Aerospace Engineering Doctoral Defense

Mechanical Behaviors at Elevated Temperature and Fatigue Strength Analysis of E-Beam PBF Additively Manufactured Ti6Al4V Components

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Abstract

High-temperature mechanical behaviors of metal alloys and underlying microstructural variations responsible for such behaviors are important areas of interest for many industries, particularly for applications such as jet engines. Anisotropic grain structures, change of preferred grain orientation, and other transformation of grains which occur both during metal powder bed fusion additive manufacturing processes, due to variation of thermal gradient and cooling rates, and afterward during different thermomechanical loads, which parts experience in their specific applications, could also impact its mechanical properties both at room and high temperatures. In this study, an in-depth analysis of how different microstructural features, such as crystallographic texture, grain size, grain boundary misorientation angles, and inherent defects, as byproducts of electron beam powder bed fusion (EB-PBF) AM process, impact its anisotropic mechanical behaviors and softening behaviors due to interacting mechanisms. Mechanical testing is conducted for EB-PBF Ti6Al4V parts made at different build orientations up to 600°C temperature. Microstructural analysis using electron backscattered diffraction (EBSD) is conducted on samples before and after mechanical testing to understand the interacting impact that temperature and mechanical load have on the activation of certain mechanisms. The vertical samples showed larger grain sizes, with an average of 6.6 μm, a lower average misorientation angle, and subsequently lower strength values than the other two horizontal samples. Among the three strong preferred grain orientations of the α phases, $\langle 1\ 1\ \bar{2}\ 1 \rangle$ and $\langle 1\ 1\ \bar{2}\ 0 \rangle$ were dominant in horizontally built samples, whereas the $\langle 0\ 0\ 0\ 1 \rangle$ was dominant in vertically built samples. Thus, strong microstructural variation, as observed among different EB-PBF Ti6Al4V samples, mainly resulted in anisotropic behaviors. Furthermore, alpha grain showed a significant increase in average grain size for all samples with the increasing test temperature, especially from 400°C to 600°C, indicating grain growth and coarsening as potential softening mechanisms along with temperature-induced possible dislocation motion. The severity of internal and external defects on fatigue strength has been evaluated non-destructively using quantitative methods, i.e. Murakami's square root of area parameter model and Basquin's model, and the external surface defects were rendered to be more critical as potential crack initiation sites.

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Zoom Link: https://asu.zoom.us/j/85219888545