36-L.0 RATIONALIZATION OF LIQUID/SOLID AND SOLID/SOLID INTERPHASE INSTABILITIES DURING THERMAL-MECHANICAL TRANSIENTS OF METAL ADDITIVE MANUFACTURING

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36-L.1 PROJECT OVERVIEW AND INDUSTRIAL RELEVANCE

Additive manufacuturing (AM) of metallic systems has been a topic of growing interest among both industry and associated research. Due to the large thermal gradients (10^3-10^7 K) and rapid rate at which these gradients flip signs in AM (> 10 Hz), steady state assumptions about the material's solidification behavior used in traditional processes are not accurate (**Fig. 36-L.1)**. The liquid/solid and solid/solid instabilities that emerge have not been well studied or qualified, which lead to deleterious evolution of the microstructure via porosity, unwanted anisotropy, or other defects [36-L.1]. Therefore, the prediction and control, and of such phenomenon is key to ensuring proper material performance in AM, and can assist in developing *in-situ* qualification and certification techniques for meeting performance criteria during printing of AM components [36-L.2].

This project focuses on using model alloy Ti-6Al-4V and Inconel 718 samples manufactured with electron beam melting (EBM) to probe the aforementioned issues. Varying rastering modes were implemented in the production of these samples, intending to analyze how instabilities evolve with different AM parameters and local thermal histories. The effects instabilities have on texture evolution, microstructure, phase fractions, defect formation, and resultant material performance will all be investigated according to methods listed in **Section 36-L.3 and Section 36-L.4**. The culmination of these investigations will elucidate how spatial and temporal transients and interfacial instabilities lead to deleterious properties in AM manufacturing, and assist in developing new analysis techniques for improved *in-situ* validation of components.

36-L.2 PREVIOUS WORK

Prior to project initiation, Ti-6-4 samples were produced with DeHoff, basketweave, and random rastering modes via EBM (**Fig. 36-L.2)** at the University of Tennessee (UT). DeHoff rastering used a circular gyration path when depositing build material, resulting in a stacking dime structure such as that seen in welding. Basketweave used a linear path from one side of the sample during the build process, and random used an undefined path for the duration for the build. Each mode was selected with the intent of exposing how varying thermal history changed the evolution of instabilities throughout the material.

36-L.3 RECENT PROGRESS

Each specimen was sectioned lengthwise into two equivalent regions, one which remained at Colorado School of Mines (CSM) and the other was sent to Los Alamos National Labs (LANL) for bulk and slit neutron diffraction testing at the High-Pressure-Prefferred-Orientation (HIPPO) beamline (**Fig. 36-L.3)**. Neutron diffraction exhibits a much higher penetration depth for analysis than X-ray diffraction, due to the use of a high energy neutron source [36-L.3]. HIPPO collects texture data from neutron scattering events in 1200 ^{3}He detectors to create a bulk texture profile of any material tested. This was completed for each of the previously named rastering modes, and data acquired from this is currently in processing via Rietveld refinement using the Material Analysis Using Diffraction (MAUD) software.

36-L.4 PLANS FOR NEXT REPORTING PERIOD

With a startup date of August 1st, 2018, this project has had limited time to cover pertinent information in literature sources. Due to this, literature review will be a primary focus for the next reporting period. Neutron slit experiments are planned at LANL in the coming months to collect texture evolution information as a function of distance from the build platform for each rastering mode. Beam time at the Advanced Photon Source (APS) at Argonne National Labs (ANL) is anticipated in 2019, where in-situ solidification experiments using the APS AM simulator will be performed to observe AM-like solidification conditions and phenomenon. Laser and optical analysis of sample surfaces will be completed to measure surface roughness for each rastering mode, and to observe any kind of evidence of phase transformations such as surface relief. A multi-university kickoff meeting for the MURI funding this effort will occur between October 24th-25th 2018 at UT, and will lead to more planned experiments along with timelines for publications and conference proceedings.

36-L.5 REFERENCES

[36-L.1] S. J. Foster, K. Carverr, R. B. Dinwiddie, F. List, K. A. Unocic, A. Chaudhary, S. S. Babu, Process-Defect-Structure-Proprty Correlations During Laser Powder Bed Fusion of alloy 718: Role of In Situ and Ex Situ Characterizations, Metallurgical and Materials Transcations A. Online (2018).

[36-L.2] S. S. Babu, A. Clarke, et. al, MURI AM Project Narrative v.1.1, University of Tennessee, 2017.

[36-L.3] S. C. Vogel, S. Takajo, M. A. Kumar, E. N. Caspi, A. Pesach, E. Tiferet & O. Yeheskel, Ambient and High-Temperature Bulk Characterization of Additively Manufactured Ti-6Al-4V Using Neutron Diffraction, The Journal of the Minerals, Metals, and Materials Society. Online (2018).

36-L.6 FIGURES AND TABLES

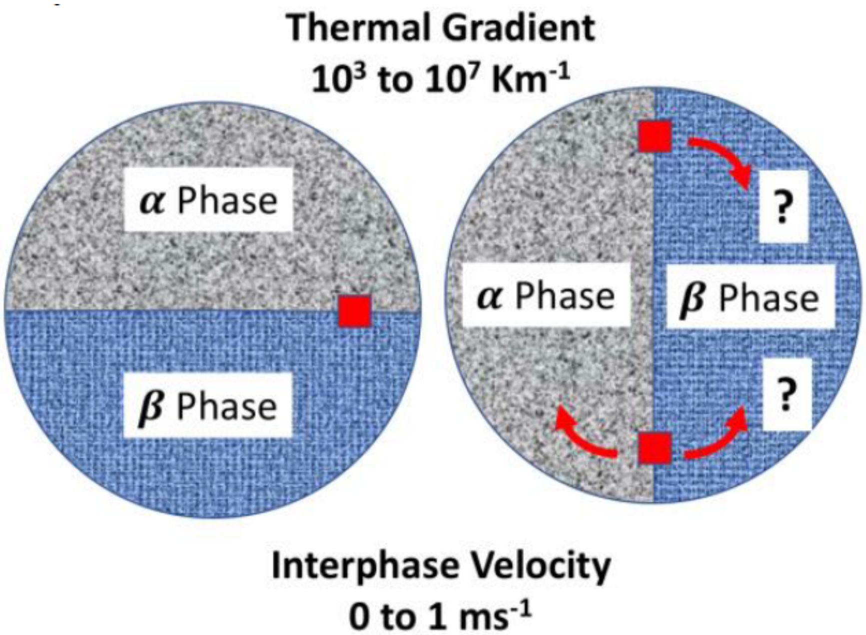

Figure 36-L.1: Illustration detailing the dynamic conditions AM material is exposed to during production.

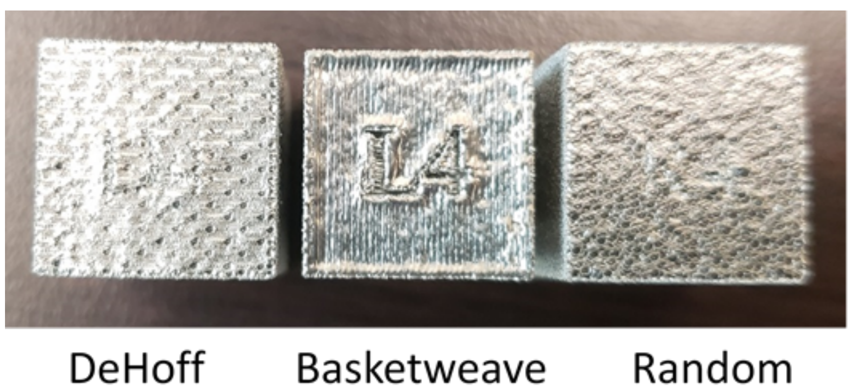

Figure 36-L.2: Illustration of initial Ti-6-4 samples with different rastering modes demonstrated. Note the clear differences in surface quality apparent between each manufacuturing pattern.

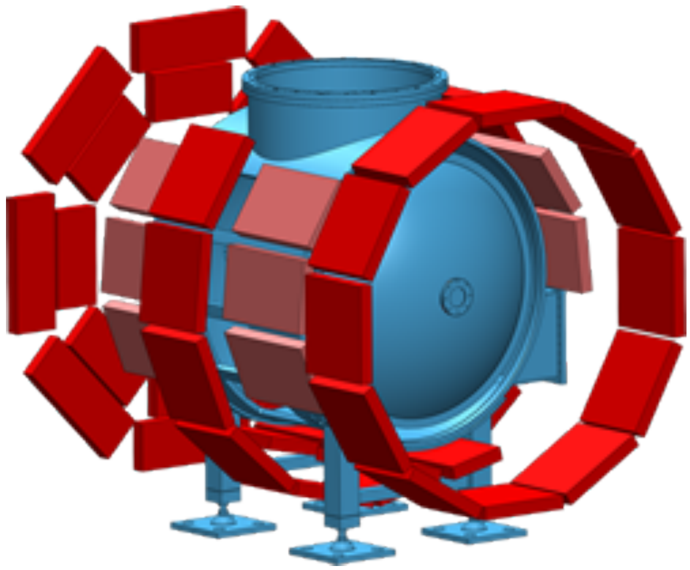

Figure 36-L.3: Rendering of the HIPPO beam line sensor arrays, visualizing the ^{3}He arrays used to detect neutron events and acquire texturing data.