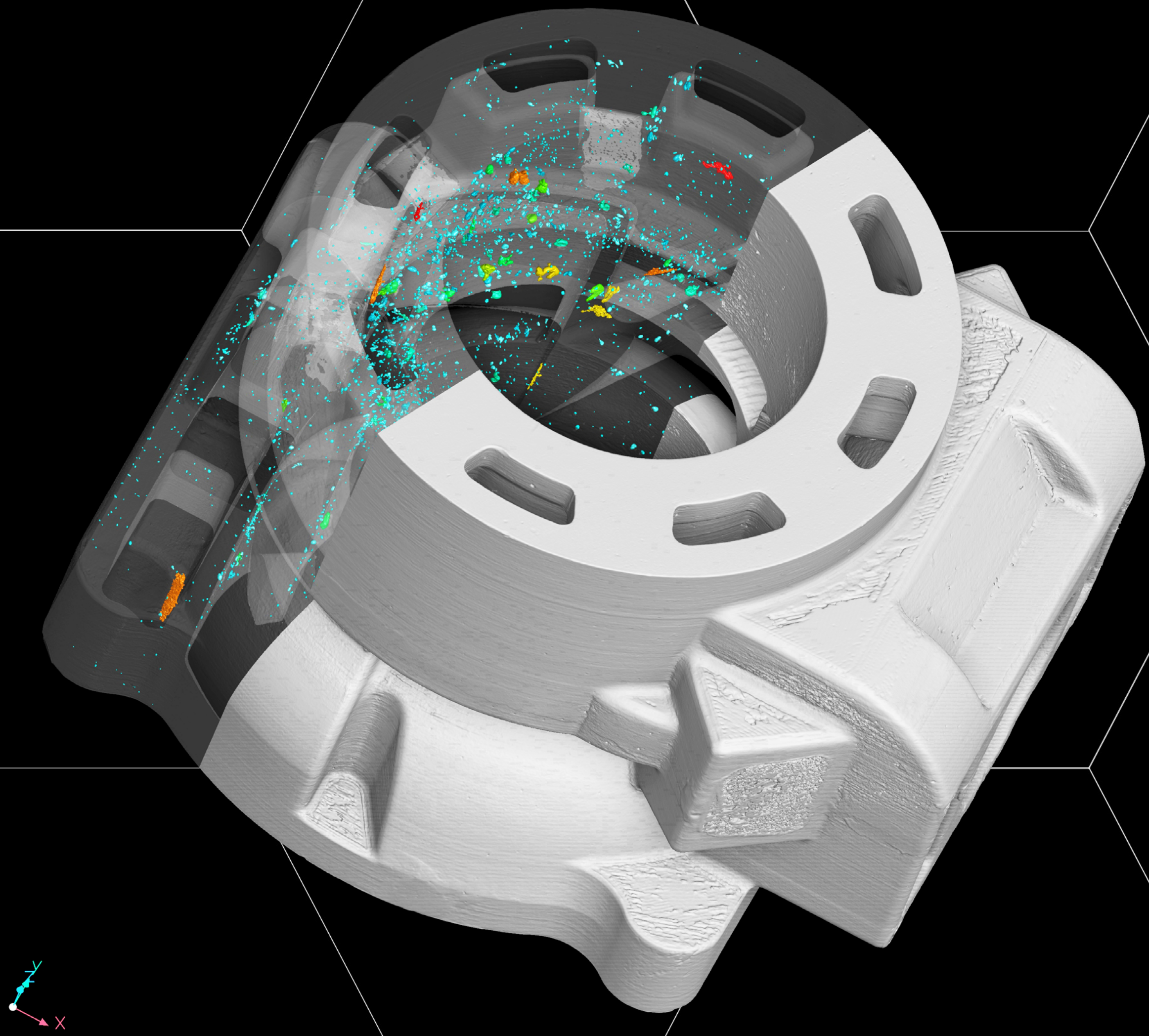


CT analysis of a two-stroke engine casting on page 4

NEWSLETTER AUTUMN 2022

It is a pleasure for me to present you with a new issue of the newsletter of our Laboratory of X-ray Micro and Nano-Computed Tomography at CEITEC BUT. You can read about some of our recent explorations, including an analysis of a car door and a casting of a two-stroke engine cylinder. We'll take you through the calibration of voxel size CT data and describe to you a 3D model of the coral structure.

Enjoy reading!

Tomáš Zikmund
Head of the laboratory

IMPROVING THE COOLING PROCESS OF INJECTION MOLDS WITH ADDITIVE TECHNOLOGIES

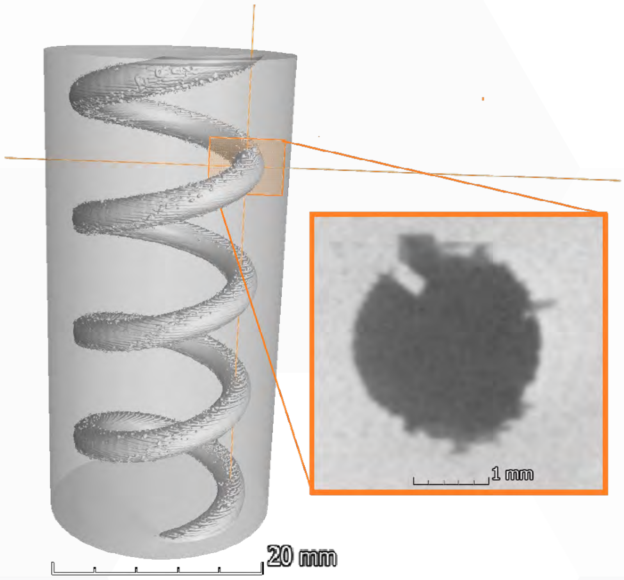


Figure 1: 3D render of scanned CT data with tomographic cross-section.

Traditional cooling involves cooling channels machined into the mold tool through standard methods such as drilling. The possibilities of such channels are limited in terms of their trajectory. This can lead to a non-uniform temperature field on the surface of the produced part, which can then significantly affect the final deformation, shrinkage or even stress of the casting.

One of the possible solutions to eliminate these negative phenomena is to produce the channels using additive technologies. This allows the cooling channels to be made that closely follow the geometry of more complex parts. This process helps these parts cool consistently. This is called conformal cooling.

Additive manufacturing is an ideal tool for this purpose, but it also brings some complications with it. One of them is the residual particles and the very rough surface inside these channels. These aspects could affect the proper flow of the cooling medium and negatively affect tempering. Therefore, the quality of the produced channels is currently being studied on reference samples using computed tomography.

In our case, the reference sample is a helical channel of circular profile with a diameter of 20 mm, made by the ADAM* method from steel 1.2344 (Figure 1), which was supplied by Tomas Bata University in Zlin. The dimensions of the sample are designed according to the requirements of CT scanning to reach the required resolution and safe detection of particles, i.e. Ø 20 mm × 40 mm. The detection of channel defects was based on a comparison with the nominal CAD model, which provides a global view of the differences from the ideal shape using colour (Figure 2).

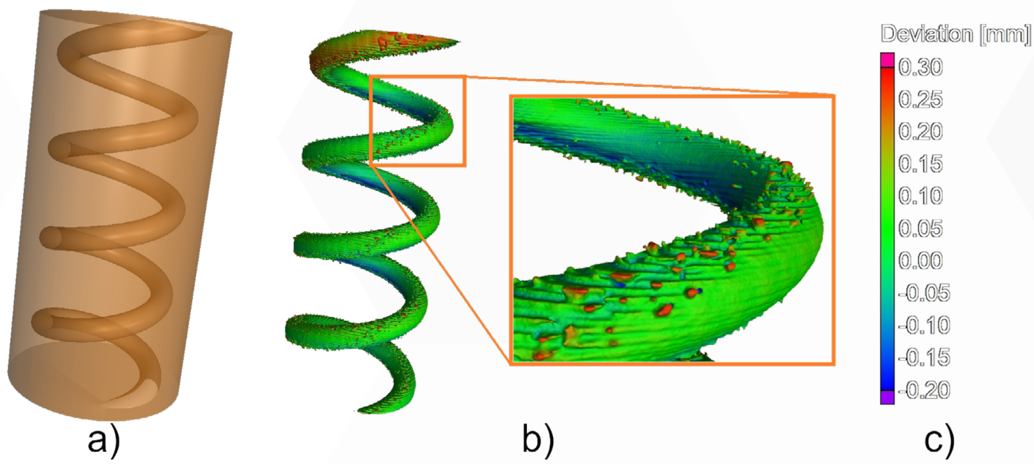


Figure 2: a) Transparent view of the nominal CAD model of the reference sample with helical tempering channel. b) Comparison with real CT data and highlight of deviations, i.e. surface roughness and particles. c) Colour-bar of the analysis.

*ADAM (Atomic Diffusion Additive Manufacturing) is an end-to-end process that starts with a plastic-bound metal powder that is formed into a 3D shape, a layer at a time.

GLUED-JOINT ANALYSIS OF PASSENGER CAR DOOR

This year we tried to find the best method for inspecting the quality of connections around the perimeter of the doors of passenger cars. Older welded joints were prone to corrosion. Therefore, a joint is now used where one sheet is bent around the other, coated on both sides with a separating insulating layer of glue, see Figure 4.

Subsequent non-destructive inspection of such a joint is a challenging task for available X-ray techniques. 2D X-ray imaging is not able to distinguish overlapping layers of metal sheets and glue and thus does not provide clear information about the distribution of the glue.

Figure 3: Car door fixed in CT system.

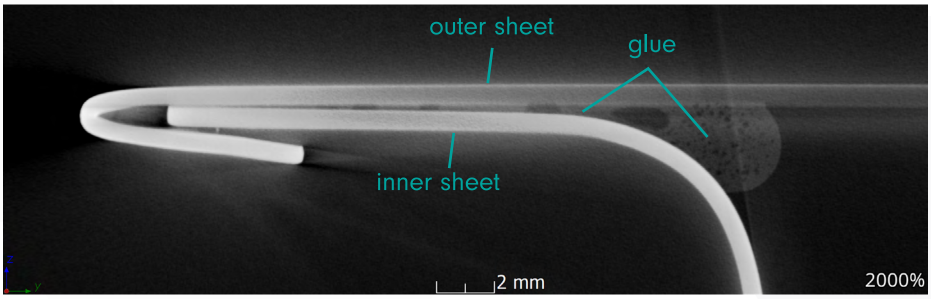


Figure 4: Transversal virtual cross-section showing analysed joint.

Tomographic analysis of the whole door is very limited due to the rotation of the sample (see Figure 3) and doesn't allow sufficient resolution for inspection. If CT is to be fully utilized, a smaller area of interest with a cross--section of a few centimeters needs to be cut out. Thus the inspection is not non-destructive anymore, although the cut part remains in its original state. However, CT analysis of this small part can provide great details of the joint and valuable information for control of the manufacturing process.

Another possible inspection method is laminography (see older newsletter), which uses the incomplete movement of the sample. Thanks to that, the sample doesn't have to be cut. This technique can visualize the distribution of the glue, but it cannot assess the thickness of the adhesive layer to a reasonable quality, considering its width in micrometer units.

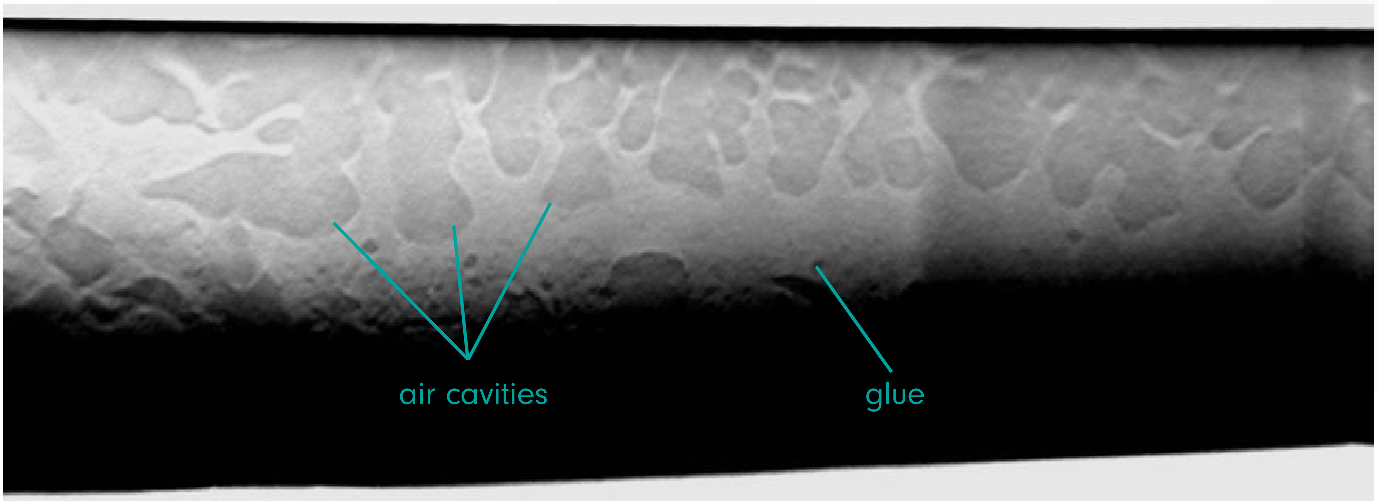


Figure. 5: Virtual cross-section through glue layer from laminographic analysis.

ANALYSIS OF A TWO-STROKE ENGINE CYLINDER CASTING

As a result of cooperation between Brno University of Technology and engineering company C.S.O., a prototype of a racing two-stroke engine is being developed to power a motocross sidecar. To this end, it was necessary to enable prototype production of an aluminum alloy cylinder using the precision casting method. As it would be uneconomical to make the molds to create the wax model using conventional machining, the models for the shell creation were printed using FDM* 3D printing from Polycast (a filament material designed to meet the needs of precision metal casting). Due to the time and cost requirements of this type of custom piece production, the goal was to minimize the number of iterations between mechanical casting tests and the modifications to the mold shell.

The CT method was used to non-destructively verify the quality of the casting and to specify critical areas in terms of defects created during casting. By analyzing the internal structure, porosity was identified throughout the casting volume and the distribution of individual pores is visualized in the context of the 3D model (Figure 6). This analysis revealed the formation of unacceptable porosity in the area of one of the castings in the front part of the cylinder (Figure 7). Based on these results, the casting simulation was calibrated including prediction criteria for the formation of stagnation and thinning and optimization of the technology was proposed to produce additional pieces without the need for additional test castings. This led to substantial savings in resources and development time. Due to the non-destructiveness of this method, it is possible to use the casting for further development of a functional sample.

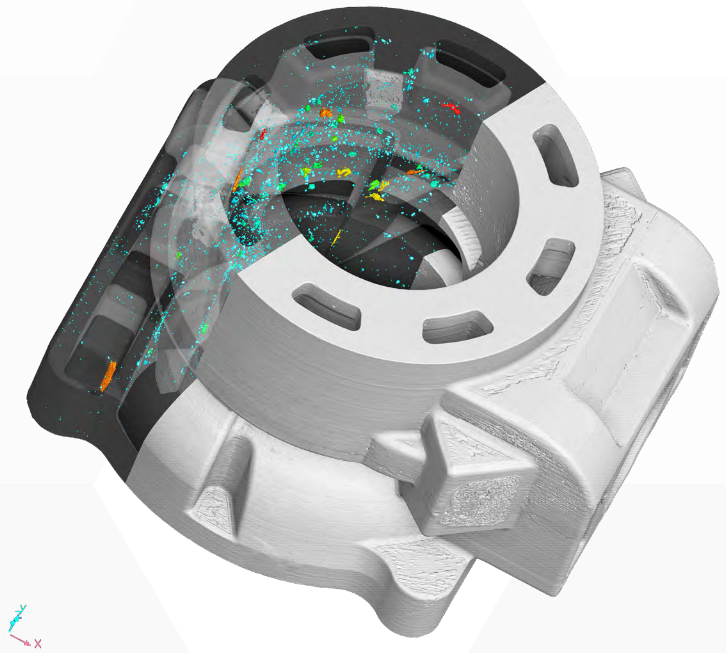


Figure 6: Distribution of detected pores in the cylinder casting shown through the transparent surface. The pores are colored according to their size.

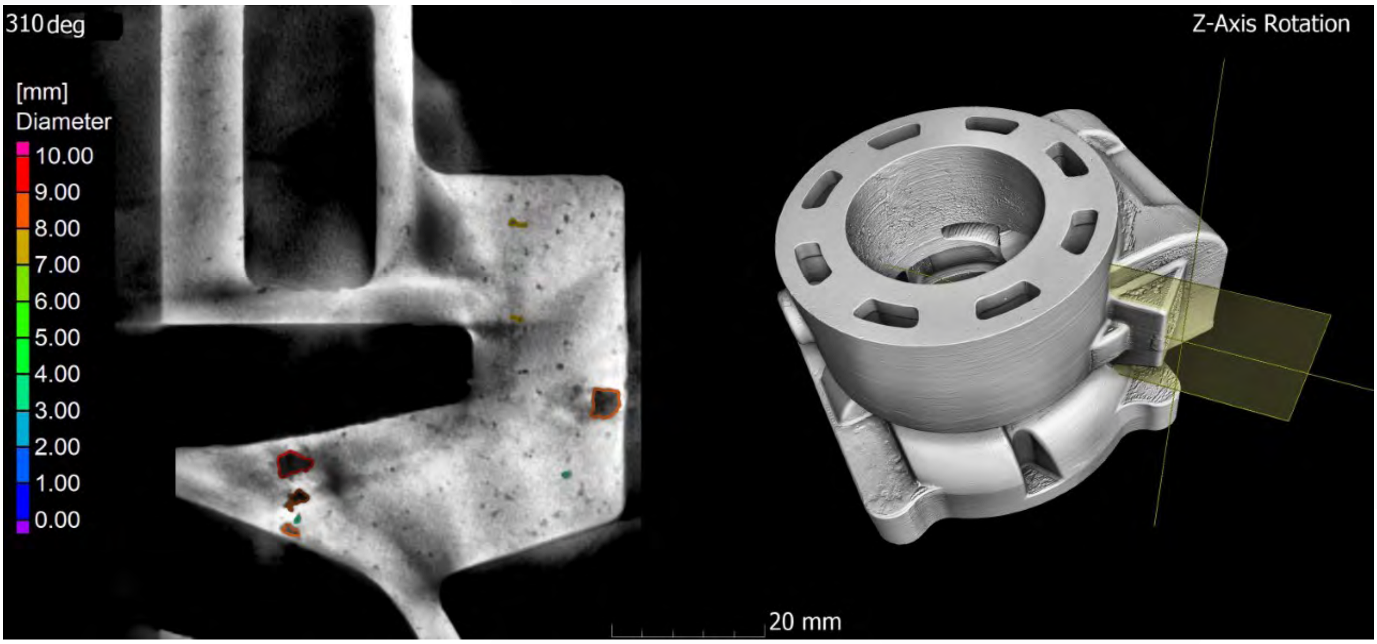


Figure 7: Example of pore detection in a tomographic slice in position shown by the yellow plane in the 3D model.

*FDM (Fused deposition modelling)

INSPECTION OF INDIVIDUAL BEADS IN A MULTI-PARTICULATE DRUG DELIVERY SYSTEM

A multi-particulate drug delivery system is a pharmaceutical oral dosage form consisting of a gelatinous capsule filled with beads containing the active ingredients (Figure 8). These beads are often produced by depositing individual active layers onto an inert core. To ensure optimal drug release, it is vital to keep the thickness of the bead's layers consistent. However, measurement of the layer thickness is a challenge for conventional microscopy due to the problematic sample preparation and the two-dimensional nature of the method. X-ray computed microtomography (micro-CT) is thus experiencing rapid growth in this area.

The beads are spherical in shape with a diameter of around one millimeter. The layers can be only units to tens of micrometers thick (Figure 10). Furthermore, the layers have very similar X-ray absorption and are thus very difficult to distinguish in conventional micro-CT systems.

Our laboratory uses a state-of-the-art laboratory nano-CT system Rigaku nano3DX with voxel resolution up to 270 nm and special imaging modes (phase-contrast and dual-energy imaging mode). Thanks to the resolution and contrast provided by this CT system, we were able to resolve, segment and evaluate the thickness of the individual layers of such a bead in all three dimensions (Figure 9). We were also able to measure the porosity of the separate layers, which is a significant parameter in the speed by which the drug is released.

Figure 8: A photo of a multi-particulate drug delivery system, which consists of a gelatinous capsule filled with individual beads.

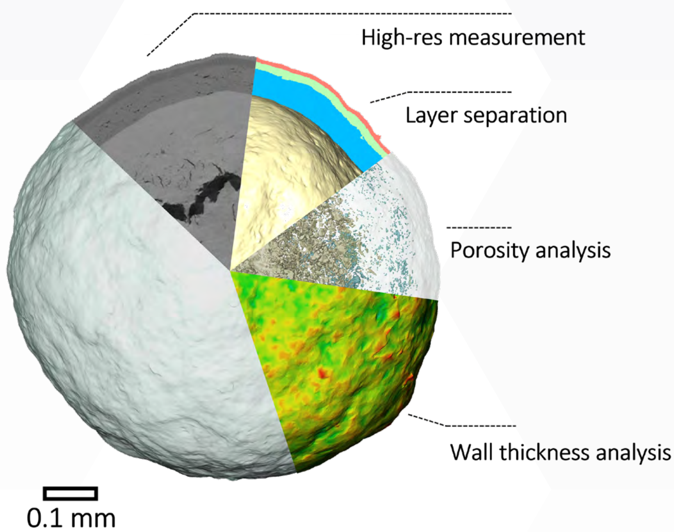


Figure 9: Possibilities in CT pharmaceutical particle analysis.

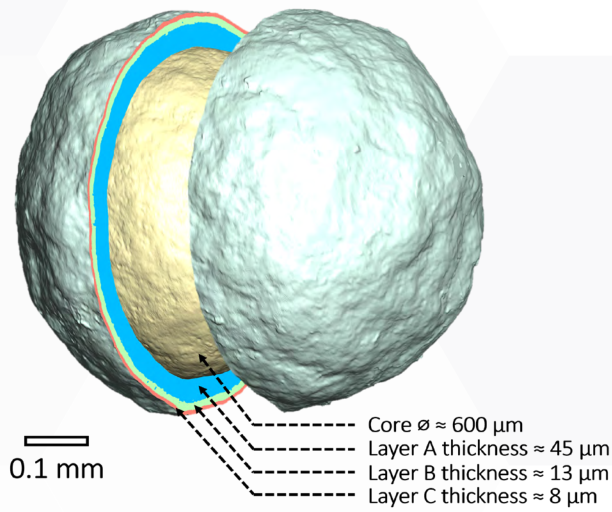


Figure 10: Visualisation of individual layers of a pharmaceutical particle (Avizo, Thermo Fisher Scientific).

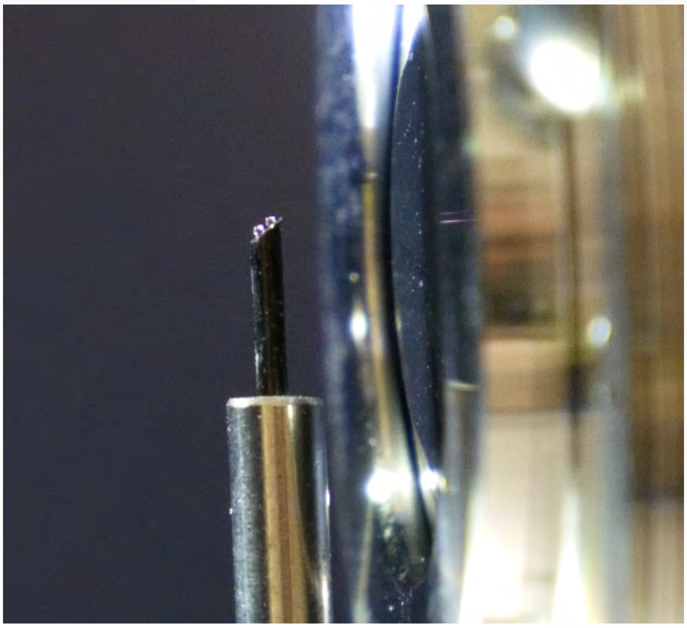
CALIBRATION OF VOXEL SIZE IN CT DATA

X-ray computed tomography (CT), is an appealing alternative to coordinate measuring machines (CMMs) for accurate, repeatable measurements of the dimensions of samples. Its main advantage is the possibility of measuring internal dimensions, which are not reachable by most other measurement devices. However, the precision and uncertainty of these measurements are strongly affected by a range of physical, mechanical, and random influences, which are described in detail in standards and norms such as the German VDI/VDE 2630 1.2.

Inaccuracy in the length of the edge of a voxel (the basic, usually cube-shaped unit of volume), often referred to simply as the "voxel size", is a major source of uncertainty in CT measurements. This inaccuracy is mainly caused by uncertainties in the size of detector pixels and distances between scanner components. Inaccurate voxel size can then noticeably skew dimensional CT measurements.

The voxel size of CT scans can be refined through calibration using specialized reference objects, which are often made of ruby. The shape of these objects is conducive to a reliable determination of their center positions and the distances between these positions using CMMs. The physical stability of ruby ensures that these reference distances do not change significantly with time. The centers of these spheres are also easy to localize in CT data, due to the high X-ray contrast of ruby and the minimal influence of image processing on this localization. The ratio of the reference and measured distances then forms a corrective factor for adjusting the voxel size.

Voxel size calibration is also desirable in high-resolution CT. However, the limited field of view of these devices restricts the size of appropriate reference objects, which makes the manufacture and CMM measurement of such objects difficult. Despite this, reference objects appropriate for high-resolution CT do exist. One such object, which is appropriate for fields of view smaller than a millimeter squared, was recently created here in Brno, as part of a collaboration between our laboratory and the company CactuX (Figure 11).



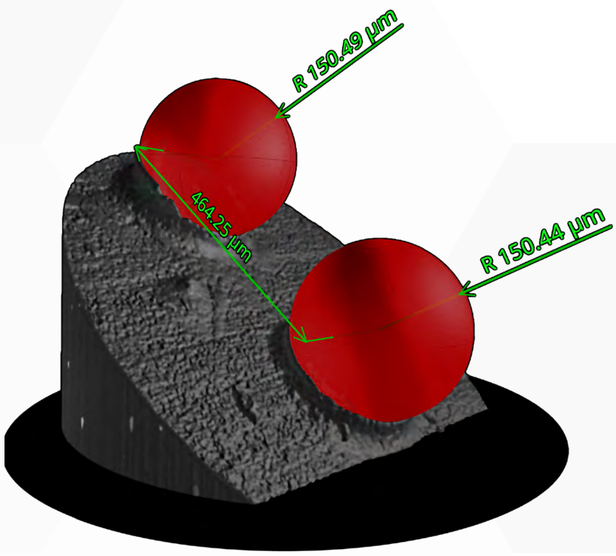


Figure 11: Photograph (left, shown alongside RTG detector) and a 3D model (right) of the reference object appropriate for high-resolution CT with a small field of view. In this case, the calibrated dimension is the distance between the centers of the two ruby spheres affixed on an angled carbon base.

CTLAB CELEBRATES 10 YEARS!

Prof. Jozef Kaiser's research group is celebrating 10 years since its foundation and its work in the field of non-destructive testing using X-ray computed tomography (CT). From the first instrument we purchased to learn about the possibilities of CT technology, we have grown to a fully equipped laboratory with our own know-how, development, and the team of professionals. We consider our main achievements to be building an international reputation, establishing long-term collaborations with industrial partners, and also participating in the development of new instruments with global CT machine manufacturers. Through the established start-up we are part of the transfer of new technologies for industrial CT. For this we are grateful to everyone who cooperated with us and co-created our focus. In the years to come, we wish to remain at the cutting edge of providing the best that CT technology has to offer and to contribute more to its development. More information on what we have achieved can be found here.

Figure 12: CTLAB team.

A DETAILED 3D MODEL OF THE CORAL STRUCTURE

Reef-building corals play an important role in the marine ecosystem – they provide food or shelter for a great number of sea animals. In addition, thanks to their symbiosis with photosynthetic algae, the corals are a source of oxygen for our planet. Corals stay for their entire life in a polyp stadium that is built on a hard calcareous shell. It had been unclear for a long time how corals form complex colonies and how the individual polyps are connected into integrated groups. One of the reasons for this mystery was the complexity of the whole system for imaging methods.

In our laboratory, we took an advantage of our long-term experience with the imaging of soft tissues. Thanks to a comprehensive approach considering both, the soft and hard tissues of the coral, we were able to create a detailed 3D model of the internal structure. This 3D model including precise volumetric analysis was taken as an input for mathematical modeling that showed highly complex and anisotropic hydrodynamic routes transporting water with prey from polyp to polyp throughout the entire colony. At the same time, this surface flow keeps the coral surface clean to prevent the settling of pathogens that not only endanger the coral itself but also block access to the sun. These findings were published in collaboration with an international multidisciplinary team led by Prof. Igor Adameyko. You can read more about this research in the journal Current Biology.

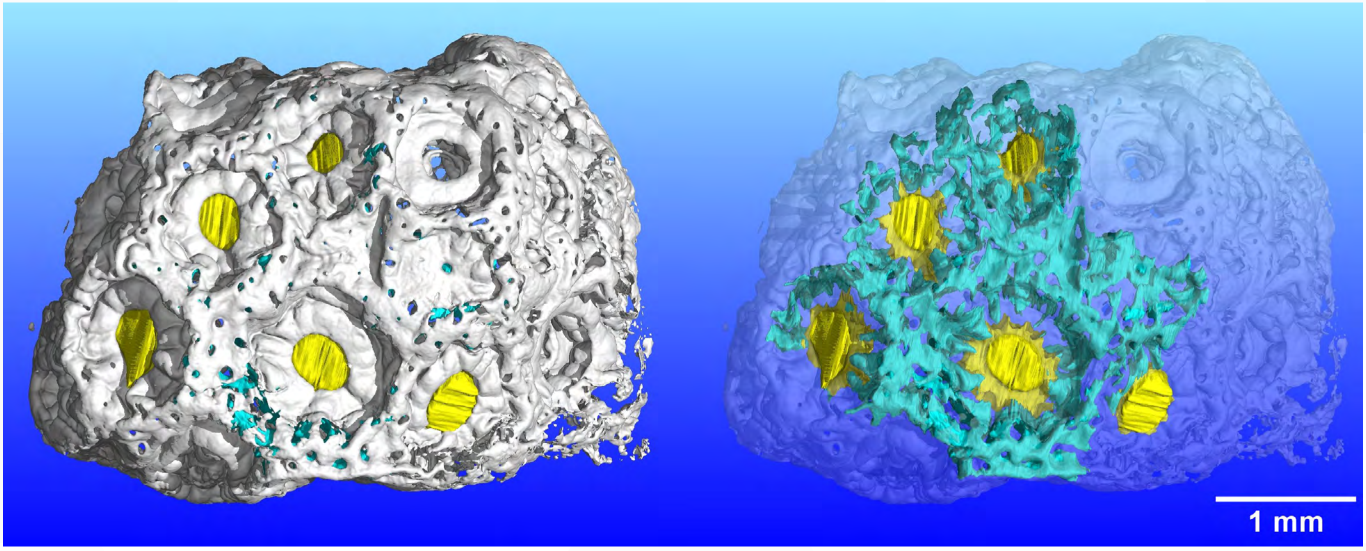


Figure 13: 3D reconstruction based on microCT analysis. White colour represents the surface of the coral, blue and yellow colour show the complex gastrovascular system.

CONTACT US

doc. Ing. Tomáš Zikmund, Ph.D.
tomas.zikmund@ceitec.vutbr.cz
+420 541 142 846

www.ctlab.ceitec.cz
ctlab@ceitec.vutbr.cz
+420 541 142 875

CEITEC BUT
Brno University of Technology, Central European Institute of Technology
Purkyňova 656/123, 612 00 Brno