

Effect of Scan Path Modifications on

Executive Summary

This research investigates a novel **triple-exposure scan strategy (TESS)** designed to mitigate the inherent challenges of fabricating pure Tungsten via Laser Powder Bed Fusion (LPBF). Tungsten is a critical material for high-temperature applications in aerospace and nuclear energy, yet it typically suffers from high porosity and micro-cracking due to extreme thermal gradients.

Our study introduces a **directional pre-heating pass** as a secondary scan to act as a localized thermal management tool. Experimental results demonstrate that this pre-heating strategy significantly improves **relative density**. We hypothesize that the secondary pass provides a specific **thermal pathway for grain growth**, facilitating a more controlled solidification and cooling phase following the primary double scan. By tailoring the scan path, we achieved a peak **Ultimate Tensile Strength (UTS) exceeding 350 MPa** and near-full densification, offering a scalable solution for high-performance refractory metal manufacturing without the need for intensive post-processing.

Background & Motivation

Tungsten LPBF Challenges:

- Thermal Extremes:** High melting point and thermal conductivity create severe gradients and rapid solidification.
- Defect Formation:** High brittleness and DBTT lead to pervasive micro-cracking causing premature mechanical failure.

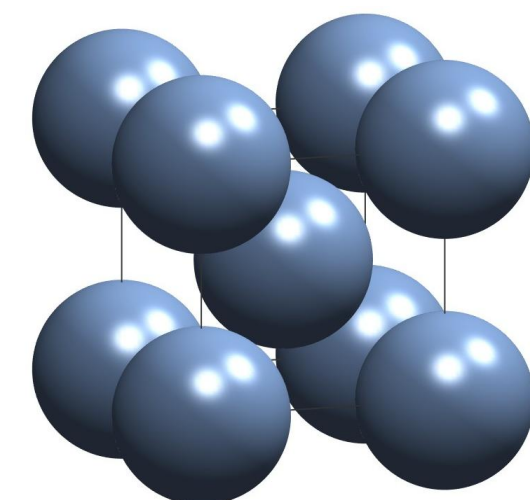
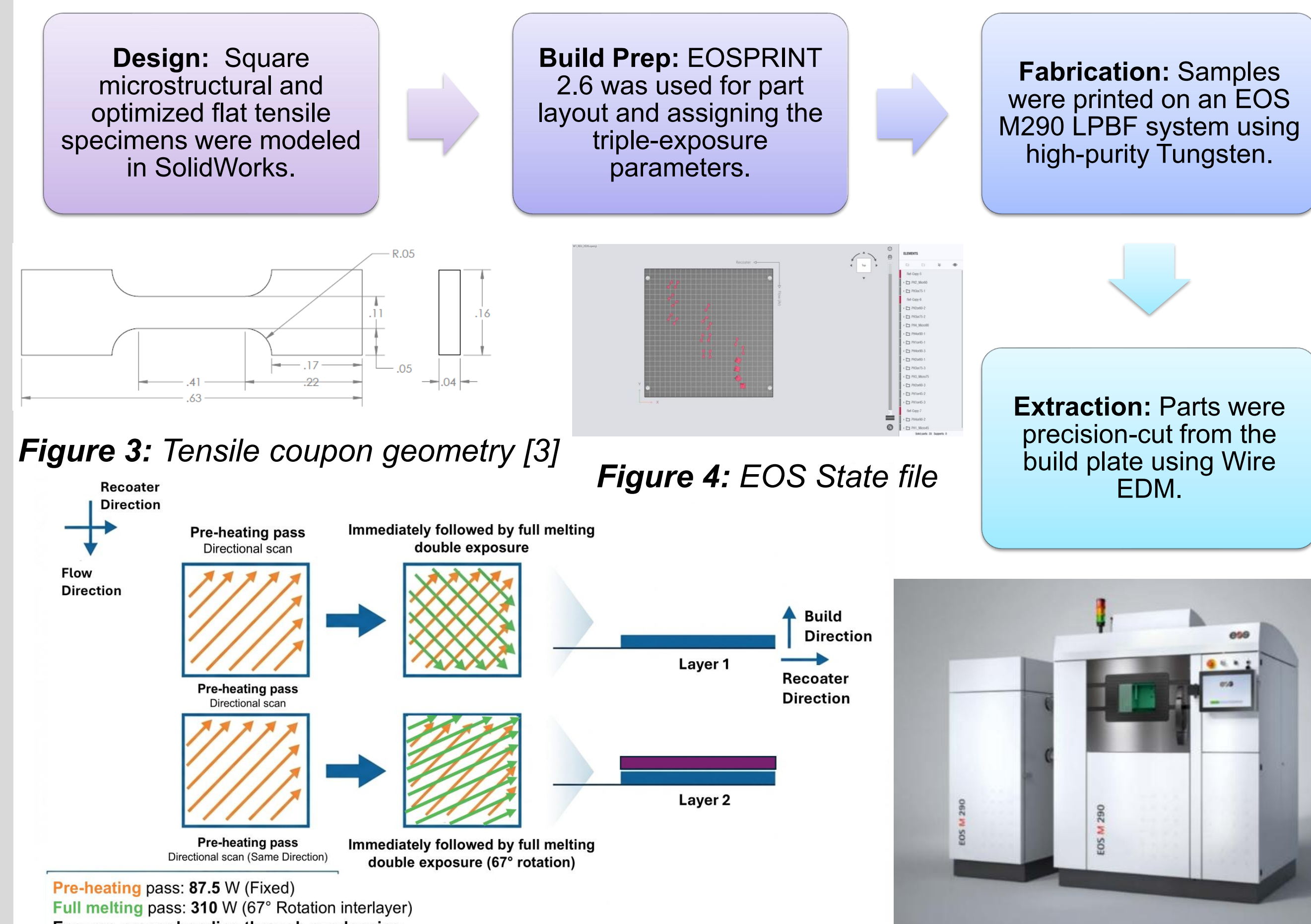


Figure 1: Body-Centered Cubic (BCC) unit cell of pure Tungsten

Current Research and Proposed Strategy:

- Existing Mitigation:** Prior strategies include broad scan path modifications, border studies, and expensive post-processing like Hot Isostatic Pressing (HIP) [1,2].
- In-Situ Innovation:** Building on IAM Lab research into optimized scan angles, we propose a **triple-exposure strategy** utilizing a **directional pre-heating pass**.
- The "Pathway" Concept:** Unlike uniform heating, this localized approach establishes a specific thermal pathway that facilitates controlled grain to reduce the internal stresses responsible for cracking.

Experimental Setup



Experimental Test Plan

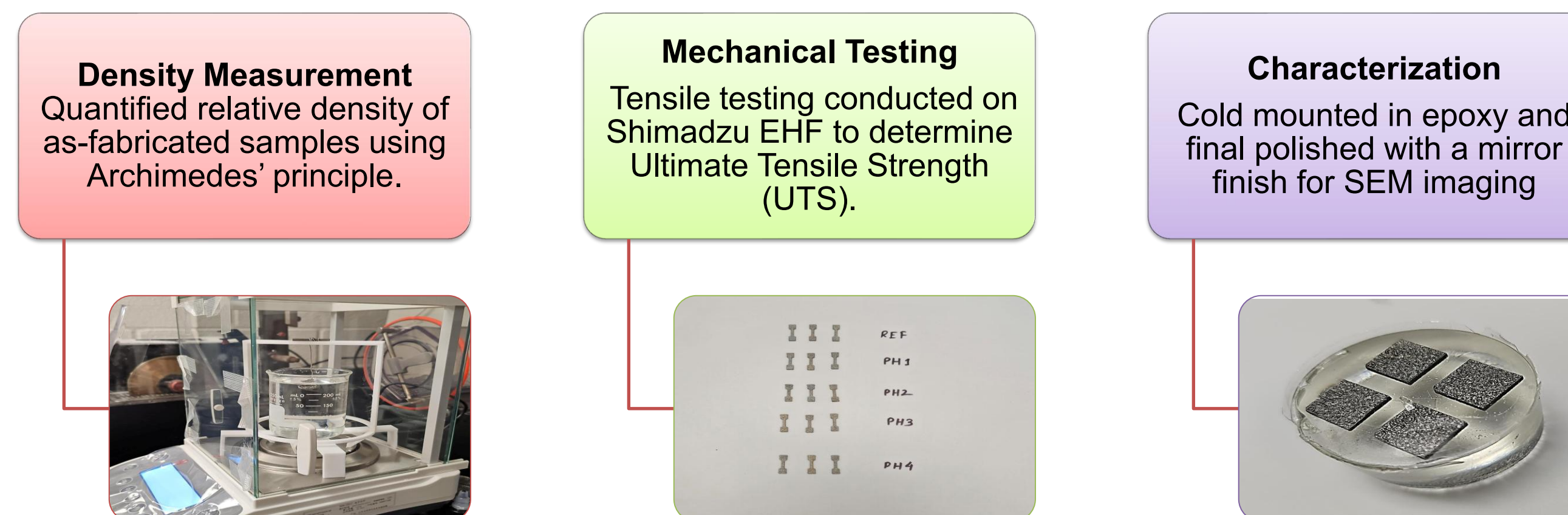


Table 1. Experimental test matrix for LPBF Tungsten samples including pre-heating parameters and specimen counts for tensile and microstructural analysis.

Sample ID	Pre-Heating Power (W)	Pre-heating Angle (°)	Melting Power (W)	Count
REF	N/A	N/A	310	3 (Tensile) & 1 (Micro)
PH1	87.5	45	310	3 (Tensile) & 1 (Micro)
PH2	87.5	60	310	3 (Tensile) & 1 (Micro)
PH3	87.5	75	310	3 (Tensile) & 1 (Micro)
PH4	87.5	90	310	3 (Tensile) & 1 (Micro)

- Density Measurement:** Relative density of as-printed samples was quantified using Archimedes' principle in accordance with ASTM B962.
- Mechanical Testing:** Uniaxial tensile testing was conducted on a Shimadzu EHF 100kN machine to determine UTS following ASTM E8/E8M.

Experimental Results

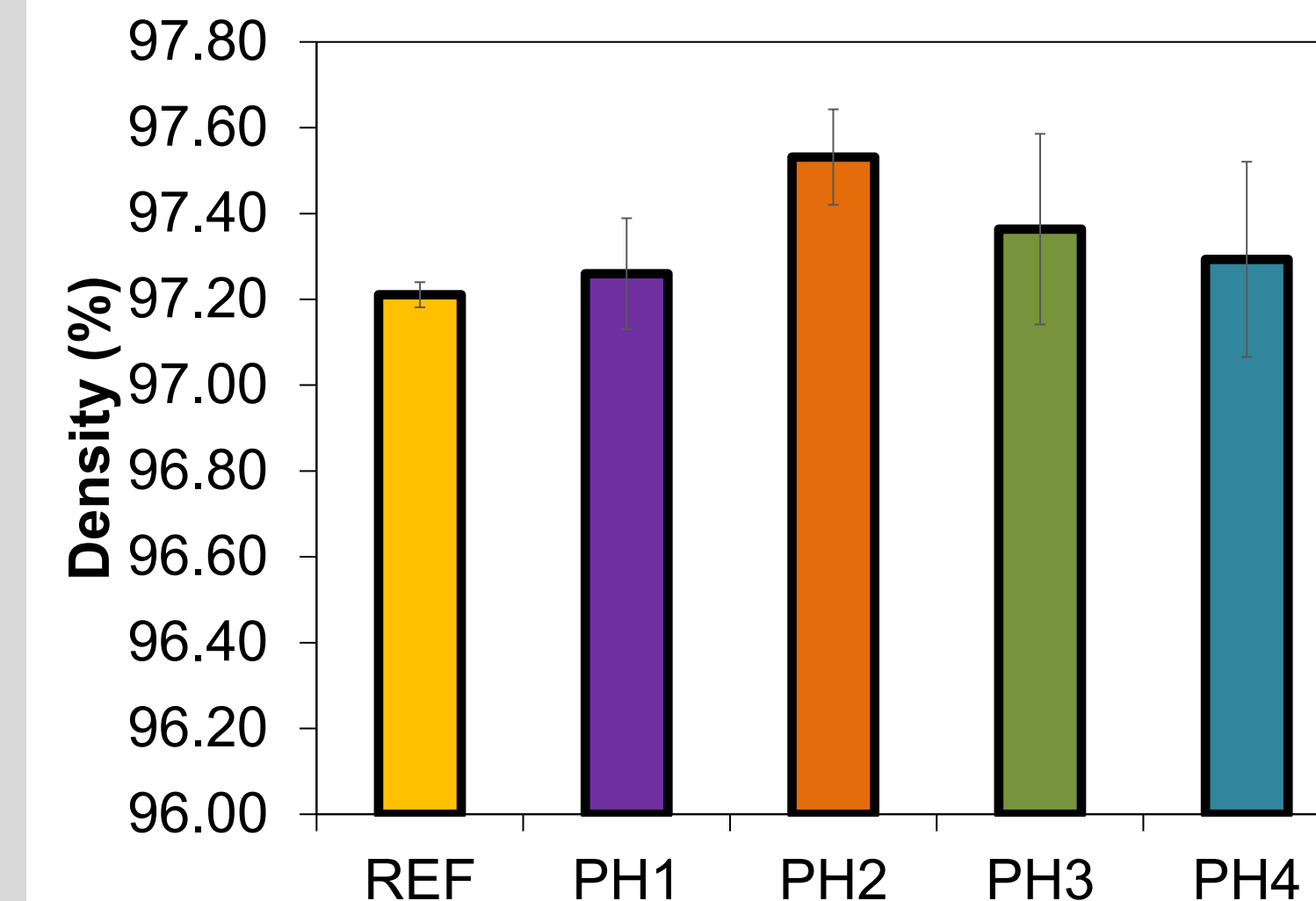


Figure 5: Relative Density of the fabricated samples

Surface Characterization: PH2 displayed optimal **"crack arrest"** and a healed appearance. Conversely, PH1 and PH3 showed continuous cracking or track formation, while PH4 was compromised by large localized pores.

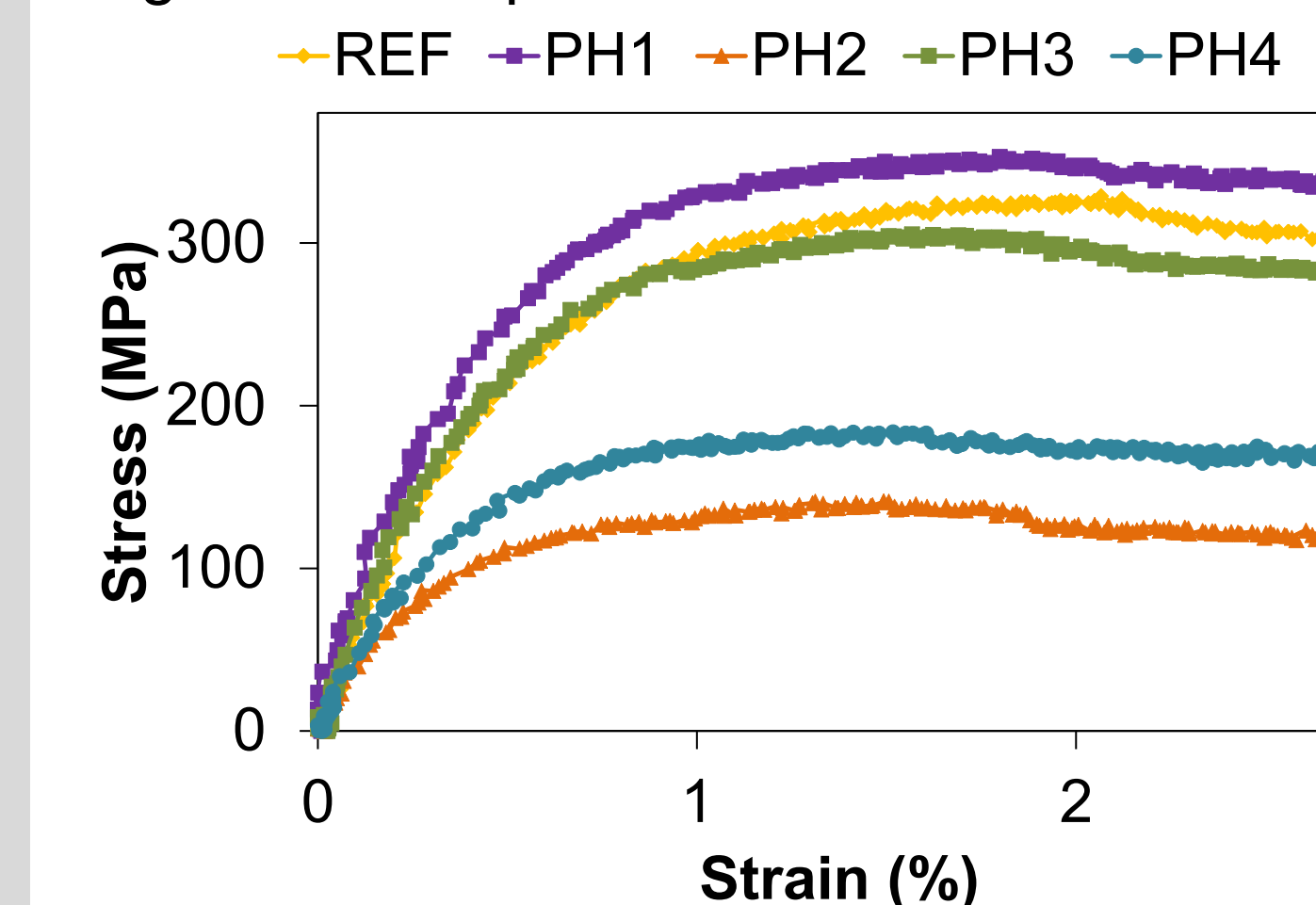


Figure 7: Stress vs. Strain Results of tensile specimens

Synthesis: The data reveals a critical trade-off: PH2 is most effective for physical crack mitigation, while PH1 optimizes mechanical performance through tailored grain orientation.

Densification: All triple-exposure samples showed significantly improved relative density compared to the reference. PH2 achieved the highest densification at approximately **97.5%**, representing a **~1.6% increase in absolute density** over the reference sample. Overall, TESS adopted samples showed higher density than as-fabricated sample.

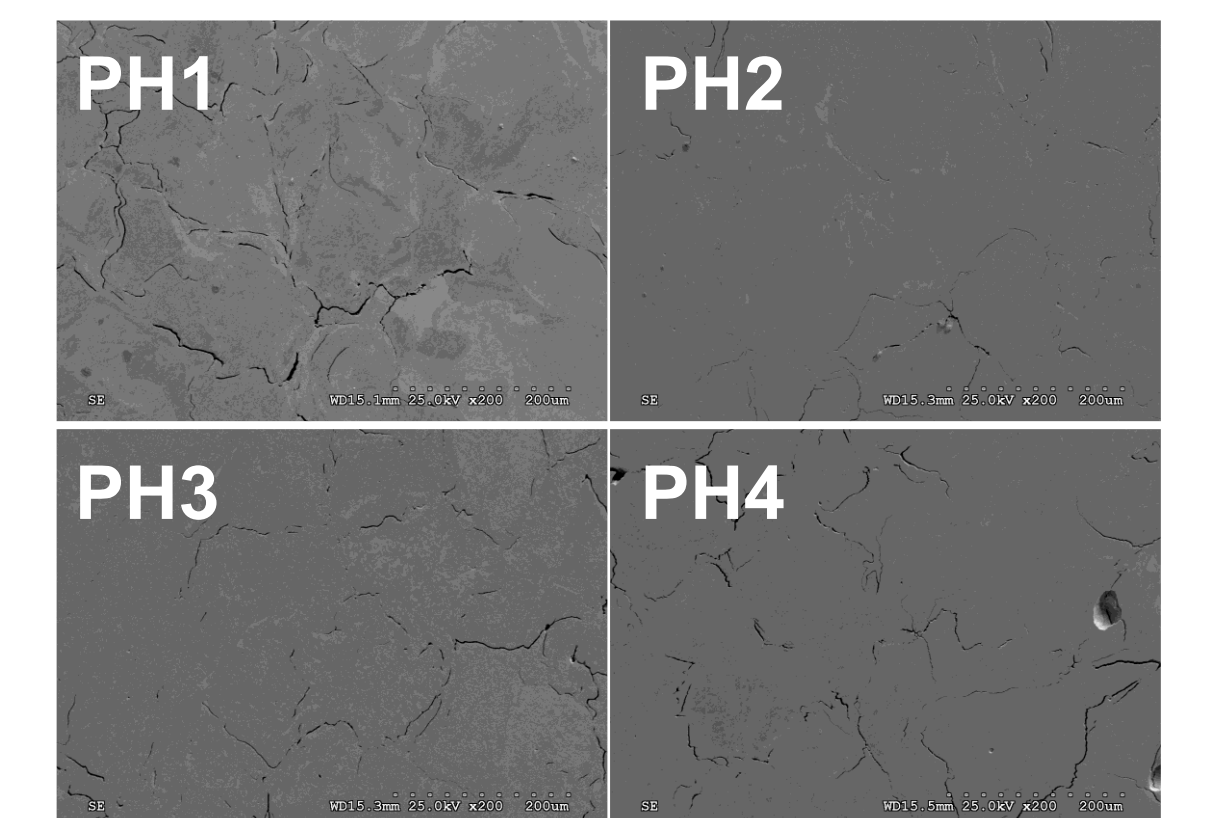


Figure 6: SEM Micrographs (PH1-PH4)

Mechanical Strength: Paradoxically, PH1 (45°) yielded the highest UTS, exceeding **350 MPa**. Despite its lower density and visible cracks, the 45° orientation significantly boosted **yield strength**.

Conclusions

- Densification & Healing:** Triple-exposure optimized relative density, with PH2 reaching 97.5% and successfully interrupting crack continuity.
- The Strength Paradox:** Peak mechanical performance (UTS > 350 MPa) occurred in PH1 (45°) despite higher visible crack density. This suggests that crystallographic orientation and texture dominate Tungsten's mechanical integrity over absolute porosity.
- Proposed Future Work:** To resolve this paradox, systematic EBSD and TEM investigations are suggested to quantify grain boundary misorientation and dislocation sub-structures, providing a mechanistic basis for the superior strength observed in the 45° scan strategy.

References

- Sidambe, A. T., Tian, Y., Prangnell, P. B., & Fox, P. (2019). Effect of processing parameters on the densification, microstructure and crystallographic texture during the laser powder bed fusion of pure tungsten. *International Journal of Refractory Metals and Hard Materials*, 78, 254-263.
- Farhang, B., Tanrikulu, A. A., Ganesh-Ram, A., Durlov, S. H., & Shayesteh Moghaddam, N. (2023). 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(6), 226. <https://doi.org/10.3390/jmmp7060226>
- Zhang, X. Q., Liu, J. Q., Zhu, X. Y., & Wu, Y. C. (2025). Effect of laser powder bed fusion process parameters on the microstructure and properties of pure tungsten. *Annals of Nuclear Energy*, 223, 111691.