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High Resolution X-ray Microscopy for 3D Characterization and Qualification of AM Materials

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Additive manufacturing holds the promise to produce geometrically complex parts with a variety of materials; particularly promising for irregular three dimensional structures which are not achievable by conventional manufacturing techniques. This brings new opportunities for prototype or customized parts, as well as functionally graded structures along with their unique, spatially-varying properties [1].

The multitude of process parameters involved in most AM methods, as well as exploration of new material compositions/powders, creates a scenario where it is necessary to have careful understanding of the influence of process on resultant part geometry and microstructure. This inspection typically benefits from being done in 3D, as the overall appeal of the additive approach is generally in producing geometrically complex parts into the third dimension. A variety of tools exist for such characterization purposes, ranging from tactile CMM machines, to optical metrology, and conventional metallography. Within this range, nondestructive tomographic imaging with X-rays offers an appealing choice for interrogation of internal structures within a sample or component across multiple length scales. As a specific variant of X-ray tomography, X-ray microscopy (XRM) leverages unique optical elements for improving spatial resolution and contrast, and can push the approach to provide structural information from the cm down to sub-micron scale.

Lab-based XRM can visualize many of the structural features that help dictate part performance: porosity, surface roughness, residual powder or lack of fusion defects, cracks, layer delamination, foreign inclusion particles, and even (to a growing extent) crystalline microstructure. With data acquisition times typically on the order of tens of minutes to hours, the technique currently finds value in the research lab rather than production setting, but the nondestructive nature of the approach provides unique chances for improving understanding of basic fundamental behavior. Processes such as mechanical deformation or heat treatment can be observed, including within *in situ* imaging arrangements, to directly observe the modifications to sample microstructure when exposed to stimulus.

This paper will present the application of high resolution lab-based X-ray imaging to additive manufacturing materials, pulling on examples from across the process chain. Beginning with feedstock powder, XRM is used to image a substantial volume of particles (Fig. 1a) and screen for characteristics like particle size and shape distributions as well as internal porosity (which, notably, is impossible to discern with 2D methods like optical or even scanning electron microscopy) [2]. Test parts, created with deliberately complex 3D structures of small dimensions, are examined to assess the fidelity and quality of as-built parts. Examples drawing on a variety of metal systems (Ti-6Al-4V, Inconel, aluminum) will be discussed, as well as ceramic (Fig. 1b) and polymeric parts. A multi-scale 3D workflow, denoted ‘Scout-and-Zoom’, is employed whereby samples are first scanned in 3D at relatively low resolution to gain context and identify potential problem locations, and then these specific regions of interest are targeted in following scans to achieve higher resolution, localized information. Identification of internal porosity, surface roughness, and cracking down to the micron scale is achievable. Such a Scout-and-

Zoom approach can also be applied to selectively sample key regions within functionally graded AM parts in a nondestructive fashion.

A recent development in X-ray microscopy for 3D grain mapping of polycrystalline materials will also be presented. This technique, laboratory diffraction contrast tomography (LabDCT), operates on the same system as conventional tomography and offers the ability to nondestructively map internal grain structures (grain morphology and orientation) by capturing diffraction information in addition to the traditional transmission signal [3]. Some early applications of the technique to metallic powder-based and fully-dense materials will be presented, along with an outlook and boundary conditions on the method in general.

References:

[1] GH Loh et al., Additive Manufacturing **23** (2018), p. 34.
[2] IE Anderson, EMH White and R Dehoff, Current Opinion in Solid State and Materials Science **22** (2018), p. 8.
[3] SA McDonald et al., Scientific Reports **7** (2017), p. 5251.

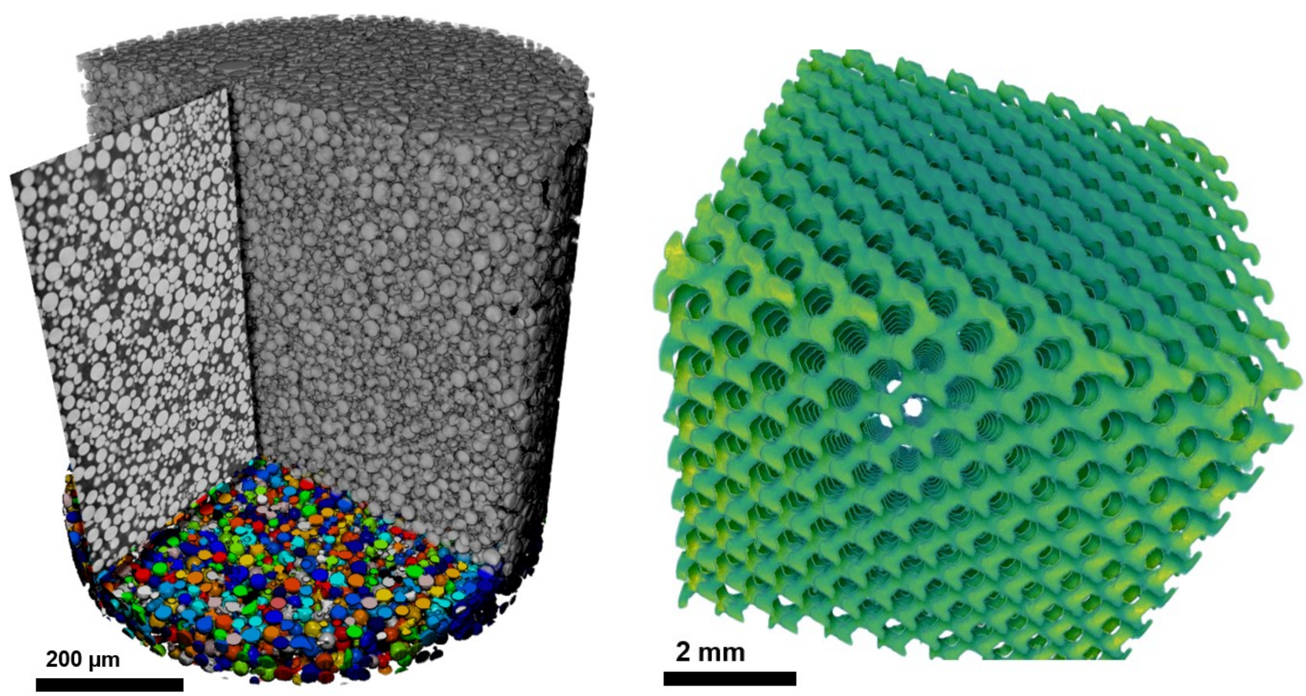

Figure 1. a) Ti-6Al-4V feedstock powder. 3D characterization reveals anomaly particles of unusual shape as well as containing internal voids or gas. b) 3D reconstruction of a ceramic network lattice for defect inspection, sample courtesy of Lithoz GmbH.