

Abstract: Laser powder bed fusion (LPBF) of Haynes 230 nickel alloys is often constrained by thermal cracking and alloy chemistry. Introducing oxide nanoparticles to the alloy offers the potential to reduce this cracking while enabling more reliable additive manufacturing of H230. Establishing an optimal processing window (of laser power and scanning speed parameters) will allow for minimized cracking and improved density in oxide-dispersion-strengthened (ODS) H230 produced with nano-yttria. The purpose of this project is to design and optimize LPBF parameters to enable reliable production of ODS H230 with superior mechanical properties suitable for high-temperature applications.

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Background

Haynes 230 is a nickel-chromium superalloy with excellent mechanical strength and thermal stability in high temperature environments. The alloy has strong oxidation and creep resistance, making it an **ideal alloy for demanding environments**, such as in gas turbine blades and other high temperature applications.

Nano-yttria (Y_2O_3) was incorporated into the H230 alloy matrix to create oxide-dispersion strengthening (ODS) in the metal. These **oxide nanoparticles hinder dislocation motion**, which enhances the material's yield strength and creep resistance. This project implemented **laser powder bed fusion (LPBF)** to produce ODS alloy samples for characterization, mechanical testing, and high temperature analysis.

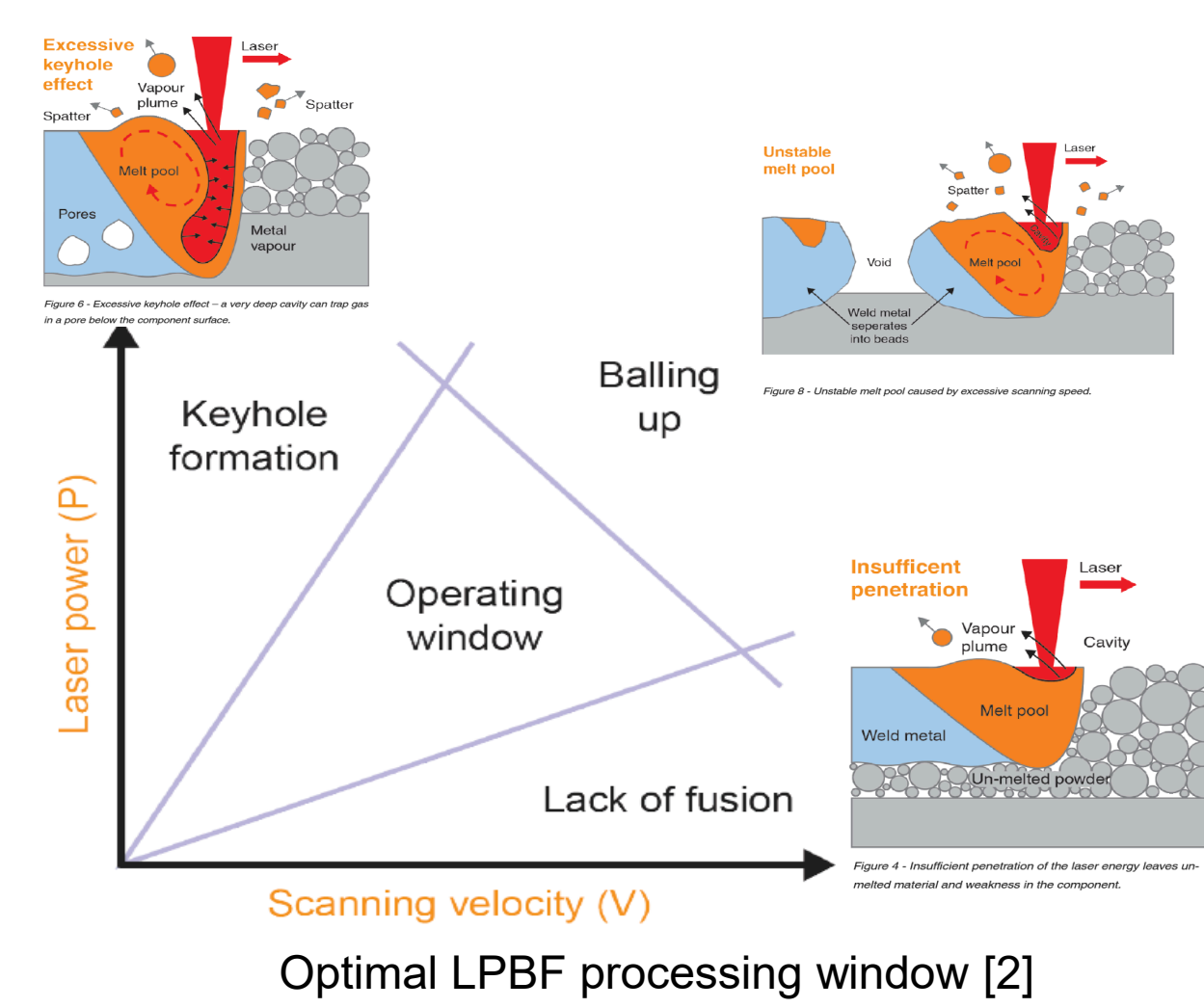
Composition of Haynes 230 alloy [1]

	Ni	Cr	W	Co	Fe	Mo	Mn	Si	C	B
Bal (wt %)	22	14	< 5	< 3	2	0.5	0.4	0.1	0.015	

LPBF is an additive manufacturing technique that melts and fuses thin layers of metal powder with a laser.

LPBF consists of 4 main steps:

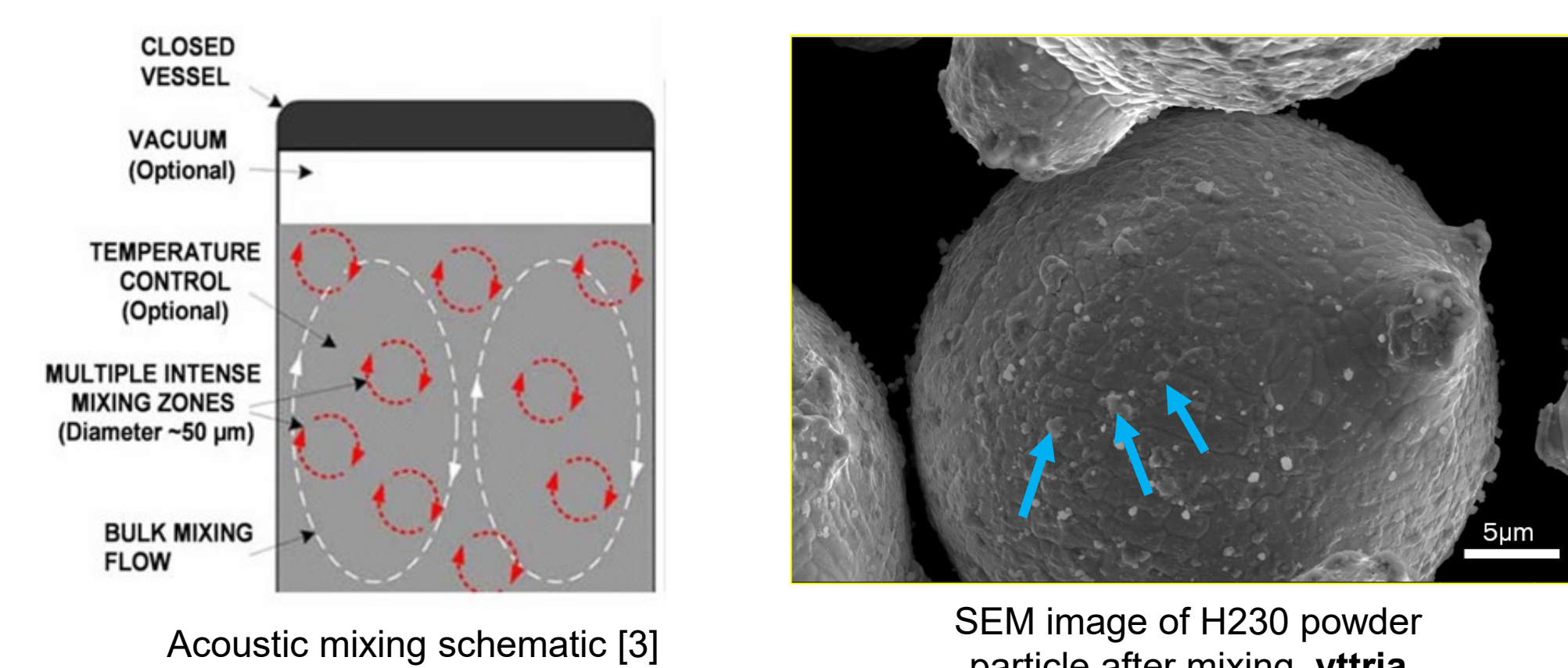
1. Powder spreading
2. Laser scanning and melting
3. Solidification
4. Layer building



Sample Preparation & Methods

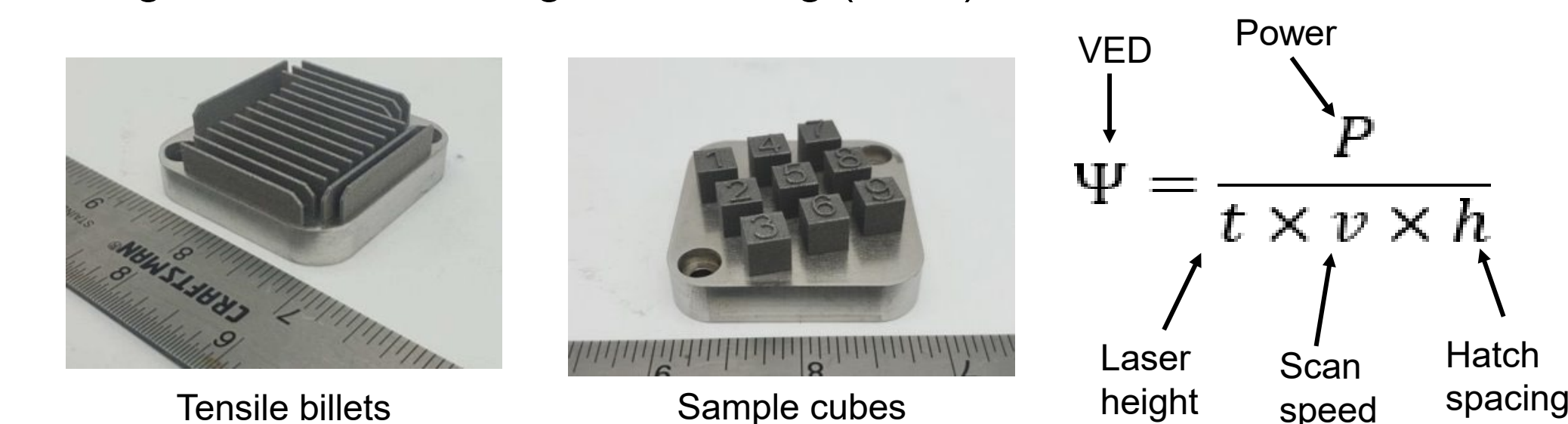
POWDER PREPARATION

Haynes 230 powder was fabricated by Linde using gas atomization. The powder was mixed with 0.75 wt % nano-yttria ($d \approx 40$ nm) via **acoustic mixing** with the Resodyn LabRAM II acoustic mixer.



SAMPLE PREPARATION

A design of experiments (DOE) was created to fabricate samples with a **range in volumetric energy densities (VED)**. Samples were fabricated with an SLM 125 printer. Tensile billets of VEDs #3 and #5 (highlighted below) were printed and made into dogbone samples using electrical discharge machining (EDM).



Design of experiments (DOE) for sample fabrication

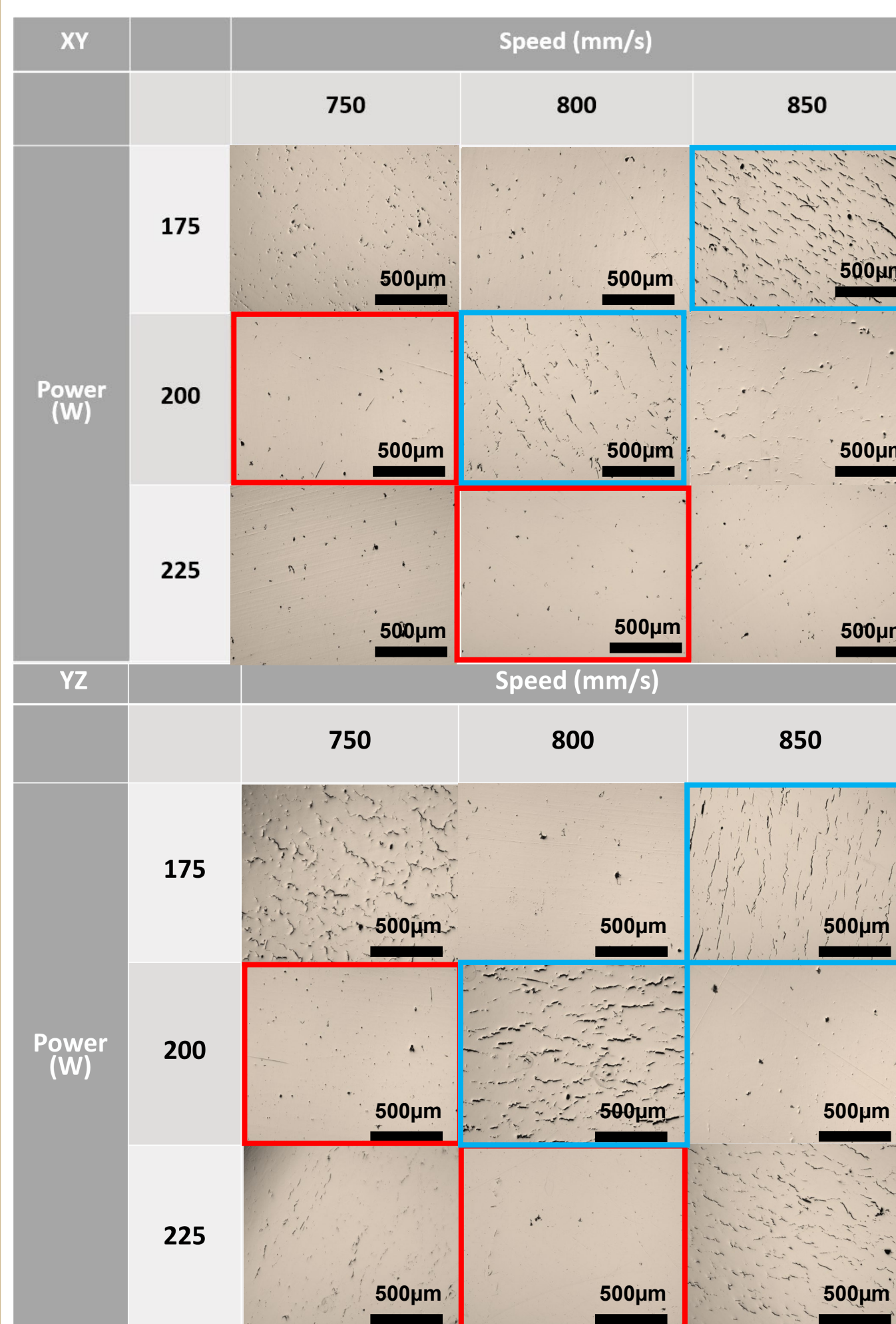
VED (J/mm ³)	Speed (mm/s)		
	750	800	850
175	77.8 (1)	72.9 (2)	68.6 (3)
200	88.9 (4)	83.3 (5)	78.4 (6)
225	100 (7)	93.8 (8)	88.2 (9)

CHARACTERIZATION METHODS

- Optical Microscopy (OM) – Olympus BX41
- Archimedes Density
- X-Ray Diffraction (XRD) – Bruker D-8 Focus
- Scanning Electron Microscopy (SEM) – Apreo 2S
- Energy Dispersive X-Ray Spectroscopy (EDS) – Oxford Instruments Ultim Max
- Vickers Microhardness – Leco Vickers Indenter
- SEM Tensile Testing – Teneo Volumescope in-situ SEM

Results - Microstructure

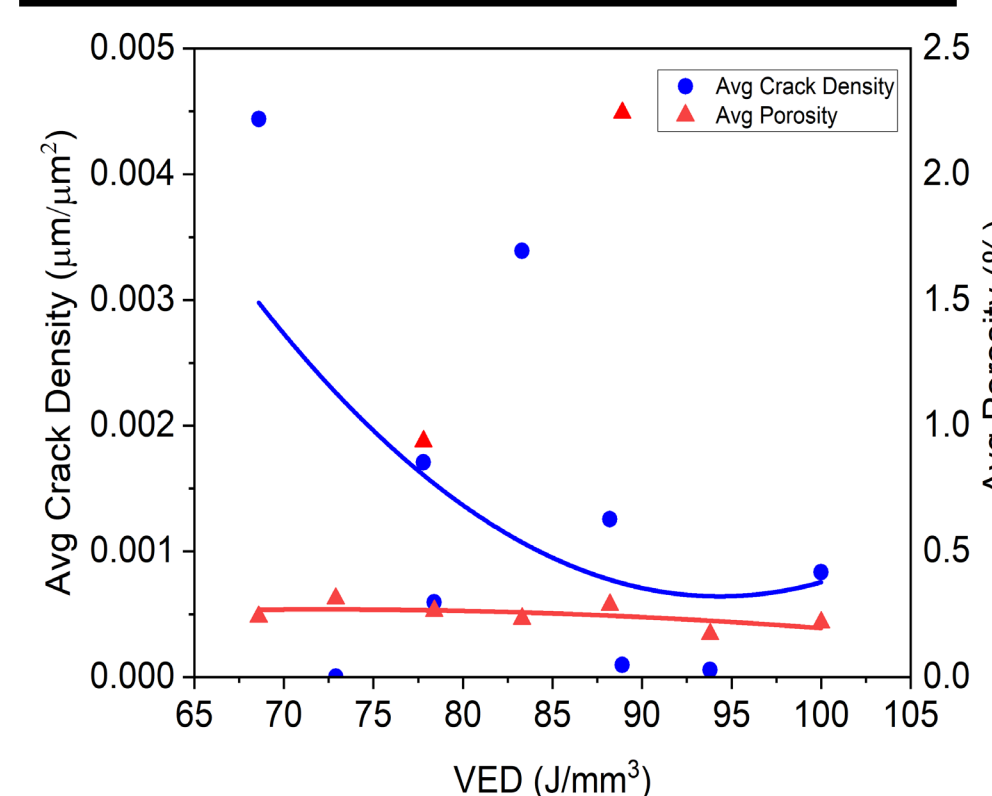
OPTICAL MICROSCOPY



- High scan speed + low laser power → lack of fusion & porosity
- High laser power + low scan speed → keyhole formation & porosity
- High scan speed + high laser power → balling up & porosity
- **Ideal parameters:** 750 mm/s / 200 W (88.9 J/mm³) and 800mm/s / 225 W (93.8 J/mm³) → minimal porosity

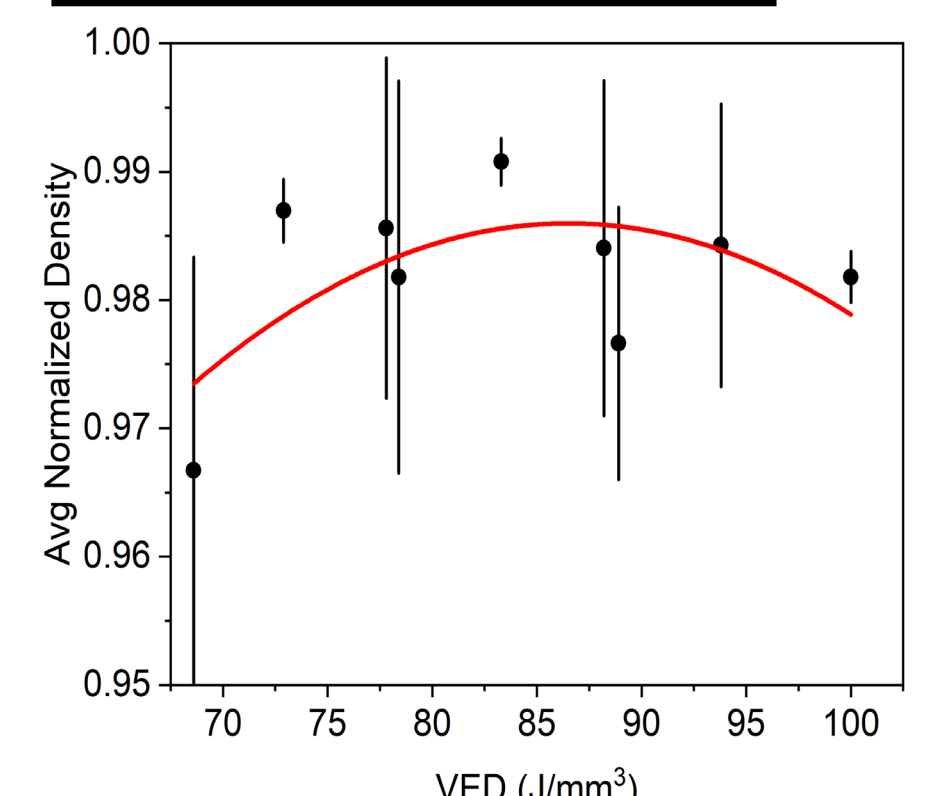
OM images of samples in XY and YZ planes. Ideal parameters outlined in red, parameters used for tensile specimens outlined in blue.

CRACK DENSITY & POROSITY



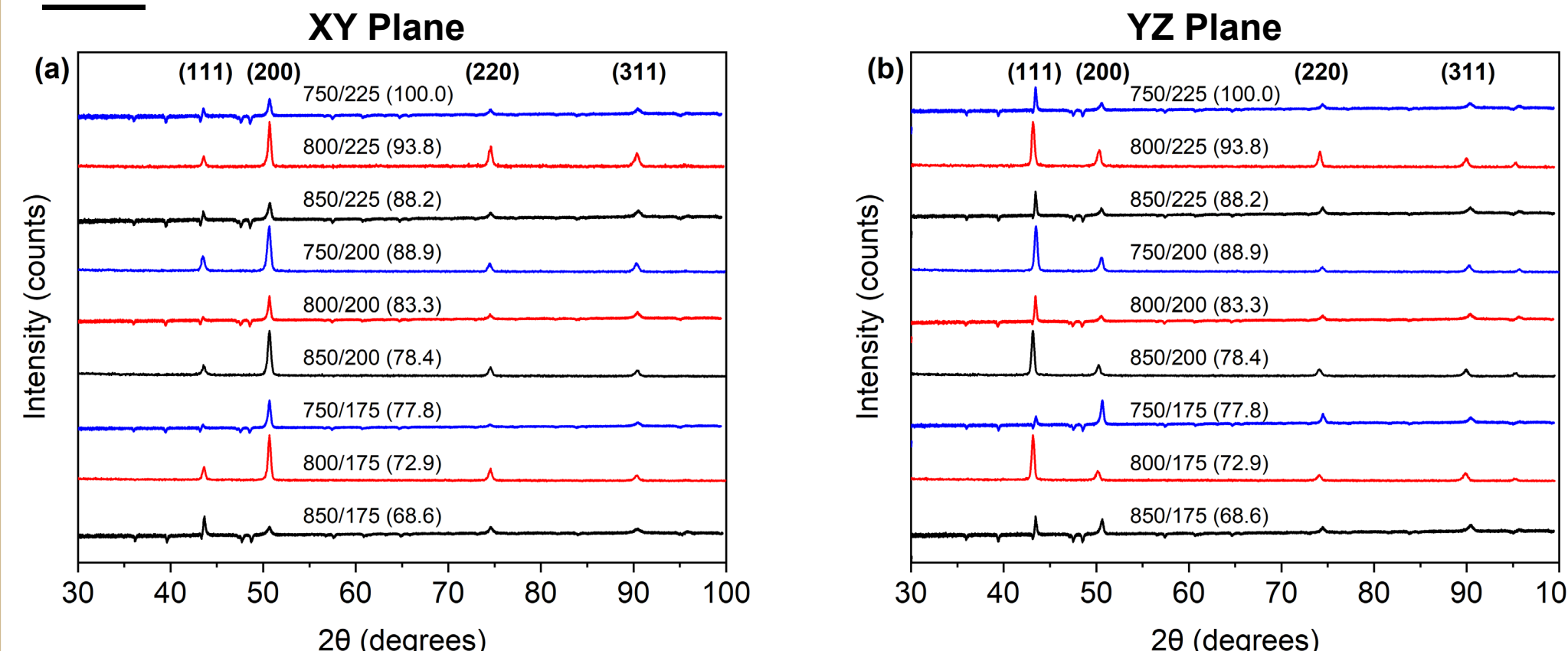
- Minimum crack density/porosity occurs at ~94 J/mm³ → **ideal**

ARCHIMEDES DENSITY



- Maximum density occurs at ~80-95 J/mm³ → **ideal**

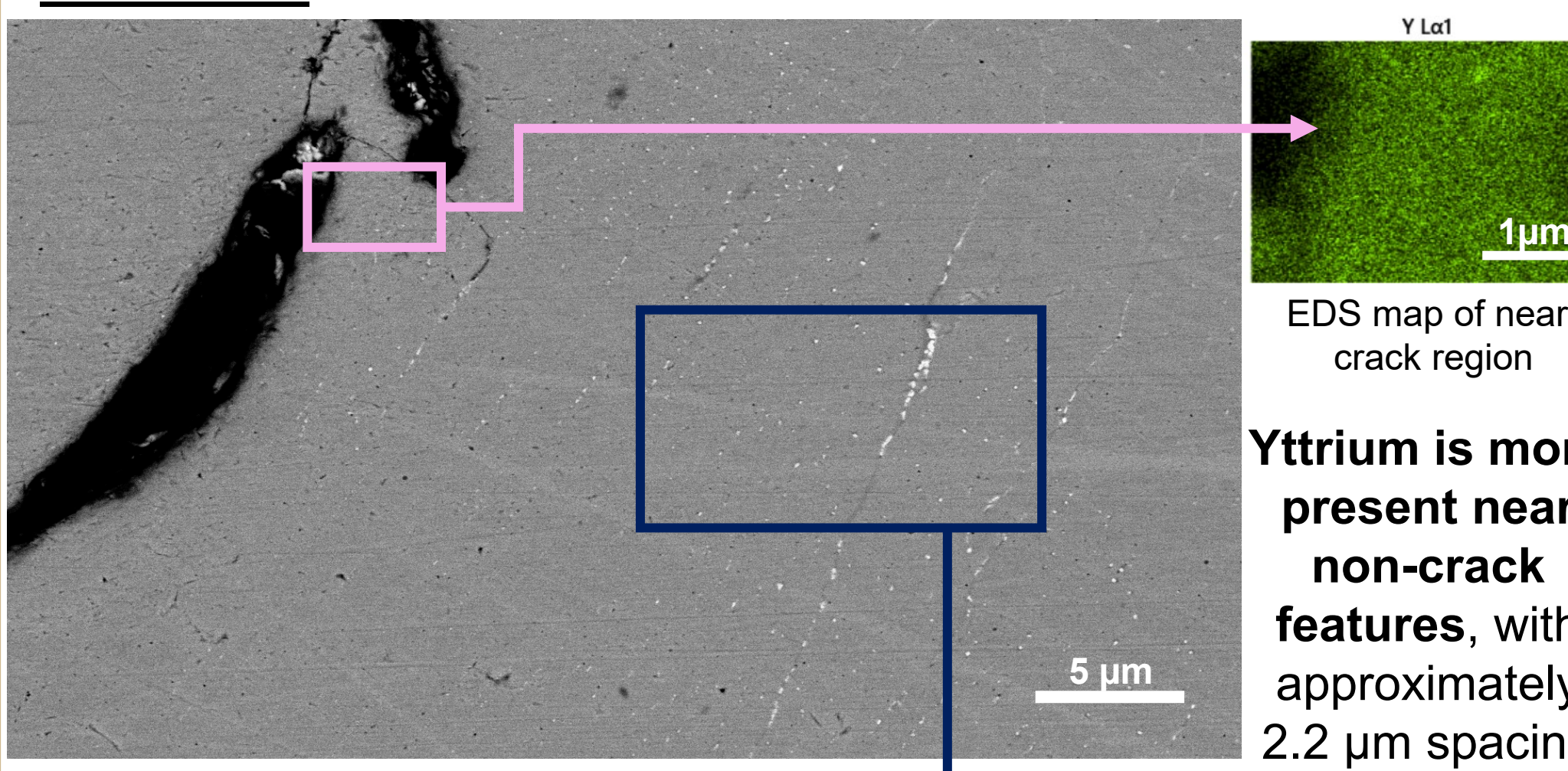
XRD



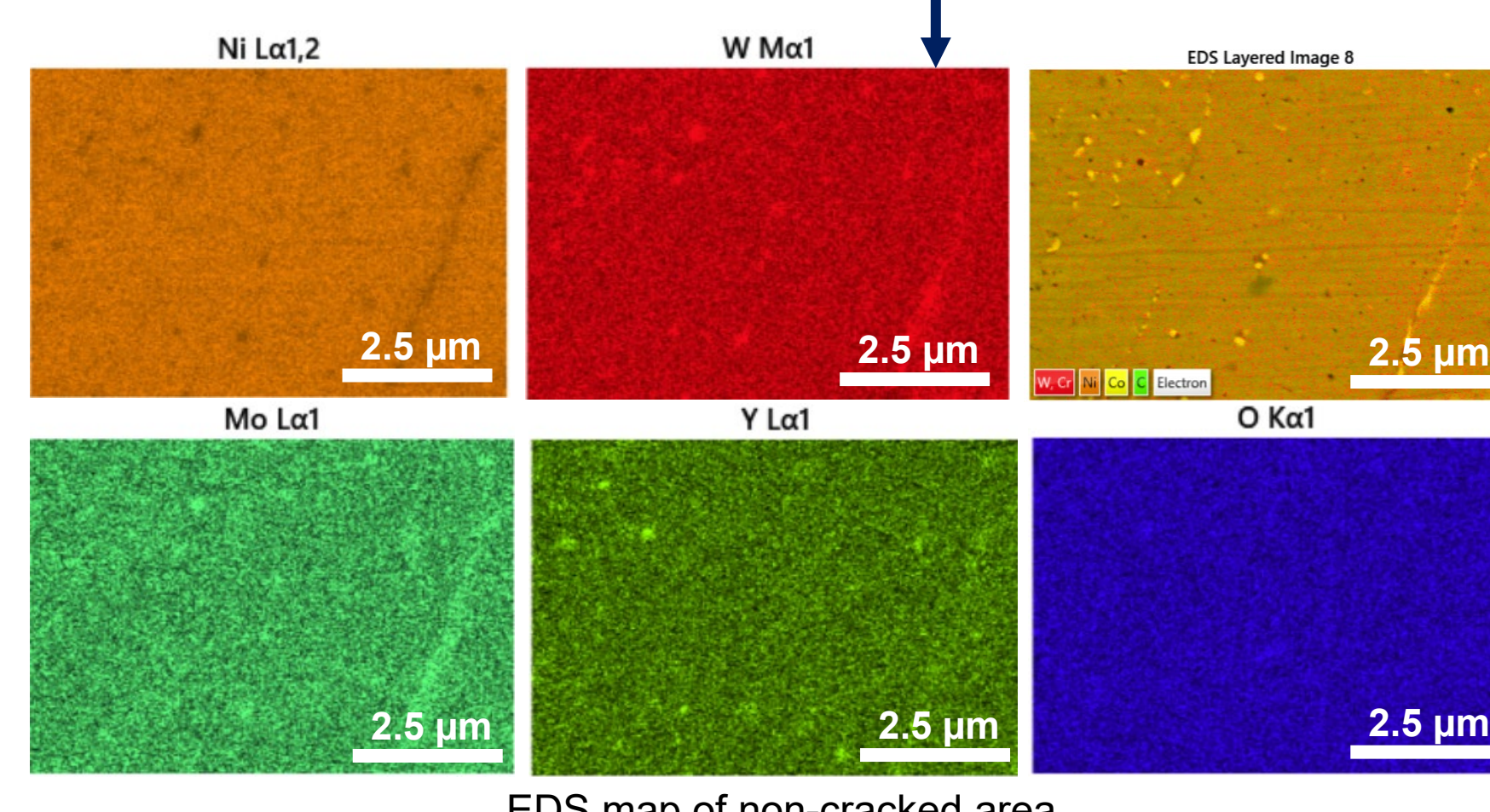
XRD spectra for all samples, labeled as "Scan Speed (mm/s)/Laser Power (W) (VED (J/mm³))"

- XY plane shows texture in (200) plane, YZ plane shows texture in (111) plane → indicates **anisotropic properties** (typical for LPBF [5])

SEM & EDS



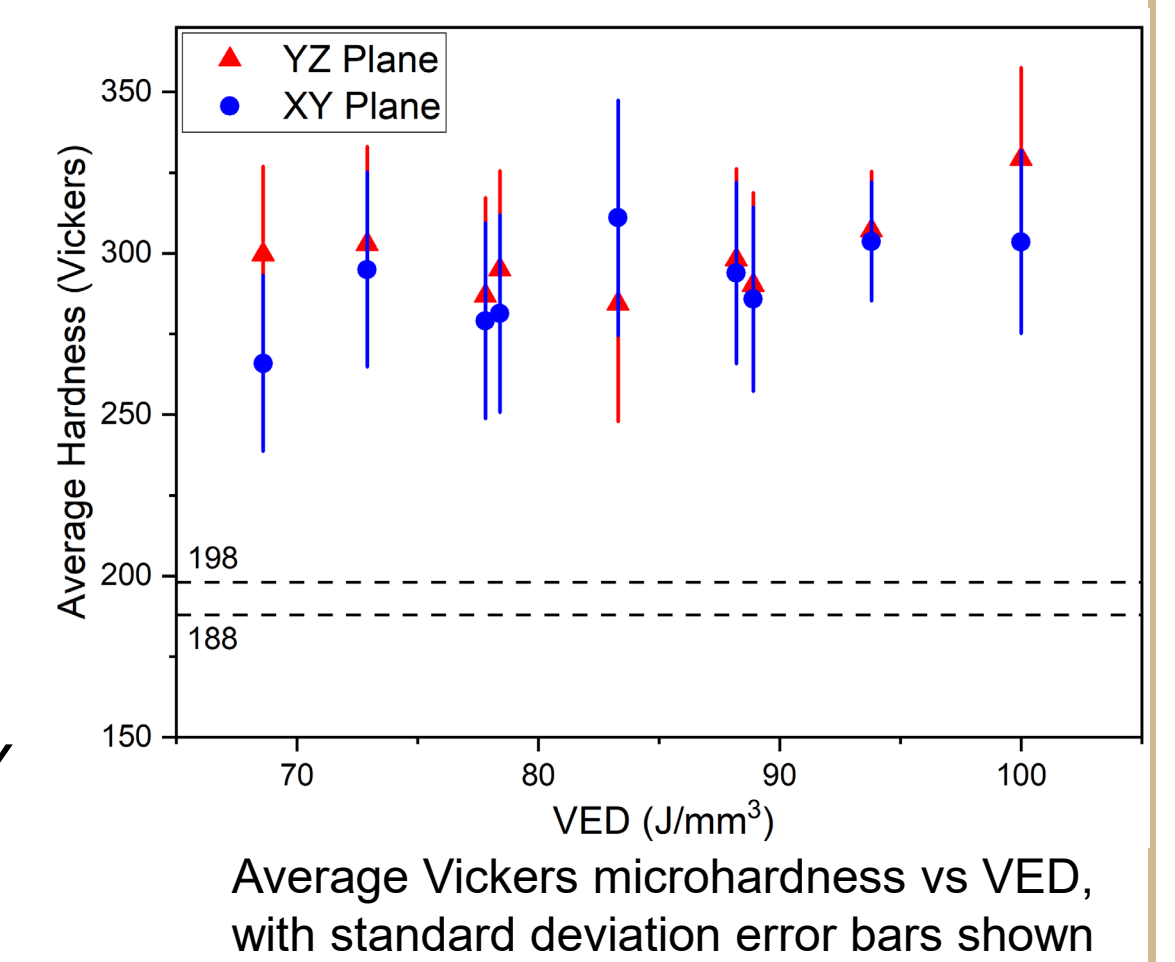
SEM image of 800 mm/s / 200W (83.3 J/mm³) sample



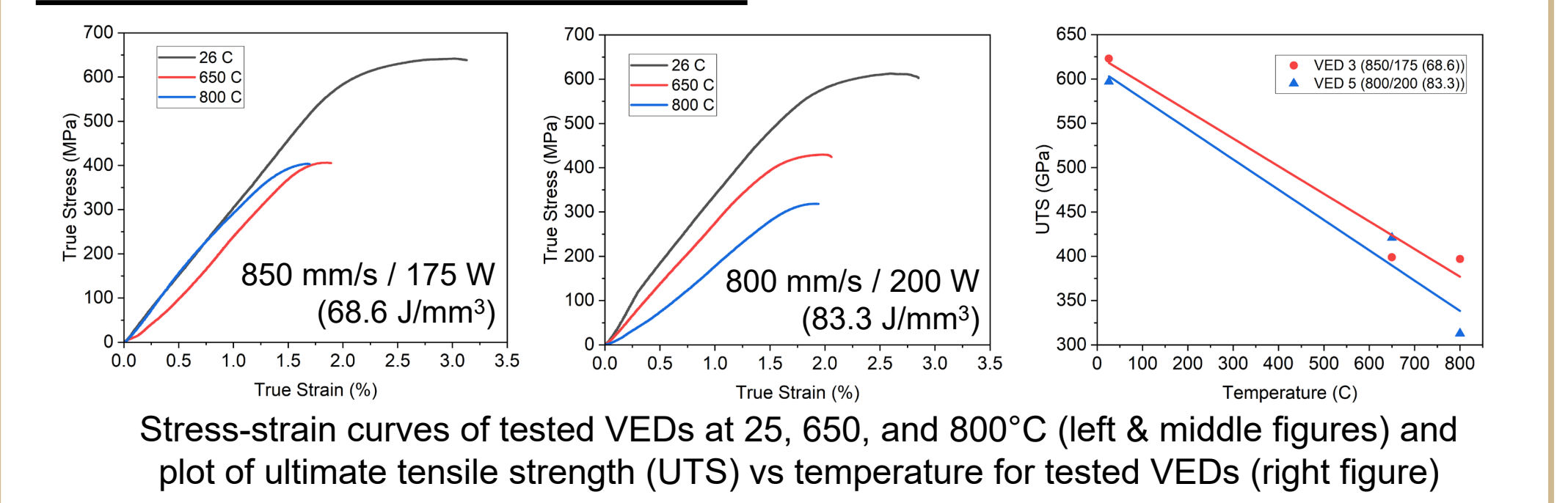
Results - Mechanical Properties

MICROHARDNESS

- Dotted lines show range of standard Haynes 230 hardness at room temperature [1].
- **ODS sample hardness is higher than standard Haynes 230**
- No significant hardness change observed between XY & YZ planes or changes in VED/processing parameters.

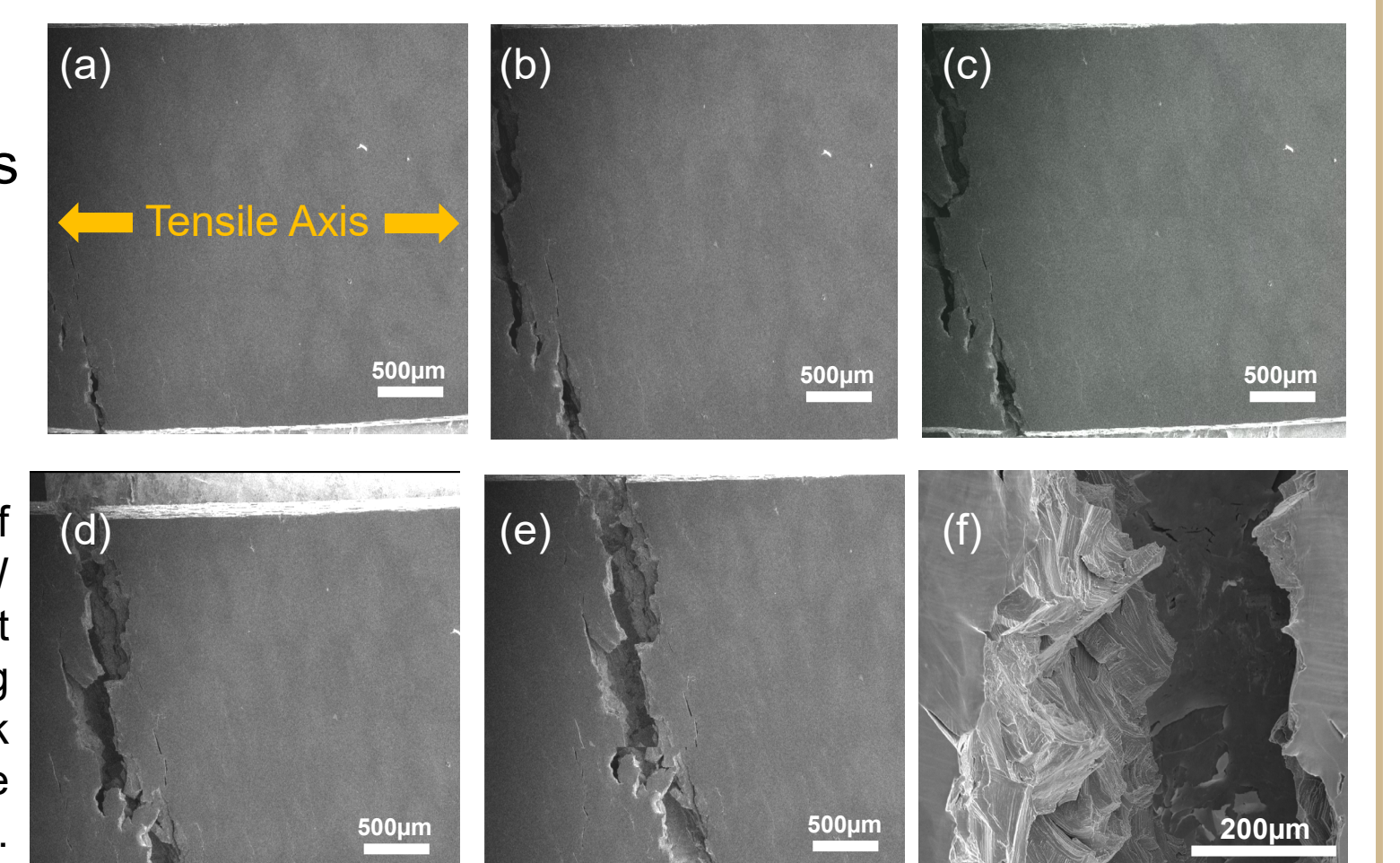


IN-SITU SEM TENSILE TESTING



- All samples had yield strengths greater than standard Haynes 230 but tensile strengths less than standard Haynes 230 [1]
- **Tensile properties decrease with increasing test temperature**

- Abrupt failure and SEM of fracture surfaces indicate **brittle behavior**



In-situ tensile test of 800 mm/s / 200 W (83.3 J/mm³) sample at 650°C, showing progression from crack initiation to fracture from figures a to f.

Conclusions & Future Work

CONCLUSIONS:

- Increasing VED can decrease crack density; Porosity is not very sensitive to VED
- XRD shows (200) texture on XY plane and (111) texture on YZ plane
- Mechanical strength decreases with increasing test temperature
- Nano-yttria and (W₂O)₃ have been identified from SEM/EDS

FUTURE EXPERIMENTATION SHOULD FOCUS ON:

- 1) Fabricating tensile specimens of samples 4 and 8 in DOE table, which display minimal cracking and porosity in OM analysis
- 2) Refining the DOE to minimize cracking and porosity via a narrower processing window
- 3) Improving mixing of nano-yttria particles to achieve even dispersion
- 4) Fabricating control samples and investigating DED printing
- 5) Determining the individual effects of cracking and porosity on mechanical properties; designing processing parameters to prioritize reducing the more critical defect.

Acknowledgements

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References

1. Haynes International. (2025). Haynes® 230®.
2. Suter, R., et al. (2017) Towards optimal processing of additive manufactured metals for high strain rate properties. *SSAP Chicago*.
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5. Yang, B., et al. (2022). Investigation of strengthening mechanisms in an additively manufactured Haynes 230 Alloy. *Acta Materialia*, 222, 117404. <https://doi.org/10.1016/j.actamat.2021.117404>