Plasticity and Damage Modeling of Stress Asymmetry and Dynamic Behavior of AFS Additive Manufactured Aluminum Alloy 2219

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ABSTRACT

The Solid State Additive Manufacturing (AM) process referred as MELD that fabricated the samples in this study, provides a new path for repairing, coating, joining and additive manufacturing metals and metal matrix composites. This research will be the first application of a physics-based microstructure-dependent internal state variable (ISV) plasticity and damage material model to capture the mechanical response of an AM Aluminum Alloy (AA) 2219 via the MELD process. In this research, a microstructure-based internal state variable (ISV) plasticity-damage model was used to capture the mechanical behavior of AFS 2219 aluminum alloy.

Aeroprobe Corporation, creator and patent holder for the MELD process, fabricated the material by pushing a solid filler rod of AA2219-T861 material through a hollow rotating tool onto an AA2219 T851 plate substrate. As feedstock, solid or powder precursor metals are pushed through a non-consumable rotating cylindrical tool. Herein, added layers are deposited and metallurgically bonded to substrate material or previously deposited layers by the heat generated from the rotating tool through plastic deformation of the filler material. Once a layer has been added, the tool height increases, and starts the deposition of the next layer. This process results in beneficial properties such as grain refinement, homogenization and reduced porosity (fully dense). This process will experience temperatures similar to those in the weld nugget zone (WNZ) in friction stir welding (FSW), ranging from 0.6-0.9 Tm, with Tm being the melting point of the material. MELD is highly scalable with AA deposition rates reaching over 1000 cm^3/hr, which allows for MELD being used for repairs, coatings, and building components.

A motivating factor driving the research for physics-based history dependent material modeling of MELD components is the ability to accurately capture the stress-state and strain rate dependence in the material caused by variations in material microstructure from the MELD processing of new or repaired

components. The ISV model incorporates microstructural content and is consistent with continuum level kinematics, kinetics, and thermodynamics. These features allow the ISV model to capture large deformations at the structural scale using the kinematic and isotropic hardening, while microscale damage is obtained from the microstructural features. The benefits of the ISV model arise from the inclusion of structure-property relationships identified from microstructural characterization and experimentation. The Bauschinger effect (BE) is an important concept, vital in the accurate prediction of cyclic stress-strain response of ductile materials such as metals. The ISV model has been successfully used to capture the behavior and damage, and the BE of different aluminum alloys and steels. The ISV model uses kinematic and isotropic hardening to help capture deformations of the material at the macro scale. To understand this hardening relationship, calculating the kinematic and isotropic hardening relationship in the material is warranted for a high-fidelity model.

Electron Backscattered Diffraction (EBSD) was used to characterize the as-fabricated microstructure, where a fully-dense equiaxed grain morphology with average grain size of 2.5 μm was observed. Micro-hardness mapping of the as-built structures, monotonic tension and compression experiments at both quasi-static (0.001/s) strain rates, tension-followed-by-compression and compression-followed-by-tension experiments were performed to obtain the set of plasticity and damage constants necessary to capture strain rate and stress state behavior of this additive material. To calibrate the plasticity-damage model, a single set of constants were determined to capture the different stress states the MELD AA2219. One set of the constants was determined from experimental true stress-strain curves for the tension and compression data. Additionally, microstructural information and data from the open literature were used as the other model constants. This research is a first of its kind for AFS AA2219, includes correlating the ISV model to the monotonic experimental results that capture the isotropic and kinematic plasticity mechanical response.

Keywords: Solid State Additive Manufacturing, Additive Friction Stir, MELD, High Rate Phenomena, Physics-Based Modeling, AA2219.