Uniaxial Creep and Creep Crack Growth Testing in 316L Stainless Steel Manufactured by Laser Powder Bed Fusion

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Abstract

Additive manufacturing, specifically laser powder bed fusion, is a novel technique which could become key to manufacturing net-shaped metal components with complex geometries. By manufacturing components in successive layers, restrictions on geometric complexity as well as better material economy, reduced manufacturing variability and a reduced manufacturing footprint could be achieved. The current issues with this technique are that very high residual stresses, significant variations in microstructure and large pores can be developed. The combination of defects and tensile stresses at the surface of the component mean that when in operation at high temperatures, defects can grow by creep processes, even without applied loads.

Data from uniaxial creep tests performed at 700 °C were analysed and compared to similar tests performed at 650 °C. Samples built in two directions were tested: vertical samples, with loading direction parallel to build direction and horizontal, with loading direction perpendicular to build direction. Properties derived from these tests were used in the FEA simulations for CCG.

CCG tests were performed on C(T) samples manufactured by LPBF. The C(T) samples were manufactured in three orientations to understand the anisotropic nature of LPBF. FEA was used to partition the resulting data; however, a new damage-based material model is required to accurately model the acceleration in creep strain before the node debonds. The C^* parameter was also deemed inappropriate to characterise sample behaviour due to arbitrary accelerations in crack growth caused by porosity not observed in wrought materials.

Metallographic analysis was performed to examine the crack path and the interaction of the main crack with existing defects. The EBSD technique and SEM were also used to understand grain structure and microstructural effects on creep behaviour. Vertical samples were found to be more creep resistant than the horizontal samples due to the resulting large grain columnar structure in the build direction, which reduced the effect of dislocation creep.

Minimum creep strain rates for vertical samples were up to a factor of 12 times smaller than those of horizontal samples, and strain rates for a given applied stress at 700 °C were double those at 650 °C. The findings are explained by reduced grain boundary diffusion when samples were loaded parallel to the columnar grain direction.