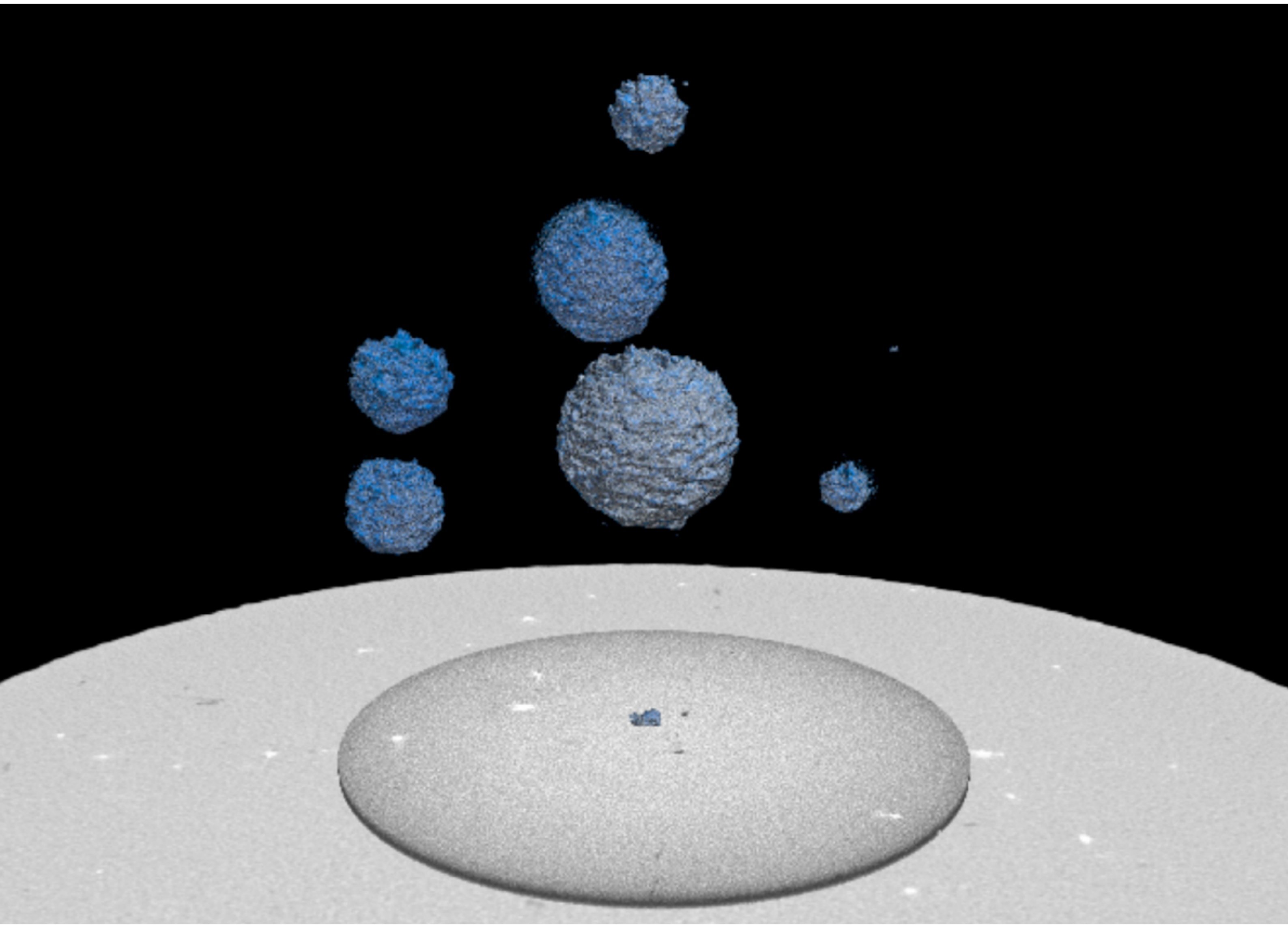
Application Note



3D X-ray Microscopy Characterization

Metal Additively Manufactured Parts

ZEISS

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Metal Additively Manufactured Parts

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Defect detection and characterization within metal additive manufacturing (AM) parts is a key to efficient and effective process development. Ideally, metal AM parts have a density greater than >99.5% to match physical properties and the reliability of traditionally machined/formed parts. However, the process parameters for fabrication can vary dramatically for different materials and shapes resulting in unwanted defects in the final part. To help better understand the interior structures of such parts, X-ray microscopy (XRM) can be used to create 3D tomographic data sets at high resolution and contrast with minimal or no sample manipulation.

Introduction

This application note highlights the unique characteristics of ZEISS Xradia Versa family, through the imaging and analysis of AM parts of different metal types: Ti6Al4V, CoCr, and 17-4-PH SS. Three cones with a diameter variation from 0.25" to 1.5" were supplied by Concurrent Technologies Corporation (CTC) in support of an America Makes project funded by National Institute of Standards and Technology (NIST). An EOS M270 laser powder bed fusion (L-BPF) machine was used to fabricate the parts. An example of one test structure is seen in Figure 1.

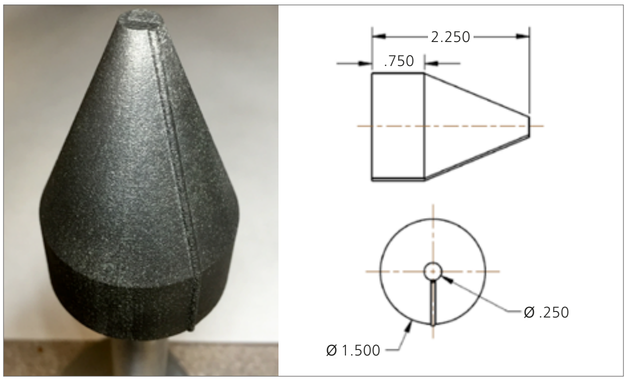

Figure 1 *Photo of single cone structure with associated dimensions in inches*

Each specimen had a purposely-designed series of printed flaws in a body-centered cubic like orientation (Figure 2), located along the centerline of the cone. The center of the flaw clusters were separated by ~ 0.25" as shown in Figure 3.

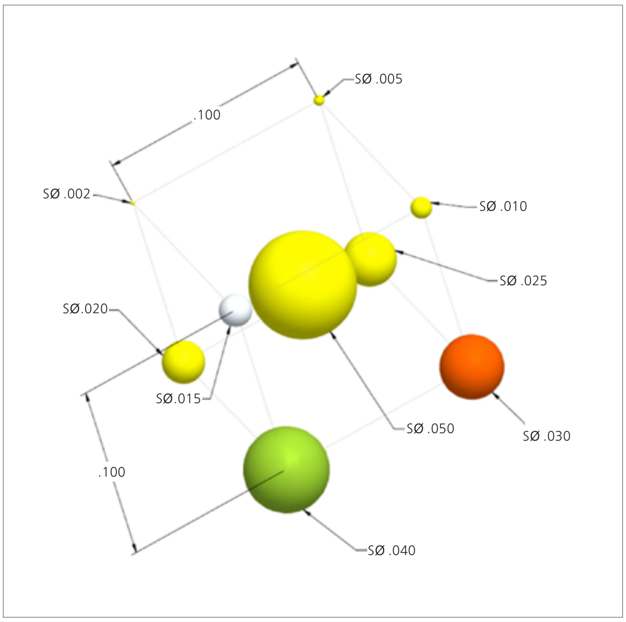

Figure 2 *Flaw layout in a body-centered orientation: The back, upper, left sphere is designed to be 0.002" (51µm) diameter while the center sphere is designed to be ~0.05" diameter (1270 µm). The color of the spheres has no specific relevance.*

Results

X-ray microscopy was performed utilizing ZEISS Xradia Versa. The unique architecture of the system allows for collection of high resolution tomography data at arbitrary regions of interest (ROI) on larger samples, a capability which is not generally possible on traditional micro-CT systems. Versa system uses a series of varying resolution detectors, providing imaging flexibility not feasible when only one detector is present. More specific details on ZEISS Xradia Versa family can be found www.zeiss.com/xradia-versa.

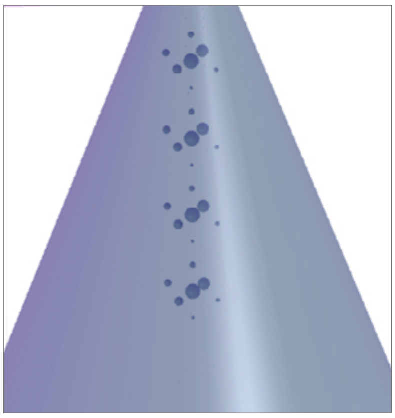

Figure 3 *Solid model representation of the ideal layout with position of the clusters shown*

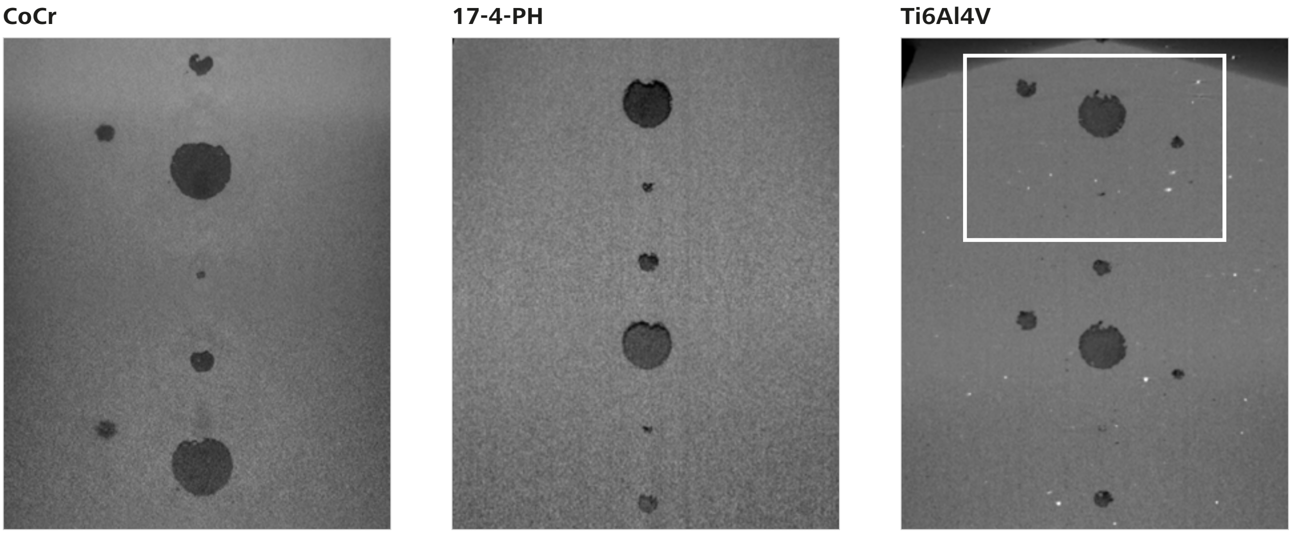

Figure 4 *Comparison of Versa XRM FFOV imaging on all three samples. Darker regions indicate less dense regions. The boxed area in the rightmost image indicates one location which was scanned at higher resolution. Slight variations in acquisition parameters result in differing FOVs, however resolution is approximately the same across all three samples.*

Scans covering the top three clusters (~3/4" from the top of the sample) were initially collected with a voxel resolution of ~12 µm. Example of the LFOV images along the axis of the sample are shown in Figure 4. For comparison, an image from a "conventional" CT system is shown in Figure 5. Since conventional CT systems requires a high geometric magnification to obtain higher resolution, the ability to obtain high resolution data on a sample of this size is limited since the source cannot get close to the ROI.

Figure 6 shows the basic differences in system architecture between XRM and traditional CT. Where CT uses a single

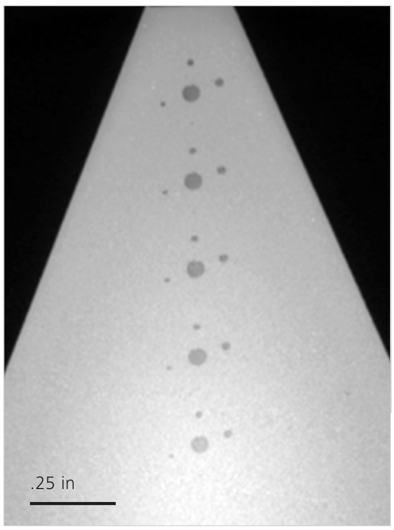

Figure 5 *Conventional CT image of Ti6Al4V part*

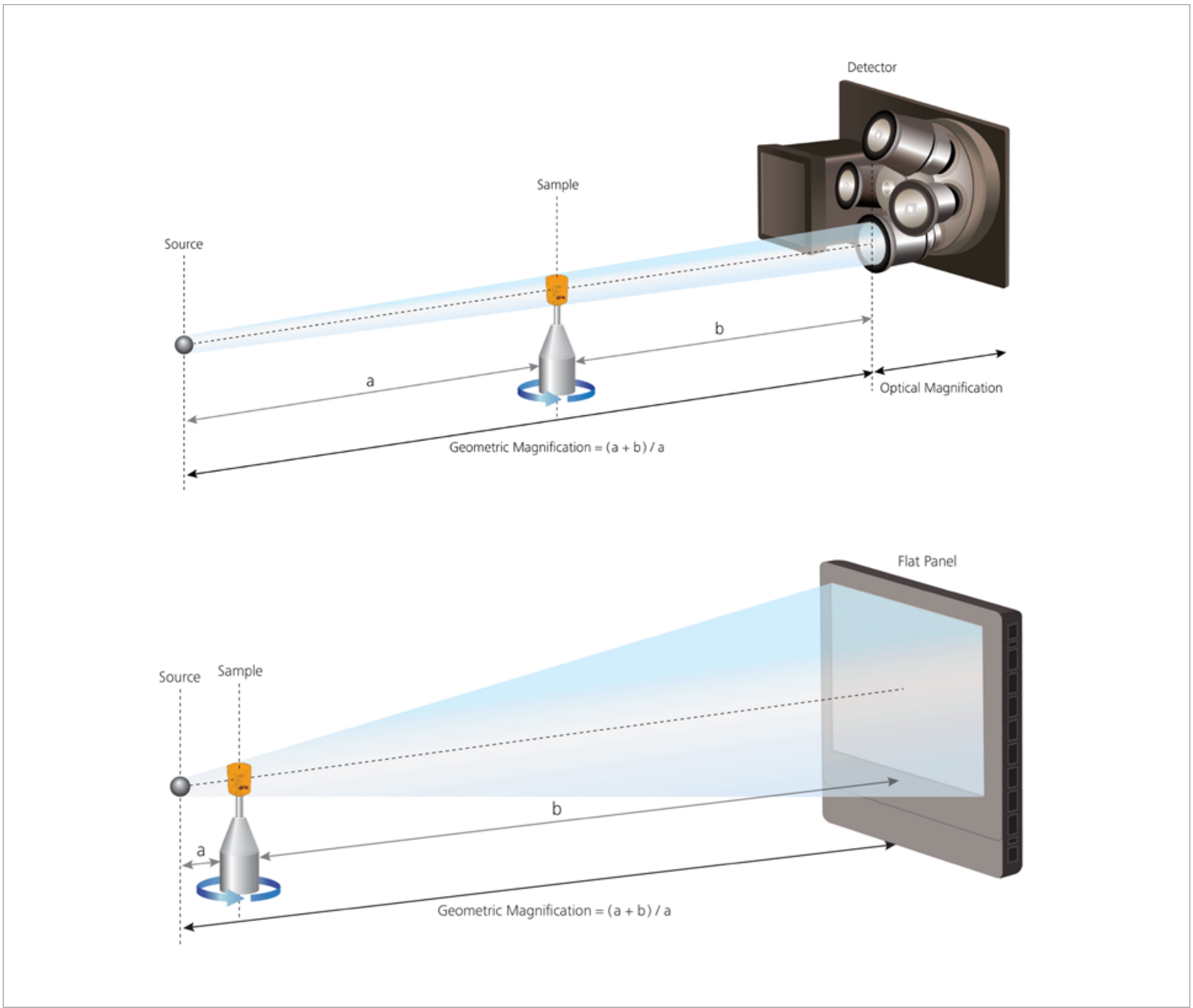

Figure 6 *Comparison between Versa architecture and traditional CT architecture. Versa is shown on the top. Note the required position of the sample to obtain high resolution imaging on a traditional CT.*

detector and relies solely on geometric magnification, XRM uses a series of microscope objectives to decouple resolution from geo mag allowing for a much more flexible imaging system.

The flexibility of Versa detector architecture, as well as sample stage, allows for a unique Scout-and-Zoom workflow providing users the ability to precisely identify any ROI within a low resolution scan and position the sample without the need to manually interact with it or reduce it in size. In this case, the high resolution ROIs for each sample were chosen as the topmost set of flaws and were imaged with a voxel resolution of 4.9 μm; the white boxed region in Figure 4 indicates the location of the high resolution scans.

For this project, the high resolution scans provided demonstrable detectability such that the smallest flaws, if properly printed, would have been visible. Figure 7 shows details of the 0.05” flaw from the high resolution scan on the Ti6Al4V sample. Within this region, Individual unmelted / sintered particles are clearly visible, as well as high-Z particles which are suspected to be contamination from the original powder.

Some of these features can clearly be measured down to ~30 µm (0.0012”). For all three material types, the 0.002” and 0.005” flaw were not visible, indicating a clear failure to print. In each sample, the smallest printed flaws visible were 0.01”, albeit in a non-ideal shape, as seen in the virtual cross-sections in Figure 8 where the same feature is shown in each of the three materials. In this particular case, the focus was on providing high resolution over a number of features; however, it would also be possible to image the intact sample at even higher resolution, near sub-micron voxel resolution, to focus on smaller ROIs.

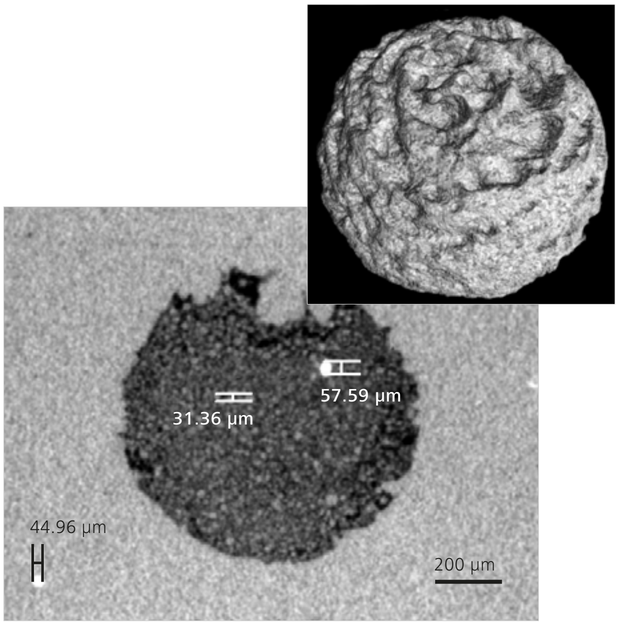

Figure 7 *Details of the 0.05” flaw in the Ti6Al4V sample. The upper right image is a 3D rendering of the flaw while the lower image shows a virtual cross section through the region. Features as small as ~30 µm (~0.0012”) are visible, demonstrating that the resolution would be sufficient to detect the smallest intended printed flaws of 0.002” and 0.005” if they were present.*

CoCr **17-4-PH** **Ti6Al4V**

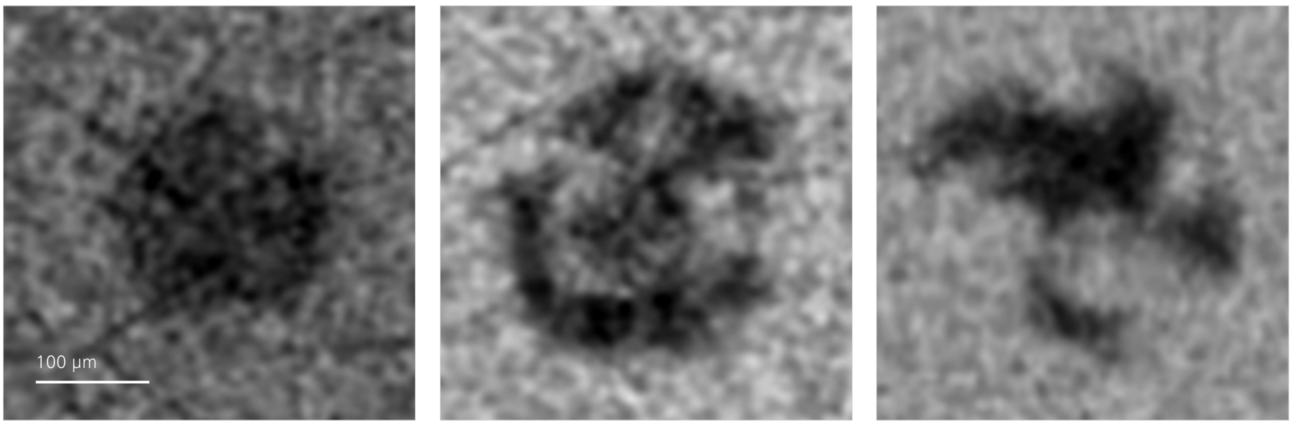

Figure 8 *Comparison of the 0.01” feature for the three samples. Varying levels of grey within each image indicate different levels of density. Lower denser (trending to air) is darker.*

Summary

As the development of metal AM for mainstream production continues to grow, so too will the need for improved understanding of the full process, from raw stock material to final part. The unique architecture of Versa, most notably the variable resolution detector coupled with a flexible sample stage, allows easy collection of high resolution tomography information for detailed analysis of complex AM parts.

The ability to Scout-and-Zoom to arbitrary locations provides a level of non-destructive analysis unavailable from conventional CT technologies. This new level of insight can be a key to improving overall process understanding for improved quality.

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