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Application of Serial Sectioning Microscopy to Additively Manufactured Metallic Samples

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Additive Manufacturing (AM), a.k.a. 3D printing, has garnered wide-spread interest in the materials and manufacturing community, as the method is capable of producing parts with geometric features and complexity that are unobtainable via conventional manufacturing. This unique capability is achieved through layer-by-layer construction of the part from analysis of a Computer-Aided Design (CAD) file. Unfortunately, the complete details of the recipe used to print the parts is typically not known to the end user, as this information is often proprietary knowledge of the manufacturer. The host of variables that can contribute to part-to-part variability, including the aforementioned "black-box" printers, has resulted in uncertain knowledge of the local processing conditions for parts of modest-to-severe complexity.

Over the past year, the authors have explored the use of a serial section microscopy system [1] to characterize the 3D topological and microstructural aspects of metallic AM laboratory samples to improve the linkage between process intent and the resultant structure. We have employed mechanical-polishing based sectioning coupled to optical and scanning electron microscopes, as this approach enables volumetric coverage of laboratory-scale samples (typical volumes ranging from 5 – 20 mm^3) while maintaining micrometer-level spatial resolution. Our initial efforts have focused on quantifying the internal porosity, microcracks, and surface roughness of AM titanium and nickel alloy samples, as, these features are easily observed and amenable to image segmentation from as-polished bright field epi-illumination optical microscopy images.

Figures 1 and 2 show results from a serial sectioning experiment of a cylindrical AM Ti-6Al-4V sample that was printed using a direct laser metal sintering process. The left pane of Figure 1 shows a mosaic bright field optical microscope image from one section, which was created by post-experiment stitching of 100 image tiles. The use of automated mosaic imaging is critical to achieving the relatively-high spatial resolution, approximately 2 μm and highlighted in the inset in Figure 1, compared to the 1 cm field-of-view. The right panel of Figure 1 shows correlated data from a North Star Imaging Model X50 micro-computed x-ray tomography scan of the same region. The serial sectioning data is able to resolve the convoluted shape of the largest pores, and readily detect smaller pores at-and-below the resolution of the CT scan. Figure 2 shows a 3D reconstruction of a sub-region of the experiment that was created using DREAM.3D software [2], demonstrating the ability to readily quantify the true distribution of pore volumes, and also highlights the linear spatial arrangement of lack-of-fusion pores [3].

References:

[1] M Uchic *et al*, in "1 International Conference on 3D Materials Science" ed. M De Graef *et al*, (John Wiley & Sons, Hoboken). ch. 30.

[2] M Groeber and M Jackson, IMMI **3** (2014), p. 5.
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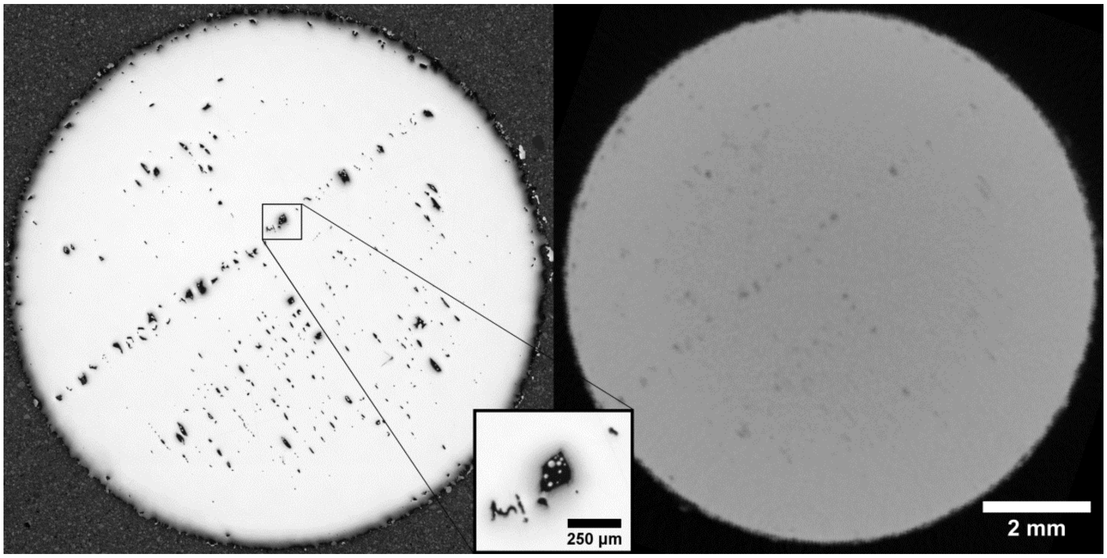

Figure 1. The left panel shows a 2D section from a serial sectioning experiment of a Ti64 AM cylinder, while the right panel shows correlated data from a CT scan performed prior to serial sectioning. The inset shows the high resolution detail of the pore structure provided from bright field optical imaging. Pixel dimensions are 2.05 μm in the optical mosaic image, as compared to 23 μm in the CT reconstruction.

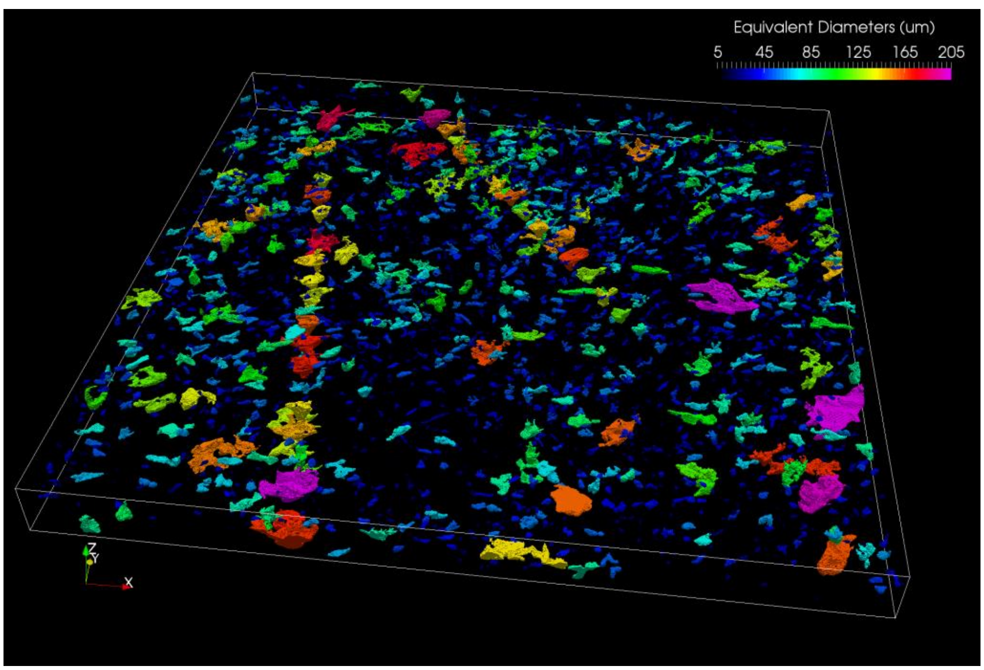

Figure 2. 3D rendering of porosity from a 6.25 x 6.25 x 0.434 mm sub-volume from the cylindrical AM sample, where the color table denotes the equivalent sphere diameter of the pore.

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