PURDUE UNIVERSITY
School of Materials Engineering

Microstructures and Mechanical Behavior of Additively Manufactured Haynes 230 ODS Alloys

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ABSTRACT: In addition to providing benefits to strength in high-temperature aerospace applications, introducing oxide dispersion strengthening (ODS) to superalloys can potentially reduce thermal cracking during additive manufacturing. This aspect provides an opportunity to improve the printability to alloys like Haynes 230, which have difficulty being additively manufactured due to their tungsten content increasing thermal stresses during cooling. By analyzing the microstructures which occur at different printing parameters and the degree of strengthening which is reached relative to the control when nano-yttria is added to achieve ODS, the directed energy deposition (DED) printing viability of Haynes 230 ODS can be assessed.

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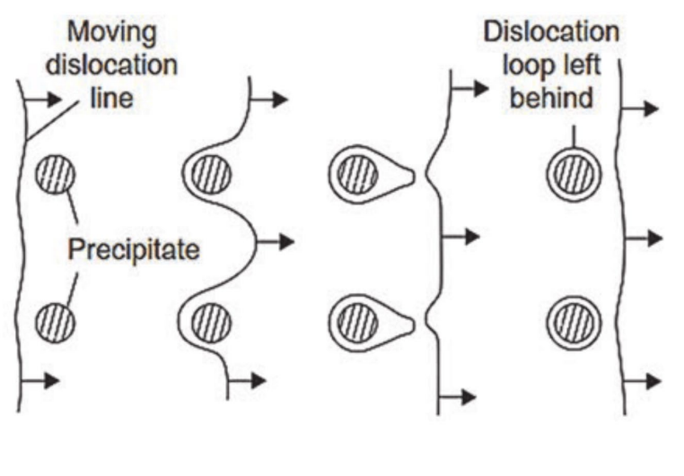
Background

Haynes 230 is a nickel-chromium based superalloy with long-term stability and mechanical properties in high temperature environments. The oxidation resistance and creep strength of this alloy make it suitable for demanding applications such as gas turbine components, chemical reactors, and in thermally extreme settings. To enhance the properties further, oxide dispersion strengthened (ODS) alloy was produced using nano-yttria ($Y2O3$) as a reinforcing phase. Oxide nanoparticles act as barriers to the glide of dislocations, thus increase yield strength, creep resistance. This project implemented directed energy deposition (DED) to produce control and ODS alloys for characterization and mechanical testing

Haynes 230 Alloy Composition [1]

Ni	Cr	W	Co	Fe	Mo	Mn	Si	C	B
Bal (wt %)	21.39	13.49	3.02	1.8	2.39	0.55	0.47	0.06	0.014

The primary goals of this project were to produce crack-free Haynes 230 alloy using DED, and introduce oxide nanoparticles to further improve the mechanical properties of the alloy.

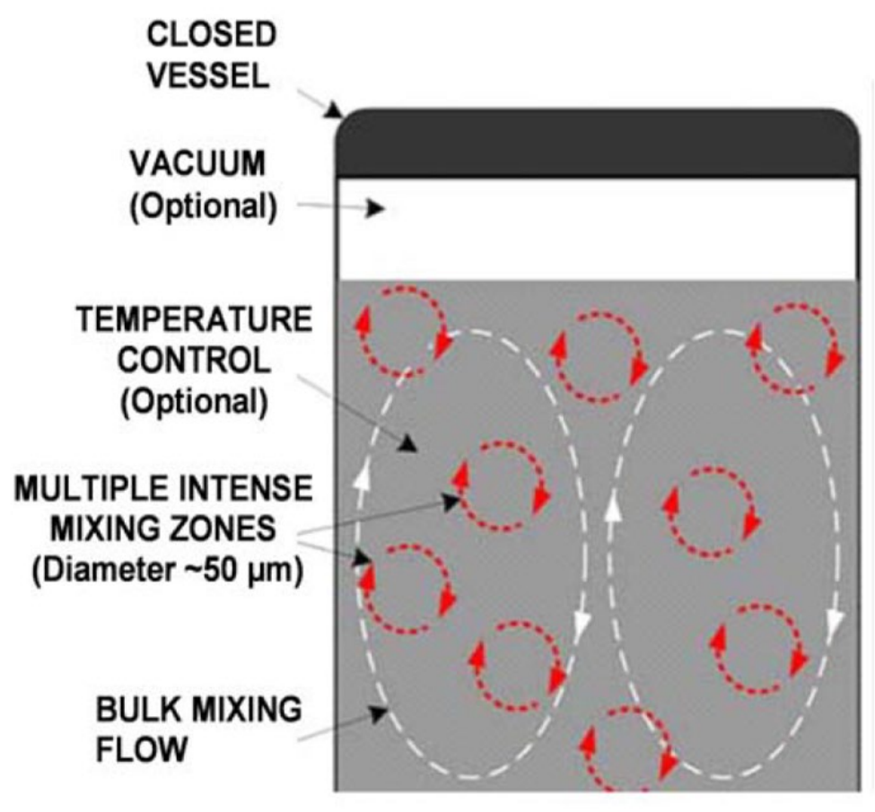


Mechanics of ODS [4]

Sample Preparation & Methods

POWDER PREPARATION:

The Haynes 230 composition was fabricated into powder form by Linde utilizing gas atomization. A portion was kept for the printing of a control group, while a second portion was infused with 0.5 wt% nano-yttria (d > 50 nm) through acoustic mixing.



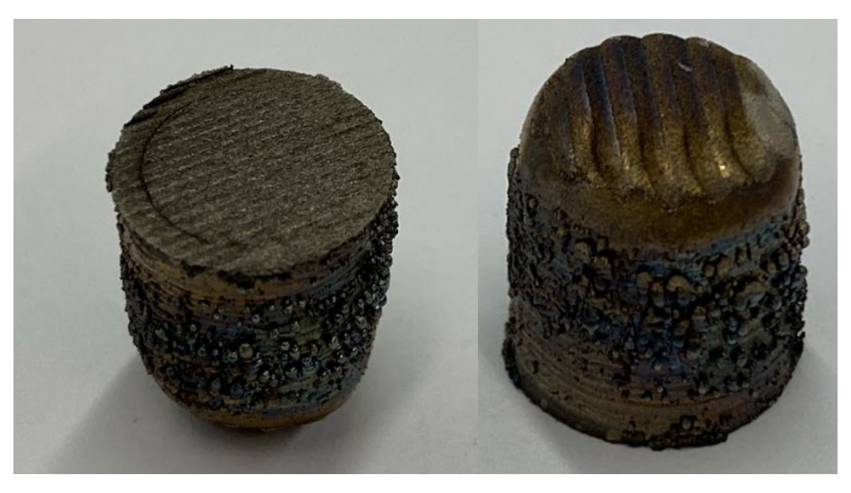
Acoustic mixing diagram [2]

Acoustic Powder Mixing

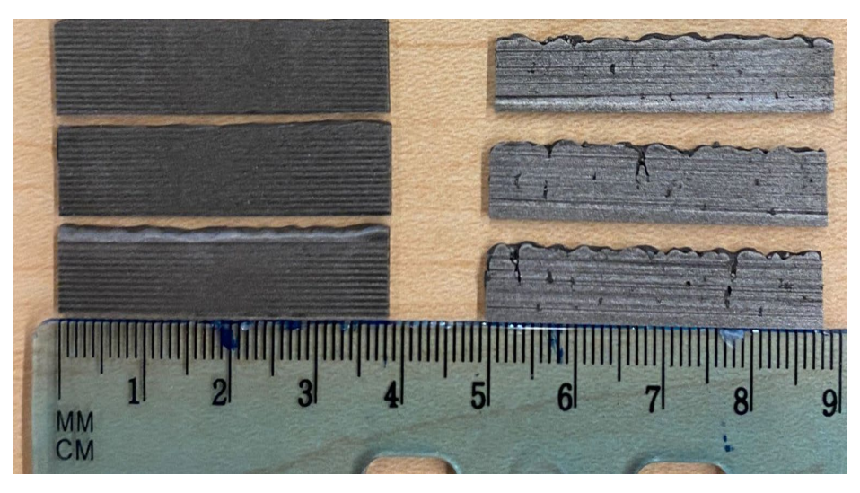
SAMPLE PREPARATION:

To obtain a baseline for DED parameters, three test stubs were fabricated at low, medium, and high energy dosages by controlling the laser power and scan speed during printing.

As the highest range of parameters performed the best, billets of control and 230 + ODS were created using the parameters. These billets were sliced into tensile and microscopy sections and polished to 0.05-1 µm finishes depending on the testing method.



A control test stub using the medium parameter group.



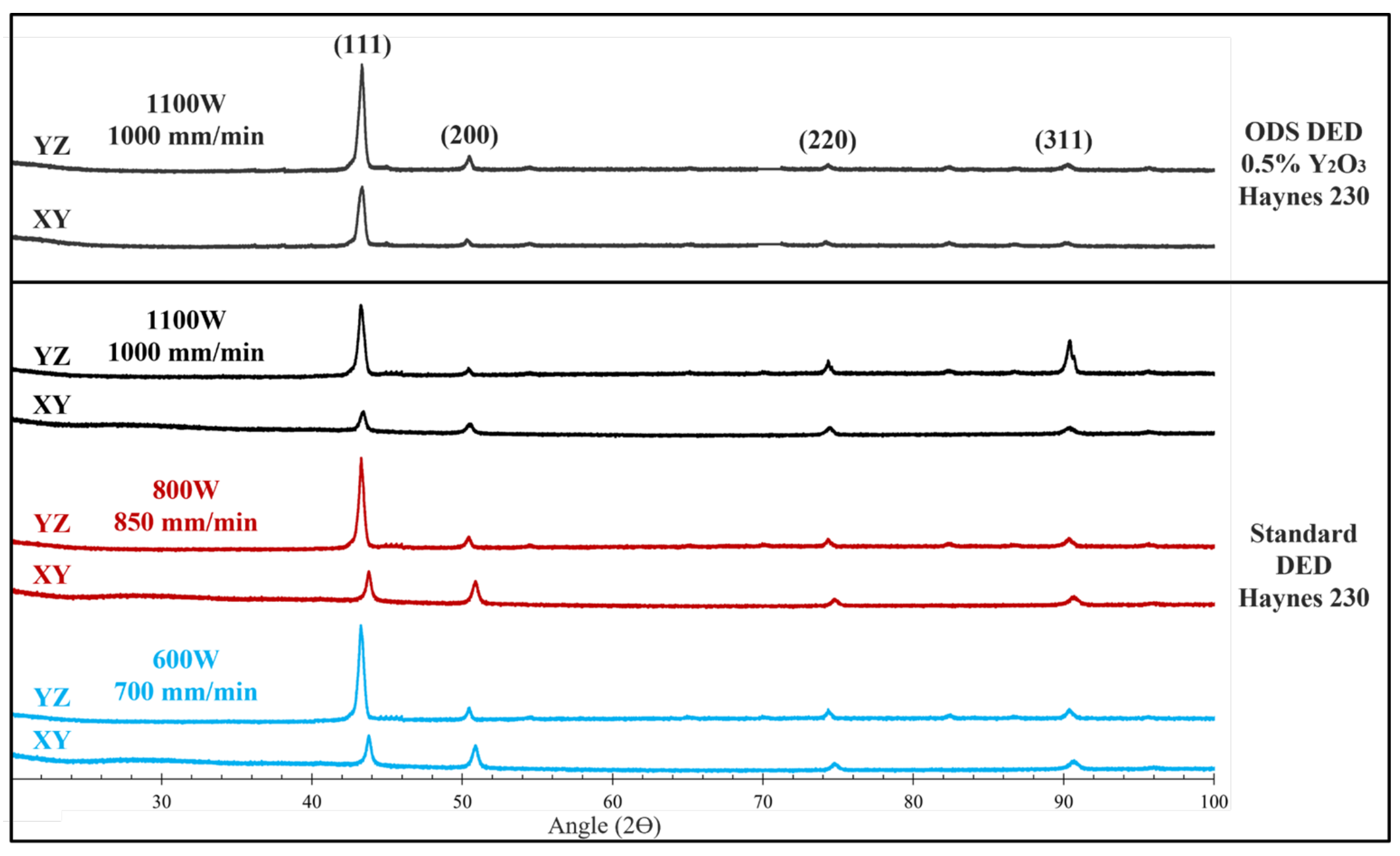
The control (left) and ODS (right) tensile billets.

CHARACTERIZATION METHODS:

- Optical Microscopy (OM) with the Olympus BX41
- X-Ray Diffraction (XRD) testing with the Bruker D-8 Focus
- Vickers microhardness testing with the Leco Vickers Indenter
- Scanning Electron Microscopy (SEM) with the Apreo 2S
- Energy Dispersive X-Ray Spectroscopy (EDS) with the Oxford Instruments Ultim Max
- Impulse Excitation Technique (IET) testing with Grindosonic MK7
- SEM Tensile Testing with a Kammrath & Weiss tensile stage

Results

Comparing XRD Profiles between the Control and ODS Alloy:



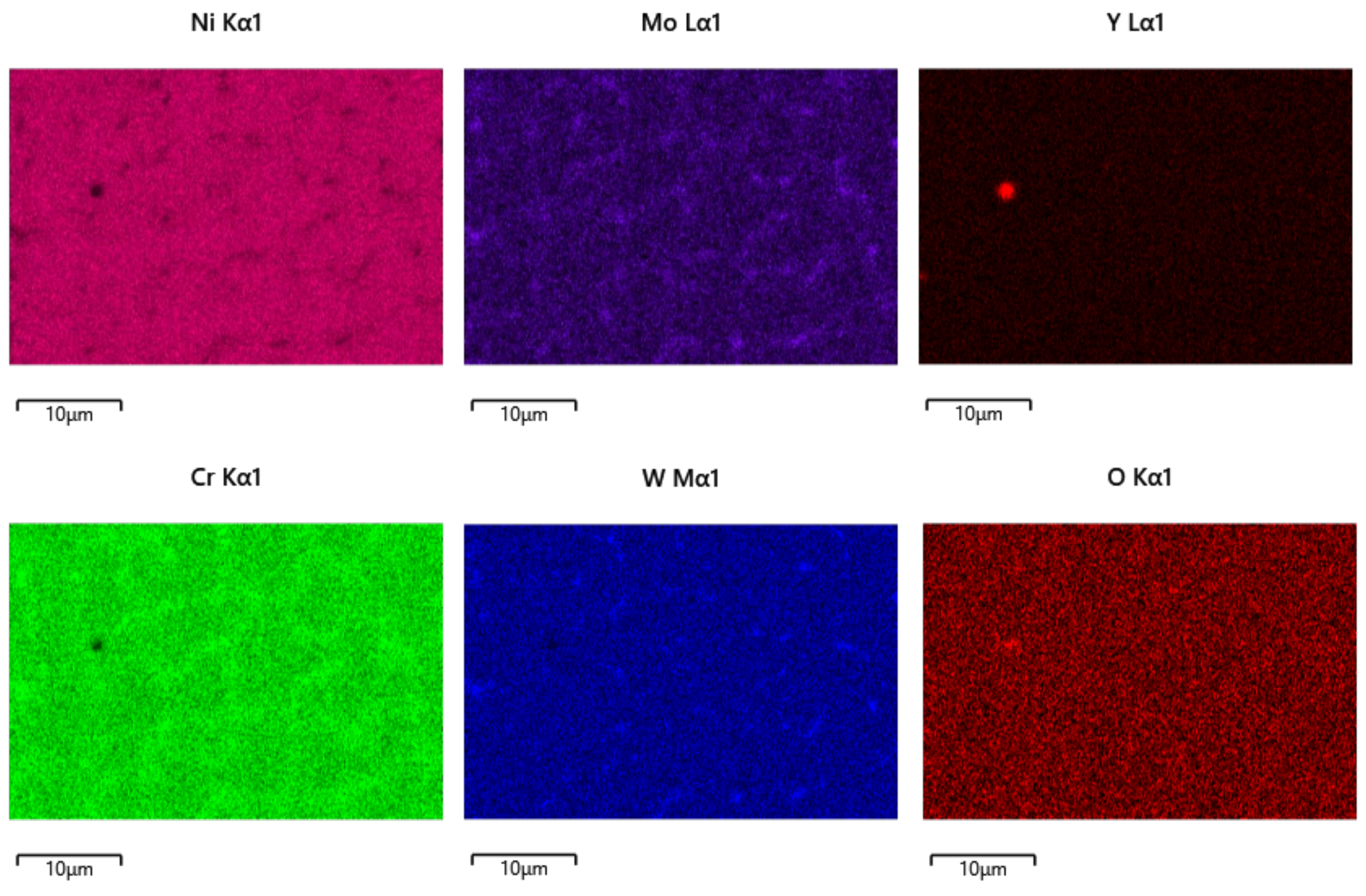
XRD Peak Intensity Ratio of (111) to (200) Planes | Reference ~2.5

Material	ODS Haynes 230	Standard Haynes 230		
Parameters	1100W 1000 mm/min	1100W 1000 mm/min	800W 850 mm/min	600W 700 mm/min
YZ	**6.6**	**7.3**	**6.7**	**6.5**
XY	**7.2**	**2.0**	**1.4**	**1.4**

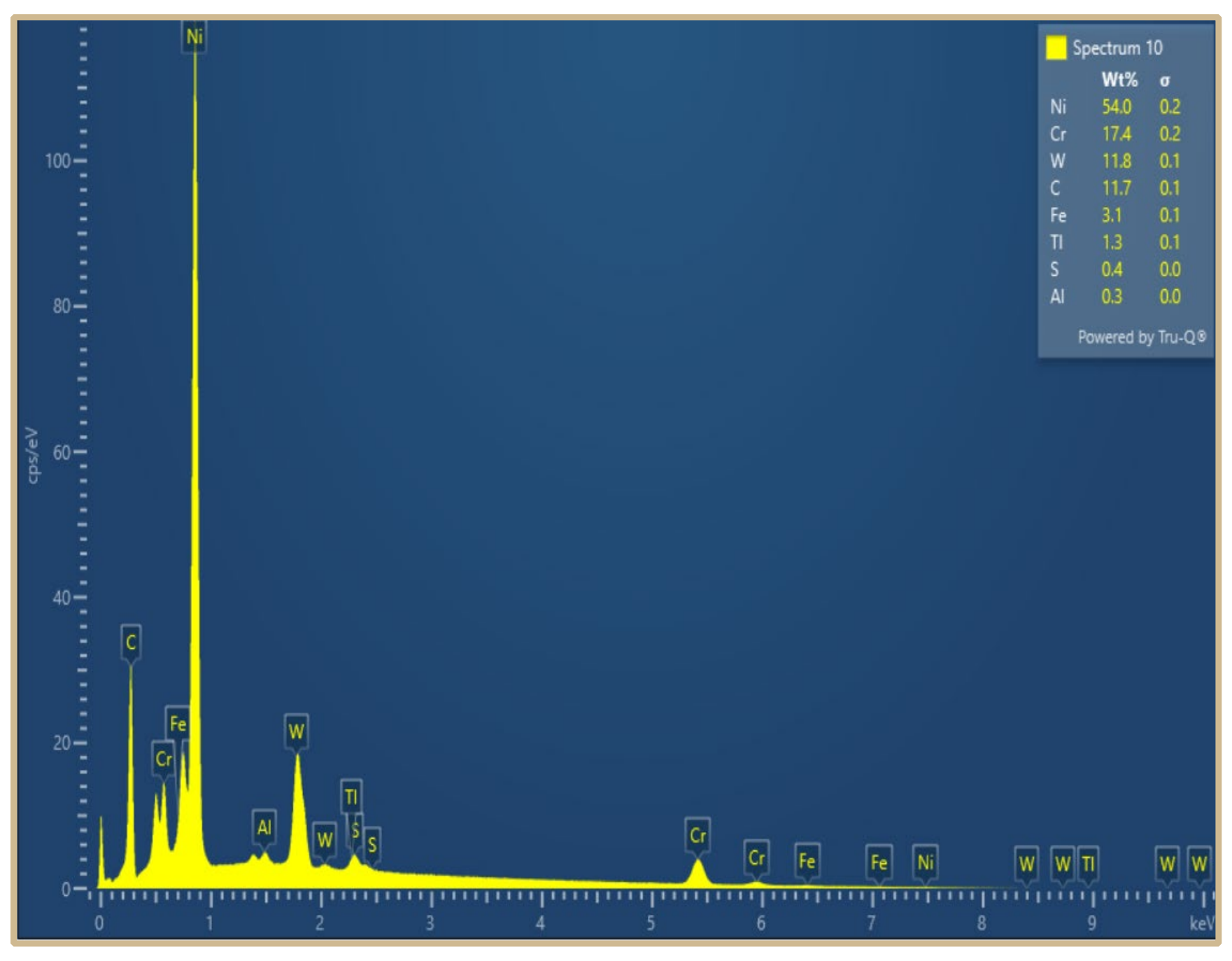
- The (111) peak dominates in the YZ plane of the standard (control) alloy, and in both XY and YZ planes of the ODS alloy. A higher energy density slightly improves the (111) texture in the YZ plane of the control alloy.

Scanning Electron Microscopy:

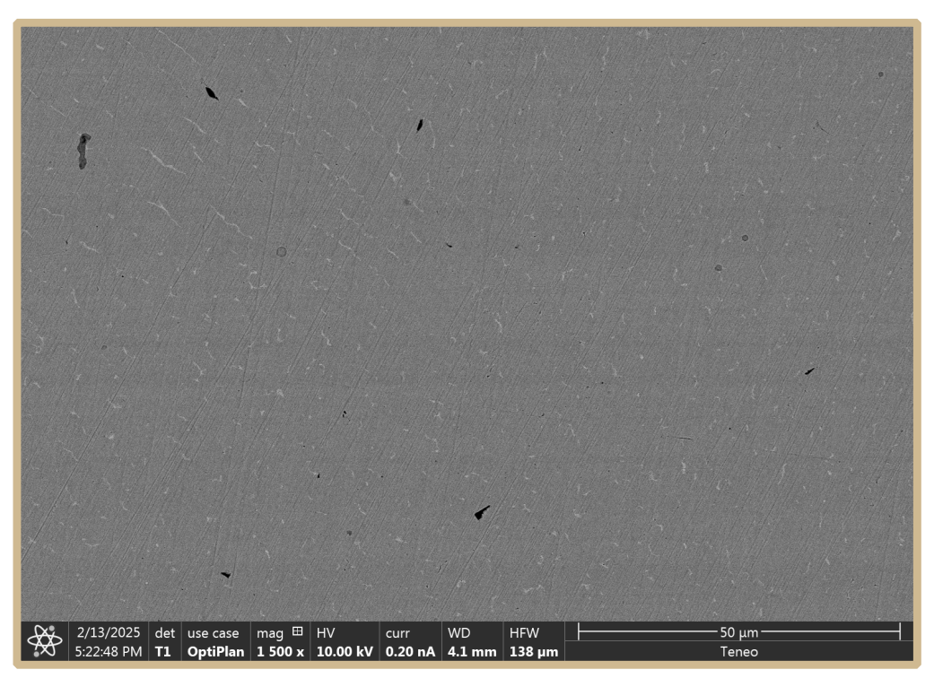
Energy Dispersive X-Ray Spectroscopy Maps of ODS Alloy



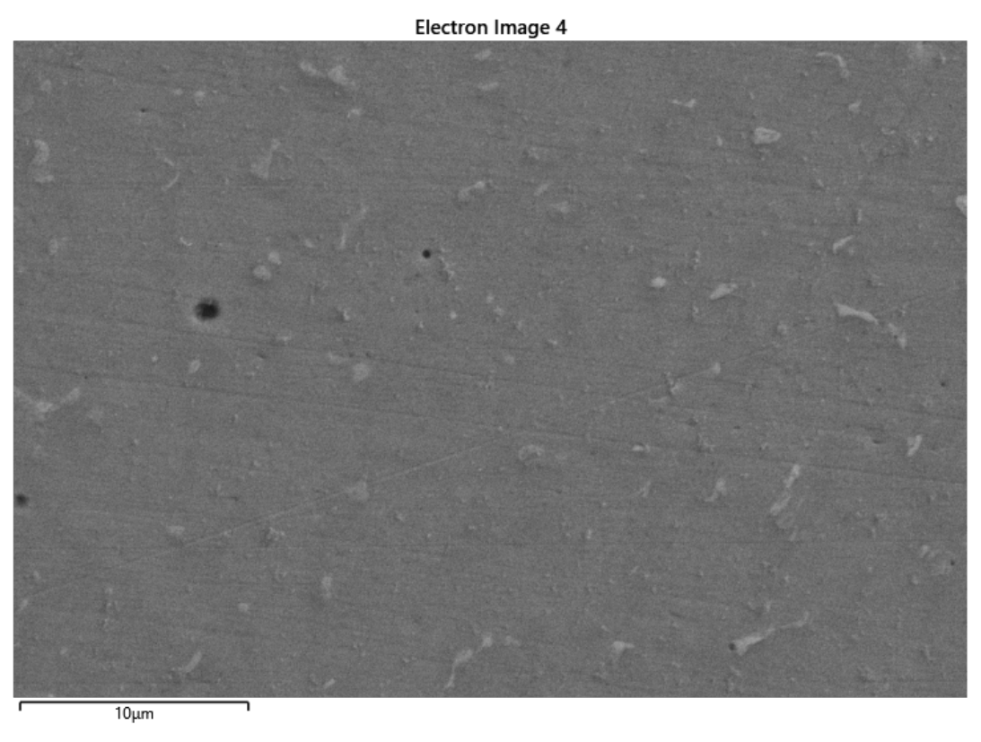
- EDS maps show carbides and yttria agglomerates in the ODS alloy.



Energy Dispersive X-Ray Spectroscopy Spectrum of ODS alloy.



An SEM image of the control sample.

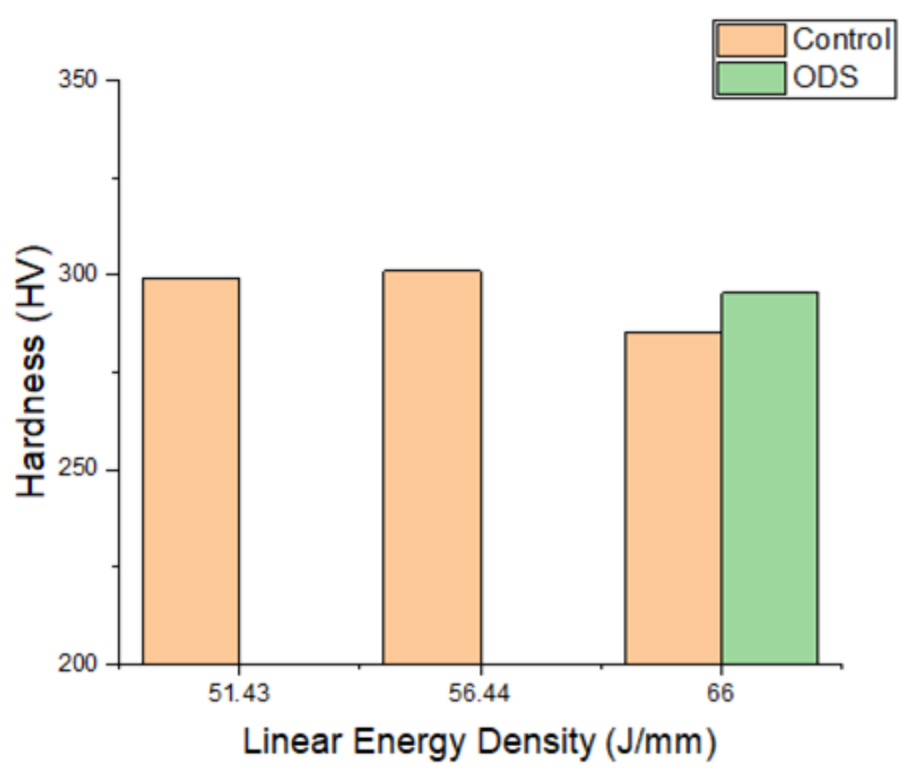


An SEM image of the ODS sample.

Results Continued

MICROHARDNESS:

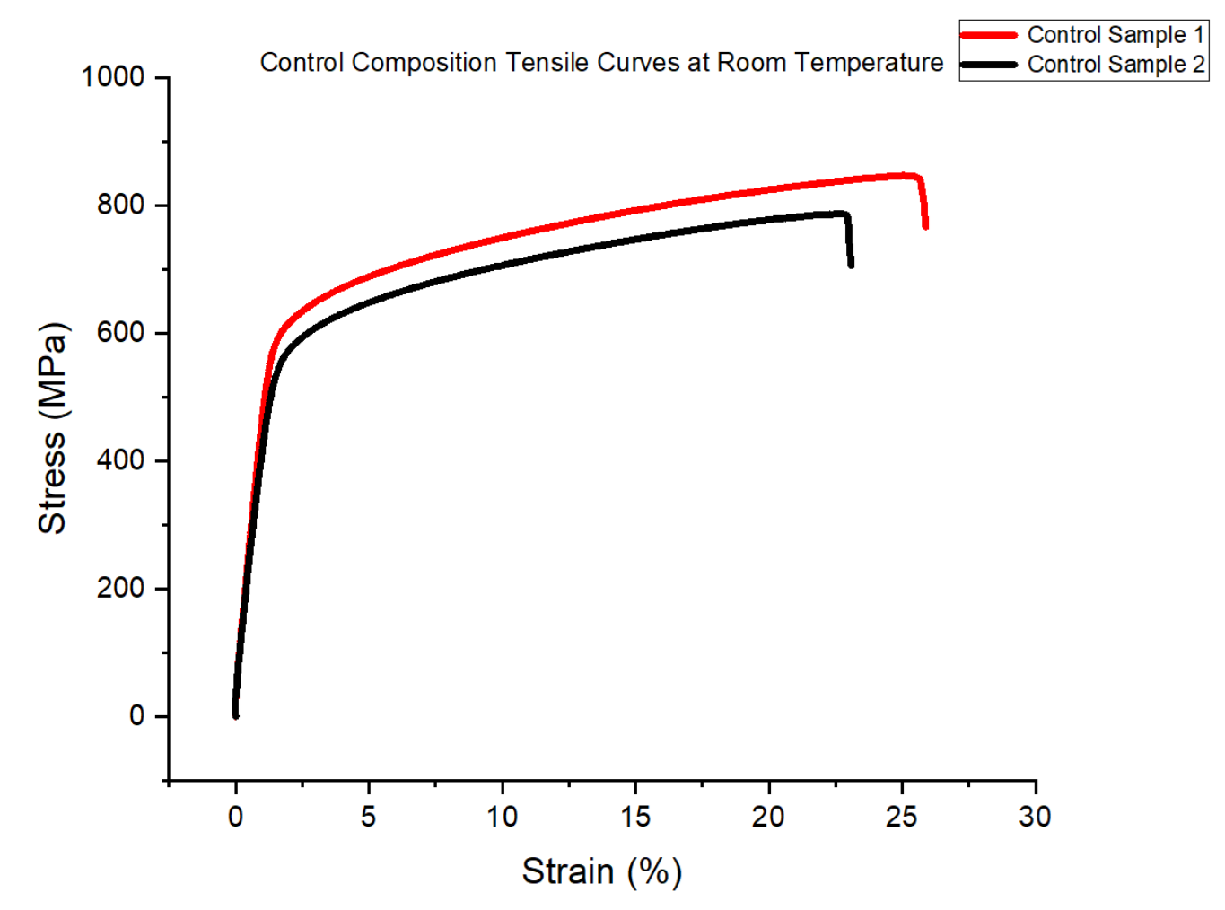
- No significant hardness change from the Control to ODS alloy.
- Consistent microhardness values throughout the samples.
- Microhardness is higher than the bulk alloy, but similar to our prior LPBF work [3].



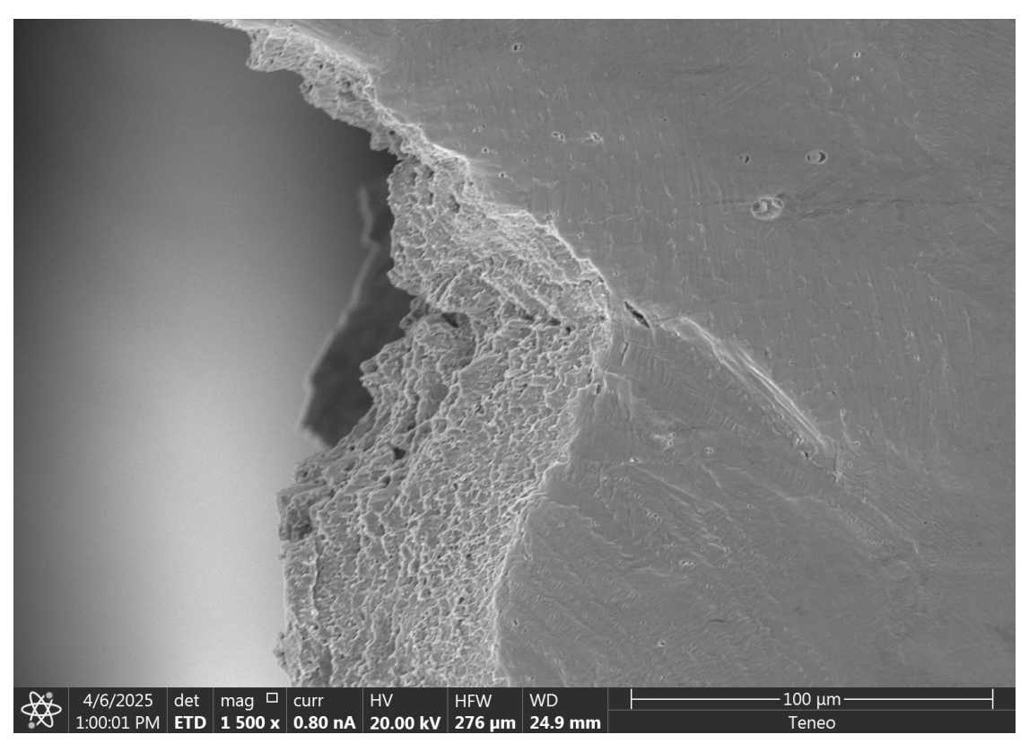
IMPULSE EXCITATION TECHNIQUE:

Material	Haynes 230 Control		Haynes 230 ODS			
Sample	Control 1	Control 2	ODS 1	ODS 2	ODS 3	ODS 4
Avg. E (GPa)	160 ± 0.03	172 ± 1.19	146 ± 0.03	115 ± 0.17	127 ± 0.22	148 ± 0.08

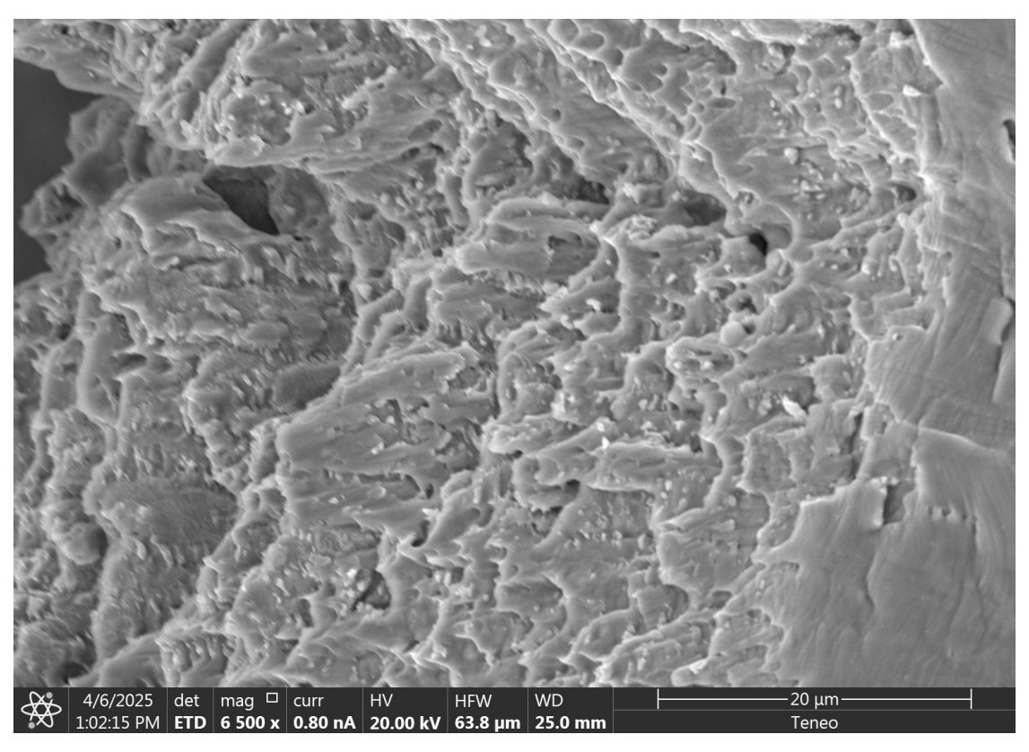
- Modulus of Elasticity drops for the ODS alloy due to its porosity.



Room Temperature Fracture Surface – SEM images:



The fracture surface at low magnification



The fracture surface at higher magnification

Conclusion

- Successful manufacturing of a crack-free Haynes 230 alloy was conducted by DED technique.
- Nano-yttria was introduced to manufacture a Haynes 230 ODS composition.
- The microhardnesses of the ODS and control alloys are similar.
- Tensile tests of the control alloy revealed good tensile behavior.
- Future experimentation should focus on

1) improving print parameters and Yttria dispersion,
2) minimizing agglomeration and porosity, and
3) investigating the high temperature mechanical behavior of control and ODS alloys.

Acknowledgements & References

ACKNOWLEDGEMENTS

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REFERENCES

[1] Haynes International. (n.d.). HAYNES® 230® alloy. Retrieved November 15, 2024
[2] Resodyn. ResonantAcoustic Mixing White Paper. pg. 8
[3] Bo Yang. Investigation of strengthening mechanisms in an additively manufactured Haynes 230 alloy. Acta Materialia 222 (2022) 117404.
[4] ResearchGate. Schematic illustration of a dislocation passing between widely spaced hard/undeformed particles

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