DEVELOPMENT OF BUILD STRATEGIES FOR THIN-WALLED Ti6Al4V COMPONENTS USING LASER POWDER BED FUSION PROCESS

A THESIS

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Abstract

Complex thin-walled components find numerous applications in aerospace, automotive and marine domains to meet the demands in design, manufacturing, durability, reliability, fuel efficiency and sustainability due to their superior properties. Although thin-walled components offer several advantages, their manufacturing presents significant challenges, especially when it comes to achieve the required geometric characteristics, uniform distribution of tolerances, surface integrity, consistency and accuracy. Laser Powder Bed Fusion (LPBF) has created interest across the industries, in particular, aerospace sectors to produce metallic components with complex geometries directly from the CAD model. In LPBF process, a thin layer of material is selectively melted and solidified, resulting in the creation of a dense and precise geometric structure. However, the rapid heating and cooling cycles in this process result in a high temperature gradient, leading to thermal distortions. These distortions, in turn, cause dimensional inaccuracies and significant variation in the mechanical performance of the parts. Therefore, the present work is focused on the development of a systematic approach based on the inherent strain method, viz. Ansys Additive Print (AAP) software to predict the residual stresses and thermal distortion induced in thin-walled Ti6Al4V components and to improve the quality of parts produced in LPBF. During the development of the work, a single cantilever beam was initially considered. Subsequently, the study was extended to the aero-engine compressor blade, as these components are the suitable representation of thin-walled parts. The process parameters, such as laser power, scan speed, and hatch distance, were varied extensively in this study. It can be noted that upto 20 % deviation in residual stress and 10% deviation in maximum distortion were obtained between numerical and the experimental results. Additionally, it was found that the use of low energy density for fabricating the thin-walled components in LPBF process resulted in a significant reduction in residual stress and thermal distortions.

Microstructure and mechanical property of the LPBF-built parts are significantly affected by the input process parameters, therefore, the study was extended further on this investigation. Ti6Al4V specimens were fabricated using EOSINT M 280 machine, considering three different energy densities as similar to the residual stress and distortion study. Increase in energy density may result in increase in width (129 μm to 165 μm) of the prior β-grain boundaries. No significant change in yield strength was observed in specimens built with lower energy densities.

Furthermore, thin-walled components will experience extreme dynamic loading conditions during its service operations. Due to this, the material will undergo severe large deformations. Hence, the study was conducted to understand the dynamic compression behaviour of Ti6Al4V alloys at high strain rates using Split-Hopkinson Pressure Bar (SHPB) experiments. SHPB tests were performed for the varying strain rates ranging from 1100 s^{-1} - 3300 s^{-1}. LPBF-built samples exhibited high strain rate sensitivity, $m > 0$ under dynamic compression, which means that the flow stress increases with increase in strain rate increases. It was also observed that there was no significant change in yield strength for samples built with low energy density. At lower energy density, the formation of a hierarchical structure of relatively fine α'-martensite, separated from each other by a dislocation density, leads to increase in yield strength. Dynamic compression of as-built and heat treated samples were compared and found that heat treated samples exhibited 12% lower yield strength than the as-built samples, as expected; this yield strength reduction was due to the transformation of α' martensite to α, lamellar α + β and retained β as confirmed by microstructure and SEM studies. Based on the above findings, it is concluded that the usage of low energy density in LPBF process exhibits superior yield strength with significant reduction in residual stress and thermal distortions in the thin-walled Ti6Al4V components.

Keywords: Ti6Al4V; Laser Powder Bed Fusion; Thin-walled parts; Residual stress; Thermal distortion; Microstructure; High strain rate; SHPB