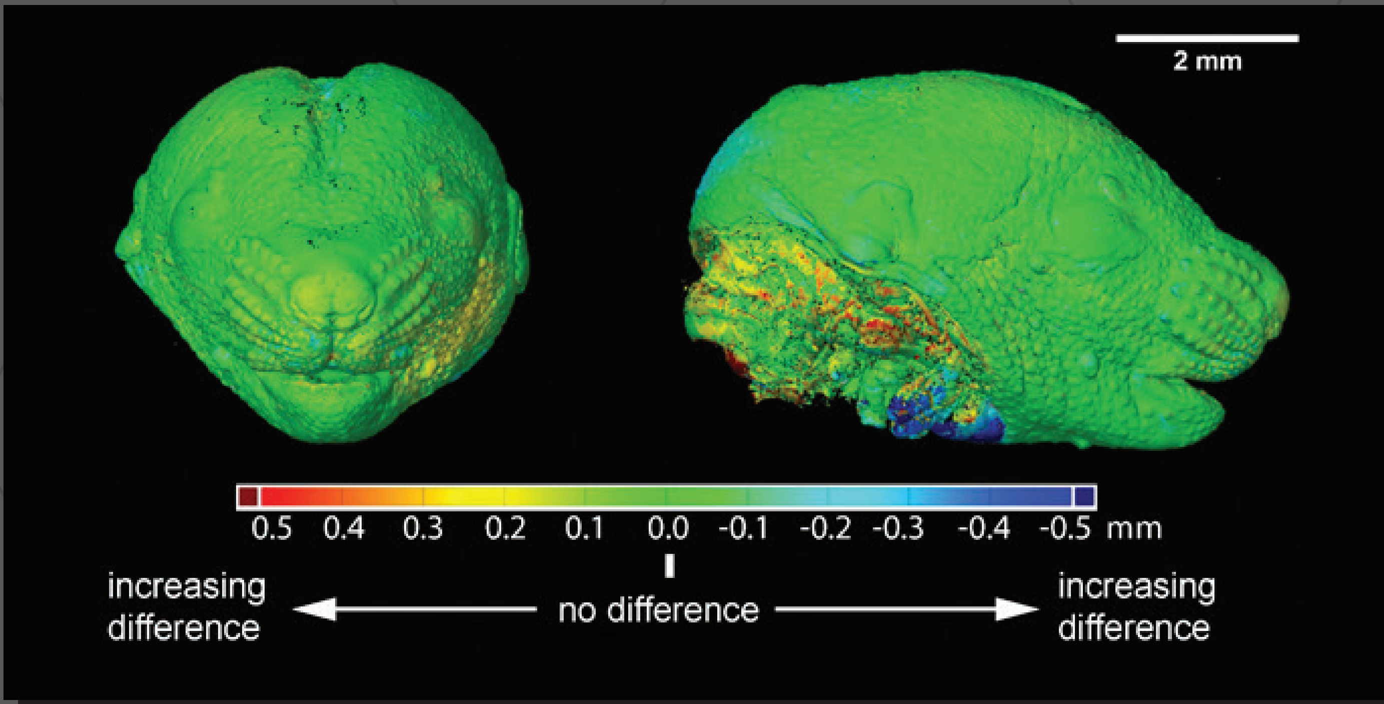

Fig. 9: Comparison of 3D models of head between control mouse embryo and mutant.

LATEST NEWS

MicroCT system Heliscan

Fig. 10: Laboratory microCT system Heliscan.

The range of our laboratory equipment was widen of fourth laboratory tomograph. This unique microCT system, a product of Thermo Fisher Scientific (Figure 10) was designed especially for the oil industry to measure long samples, such as geological boreholes. The main characteristic of the system is the way of scanning the measured object. The object is placed along the helical trajectory (Figure 11) which results in an elimination of the cone beam artefacts occurring in the standard circular trajectory (Figure 12). The helical trajectory allows to get continuous, geometrically accurate 3D images of long samples without stacking images. Furthermore, this system is presented with a patented iterative reconstruction providing a high resolution image and a large signal-to-noise ratio. The system enables to measure high quality data up to a 0.8 μm voxel resolution. In our laboratory, Heliscan's properties (http://ctlab.ceitec.cz/equipment/) will be tested not only by its using in material research but also in the field of natural sciences.

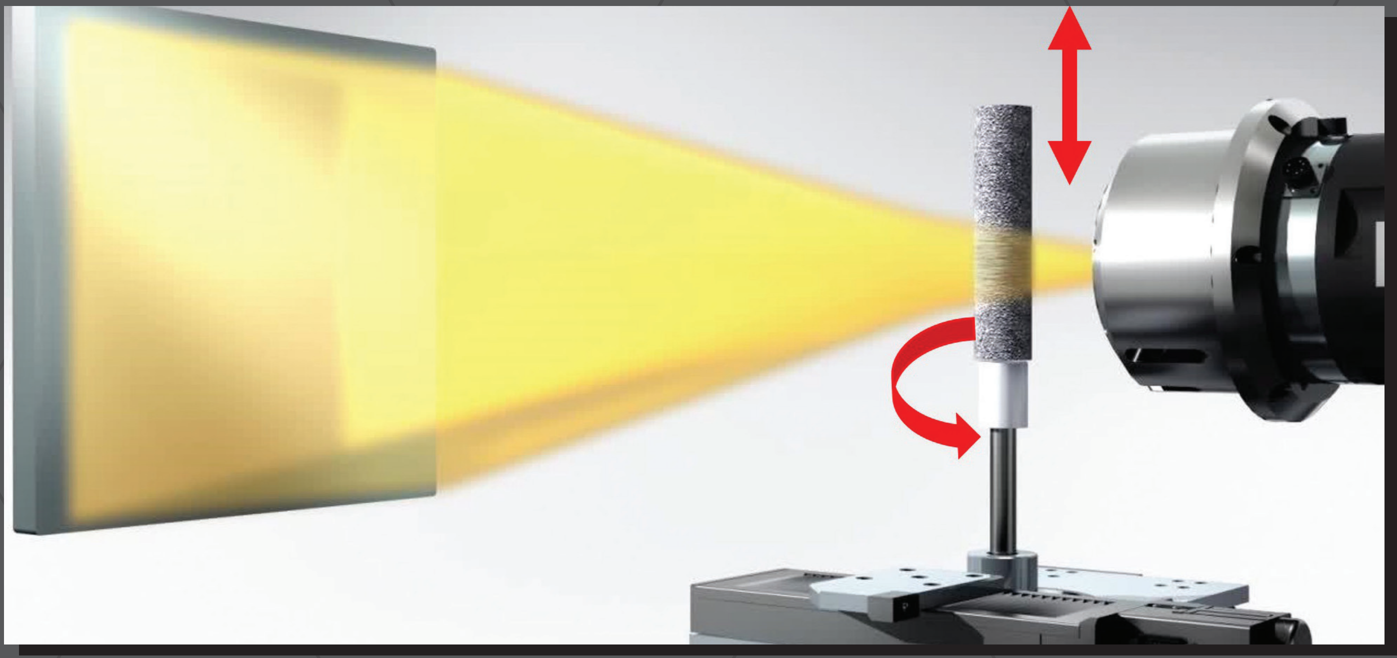

Fig. 11: The principal of helical trajectory measurement.

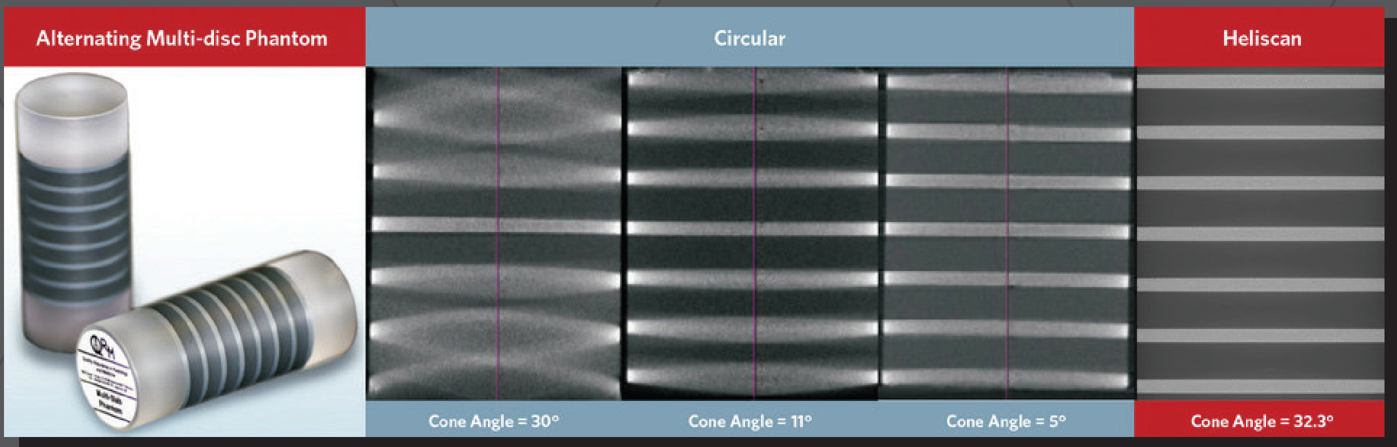

Fig. 12: Tomographic measurement: differences between circular and helical trajectory.

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