Probing Mechanical Heterogeneity of Additively Manufactured Stainless Steel Using Digital Image Correlation

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The purpose of this work was to investigate the microstructural and mechanical heterogeneity of additively manufactured (AM) 316L stainless steel. AM is a novel technology facilitating the production of geometrically complex parts that could not be produced otherwise. Parts can be made with short lead time and low upfront cost. The layer-by-layer approach of manufacturing produces near-net shape parts with minimal need of post-processing. The production of AM parts generally produces columnar grains with smaller dendritic cells forming within grains causing anisotropic mechanical properties [1]. Grain and cell properties are heavily dependent on process parameters including scan speed, laser power, hatch spacing, and layer height [1-3]. Microstructural variation impacts mechanical properties such as hardness, yield strength, and tensile strength [3].

An Optomec LENS 500 DED machine was used to manufacture samples with commercially available 316L powder. Given the nature of AM, parts can be made with varying process parameters by editing specific lines of the printing file. The different processing parameters tested in this work were laser scan speed and laser power. All samples were manufactured with a hatch distance of 0.015 inches and a layer height of 0.015 inches. Initially, a parameter study was performed to ensure parts would be manufactured with a density upwards of 99%. It was found that the range of scan speed with a laser power of 400W was 18 to 54 inches per minute (ipm), and the range of laser power with a scan speed of 30 ipm was 300 to 700 W.

After determining the parameter range to be tested, microstructural characterization samples were manufactured with the gradient parameter ranges outlined above. The samples were then cut parallel to the build direction. A solution annealing (SA) heat treatment was then performed (1121°C for 2 hours) on one of the cut samples to compare the as-built (AB) and SA conditions. It was found that varying scan speed did not significantly impact the microstructure in terms of cell and grain size. When varying laser power, a significant change in microstructure was observed. As the laser power increased, the cell and grain size exponentially increased.

The hardness of each sample was measured using Vickers hardness (HV) and can be found in Fig. 1. It was found that the SA heat treatment reduced the hardness by about 20 HV on average for both the gradient power and gradient speed samples. No significant change was observed when varying the scan speed which corresponds well to the lack of change in microstructure. Laser power on the other hand showed a significant drop in hardness as laser power increased. This result was expected due to the higher laser power having higher residual heat and causing an annealing effect in the heat affected zone outside of the melt pool region.

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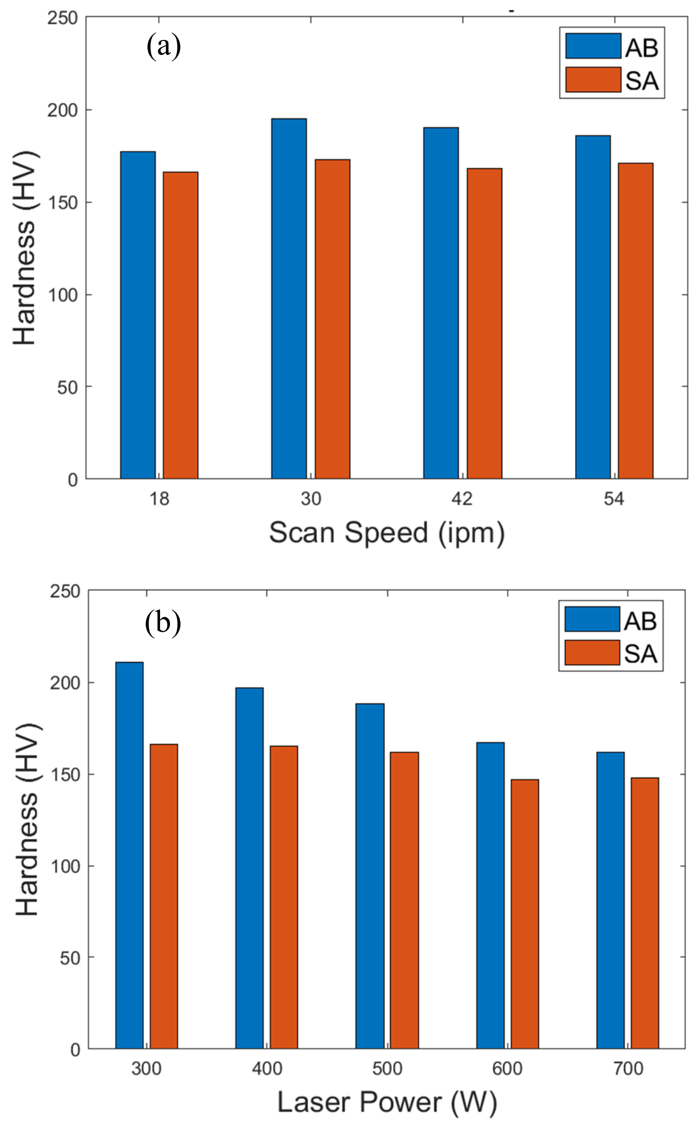

Fig. 1. Hardness (HV) vs (a) laser scan speed and (b) laser power.

Tensile bars with gradient parameters were also manufactured to be tensile tested using digital image correlation (DIC). DIC allows for local strain tracking under global stresses. Two samples, AB and SA gradient speed, were tested in this work. The tensile test was performed at a strain rate of $6.6x10^{-4}$ s^{-1} to failure. The tensile test results can be found in Fig. 2. It was observed that the SA samples had higher ductility compared to the AB samples which was expected due to the decrease in hardness and reduction of residual strain. Interestingly, however, the solution annealed sample had a higher tensile strength. This result was not expected given that hardness has been found to be an indicator of tensile strength. It was also observed that strain accumulated along the interface between parameter changes. Further investigation showed a decrease in interfacial hardness.

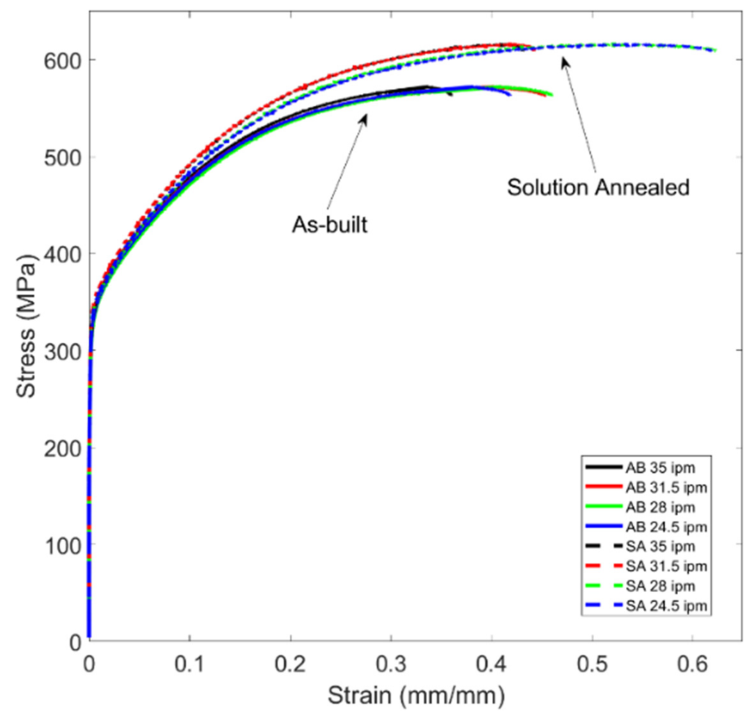

Fig. 2. Stress vs strain of gradient speed AB and SA samples

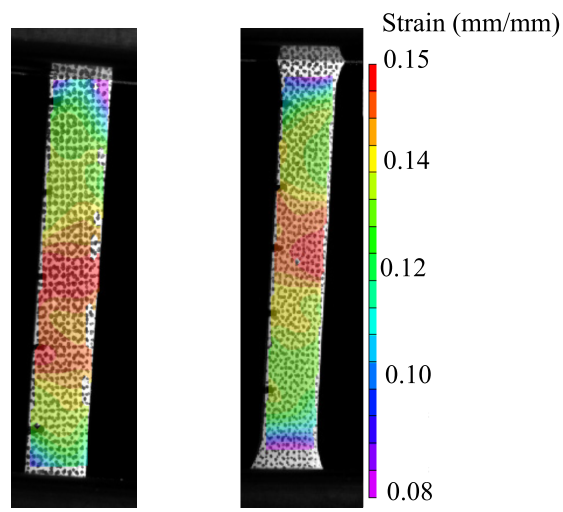

Fig. 3. DIC mapping of (a) AB at 500MPa and (b) SA at 500MPa where purple represents low strain and red represents high strain.

This work has proved that DIC can be used to determine localized strain under global stresses on AM samples as well as gradient parameter samples. Future work is planned to test the gradient power samples as well as investigate the decrease in interfacial hardness and increase in tensile strength of the SA condition. Future publications are being written in regards to this work.

Statement of Research Advisor

John developed a strategy to fabricate and validate the use of microstructurally graded specimen to study microstructure- property relationship for additively manufactured steel. The developed method is valuable for increasing the testing throughput to qualify additive manufactured alloys for high- temperature extreme environments in a range of energy and aerospace applications.

- *Xiaoyuan Lou, Materials Engineering*

References

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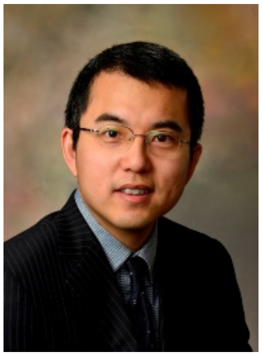
[3] Gor, M.; Soni, H.;Wankhede, V.; Sahlot, P.; Grzelak, K.;Szachgluchowicz, I.; Kluczy´ nski, J. A Critical Review on Effect of Process Parameters on Mechanical and Microstructural Properties of Powder-Bed Fusion Additive Manufacturing of SS316L. Materials 2021, 14, 6527.

Authors Biography

John Snitzer is recent graduate from the department of Materials engineering. He has designed gradient specimens to be tested using DIC to reduce the qualification time for AM materials in critical applications. He will be attending Purdue University for a graduate degree in Nuclear Engineering as a DOE-NE graduate fellow.



Dr. Xiaoyuan Lou is an Associate professor in the department of Materials Engineering. He oversaw the work performed and provided perspective into industry applications. He focuses on developing advanced manufacturing methods for applications in extreme environments, where components see high temperature, corrosion and oxidation, irradiation, etc.