

YIELD SURFACE EVOLUTION IN LPBF SS316L: EFFECTS OF ORIENTATION AND PRE-DEFORMATION

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1. Introduction

Laser powder bed fusion (LPBF) is an additive manufacturing (AM) technique, which has enabled the production of complex stainless steel 316L (SS316L) components with desired geometries and applications across aerospace, biomedical and energy sectors. However, the layer-by-layer fabrication process introduces inherent microstructural anisotropy, residual stresses and directional mechanical properties [1]. Conventional uniaxial testing methods are insufficient to fully describe the mechanical behavior of such materials under real service conditions, where multiaxial stress states are dominant.

The concept of the yield surface provides a comprehensive framework to characterize the onset of plastic deformation under complex loading conditions. Despite its importance, experimental identification of yield surfaces for AM materials remains limited. This study addresses this gap by investigating the initial yield surface and its evolution under plastic pre-deformation in LPBF-manufactured SS316L, considering different build orientations and comparing the results with wrought material.

2. Materials and methods

SS316L specimens were fabricated using LPBF system (Renishaw AM250) in three distinct build orientations: horizontal (XY), inclined at 45° (ZX) and vertical (Z). The as-built samples underwent stress-relief heat treatment before machining into

thin-walled tubular specimens suitable for multiaxial testing.

The mechanical testing was performed on the MTS 858 biaxial testing machine under controlled axial and torsional loading conditions at room temperature (23°C). Vishay 120Ω temperature compensated strain gauges were bonded on the outer surface of the tubular specimens to measure and control axial, shear and hoop strain. A single-specimen probing methodology was employed to determine yield points across 16 distinct strain paths in the axial–shear strain space [2]. The loading process during probing stage was strain controlled maintaining a constant ratio of the strain components. Subsequently, the unloading was carried out under stress control until zero force and torque were reached. Yield surfaces were determined at 0.001% offset definition of yield using Szczepiński anisotropic yield criterion (Eq. (1)) at initial state and subsequently tracked after controlled tensile plastic pre-strain equal to 0.35%, 0.5% and 0.8%.

$$f(\sigma) = A\sigma^2 + 2B\sigma\tau + C\tau^2 + 2D\sigma + 2F\tau - 1 = 0 \quad (1)$$

Additionally, microstructural characterization was carried out using electron backscatter diffraction (EBSD) to correlate grain morphology and orientation with the observed mechanical anisotropy.

3. Results and discussion

The results revealed a strong dependence of mechanical behavior and yield surface characteristics on the printing orientation. As shown

in Fig. 1, the initial yield surfaces of LPBF specimens exhibit an elliptical shapes compared to the nearly symmetric yield surface of wrought SS316L. Among the AM specimens, the XY and ZX orientations demonstrated relatively higher yield strength and more uniform behavior, whereas the Z-oriented specimens showed the lowest strength and the most pronounced anisotropy. This behavior is attributed to the orientation of melt pool boundaries and interlayer defects relative to the loading direction.

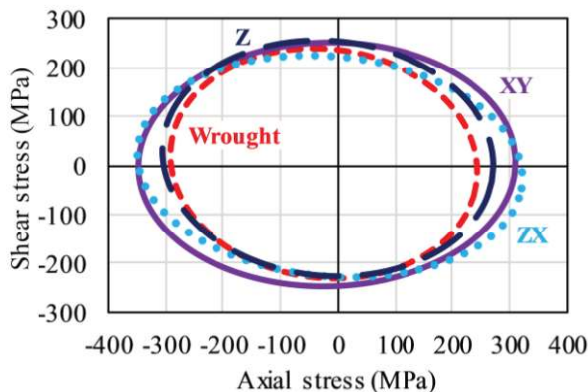


Fig. 1. Comparison of the initial yield surfaces at $10\mu\epsilon$ offset definition of yield.

The evolution of the yield surface under plastic pre-deformation demonstrated complex hardening–softening behavior [2]. For wrought SS316L, the yield surface initially contracted (indicating kinematic softening) and then expanded with increasing pre-strain value, reflecting isotropic hardening mechanisms. In contrast, LPBF specimens exhibited orientation-dependent evolution, with non-uniform contraction, expansion and rotation of yield surfaces. The significant rotation of the yield surface was observed in LPBF specimens, particularly in XY and ZX orientations, indicating directional redistribution of internal stresses and anisotropic hardening. The Z orientation showed comparatively smaller rotation but more pronounced softening effects.

Microstructural analysis using EBSD revealed that the anisotropic mechanical behavior is strongly correlated with grain morphology. As shown in Fig. 2, while wrought SS316L exhibits equiaxed grains and isotropic structure, LPBF specimens show orientation-dependent grain structures. In particular, the Z-oriented samples contain columnar grains aligned along the build direction, which contribute to reduced ductility and directional strength. In contrast, XY and ZX orientations exhibit more equiaxed or mixed grain structures, leading to improved mechanical performance.

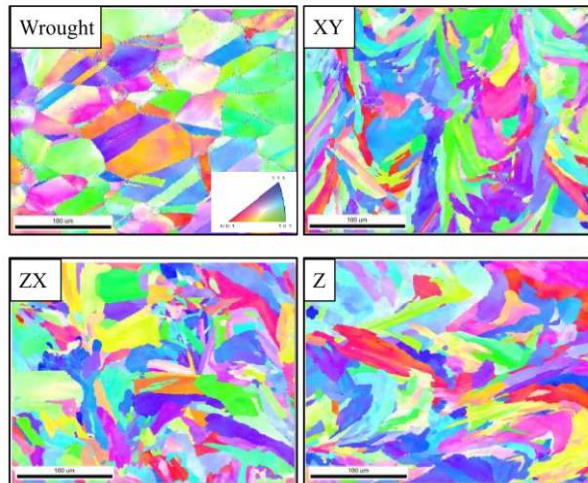


Fig. 2. IPF maps of specimens tested.

4. Conclusions

This study provides a comprehensive experimental investigation of the yield surface and its evolution in LPBF-manufactured SS316L, highlighting the critical role of printing orientation and plastic pre-deformation. The results demonstrate that AM materials exhibit significant anisotropy in both initial and evolving yield surfaces, with distinct behavior depending on build direction. The findings emphasize that conventional isotropic yield criteria are insufficient to describe the mechanical response of LPBF materials accurately. Instead, advanced anisotropic models, supported by experimental data such as those presented in this work, are necessary for reliable prediction of material behavior under complex loading conditions.

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References

- [1] Dubey, V.P., Przygucka, D., Pawlik, M., Kowalewski, Z.L., Wood, P., Kopec, M. Microstructural studies on early-stage deformation in thin-walled LPBF-manufactured SS316L considering its printing orientation. *Mater. Today Commun.*, 2026, 50, 114531.
- [2] Dubey, V.P., Kopec, M., Przygucka, D., Pawlik, M., Wood, P., Kowalewski, Z.L. Effect of the printing orientation on the yield surface and its evolution reflecting plastic pre-deformation of additively manufactured stainless steel 316L. *Int. J. Adv. Manuf. Technol.*, 2025, 140(1), 313-334.