

# Investigates The Influence of Build Orientation on The Fatigue Behaviour of Lpbf-Fabricated 316l Stainless Steel

G. Pugalvendhan<sup>1</sup>, Dr. B. Anandavel<sup>2</sup>, and Dr. K. Venkatesan<sup>3</sup>

<sup>1</sup>PG Student, Department of Metallurgical Engineering, Government College of Engineering, Salem - 11

<sup>2</sup>Assistant Professor [Sr. Grade], Department of Metallurgical Engineering,  
Government College of Engineering, Salem - 11

<sup>3</sup>Head of the Department, Department of Metallurgical Engineering  
, Government College of Engineering, Salem – 11

**Abstract**—Laser Powder Bed Fusion (LPBF) is an advanced metal additive manufacturing process extensively used for producing complex geometries with high dimensional accuracy. However, the layer-wise fabrication inherent to LPBF induces anisotropic microstructural features, directional solidification patterns, and orientation-dependent defect distributions. These characteristics significantly influence mechanical performance, particularly fatigue behaviour, where crack initiation and propagation are strongly affected by build orientation, internal porosity, and interlayer bonding quality. The present study investigates the influence of build orientation on the fatigue crack propagation behaviour of LPBF-fabricated 316L stainless steel by comparing specimens manufactured at 0° orientations relative to the build platform. The hypothesis of this research is that specimens fabricated at a 20° orientation require greater time for crack propagation than those built at 0° orientation. This is attributed to crack deflection across inclined layer boundaries, increased crack path tortuosity, and variation in the effective stress intensity factor caused by anisotropic microstructural alignment. Fatigue specimens were produced using LPBF process to ensure high density and consistent microstructure. Post-fabrication machining and surface finishing were performed to minimize surface roughness effects and isolate orientation-dependent fatigue behaviour. Mechanical characterization was conducted and Fractographic analysis was carried out to identify crack initiation sites, examine crack growth patterns, and correlate failure mechanisms with build orientation and defect morphology. The experimental results demonstrate that build orientation significantly influences fatigue crack growth characteristics. Specimens fabricated at 20° orientation exhibited modified crack propagation paths due to interaction with inclined interlayer boundaries, resulting in increased

crack deflection and extended effective crack length compared to 0° specimens. The findings indicate that angular build orientation alters crack propagation mechanisms and contributes to differences in fatigue life. This study establishes a direct correlation between build orientation and fatigue crack propagation behaviour in LPBF 316L stainless steel, providing insights for optimizing component orientation during fabrication to enhance fatigue performance and structural reliability in critical engineering applications.

**Index Terms**—Laser Powder Bed Fusion (LPBF), 316L Stainless Steel, Build Orientation Fatigue Crack Propagation, Anisotropic Microstructure, Crack Deflection, Stress Intensity Factor, Fractographic Analysis.

## I. INTRODUCTION

Rapid Prototyping (RP) originally referred to technologies used to quickly create physical models from digital designs for evaluation and testing. However, with advancements in machine precision, materials, and process control, these technologies can now produce fully functional parts. As a result, the term Additive Manufacturing (AM) was adopted to better represent their expanded capabilities.

Additive Manufacturing involves creating three-dimensional objects directly from CAD models by building them layer by layer. Unlike traditional methods such as machining or casting, AM does not require complex tooling or multiple processing steps, making production simpler and more flexible.

In this process, a 3D model is sliced into thin layers, which are sequentially formed to produce the final part. Smaller layer thickness improves accuracy and surface finish. Different AM systems vary based on

materials, layer formation techniques, and bonding methods, which influence properties like strength, cost, and production speed.

Overall, AM has evolved beyond prototyping into a key manufacturing technology, enabling complex designs, reducing production time, and transforming modern engineering and industrial practices.

## II. LASER POWDER BED FUSION

A typical PBF-LB machine consists of a build platform, recoater, powder dispenser, powder collector, and a laser system (laser and scanner), as shown in Figure 1.1. Laser Powder Bed Fusion uses a high-powered laser to selectively melt metallic powder in an inert atmosphere. The laser scans based on sliced CAD data, forming localized melt pools that rapidly solidify into dense structures. The process begins with a 3D CAD model, which is sliced into thin layers (typically  $\sim 40 \mu\text{m}$ ). These layers are transferred to the machine as scan data. Powder is spread over the build platform using a recoater, and the laser melts the material according to the layer pattern. After each layer, the build platform lowers, and a new layer of powder is deposited. This sequence repeats until the component is fully built.

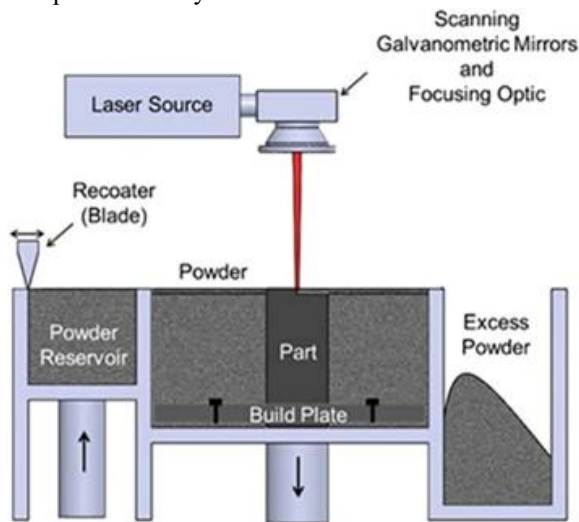


Figure 2.1. Schematic of PBF – LB process

The entire process occurs in an inert gas environment (usually nitrogen) to minimize oxidation. After fabrication, unmelted powder is collected and reused after sieving. Finally, the part is removed from the build platform using electrical discharge machining (EDM).

## III. METHODOOOGY

The study begins with a literature review on fatigue behavior of 316L stainless steel, comparing conventional processes like forging with additive manufacturing, focusing on fatigue mechanisms, manufacturing effects, defect formation, and existing data. Based on this, 316L stainless steel is selected due to its corrosion resistance and strength, and specimens are fabricated using Laser Powder Bed Fusion (LPBF), where metal powder is melted layer by layer. The fabricated samples, built at  $0^\circ$  orientation, may contain defects such as pores and residual stresses due to rapid thermal cycles. After fabrication, specimens are removed using wire-cut EDM, machined, and polished to ensure proper geometry and minimize surface irregularities. Fatigue testing is then performed under cyclic loading to determine fatigue life, represented through S–N curves. Fracture surfaces are analyzed using Scanning Electron Microscopy (SEM) to identify crack initiation, propagation, and defects. Fatigue data for forged 316L are collected from literature under comparable conditions, and finally, a comparative analysis is conducted to evaluate the influence of LPBF on fatigue performance by correlating experimental results with microstructural features and defects.

## IV. LITERATURE REVIEW

Edin et al. (2022) developed a rapid method to evaluate stress-relief heat treatment in LPBF 316L using distortion measurements. They found that heat treatment at  $\sim 900^\circ\text{C}$  minimized residual stress and distortion by dissolving sub-grain structures. However, this also reduced strength slightly while improving ductility, highlighting a trade-off between stress relief and mechanical properties. Upon further optimization for boiler-grade alloy steels (T11/T91), identifying that maintaining high transient current immediately before forging improves penetration and bead geometry. These studies provided the first systematic parameter maps for industrial MIAB operation. Finite-element modelling (FEM) has been central to understanding magnetic flux distribution and force generation during MIAB welding. Liu et al. (2022) developed a numerical model for laser-ultrasonic inspection to detect microdefects ( $\approx 0.01\text{--}0.1 \text{ mm}$ ) in LPBF 316L stainless steel. Their

results showed that ultrasonic wave features (arrival time and amplitude) correlate with defect size and location, enabling accurate detection and sizing of small surface flaws. This approach improves non-destructive evaluation of defects that significantly affect fatigue and corrosion performance. Later works by other researchers integrated experimental validation with FEM predictions, confirming the relationship between electromagnetic force and measured arc rotation speed.

Yin et al. investigated how surface roughness affects laser ultrasonic (LU) inspection in LPBF 316L stainless steel. They found that increased roughness amplifies noise, reduces signal clarity, and lowers defect detection accuracy by scattering ultrasonic waves. The study highlights that surface condition significantly impacts non-destructive testing reliability, requiring post-processing or signal optimization for accurate defect detection. He performed comprehensive testing on MIAB-welded T11 low-alloy steel tubes for high-pressure applications. The thermo-mechanically affected zone (TMAZ) exhibited grain refinement, bainitic/acicular ferrite transformation, and increased hardness. Welded specimens often showed higher tensile strength than base metal, with no internal defects when high arc currents were used.

## V. EXPERIMENTAL INVESTIGATION

### 5.1. Materials And Process Selection

316L stainless steel is selected due to its high corrosion resistance, strength, and wide engineering applications. Laser Powder Bed Fusion (LPBF) is chosen to fabricate specimens and study their fatigue behaviour against forged 316L.

### 5.2. Fabrication Process

Specimens are fabricated using LPBF by melting metal powder layer by layer with a high-energy laser based on a CAD model. Rapid heating and cooling produce fine microstructure but may introduce defects like pores and residual stresses.

### 5.3. Specimen Preparation

Fabricated specimens are removed using wire-cut EDM and then machined and polished to required geometry. Proper surface finishing minimizes

irregularities and ensures consistent fatigue testing results.

### 5.4. Mechanical Testing

Fatigue testing is conducted under cyclic loading to determine the number of cycles to failure. The results are used to generate S–N curves representing the material’s fatigue behaviour.

### 5.5. Microstructural Analysis

Fracture surfaces are examined using SEM to study crack initiation, propagation, and internal defects. This analysis helps identify the microscopic causes of fatigue failure.

### 5.6. Literature Data Collection

Fatigue data for forged 316L are collected from research papers under comparable testing conditions. These data serve as a reference for evaluating LPBF specimen performance.

## VI. RESULT & DISCUSSION

### 6.1. Tensile Test

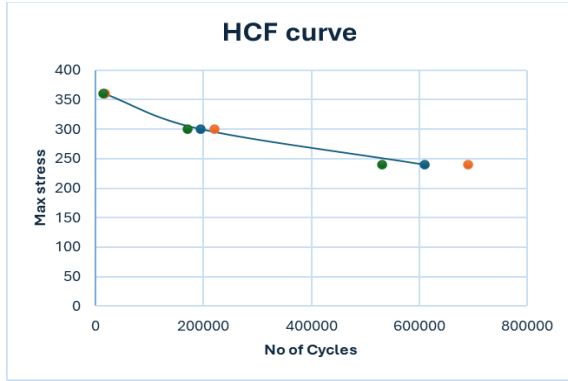
The tensile test is used to determine how a material behaves when it is pulled until it breaks. The test shows important mechanical properties such as strength, ductility.

ID no	Specimen dimension (mm)	U.T.S (Mpa)	Y.S (Mpa)	Elongation (%)
T1	3.6 x 3.2	613	508	15.29
T2	3.6 x 3.2	601	484	9.1

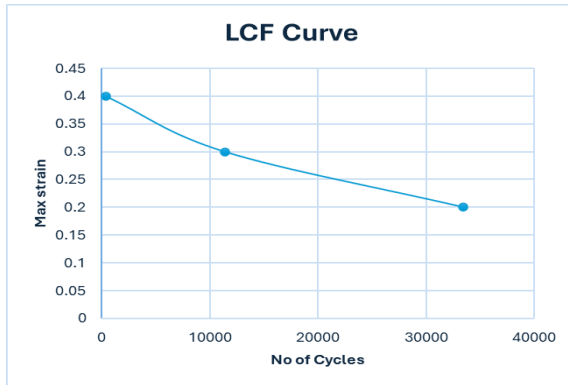
Table 6.1. Tensile Test results

### 6.2. Fatigue Test

A fatigue test studies how a material fails under repeated or cyclic loading, even when the applied stress is lower than the material’s tensile strength. Many engineering parts break this way, not by one big load but by millions of tiny loads. In a fatigue test, a specimen of a 316L Stainless Steel is placed in a fatigue testing machine and subjected to repeated tension.



Graph 6.1. S-N curve of HCF



Graph 6.2. S-N curve of LCF

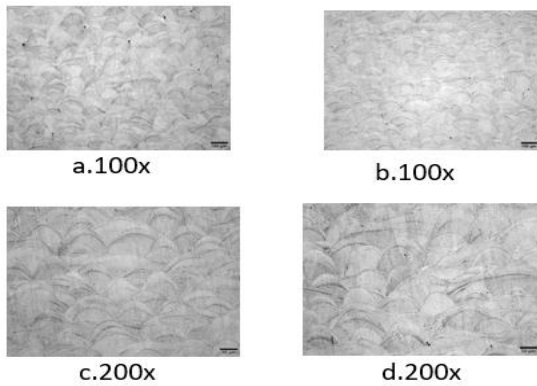


Figure 6.1. Microstructures before Fatigue Test

### 6.3 Slip Bands

#### 6.3.1 Observation

Slip bands appear as parallel or slightly curved dark lines inside individual grains in the microstructure.

### 6.4 Grain Boundary Region

#### 6.4.1 Observation

Grain boundaries appear as irregular lines separating grains with different orientations.

### 6.5 Inclusion / Second Phase Particle

#### 6.5.1 Observation

These appear as dark spots or irregular particles embedded within the matrix.

### 6.6 Possible Microcrack Initiation

#### 6.6.1 Observation

There are no microcrack as very fine sharp dark lines or discontinuities in the microstructure.

## VII. CONCLUSION

In conclusion, 316L stainless steel exhibits robust static strength with an average UTS of 607 MPa, yet its longevity is strictly governed by cyclic loading conditions and microstructural stability. Experimental data shows a significant extension in fatigue life—increasing from under 20,000 to over 600,000 cycles—as stress is reduced from 60% to 40% of UTS. This degradation process is driven by the accumulation of persistent slip bands and dislocation pile-ups at grain boundaries and brittle inclusions, which act as primary sites for microcrack initiation. Ultimately, because the transition from elastic deformation to fatigue fracture is a localized process, optimizing the material's resistance depends heavily on minimizing internal inclusions and surface defects that trigger these crack-nucleation mechanisms.

## REFERENCES

- [1] Y. Aghayar et al., “Microstructure tailoring of laser powder bed fused 316L impellers for enhanced mechanical properties and optimum electrochemical characteristics through hot isostatic pressing,” *Mater. Sci. Eng. A*, vol. 925, 2025, doi: 10.1016/j.msea.2025.147916.
- [2] N. Ahmed et al., “Process parameter selection and optimization of laser powder bed fusion for 316L stainless steel: A review,” *J. Manuf. Process.*, vol. 75, pp. 415–434, 2022, doi: 10.1016/j.jmapro.2021.12.064.
- [3] M. A. Obeidi et al., “Comparison of the porosity and mechanical performance of 316L stainless steel manufactured on different LPBF machines,” *J. Mater. Res. Technol.*, vol. 13, pp. 2361–2374, 2021, doi: 10.1016/j.jmrt.2021.06.027.

- [4] K. O. Akimov and K. V. Ivanov, "Effect of low-energy high-current electron beam treatment on LPBF 316L stainless steel," *Next Mater.*, vol. 9, 2025, doi: 10.1016/j.nxmte.2025.101328.
- [5] B. S. Alquaity, "Influence of nozzle diameter and gas flow on spatter removal in LPBF: A CFD approach," *Results Eng.*, vol. 25, 2025, doi: 10.1016/j.rineng.2024.103759.
- [6] Anand et al., "Tribocorrosion behavior of nickel-free duplex and 316L stainless steels fabricated by LPBF in artificial seawater," *J. Mater. Res. Technol.*, vol. 38, pp. 2197–2211, 2025, doi: 10.1016/j.jmrt.2025.08.070.
- [7] Baslari et al., "Embedding of Y3Al5O12: Ce within 316L stainless steel parts by LPBF," *Addit. Manuf. Lett.*, vol. 8, 2024, doi: 10.1016/j.addlet.2023.100186.
- [8] Bevan et al., "Effect of heat treatment on recrystallisation of thin-walled 316L by LPBF," *Mater. Des.*, vol. 258, 2025, doi: 10.1016/j.matdes.2025.114592.
- [9] M. Bojinov et al., "Corrosion of 316L stainless steel produced by LPBF," *Materialia*, vol. 34, 2024, doi: 10.1016/j.mtla.2024.102055.
- [10] Crisafulli et al., "Microstructural characterization and mechanical behaviour of LPBF 316L," *Theor. Appl. Fract. Mech.*, vol. 131, 2024, doi: 10.1016/j.tafmec.2024.104343.