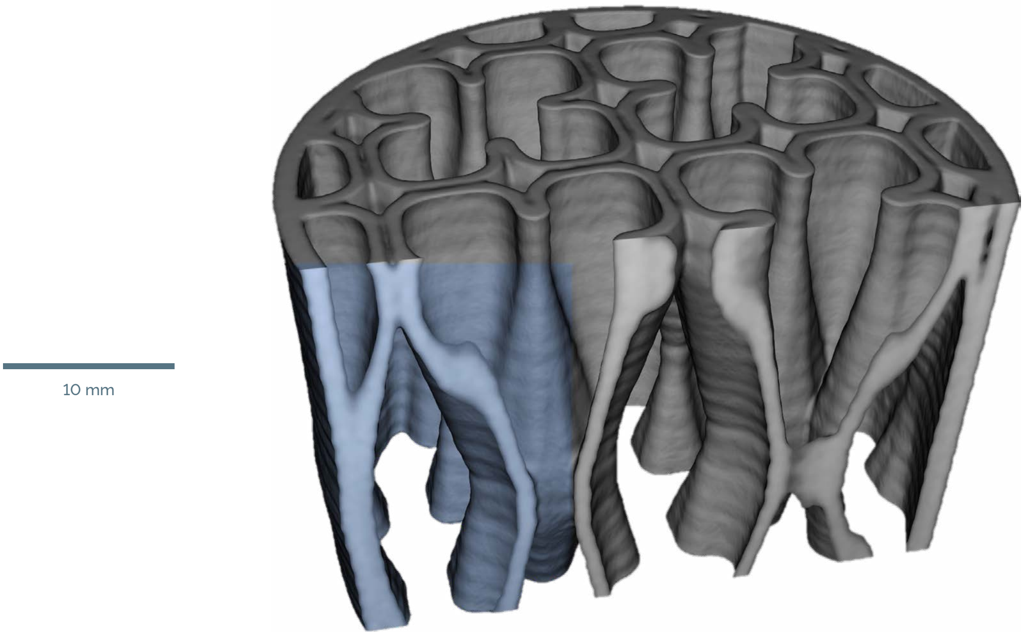
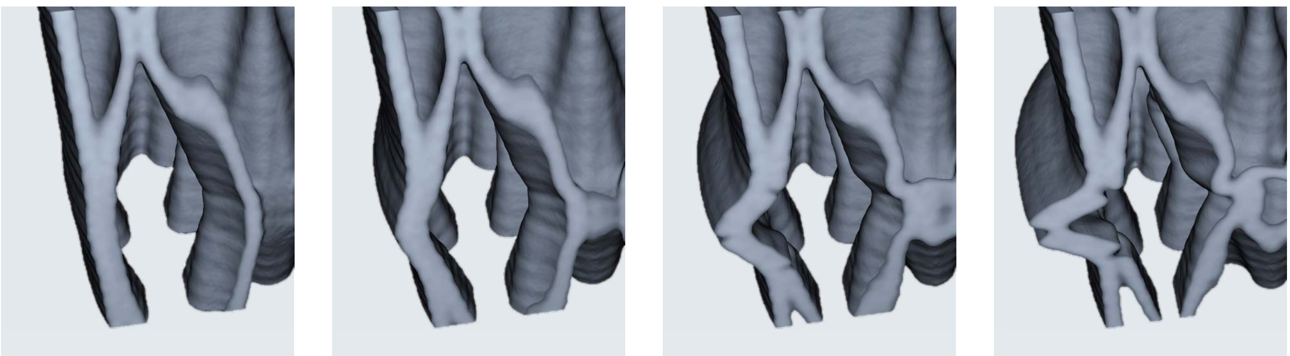
# Dynamic CT Compression of Complex 3D Printed Parts

## Uninterrupted in situ testing using dynamic X-ray micro-CT



## Abstract

Additive manufacturing (AM) is a promising new manufacturing technique that also requires new methods for inspection and validation. The technique of dynamic micro-CT, where uninterrupted 3D data with high temporal resolution is collected during in situ experimentation, is an ideal method for the complex and intricate geometries often found in AM parts. In this application note we use a **TESCAN UniTOM XL** and dynamic CT to collect uninterrupted 3D data on several 3D printed plastic parts while they are undergoing a compressive load. With a high temporal resolution of **5.8 seconds/rotation**, we were able to clearly visualize the internal change occurring during the load testing.

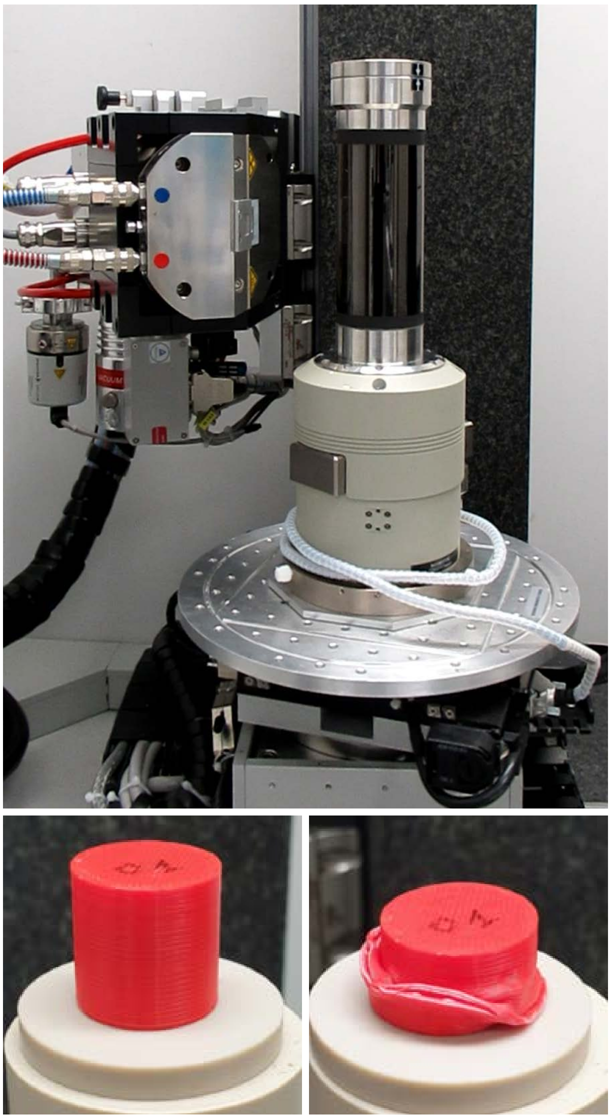
## Background

The technical advantages of additive manufacturing have drawn great attention over the last few years. AM techniques are able to generate complex and unique shapes unattainable with traditional subtractive manufacturing and, in many cases, with greater efficiency and lower cost.

As promising as this potential manufacturing paradigm shift is, there are still a number of obstacles to overcome concerning the quality of the final part. Aside from the inherent challenges in the production process regarding defects and dimensions, greater understanding of the performance of an AM part, especially when subjected to specific external conditions such a heating or loading, is very desirable but not always easy to obtain. For structures with complex and/or hidden structures, traditional mechanical testing methods will provide general insight to the bulk mechanical properties, but the change of individual features can only be evaluated destructively at the end of the test. In this situation, one can only infer from the initial and final states what actually happened during the test.

## Dynamic micro-CT and the importance of temporal resolution

Micro-CT, a technique employing x-rays to collect 3D data, has proven extremely useful for non-destructive examination. As the technique and its capabilities have matured, it is now being used to better understand the change occurring in 3D structures while undergoing mechanical testing.



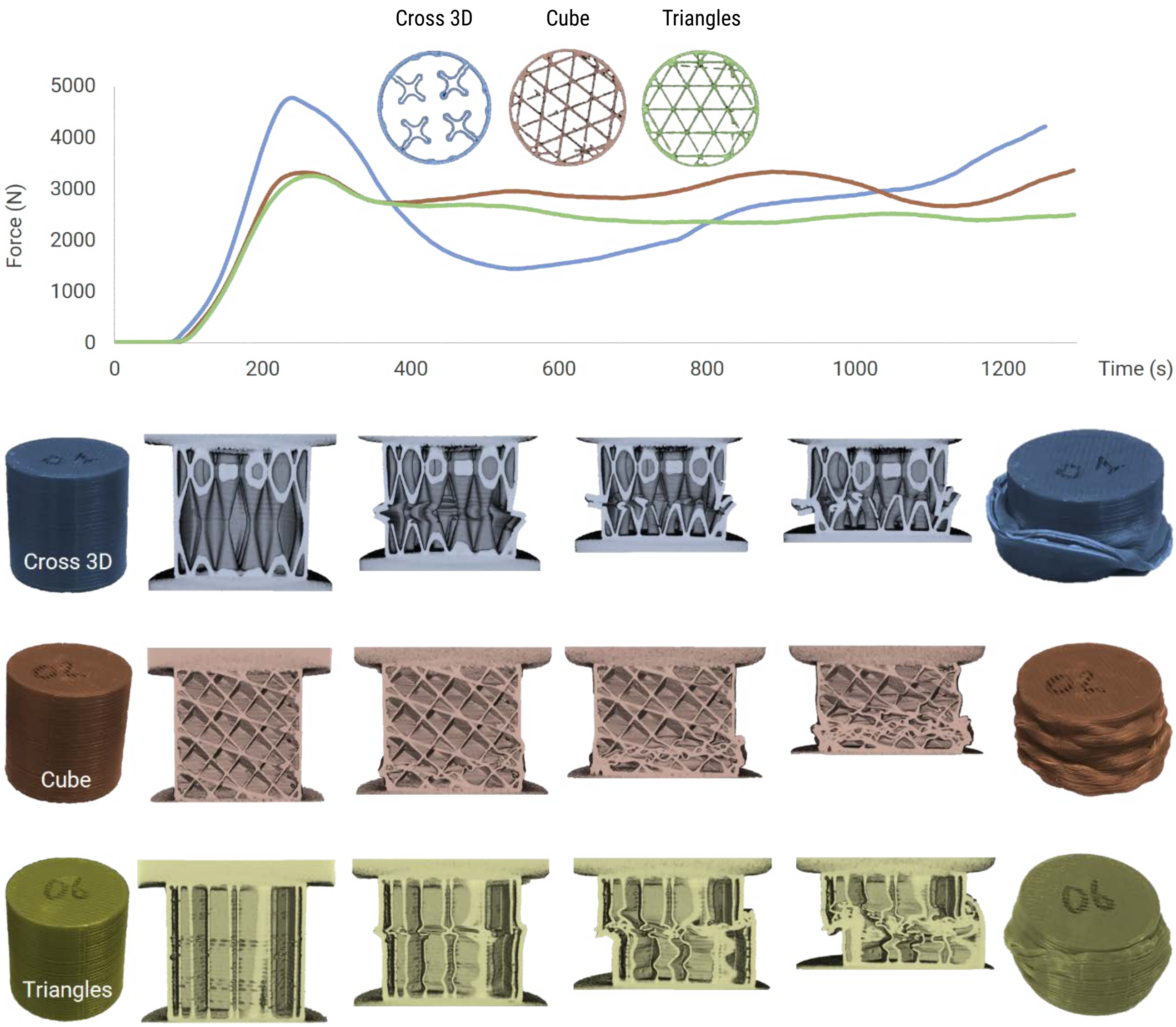
▲ **Figure 1:** (left) Deben load cell installed in UniTOM XL; (top right) uncompressed sample; (bottom right) compressed sample

**In situ** micro-CT enables the 3-dimensional inspection of processes inside a sample under changing external conditions (such as load or temperature), but it has been mostly relegated to interrupted processes where the stimulus is paused, also referred to as time-lapse imaging. To enable a clearer picture, **TESCAN** employs the method of **dynamic CT**, which refers to the most advanced subset of time-resolved 3D x-ray imaging utilizing high temporal resolution, where a sample is imaged continuously as it is changing and there is no interruption during the process.

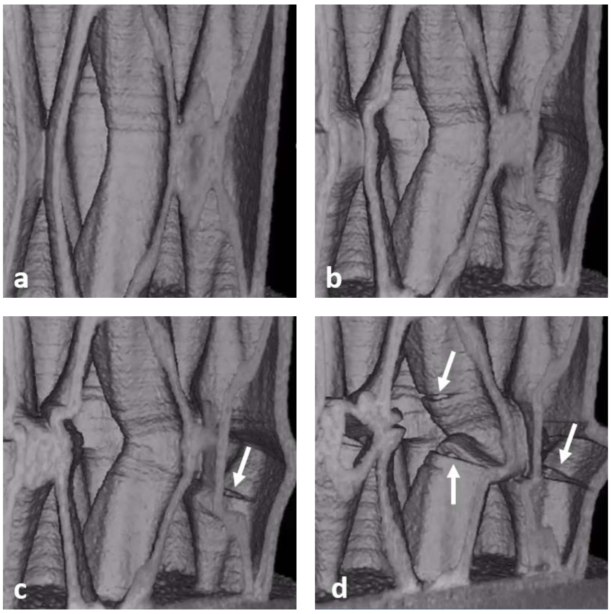
The difference between dynamic CT and time-lapse can be thought of as the difference between a stop motion animation and a smooth video. The stop motion has clear missing information between individual time points and insufficient temporal resolution to capture every detail, while the smooth video has enough temporal resolution to fill in the gaps and provide a complete story. Similarly, the advantage of dynamic CT to perform continuous acquisition on micro-CT lies in the ability to perform uninterrupted, real in situ experiments. The high temporal resolution employed for dynamic CT allows the user to capture data throughout the process, thus avoiding undesirable effects, such as relaxation, which may happen if a pause is required each time a tomogram is collected.

## Materials and methods

To illustrate the value of dynamic CT in additive manufacturing, we examined in situ 3D deformation of three plastic parts printed with different infill patterns, which are the invisible internal support structure of the sample. We used a **TESCAN UniTOM XL** micro-CT, collecting 220 tomograms over 22 minutes with a temporal resolution of 5.8 seconds per sample rotation and a voxel size of 59 µm, while continuously compressing each sample. A Deben CT5000RT was used as the load cell and we utilized a TESCAN in situ interface kit for “no-cable-wrap” operation during continuous rotation and data collection. Images of the load cell and the initial and final states of one of the samples are shown in **Figure 1**.




▲ **Figure 2:** (top) load curve showing measured force over times; (bottom) example images of each sample at different times during the test




◄ **Figure 3:** Detail of layer separation on the Cross 3D sample at different time points during compression.
a) 3.5 minutes b) 5.8 minutes c) 6.5 minutes d) 8.3 minutes

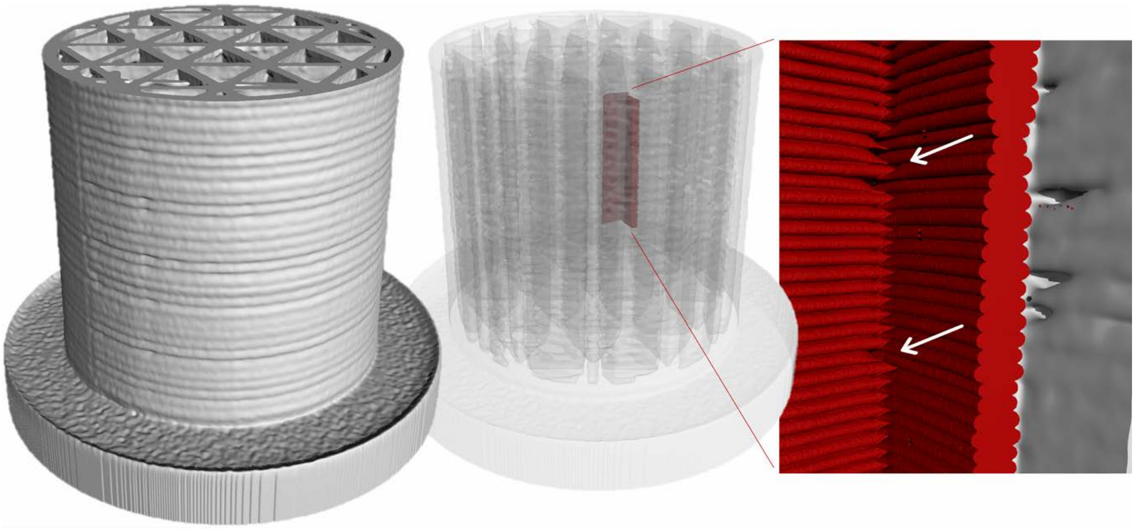
Infill patterns are required for supporting subsequent layers and for part integrity, but the patterns also have a big impact on the performance of 3D printed parts. There isn't any single infill pattern for all applications. The decision of what pattern to use and how much to use strongly depends on the final shape and application of the part, as well as the printing technique, time and cost. For this example, three different common infill patterns were selected: Cross 3D, Cube, and Triangle.

## Results and discussion

**Figure 2** shows the load curve vs time for three different infill patterns, Cross 3D, Cube and Triangle, along with representative 3D renders and virtual slices for each sample at different time points. Some clear observations can be made from both the load curve and the images. From the load curves we see an overall similarity in behavior, but the Cross 3D pattern is able to initially carry a larger load and then quickly drops below the other two samples, before recovering again. If we look at the 3D visualization, we see an initial collapse in a single layer followed by unrestrained compression of that layer until it collapses upon the next layer. Looking at the final state we see that most of the deformation had occurred in a small region, with a large amount of deformation of the outer walls. In contrast, the cubic sample appears to maintain overall geometry integrity, with localized buckling throughout. Initially, there is a failure in a single layer toward the bottom, but as we examine the progression, we see several layers throughout the height of the sample collapsing. The triangle infill has a notably different path, with a clear shear happening where the sample "slides" along a preferred direction.

Along with providing 3D observations about the entire sample, it is also possible to focus on specific points of the sample and observe localized change during certain time frames. For instance, if we look closer at some of the change in the Cross 3D sample, as shown in **Figure 3**, we can see clear separation between individual layers as load increases. Here we see the progression of failure over ~5 minutes where defects are clearly visible. These specific failures may indicate a lack of fusion between certain layers and the need for a change in the initial build parameters.

Finally, a multi-scale approach can be taken with samples like these, where higher spatial resolution scans are performed before and/or after the mechanical test to get a better understanding of the microstructure in specific locations. For instance, on the triangle infilled sample, prior to compression we performed a higher spatial resolution volume of interest scan (VOIS) at 8.5 µm voxel based on information obtained from an initial lower resolution scan. Within our visualization package, Panthera™, the lower resolution scan showed some anomaly on the surface of one of the struts. Through an easy-to-use workflow we selected this region for a semi-automated higher resolution scan. The multi-scale approach is illustrated in **Figure 4**. With the higher resolution results, we can see the individual build layers and clear indications of an irregularity in the build pattern resulting in voids, which could be points of initial failure, potentially leading to the shearing behavior seen in the dynamic CT results.



▲ **Figure 4:** (left) overview scan of the full sample; (center) overlay of VOIS (red) showing location within the full sample; (right) and detail of print defects (voxel size of 8.5 µm).

## Summary

As additive manufacturing matures, with more complex and intricate geometries becoming commonplace, it will be necessary to have the correct tools in place to provide further insight and understanding as to how these unique parts perform under a variety of conditions. With dynamic CT, fully enabled across the entire line of TESCAN micro-CT solutions, it is now possible to collect continuous and uninterrupted 3D data during these processes. In this study we used a **TESCAN UniTOM XL** and the technique of dynamic CT to observe the change of internal and hidden structures of 3D printed parts as they underwent compression loading. This example illustrates the potential of dynamic CT as a valuable means to better understand what internal (and invisible) changes are contributing to the overall performance of a 3D printed part undergoing a mechanical loading.

To access a video showing some this experiment in action please visit our YouTube channel, TESCAN YouTube →, use this QR code:

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