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Analysis of Porosity Effects on Spall Failure of Additively Manufactured 316L SS

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Abstract

Additive manufacturing (AM) allows for tuning of mechanical properties for unique functionalities, and stainless steel is a prime candidate for use in many applications due to its high strength, ductility, and corrosion resistance. AM fabricated 316L stainless steel samples with intentionally random pore placement are compared to samples with known pore placement to study the interaction of the shock wave with individual and grouped pores. Velocity profiles were obtained using photon doppler velocimetry (PDV) probes placed strategically along the location of the known pores to understand the limits of local influence for the known pores. Post-mortem characterization of soft-recovered samples using electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM) was performed to investigate the strain accommodation around pores. It was observed that shock wave fronts are highly dispersed and slow as they propagate through the pore due to strain accommodation around individual pores. As a result, there is shifting of the spall plane away from the impact face. This slow wave front propagation also results in slow rise time and lack of velocity plateau in the collected velocity profiles when areas with pores were probed.

1. Introduction

Additively manufacturing (AM) is a powerful technique that provides control over the material microstructure and as such the resulting mechanical properties under complex loading conditions. However, to take full advantage of the process, it is imperative to understand the relationship between build parameters during the AM process, the resulting microstructure, and the ensuing changes in properties such as strength and failure mechanisms. This work focuses on understanding the effects of heterogeneities like tailored porosity on the shock compression and eventually dynamic failure of AM fabricated 316L SS, investigated using gas gun plate impact experiments. The understanding developed will enable design of additively manufactured parts with specific porosities to meet desired strength criteria, allowing for replacement of standard wrought stainless steel or for further performance improvement, e.g., to handle higher or more targeted loads.

2. Results

Plate-on-plate impact experiments were conducted on AM 316L SS samples with a variety of pore locations, pore sizes, and porosity percentages using the 80-mm single-stage gas gun at Georgia Tech. The following investigations were conducted

a. Effects of pore sizes on spall failure mechanisms were investigated by impacting samples with controlled random porosity with pores sizes of 200 µm, 350 µm, and 500 µm, and each with pore volumes of 1%, 3%, and 5%.
b. Effects of impact speed on spall failure mechansisms were investigated by impacting samples with controlled random porosity with 500 µm pores and 5% pore volume at 250 m/s and 400 m/s.
c. The effect of an individual pore on spall failure mechanisms was investigated by placing a single pore of ?? µm in the center of the sample for impact at 400 m/s.

For the 200 µm pores, the 1% and 3% porosity samples showed little difference compared to the AM sample with no porosity. However, when the porosity was increased to 5%, a shifted spall plane was evident, demonstrating aleration of the shock wave interactions within the sample. Free surface velocity profiles measured using photon doppler velocimetry (PDV) showed slower rise time and a lack of velocity plateau, most likely due to the slowing of the shock wave as it moves through the pores due to strain accommodation. The effects were also confirmed through EBSD and TEM analysis. The slowing of the shock waves became more evident as the pore size was increased. The 350 µm samples at 3% and 5% porosity had no spall plane visible in the cross section, but did have extensive pore collapse. However, the 500 µm had no obvious spall plane and incomplete pore collapse, suggesting that larger pores led to further slowing of the shock wave. Increasing the impact speed to 400 m/s for the 500 µm at 5% porosity samples led to a slower rise time than the non-porous sample, but spall initiation was limited in proximity to pores as compared to the non-porous sample.

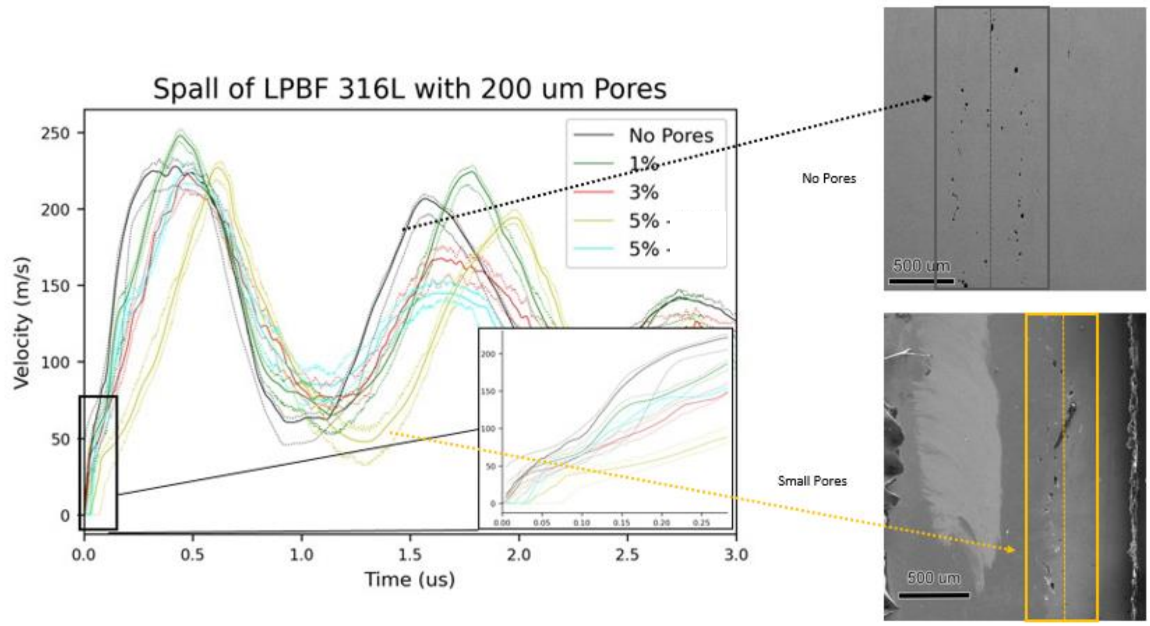

Fig.1 – PDV profiles showing different wave profiles indicative of differences in spall behavior of AM 316L SS with varying porosity and volume percents for samples with 200 µm pores

The study of single pores in AM 316L SS under dynamic tensile loading show differences in the spall failure mechanisms due to shock wave interaction with the pore as seen from the PDV velocity profiles measured from the sample back free surface.Further work is needed to elucidate these differences and correlate them directly with porosity.

3. Conclusions

The improvements in additive manufacturing technology have led to widespread use in industry as well as expanded our ability to tailor materials for strength or other mechanical properties. By controlling porosity, including introducing intentional porosity, we can alter the microstructure to influence the nature of shock wave interactons with porosity in a way that increases a material's resistance to spall failure.

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