

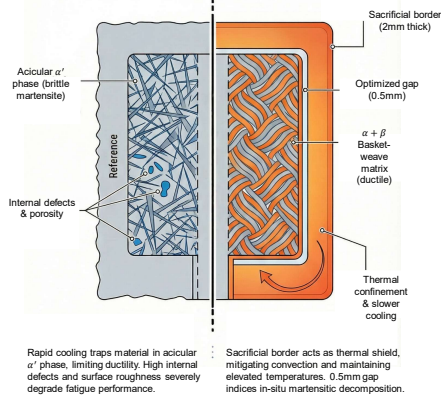
Executive Summary

- Objective:** Investigated the fatigue life and endurance limits of LPBF Ti-6Al-4V coupons with varying internal gap geometries (0.5 mm, 1.0 mm, and 2.0 mm).
- Methodology:** Conducted uniaxial tension-tension fatigue testing ($R = 0.1$) and applied mathematically optimized asymptotic Basquin models.
- Key Finding:** Counter-intuitively, the 2.0 mm gap exhibited the highest fatigue limit (137.7 MPa), outperforming both the 0.5 mm and 1.0 mm geometries in the high-cycle regime.

Background & Motivation

The LPBF challenge:
Rapid cooling & Brittle microstructure

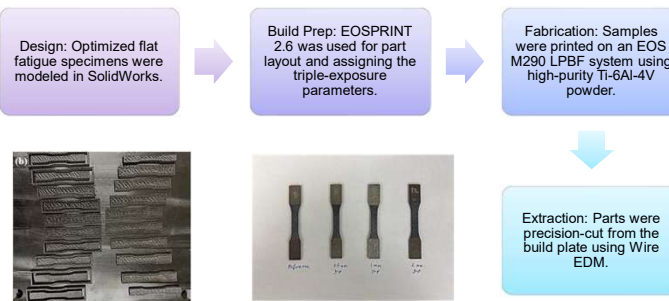
The solution:
Innovative border design & thermal confinement



High-Fidelity Fatigue Study:

Establishing high-fidelity S-N curves to quantify how gap size dictates transition from Low-Cycle Fatigue (LCF) to High-Cycle Fatigue (HCF). Predictable life cycles enable precise service life prediction for 3D-printed aerospace components.

Experimental Setup



- Power:** 285 W
- Hatch distance:** 110 μm
- Scanning speed:** 960 mm/s
- Layer thickness:** 40 μm
- Border gap:** 0.5, 1, and 2 mm
- Sample size:** 28 mm (gauge length) x 8 mm (gauge width) x 2 mm (thickness)



Experimental Test Plan

Table 1. Experimental test matrix for LPBF Ti-6Al-4V samples including fatigue test parameters and number of specimens

Sample ID	Frequency (Hz)	F_{min} (kN)	F_{max} (kN)	Stress amplitude (MPa)	Count
Reference	50	0.546	5.46	300	1 (Fatigue)
	50	0.182	1.82	100 (runout)	1 (Fatigue)
	50	0.364	3.64	200	1 (Fatigue)
G0.5	50	0.546	5.46	300	1 (Fatigue)
	50	0.728	7.28	400	1 (Fatigue)
	50	0.273	2.73	150	1 (Fatigue)
	50	0.364	3.64	200	1 (Fatigue)
	50	0.728	7.28	400	1 (Fatigue)
G1	50	0.546	5.46	300	1 (Fatigue)
	50	0.728	7.28	400	1 (Fatigue)
	50	0.273	2.73	150	1 (Fatigue)
G2	50	0.364	3.64	200	1 (Fatigue)
	50	0.546	5.46	300	1 (Fatigue)
	50	0.728	7.28	400	1 (Fatigue)

- Fatigue study:** Number of cycles have been obtained using various stress amplitudes and were used to plot S-N curves. Fatigue limits have been calculated using optimized asymptotic Basquin models in MATLAB.
- Mechanical Testing:** Uniaxial tensile testing was conducted on a Shimadzu EHF 100kN machine to determine number of cycles endured before fracture.

Experimental Results

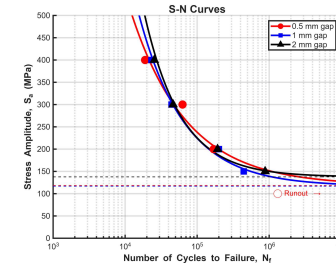


Figure 1. S-N curves

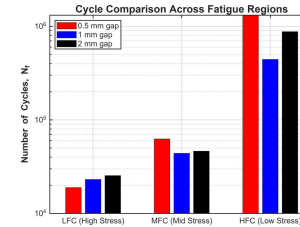


Figure 2. Cycle comparison

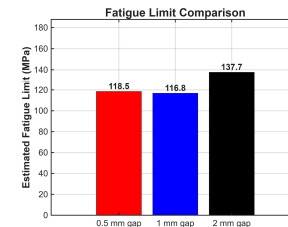


Figure 3. Fatigue limit comparison

S-N curves: The curves clearly demonstrate the transition into infinite life. At elevated stress amplitudes, fatigue life remains consistent across all sets, driven primarily by the bulk yield behavior of the Ti-6Al-4V matrix. As stress decreases, the curves drastically diverge, highlighting extreme fatigue sensitivity to internal gap geometries in the high-cycle regime. The 2.0 mm gap exhibits the shallowest degradation slope and asymptotes at the highest stress level, demonstrating superior mathematical resistance to crack propagation.

Fatigue regions: All samples fail rapidly under 26,000 cycles, showing that massive plastic strain overrides the influence of gap size at extreme stresses. Minor separations begin to emerge, with the smallest 0.5 mm gap slightly delaying failure compared to the larger gap geometries. Gap size definitively dictates survival (2 mm shows higher number of cycles in HFC).

Fatigue limit: The mathematically optimized Basquin fits reveal that the 1.0 mm gap yields the poorest fatigue resistance, stabilizing at an endurance limit of 116.8 MPa. The 0.5 mm gap offers only a marginal improvement (118.5 MPa) over the 1.0 mm baseline. Counter-intuitively, the widest 2.0 mm gap achieves a dominant endurance limit of 137.7 MPa, outperforming the tighter geometries by approximately 17%.

Conclusions

- Gap Size Sensitivity:** Fatigue life is highly sensitive to gap size, particularly in the high-cycle regime.
- Performance Anomaly:** The 2.0 mm gap demonstrates superior fatigue resistance at lower stress amplitudes compared to 0.5 mm and 1.0 mm gaps.
- Model Accuracy:** Applying an asymptotic modification to Basquin's equation successfully models the exact endurance limits without requiring infinite physical runouts.
- Future Work:** Conduct fractography (SEM) on the failure surfaces to identify the crack initiation sites and understand why the 2.0 mm gap outperformed the others.

References

- Farhang, Behzad, Ahmet Alptug Tanrikulu, Aditya Ganesh-Ram, Sadman Hafiz Durlov, and Narges Shayesteh Moghaddam. "Innovative fabrication design for in situ martensite decomposition and enhanced mechanical properties in laser powder bed fused Ti6Al4V alloy." Journal of Manufacturing and Materials Processing 7, no. 6 (2023): 226.