Computational Modeling for Identifying Voids in Additively Manufactured Al-Si10-Mg

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Abstract

Additive manufacturing (AM) is a quicker and more cost-effective technique to produce complex parts that can perform similar to or better than conventionally manufactured parts. However, due to the dissimilar microstructure compared to conventional parts, there is a lack of understanding in the physical and mechanical response of AM alloys under different loading conditions and strain rates, and thus the suitability of using AM parts is uncertain. Notably, the presence of voids in AM metal alloys is more prevalent. By developing a computational model that can represent plasticity and track fracture initiation at the void sites in AM alloys such as Al-Si10-Mg, the failure response can be predicted. Therefore, the objective of this research is to use in-situ micro-computed tensile testing to identify individual voids or networks of voids that are likely to cause fracture initiation in an AM Al-Si10-Mg alloy.

1. Introduction

Due to the nature of additive manufacturing, voids in a printed part are larger and more ubiquitous than in its wrought counterpart. Larger voids, defined here as ≥ 150 μm in diameter, are sites that create appreciable stress concentrations, which lead to fracture initiation, fracture propagation, and, ultimately, failure of the part. Aluminum alloy, A1-Si10-Mg, tensile specimens were additively manufactured using laser powder bed fusion (LPBF). The build plate was subjected to stress-relief annealing at 550°C for 2 hours before the samples were removed from the plate using wire electrical discharge machining (EDM). It should be noted that different regions of an as-printed AM part exhibit different microstructural features that can therefore influence fracture initiation and propagation. A schematic illustrating these regions in a cross-section of a tensile specimen is provided by Figure 1(a). In order to isolate the contribution of each region to failure, specimens were mechanically polished to varying thicknesses. Some specimens were polished from two sides while others were thinned on only one side, as seen in Figure 1(b). Images were collected in-situ using micro-computed tomography (MCT) during uniaxial tensile loading at a displacement rate of 0.05 mm/s. The resulting tomographs acquired at different displacement intervals until test sample failure were examined, and large voids were identified and tracked during deformation.

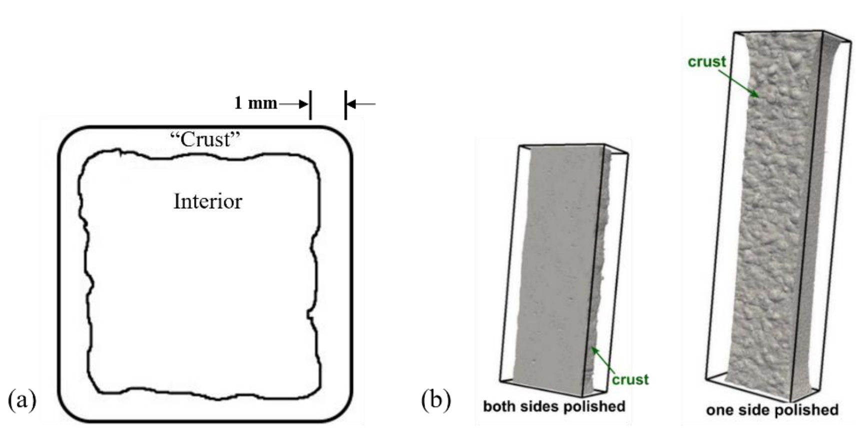

Fig.1 – (a) Cross-sectional schematic of an AM alloy showing the different regions of the final part; the crust region is approximately 1 mm in thickness. (b) Reconstruction from MCT of the two types of specimen.

2. Results

Figure 2 shows a comparison of the experimental force-displacement response with simulation results, where the drops in force correspond to the displacements at which the samples were held to acquire the MCT scans. The computational model used Voce hardening to capture plasticity and a Cocks-Ashby model for void growth. Simulation results shown in Figure 2 were acquired by directly meshing the initial state of the test sample from the MCT data. In addition to the model prediction being in excellent agreement with the force-displacement response, high-fidelity modeling (not shown) was able to accurately capture the specific pores at which failure initiation occurred. Using this information, the characteristics of those pores that caused failure to initiate at their location can be determined. In order to study the evolution of large voids, segmentation of the MCT data was performed at each load step. The characteristics (e.g., shape, volume, and location) of each void, and the coalescence of individual voids or networks of voids were tracked during deformation.

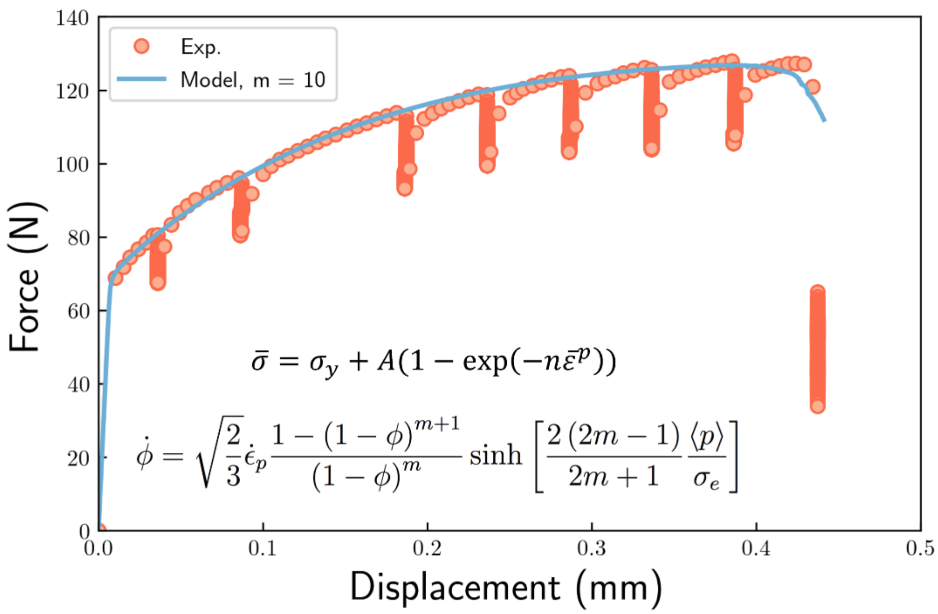

Fig.2 – Force-displacement of in-situ experimental results and model predictions after material calibration of an AM Al-Si10-Mg sample thinned on two surfaces.

3. Conclusions

The certification and qualification of AM parts for deployment requires many steps that are time-consuming and expensive. Developing a computational model to predict the failure in AM parts could reduce these qualification burdens and lead to more AM utilization in impactful applications. Identifying the characteristics of inherent porosity that often lead to failure in AM metals using 3D imaging in-situ mechanical loading can be used to develop these modeling tools.

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