Effect of Build Orientation on the Yield Surface of Stainless Steel 316L Fabricated by Laser Powder Bed Fusion Melting (LPBF-M)

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Abstract. The Laser Powder Bed Fusion Melting (LPBF-M) method was used to additively manufacture stainless steel 316L tubes in three different orientations. The yield surface approach was implemented to assess the variation of mechanical properties within the as-built specimens. Yield surfaces were determined for each build orientation based on the definition of yield stress for 0.005% plastic offset strain. The initial yield surfaces obtained for the as-built material exhibit anisotropic behaviour, possibly resulting from the preferred grain orientation developed during LPBF-M processing.

Possible Sessions

23. Testing of Additive Materials, 16. Novel Experimental Techniques

Introduction

Stainless steel 316L (SS316L) is widely used in several industries due to its exceptional mechanical properties, corrosion resistance, weldability, and formability [1]. Additionally, its low thermal conductivity, high melting point, and other distinctive attributes make it well-suited for additive manufacturing (AM) [2]. Several AM technologies, such as Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Fused Deposition Modeling (FDM), and Binder Jetting (BJ), are used for the fabrication of SS316L. Selecting the right printing technology and parameters is crucial to manufacture crack-free components with minimal porosity. Uniaxial tensile tests carried out on SS316L produced through various AM processes show enhanced mechanical properties in the horizontal and 45° orientations compared to that in the vertical orientation [3]. However, uniaxial testing methods to characterize materials provide only limited data concerning the mechanical strength and damage of materials in a single direction which does not simulate the real-world stress conditions encountered by materials in most engineering applications. To fully understand all aspects of material's behaviour, such as initial texture or anisotropy, yield surface identification in the biaxial or triaxial stress space is important. The yield surface can be described as a region in the stress space where the material always behaves as elastic. The effects of yielding, along with that of isotropic and kinematic hardening, can all be described by using the yield surface.

Therefore, this research aims to conduct an experimental investigation of yield surface identification in the biaxial stress space based on the offset yield point definition for AM SS316L in three different build orientations. Subsequently, the effect of building orientation on the yield surface was assessed.

Materials and Methods

The material investigated in this research was AM SS316L, which was additively manufactured by using the Renishaw AM 250 system and the SS316L powder feedstock. The round tubes were printed in three orientations (XY – horizontal, Z – vertical and ZX – 45°) using the process parameters outlined in Table 1.

Region	Layer thickness [μm]	Hatch distance [mm]	Beam Comp [mm]	Focal point [mm]	Power [W]	Point distance [μm]	Exposure time [μs]	Scan speed [mm/s]	Energy density [J/mm3]
Volume Fill Hatch	50	0.11	0.025	0	195	60	80	750	47.27
Scanning strategy	Meander								

Table 1. Process parameters applied during AM

Following the AM process, the newly formed specimens were exposed to stress relief by undergoing a 470°C soak for a duration of 6 hours. This was done while the specimens were still attached to the build plate. The tubes were detached from the building plate using wire cutting and then further machined to produce the tubular specimens.

The mechanical testing was performed on the MTS 858 biaxial testing machine 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 components. Yield points were determined by the technique of sequential probes of the single-specimen along different paths in the plane stress state. Starting from the origin, loading in each direction took place until a limited plastic strain was observed (in our case it was 1.5×10^{-4}). The limited plastic strain of 1.5×10^{-4} (0.015%) was employed for probing in individual loading paths to ensure, that the plastic offset strain falls within the appropriate range of the yield definition assumed. 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. The experimental procedure was performed along 17 stress paths, starting with simple tension and finishing with tension in the same direction. The loading and unloading were carried out for the following strain paths 0°, 30°, 45°, 60°, 90°, 120°, 135°, 150°, 180°, 210°, 225°, 240°, 270°, 300°, 315°, 330°, 360° in the $(\varepsilon_{xx}, \sqrt{(3/(1+\ \nu)^2)}\varepsilon_{xy})$ strain plane. Based on the stress-strain characteristic, the yield points for each path at 0.005% plastic offset strain were determined. The yield surface was obtained by fitting the experimental yield points with the Szczepinski anisotropic yield equation using the least squares method [4].

Results and Discussion

Figure 1(a) shows the XY – horizontal printed AM SS316L response in biaxial stress plane to the strain controlled loading program. It can be observed, that there is negligible deviation from linearity during loading and unloading for each paths. Similar results were obtained for the Z – vertical and ZX - 45° printed AM SS316L. Figure 1(b) depicts a cumulative representation of the initial yield surface of each build orientation in the biaxial stress space that were obtained from experimental results at 0.005% plastic offset strain. It can be observed, that the yield surfaces have distinct shapes. Whereas, the size of yield surface representing the XY orientation is larger than the other two build orientations of SS316L. The Z – vertical printed SS316L showed lower tensile yield properties and comparable yield properties in other directions as compared to that of XY – horizontal and ZX - 45° printed AM SS316L. Previous studies have shown, that when SS316L is printed in the vertical orientation, the tensile properties is lower than in horizontally printed specimens [5].

The yield surfaces for each build orientation confirm the presence of initial anisotropy at 0.005% plastic offset strain with a slight shift in the compression direction. Additionally, the yield surface axis ratios for each build orientation are smaller than that of the Huber-von Mises isotropic yield surface (1.73). The major axes ratio values of the yield surfaces were 1.60, 1.44 and 1.58 for XY (horizontal), Z (vertical) and ZX (45°) build orientations, respectively. The results strongly indicate the presence of texture in each build orientation.

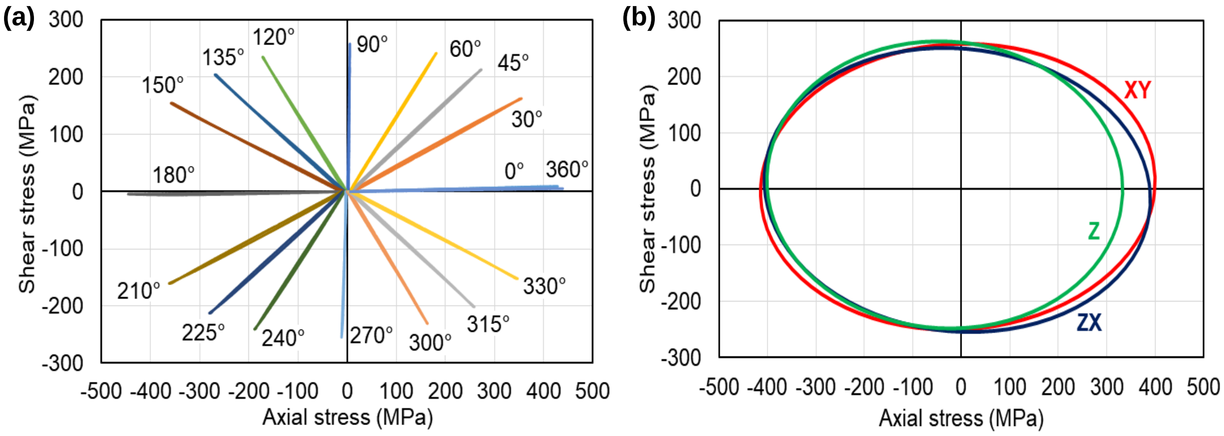

Fig. 1. Stress response to the strain controlled loading program for XY build orientation **(a)** and comparison of the yield surfaces for three build orientations **(b)**.

Conclusion

In this paper, an experimental approach was performed to investigate the effect of build orientation on the LPBF-M AM stainless steel 316L behaviour using the yield surface concept. The 0.005% plastic offset strain was adopted as yield definition. Such approach was found to be suitable for sequential probing technique under strain-controlled paths during the yield surface determination. The initial yield surfaces of the as-built AM SS316L for three build orientations (XY – horizontal, Z – vertical and ZX – 45°) were identified. It was observed that the size of yield surface for XY build orientation was largest and the tensile yield properties for Z build orientation was lowest in comparison among three build orientations. Such behaviour can be attributed to the texture presence in the material tested.

References

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