doi:10.1017/S1431927619002447
Microsc. Microanal. 25 (Suppl 2), 2019

3D Reconstruction of an Additive Manufactured IN625 Tensile Sample Using Serial Sectioning and Multi-Modal Characterization

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The Air Force Research Laboratory is currently conducting a series of Challenge Problems to benchmark the capability of modeling and simulation methods towards processing-structure-property prediction in Additive Manufacturing (AM) of metallic components [1]. One of the four challenges addresses structure-to-property prediction at the local scale, i.e., grain-level, where the challenge participants are asked to predict the evolution of elastic strains of selected grains within a millimeter-scale, AM polycrystalline tensile sample, Fig. 1a. This sample had been characterized during testing via High Energy X-ray Diffraction Microscopy (HEDM) methods [2] to small macroscopic strains (< 2%).

While HEDM methods provide an accurate, *in-situ* diagnostic for the local crystal orientation and average elastic strain tensor within grains that are larger than 5 to 10 micrometers in diameter, current data inversion techniques cannot easily reconstruct features smaller than this size in millimeter-scale volumes. The metallic alloy used in this study is IN625, which contains many micrometer-scale and smaller features such as annealing twins, pores, and carbide precipitates. Thus, in order to provide modeling and simulation toolsets with a 3D reconstruction the of entire gage volume (500 x 500 x 840 micrometers) with ~1 micrometer resolution, advanced serial sectioning microscopy has been employed after testing to complement the HEDM experiments.

The LEROY serial sectioning system at AFRL (Fig. 1b) was used to perform the multi-modal 3D characterization experiment [3]. This system incorporates a modified RoboMet.3D to perform automated multistep mechanical polishing, which removed ~1 micrometer per section while minimizing subsurface damage. A Python-scriptable Tescan Vega SEM with Bruker EBSD system was used to automatically collect both normal-incidence backscattered SEM images (Fig. 1c) and EBSD maps (Fig. 1d) on each section. The EBSD and BSE scan resolutions were 1.00 and 0.59 micrometer, respectively. In addition, bright field epi-illumination montage images (Fig. 1e) were collected using a Zeiss AxioVert 200M inverted optical microscope with 0.52 micrometer resolution. The average cycle time per section was 63 minutes and 900 sections were collected, resulting in a cumulative time of over 40 days and more than 3 TB of data.

The multi-modal data set was collectively analyzed to create a 3D reconstruction of the tensile sample. Optical montage image data was used for stack registration, as the thermoset mounting material provided a random structure to use for unbiased section-to-section alignment. Custom scripts were developed to optimize the non-linear registration of both the BSE images and EBSD maps to the optical image stack. Pores and carbides larger than 1 micrometer in size were segmented from the BSE image data, and, subsequently fused with dictionary-indexed [4] EBSD maps. Lastly, DREAM.3D software [5] was used to generate 3D reconstructions of the data (Fig. 1f) for the aforementioned AM Challenge Problem. The associated presentation will highlight novel workflows for experimental collection, post-processing, and analysis of multimodal serial section data [6].

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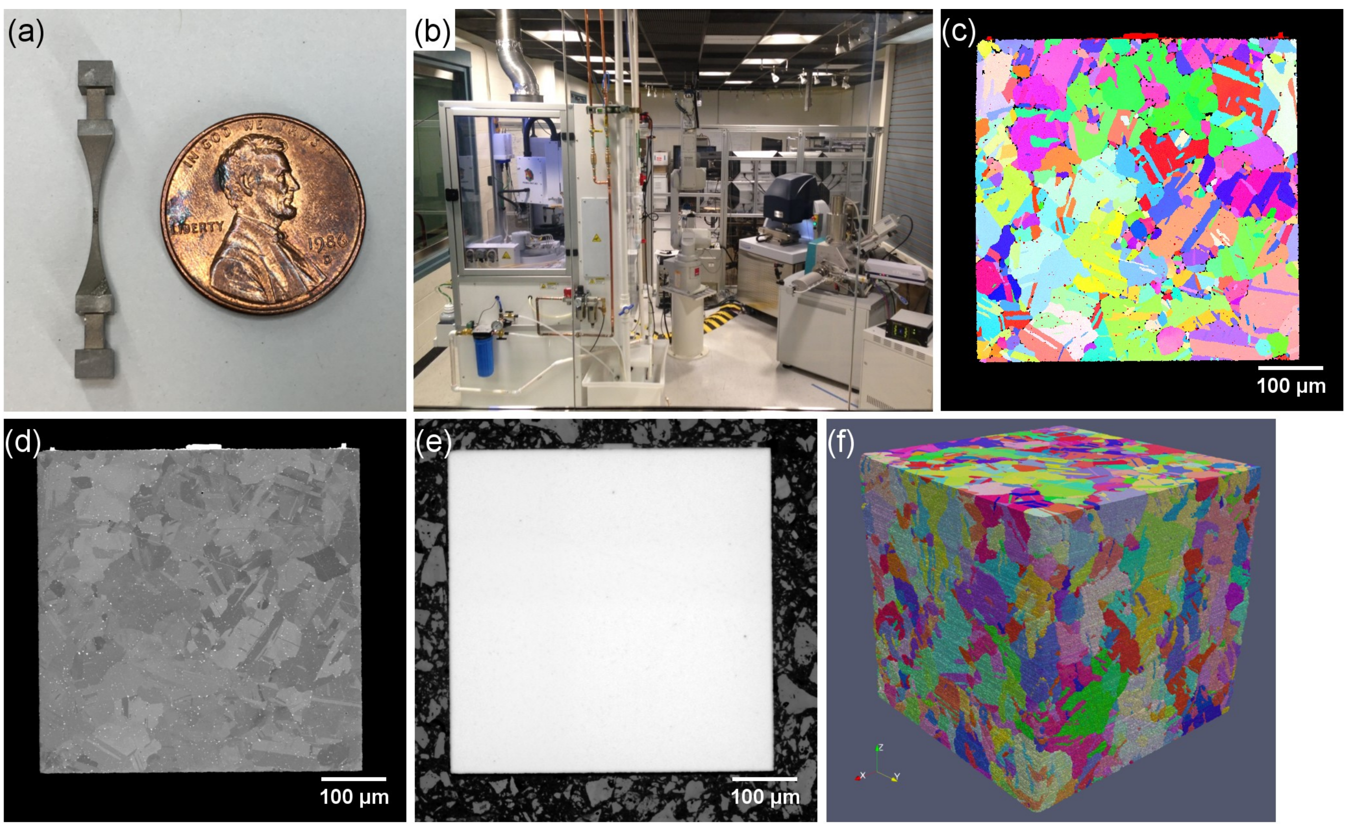

Figure 1. (a) Image of a representative AM IN625 HEDM tensile sample; (b) Image of the LEROY multi-modal serial sectioning system at AFRL used in this study; (c) Inverse Pole Figure map generated from an EBSD map of a representative section; (d) normal incidence backscatter SEM image (20 kV, ~1 nA) from same section shown in (c); (e) subregion of bright field optical microscope montage image, again from same section shown in (c); (f) 3D reconstruction of a subregion of the tensile sample (500 x 500 x 580 micrometers), which has ~1 micrometer voxel resolution.

https://doi.org/10.1017/S1431927619002447 Published online by Cambridge University Press