Effects of cyclic elastoplastic deformation on microstructure and residual stress of AISI 316L fabricated via Laser-Powder Bed Fusion

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Background

Additive Manufacturing (AM) technologies based on localised melting of powder precursors such as Electron Beam Melting (EBM) or Laser-Powder Bed Fusion (L-PBF) have emerged in the last few decades as an excellent alternative to traditional subtractive-based fabrication of metallic structural components [1]. In particular, the possibility to fabricate complex-shaped parts with intricate multiscale features, such as cellular architectures, opens a whole new spectrum of opportunities, allowing for instance to optimise the efficiency of the final products and to reduce materials consumption. Nonetheless, it is known that powder-melting AM technologies are not free of problems, primarily due to the unavoidable high thermal gradients involved during the fabrication, triggering the formation of porosities and other material inhomogeneities, such as, but not limited to, multiscale residual stress [2]. Such inhomogeneities are expected to result in inaccurate estimation of the fatigue performance of the additively manufactured components, especially when dealing with the High Cycle Fatigue (HCF) regime. Conversely, in the specific context of Low Cycle Fatigue (LCF) regime, a fundamental understanding of the role of these inhomogeneities is yet to be achieved, mainly due to the nonlinear material response experienced, i.e., cyclic plasticity[3]. In LCF regime, the occurring plastic deformation is known to have an impact on mechanical properties via dynamic strain hardening or softening mechanisms [4], and it is also expected to have an impact on residual stress and its interplay with the material microstructure. Despite the importance of understanding this mutual relationship, the current literature result is still limited.

Current Investigation

In this study we investigate the evolution of residual stress and microstructural characteristics of L-PBF AISI 316L stainless steel cylindrical specimens subjected to cyclic elastoplastic deformation at room temperature. With the aim of monitoring the evolution of these characteristics during a LCF test, n.4 specimens were mechanically tested at a different number of applied loading cycles at a constant strain amplitude and load ratio, see Figure *1*. The macroscopic response of the material showed a brief cyclic hardening behaviour, followed by a persistent softening stage.

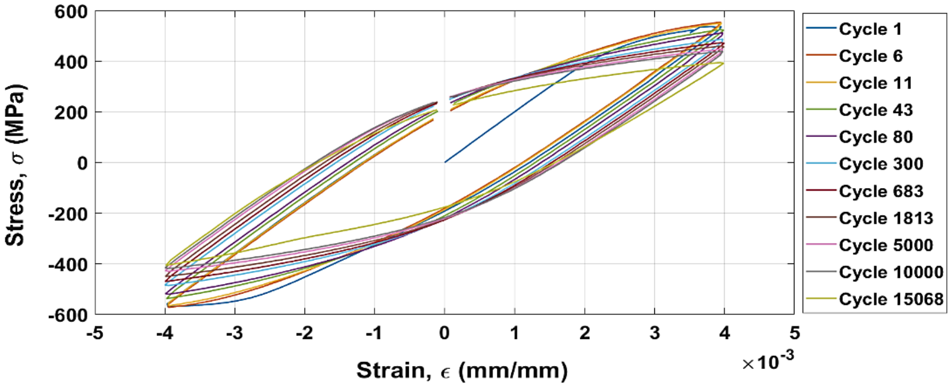

Figure 1: Strain-controlled stress-strain cycles of L-PBF AISI 316L cylindrical specimen. Strain rate and strain amplitude were set at $4*10^{-3}$ s^{-1} and 0.4% respectively.

Following, Neutron Diffraction (ND) was used to map the radial distribution of the three Types I principal residual stresses, and to gain insights into the finer-scale deformation mechanisms via peak broadening analysis. Texture analysis was eventually performed to unveil possible correlations of the microstructure preferential orientation with the presence of residual stress in the materials. Example results for as built and fatigued samples are reported in Figure 2. Results and implications of this research are widely discussed.

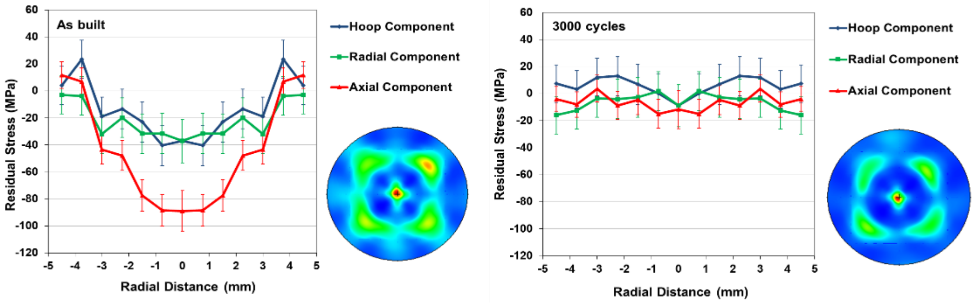

Figure 2: Residual stress distribution and pole figure for the FCC (220) Bragg reflection for the (left) as built and (right) fatigued sample.

References

[1] S. Gorsse, C. Hutchinson, M. Gouné, and R. Banerjee, *Sci. Technol. Adv. Mater.*, Vol.18 (2017), p. 584–610
[2] D. Guo *et al.*, *Mater. Des.*, Vol. 207(2021), p. 109782
[3] M. Pelegatti *et al.*, *Int. J. Fatigue*, Vol.165 (2022), p. 107224
[4] S. G. Hong and S. B. Lee, *Int. J. Fatigue*, Vol. 26 (2004), p. 899–910