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Helical Scanning with Iterative Reconstruction Technology

The Next Generation in microCT

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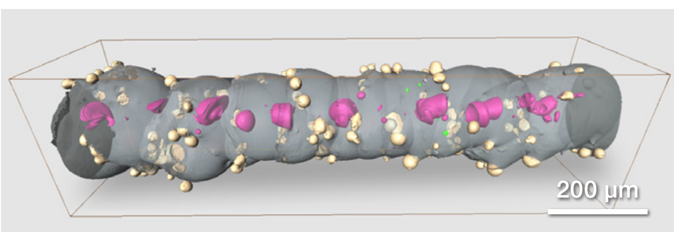

A part of a titanium additively manufactured scaffold.

Introduction

Current micro-computed tomography (CT) systems are increasingly becoming part of the failure and material analysis suite of tools. Material scientists and laboratory professionals are now using these in many industries and academic labs. Gone are the days when multiple cross-sections were the only way to see the inner architecture of a sample in order to understand the internal structures, geometry, and composition. Today, the options available to the analyst are vast and less complicated, faster, and extremely accurate.

New laboratory microCT platforms provide a wide variety of analysis with minimal sample preparation—no staining or slicing, cutting or cross-sectioning. They give the researcher quick and easy quantitative X-ray 3D imaging of almost any structure that can fit onto the analysis stage. The investigator can gain a thorough understanding of the sample and even take measurements of the internal dimensions without the need to do any sample preparation.

Many types of microCT systems are available on the market. However, to perform their internal examinations for a variety of research applications, professional labs, including those in the industrial sector, are now turning to a new generation of microCT technology. This new generation features helical scanning and iterative reconstruction technology that produce unsurpassed image fidelity and deliver the highest signal to noise ratio compared to traditional circular scanning technology.

Background

The medical industry took the lead in CT scanning in the 1970s. These systems were used to create 3D images of parts of the human body with resolutions in the region of 1,000 µm for older systems and approximately 500 µm for the more modern devices. From that lead, rose industrial CT scanners, and then later, laboratory microCT scanners emerged.

These newer, compact instruments provide improved resolution in the region of 0.5 µm. To examine various materials, they offer various X-ray sources, voltages, and current adjustments alongside the higher resolution. Modern microCT systems are used in many areas of industry, from in situ production process control to essential laboratory utilization.

Currently, microCT scanners are being used to detect and examine flaws in the production processing of complex machined and molded parts, such as voids, porosity, and cracks. The scanners give the operator the ability to begin to understand the complex microstructure of the sample, simply and quickly.

The microstructure is the very fine structure of a material that can be seen and examined only with a microscope or, in this case, a microCT scanner. By understanding the microstructure, one can predict the behavior of a component, such as revealing any small flaws that could escalate into catastrophic failure.

As an example, studies are currently underway looking at materials to make lives safer in the air by studying fatigue damage in composites that are used in plane manufacturing [1]. Many companies are now also using microCT scanners in the quality control for additive manufacturing processes [2] [3] [4].

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What is microCT?

X-ray guns produce a conical beam of X-rays originating from a micro spot source (Figure 1). The material partially absorbs X-rays in varying amounts, and a portion is transmitted. Harder materials within the sample will absorb more X-rays, meaning fewer will strike the detector. Conversely, a lighter material in the sample will allow more X-rays through it, and therefore, more will reach the detector.

The transmitted component provides a projected image on the detector. In conventional circular microCT scanners [5], the sample is rotated at a distance from the source. The central point in front of the source will be entirely in focus, and as the test piece turns, an image is captured so that a full 3D model can be constructed.

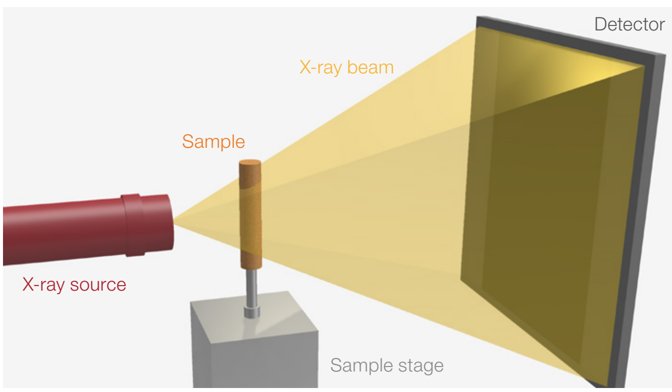

Figure 1. The microCT setup.

The detector is then mapped using either open source or proprietary software, and a 3D model is constructed. Adding color to the segmentation of different components within the sample allows for a quick and easy understanding of the composition of the test piece. In Figure 2 [6], we can see that there are three main components in the CuAlZr alloy. The GRAY alloy has large RED pores in the material and smaller BLUE dense particles distributed unevenly in the sample.

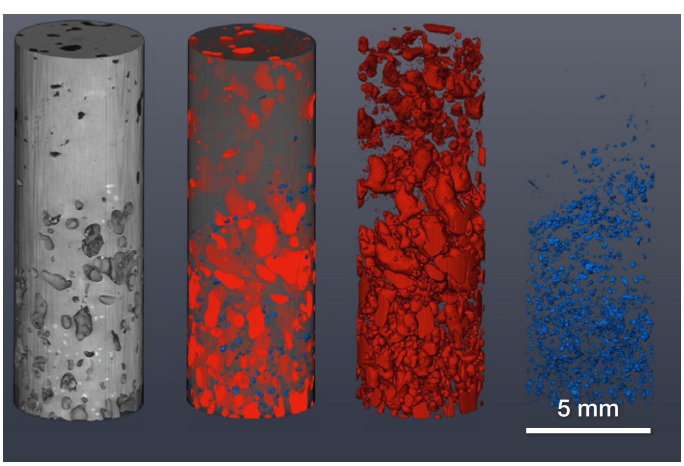

Figure 2. From left to right: A sample of CuAlZr alloy [6] X-ray image; surface-rendered X-ray image in red; the distribution of the pores within the sample in red; the dense particles in blue.

What are the advantages of microCT with helical scanning?

MicroCT systems equipped with helical scanning are the most versatile microCT systems in the world, providing quantitative analysis in a wide range of materials science applications.

These systems provide an advantage over conventional circular scanners in three areas:

- Fast, stitch-free images and improved signal to noise ratio.
- Versatility in the lab and industrial applications, including availability of two X-ray source options.
- Accuracy and precision in measurement capability.

Helical scanning provides the sample with a spiral route covering the whole sample. It passes through the central beam path of the X-ray beam. The central beam path is the ideal channel, as it is the shortest distance to the detector. Unlike conventional circular microCT scanners, helical scanner algorithms can create a seamless image for higher volume samples.

Conventional microCT scanners must realign the sample and perform three or more scans for a complete scan of a sample. Then, these scans then must be stitched together. The stitching process can cause an anomaly, which can be seen in Figure 8.

High Flux—Improved Signal to Noise

Noticeable differences exist in the quality of the results between microCT systems with helical scanning versus the older technology of circular systems.Most circular CT tools have the sample mid-point between the source and the detector, which would be okay if all samples were homogenous; alas, no test piece is, particularly in materials science applications. The samples are then rotated so that a full picture in three dimensions can be made. However, this approach is not without its consequences, as we will see below.

In Figure 3, one can see that X-ray guns produce a conical beam originating from the point source. In the circular mode, being further back from the sample means more X-rays are unused, so it is highly inefficient. Typical circular scanners need to have the detector far from the emitting source so that the cone angle is reduced and more of the sample is in focus.

Helical scanning, such as that found on the Thermo Scientific™ HeliScan™ microCT, brings the detector much closer to the X-ray source. Reducing this distance increases the net X-ray flux and so produces low-noise images.

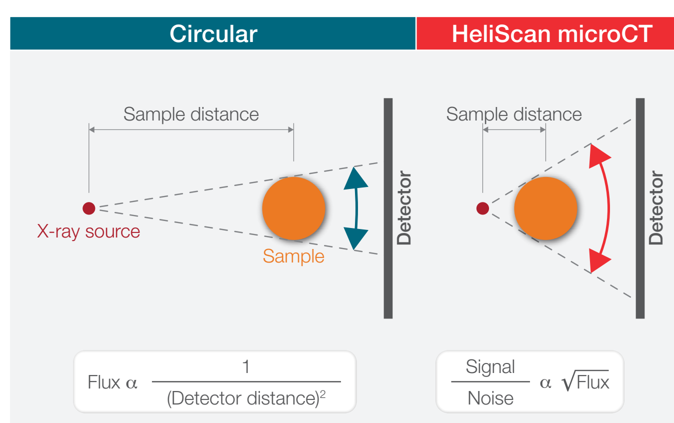

Figure 3. Low cone angle—Sample and detector far away from the source: low flux, low signal to noise ratio. High cone angle—Sample and detector closer to the source: high flux, improved signal to noise ratio. [7]

Bringing the sample closer to the X-ray source increases the cone angle, which increases the inherent geometric inaccuracies in traditional circular scanners (Figure 6). Helical scanning resolves this artifacting by rotating the samples in the helical formation (see Figures 4 and 5), with the integrated algorithms creating the seamless final image.

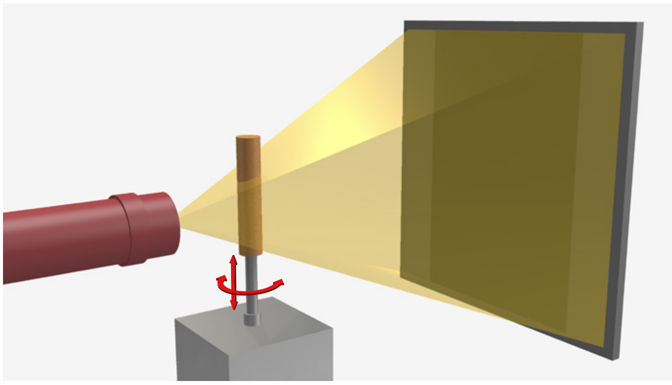

Figure 4. Imaging the sample at the bottom of sample.

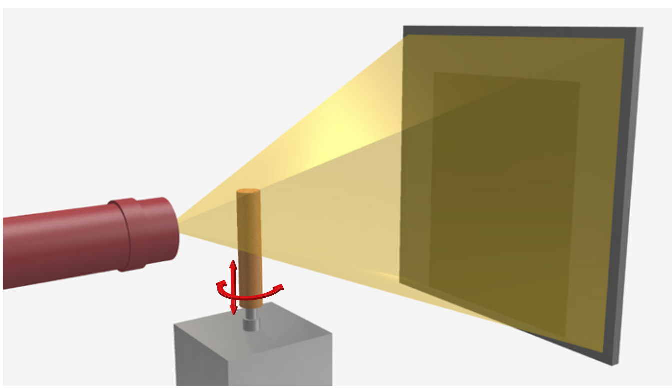

Figure 5. Imaging the sample at the top of the sample.

The benefit of helical scanning is that every part of the test piece has the sample's optimum X-ray image projected onto the detector. As the sample is rotated in small steps, it is moved in the Z direction so that every part of the sample is in the ideal central plane through multiple cycles of a helix. This whole operation is entirely automatic; the analyst starts the system and does not need to set up the helix path, as the software perfectly aligns the data from each point.

Sample preparation is crucial and helps immensely so that the sample does not move off-center during the scan.

Advantage of High Flux and Helical Scanning

The central image in Figure 6 shows that the best picture in circular systems with a small cone angle of 5° (i.e., the sample is a long way from the X-ray source) still possesses focus artifacts away from the central part of the image. The more normal distance of a circular system with a cone angle of 11° shows the issue more readily. With the HeliScan microCT, for example, a high cone angle coupled with the greater X-ray flux means that every part of a large volume image is in focus.

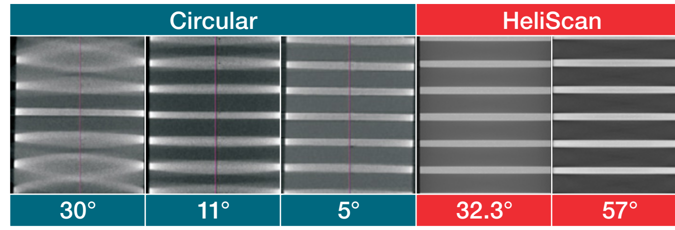

Figure 6. No distortion effects for the HeliScan microCT systems, unlike circular systems. [7]

High Resolution with Two X-ray Source Options

The versatility of helical scanning is further demonstrated when imaging low-density materials. The tool's X-ray source can be changed from tungsten (W) to lanthanum hexaboride (LaB_6), for a dramatically improved resolution at high magnification. Figure 7 shows a 400 nm voxel size using a LaB_6 source versus 800 nm from a W source on the low-density material present in a lithium-ion battery.

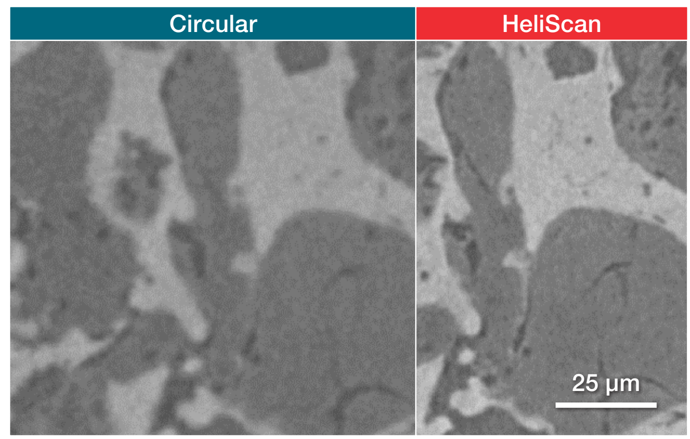

Figure 7. AlSi composite sample visualized with (left) standard W-filament and (right) Lab_6-filament X-ray source.

High-Resolution, Stitch-Free Images

This versatility does not only pertain to the ability to have high-resolution images of internal parts of a solid object or low- and high-density materials. It can work on larger volume samples than circular systems, up to six times faster and with more accuracy, and the whole object will be in focus the first time.

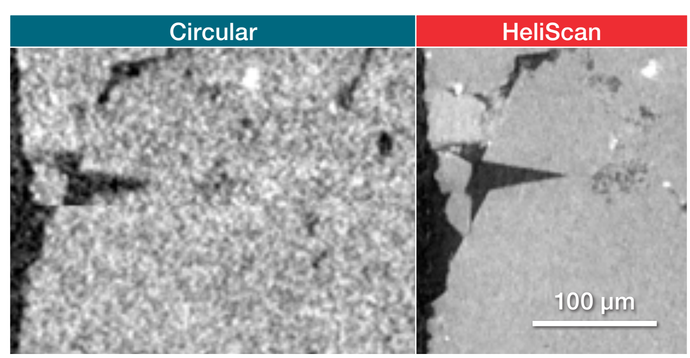

Figure 8. Signal to noise ratio improvement. [7]

Stitching errors seen in the circular scan in Figure 8 are never present in helical scans, as there is no stitching of multiple images required. The signal to noise ratio improvement using helical scanners is unmistakable when using similar scan times.

Locating the sample and detector closer to the source allows a higher signal to noise ratio and more information from fewer exposures.

Having such a high flux means that a "Scout Scan" can give a 3D image in approximately 10–15 minutes. These lower resolution scans provide enough detail for a good understanding of the sample under test.Once the overview scan is complete, a more detailed analysis can be set up, such as the high-resolution image in Figure 8 or the titanium scaffold piece from a medical sample providing a voxel size of 313 nm in Figure 9.

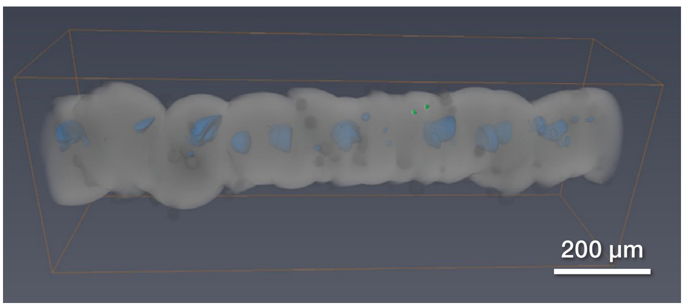

Figure 9. Titanium scaffold from a medical sample. [7]

The versatile nature of the system also enables the identification of defects inside a complex shape quickly and efficiently. For example, in Figures 10, 11 and 12, the CAD drawing shows a titanium nozzle for gas-mixing injection. The helical scanner produces the 3D reconstructed model. The internal integrity is analyzed for flaws; a slice from the 3D image shows the high surface roughness inside the injection nozzle and a broken wall in the inner channel.

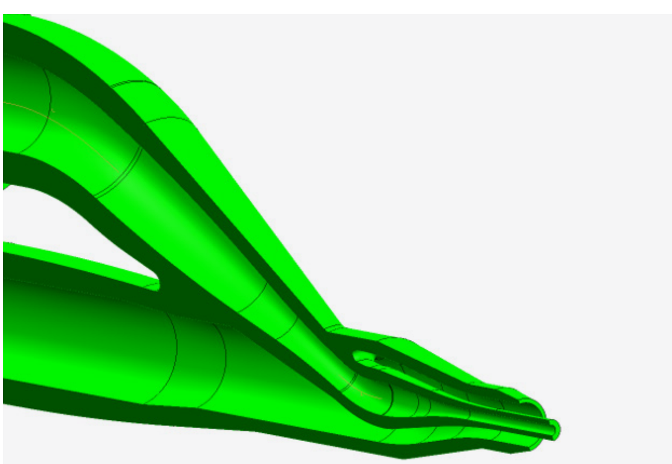

Figure 10. CAD Diagram for injection system. [6]

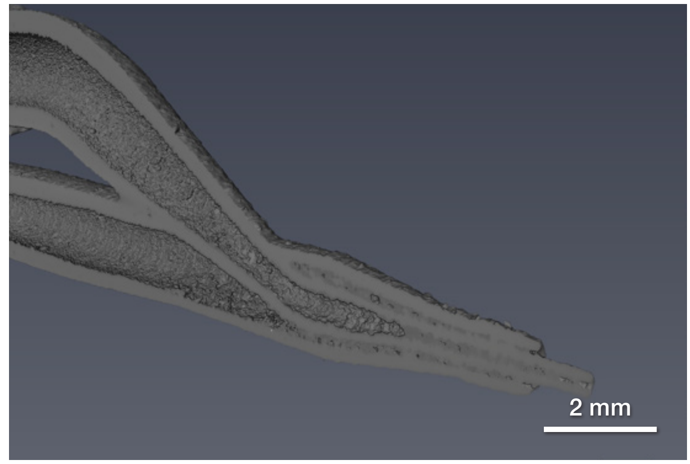

Figure 11. 3D image reconstruction of the injection system showing the structure. [6]

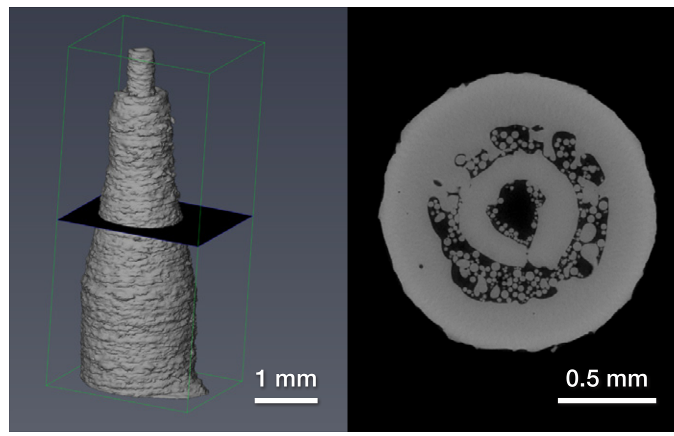

Figure 12. Slicing the 3D scanned object shows the inner wall broken allowing mixing to occur inside the injector. [6]

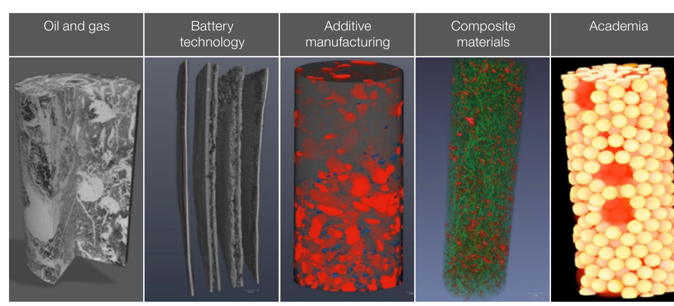

Figure 13. The versatility of the system allows the lab to support multiple sample types, giving stitch-free scanning of larger volumes and regions of interest with helical scanning. [7]

If the correct power setting is not selected in a conventional circular system, the X-rays have insufficient energy to penetrate the sample under test. With helical scanning, this is adjusted automatically and ensures that the ease of operation is maintained.

Accuracy and Precision in its Measurement Capability

Not only does helical scanning provide in-depth analysis of internal structures, it can be used as a measurement tool. Figure 14, shows a scaffold section that has specifications for the thickness of the columns of 260 µm. The resulting 3D scan post-imaging and subsequent measurement shows the actual titanium scaffold strut to be 310 µm. Because of patented microCT system self-calibration and helical trajectory stabilization technology, the reconstructed volumes are exact regardless of the samples size and experimental setup.

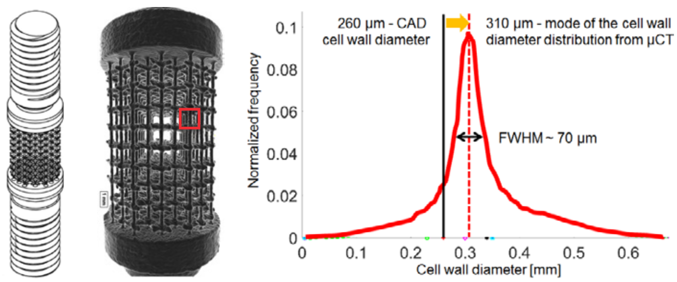

Figure 14. Showing left to right: CAD drawing of a Ti scaffold to aid bone growth; the resulting 3D scan post-imaging in the HeliScan microCT of the actual part; a graph of the column diameter taken at the red indicated square. [6]

Where helical scanning fits into the laboratory operation

In a laboratory, there are overlaps between many of the techniques, but each plays its part in providing the analyst with the tools to supply the required information.

Helical scanning is now becoming an integral part of the lab suite of tools and provides much-needed information without the need for costly cross-sectional analysis.

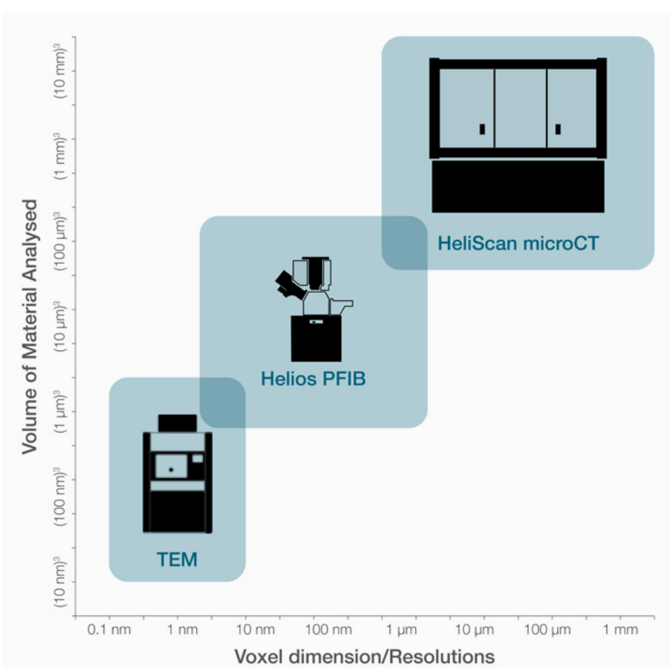

Figure 15. Typical analytical methods available in the modern laboratory.

With helical scanning, one can see both internal and external surfaces, allowing the whole sample to be reviewed, not just one micro-section. This helps researchers understand all possible defective areas and more efficiently identify issues before performing a cross-section and subsequent compositional analysis.

Figure 16 shows a practical example of a helical scanner in a lab environment. This instrument can be the first step in a multiscale collaborative workflow. Selecting a region of interest (ROI) is done based on the high-resolution visualization. Once an area has been identified, an advanced dual focused ion, plasma focused ion, or electron beam can mill away large volumes to reach the selected ROI. Then, a TEM can produce detailed images and chemical composition of the ROI.

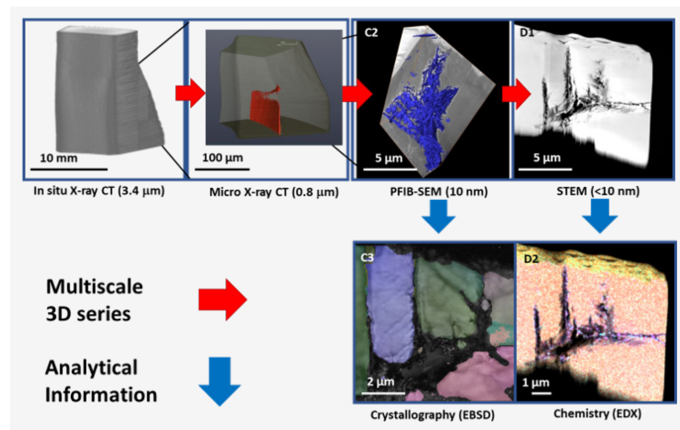

Figure 16. Stainless steel weld multi-scaled visualization from microCT to PFIB to TEM.

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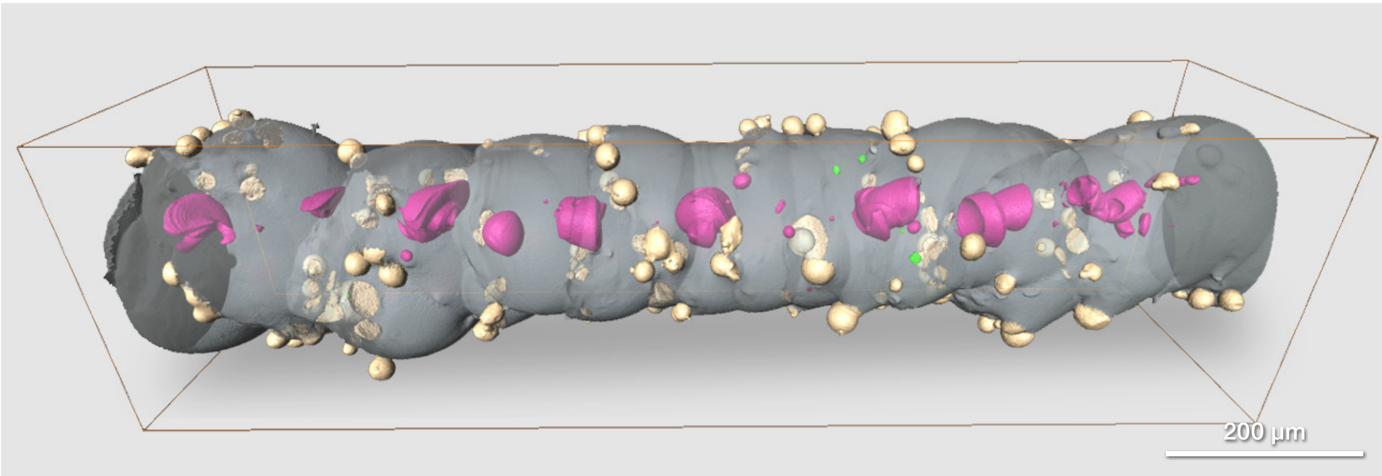

Summary

The advantages of using a helical scanner over conventional circular systems is the versatility to study a wide variety of samples. A simple analysis of large-volume, complex, geometric shapes to imaging both high- and low-mass materials make it a very compelling option for the laboratory expert. The accuracy and precise measurement capability also allows in-line use for manufacturing processes. Last, but certainly not least, are the improvement of the signal to noise ratio and stitch-free imaging when compared to conventional circular scanning systems. Acquisition of a high-resolution image means that details once hidden by a noisy image are now clear, and maybe the next step in the analysis plan is no longer required.

This technology provides a vital pivot point in today's modern laboratory with its ability to not only image internal artifacts and surfaces but to provide measurement capability with high accuracy and precision. It allows the scientist to understand the issue at hand quickly, and the next steps in an analysis plan can be achieved with much more certainty, reducing the cost per sample by increasing laboratory productivity.

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