Location-specific microstructures and properties of Haynes 282 with laser-wire DED processing

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Motivation

- Haynes 282 is widely used in energy applications due to balance of phase stability, strength & corrosion resistance
- Haynes 282 is highly weldable precipitate strengthened Ni-base superalloy being targeted across additive manufacturing modalities
- LW-DED is cost-effective alternative to laser powder bed fusion with ~ 1 mm feature size: cleaner, less scrap, cheaper feedstock
- The correlation between location-specific microstructures & mechanical properties is not well documented

Objectives

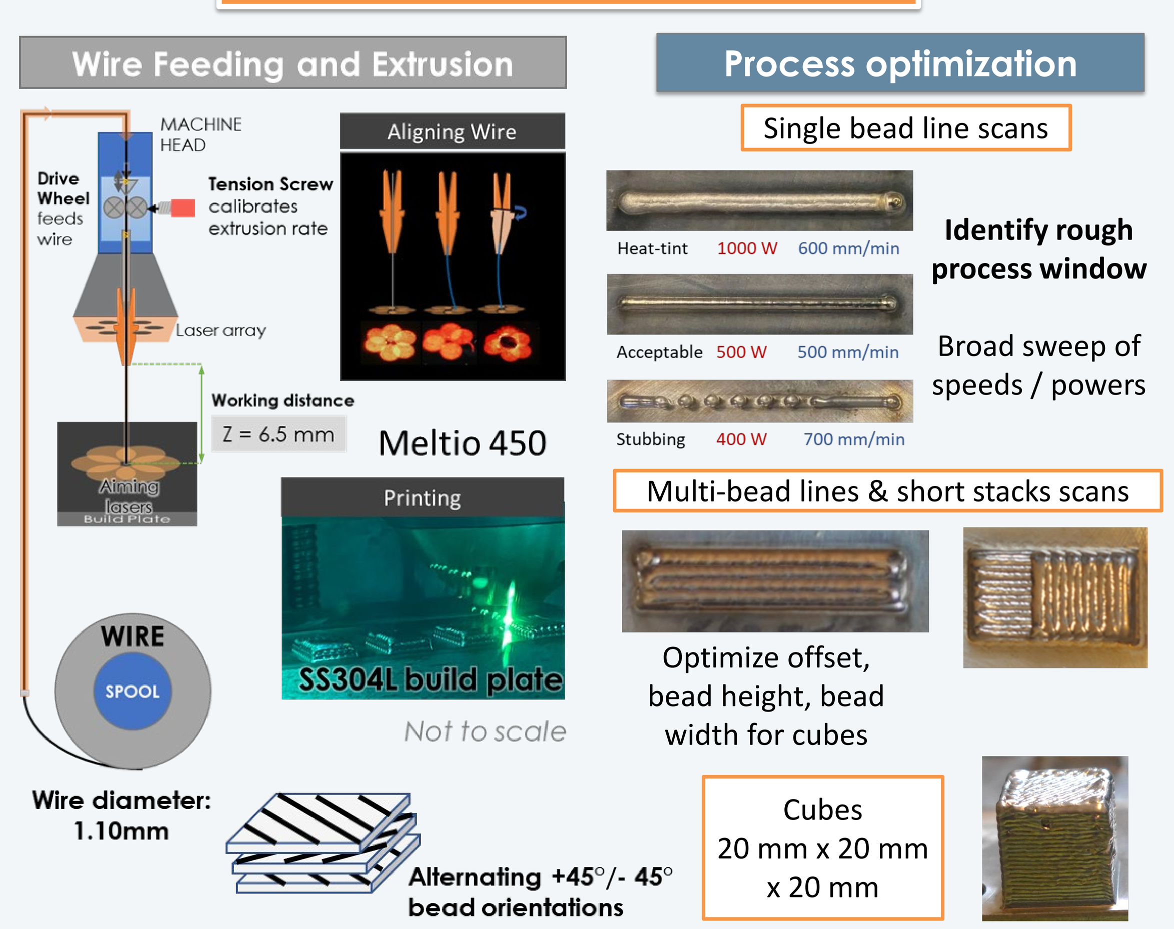
- Develop better processing for laser-wire direct energy deposition (LW-DED) for Haynes 282
- Understand the correlation between location-specific microstructures and mechanical properties
- Provide valuable insights into future printing parameters and heat-treatment optimization

Materials and Processing

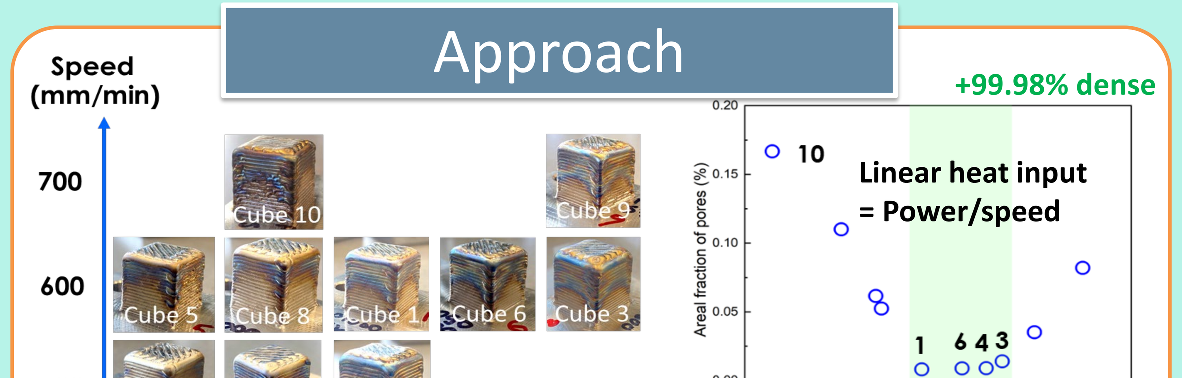
Feedstock Material: **Haynes 282 Wire** — Diameter 1.10 mm

wt%	Ni	Cr	Co	Mo	Ti	Al	Fe	Mn	W	C	B
H282	56.8	19.3	10.2	8.48	2.24	1.51	0.97	0.09	0.08	0.06	0.005

LW-DED with Meltio 450



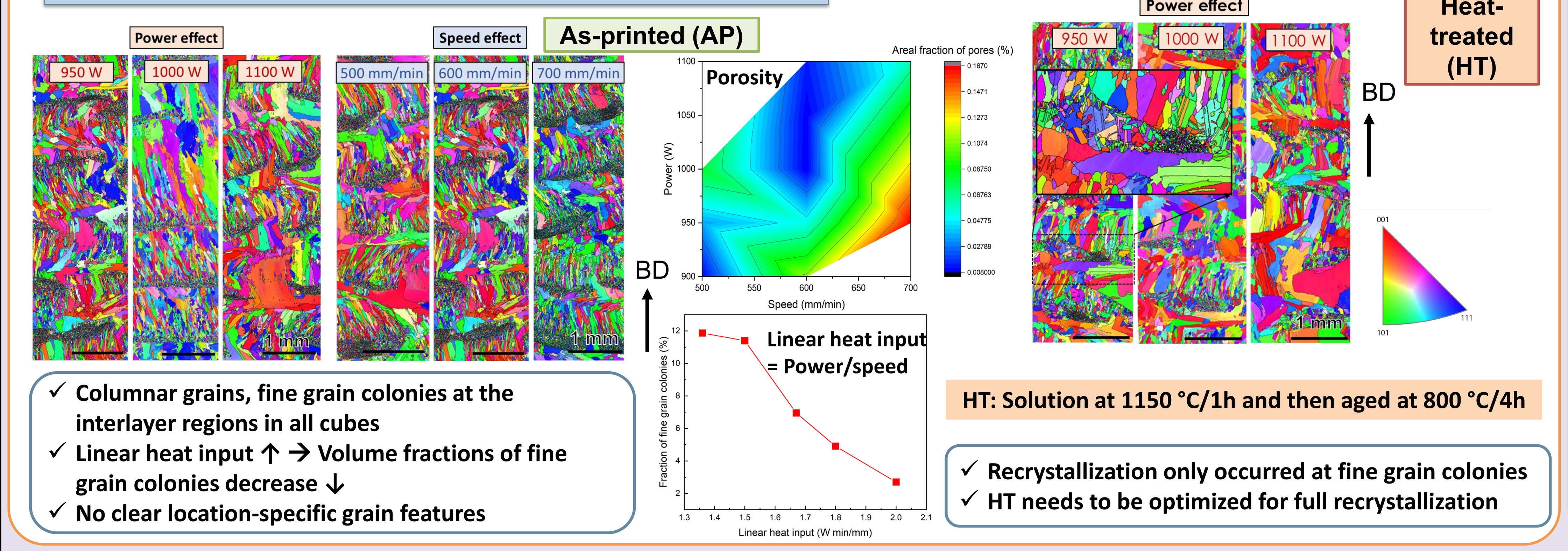
Approach



- ✓ Location-specific microstructures (SEM/EDS, EBSD, APT, Neutron diffraction)
- ✓ Location-specific mechanical properties (Vickers microhardness, compression tests)

Microstructures

Variability of grain structure with processing parameters



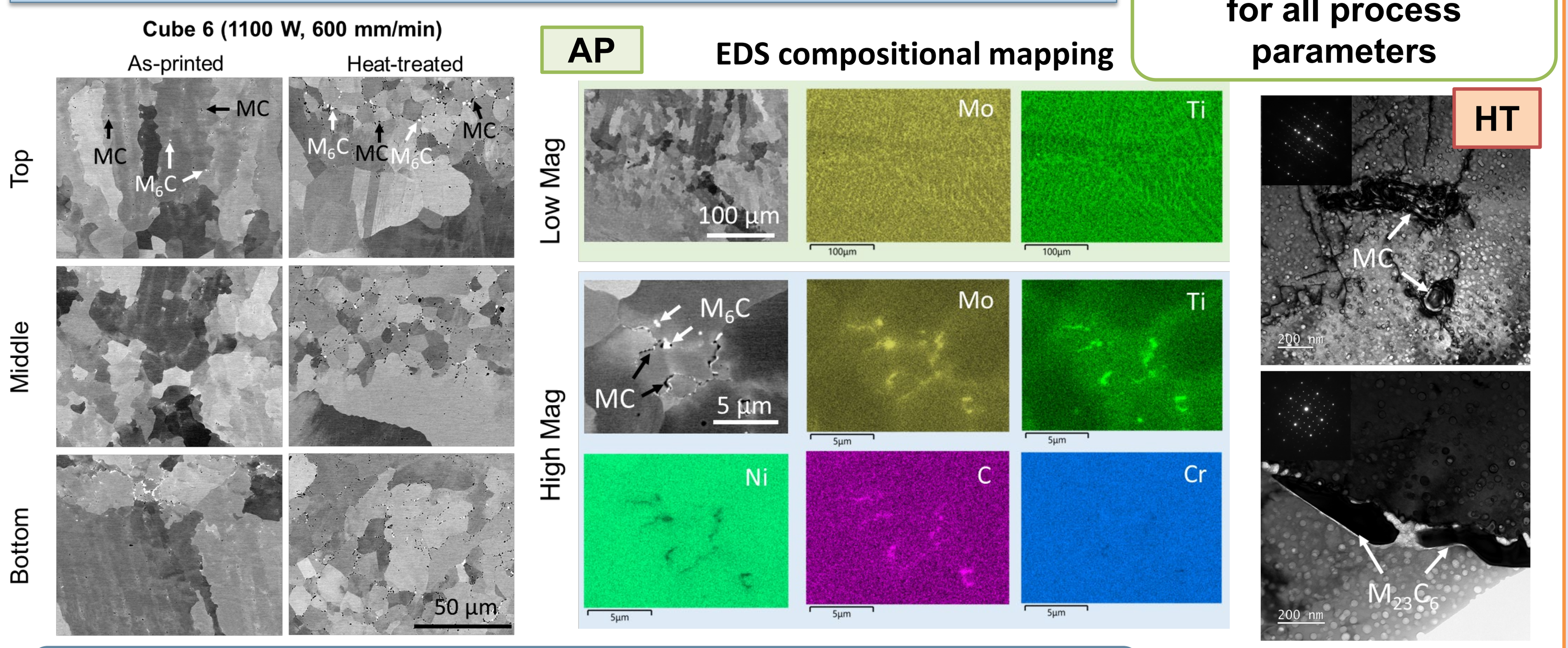
- ✓ Columnar grains, fine grain colonies at the interlayer regions in all cubes
- ✓ Linear heat input ↑ → Volume fractions of fine grain colonies decrease ↓
- ✓ No clear location-specific grain features

HT: Solution at 1150 °C/1h and then aged at 800 °C/4h

- ✓ Recrystallization only occurred at fine grain colonies
- ✓ HT needs to be optimized for full recrystallization

Variability of carbides with processing parameters/locations

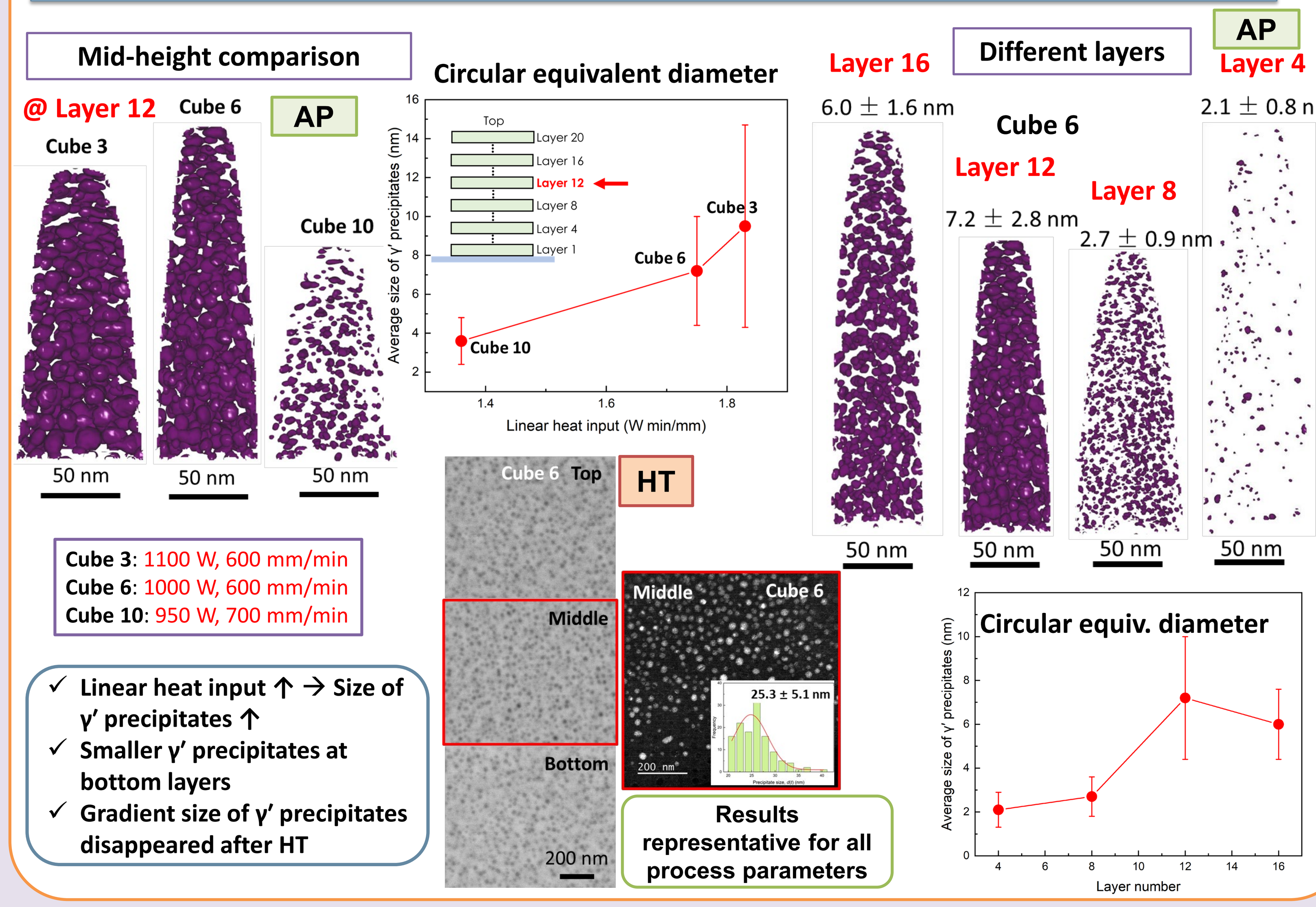
Results representative for all process parameters



- ✓ Chemical segregations of Mo and Ti are present due to their high melting points
- ✓ Mo-rich M_6C and Ti/Mo-rich MC carbides mainly formed at the interlayer regions

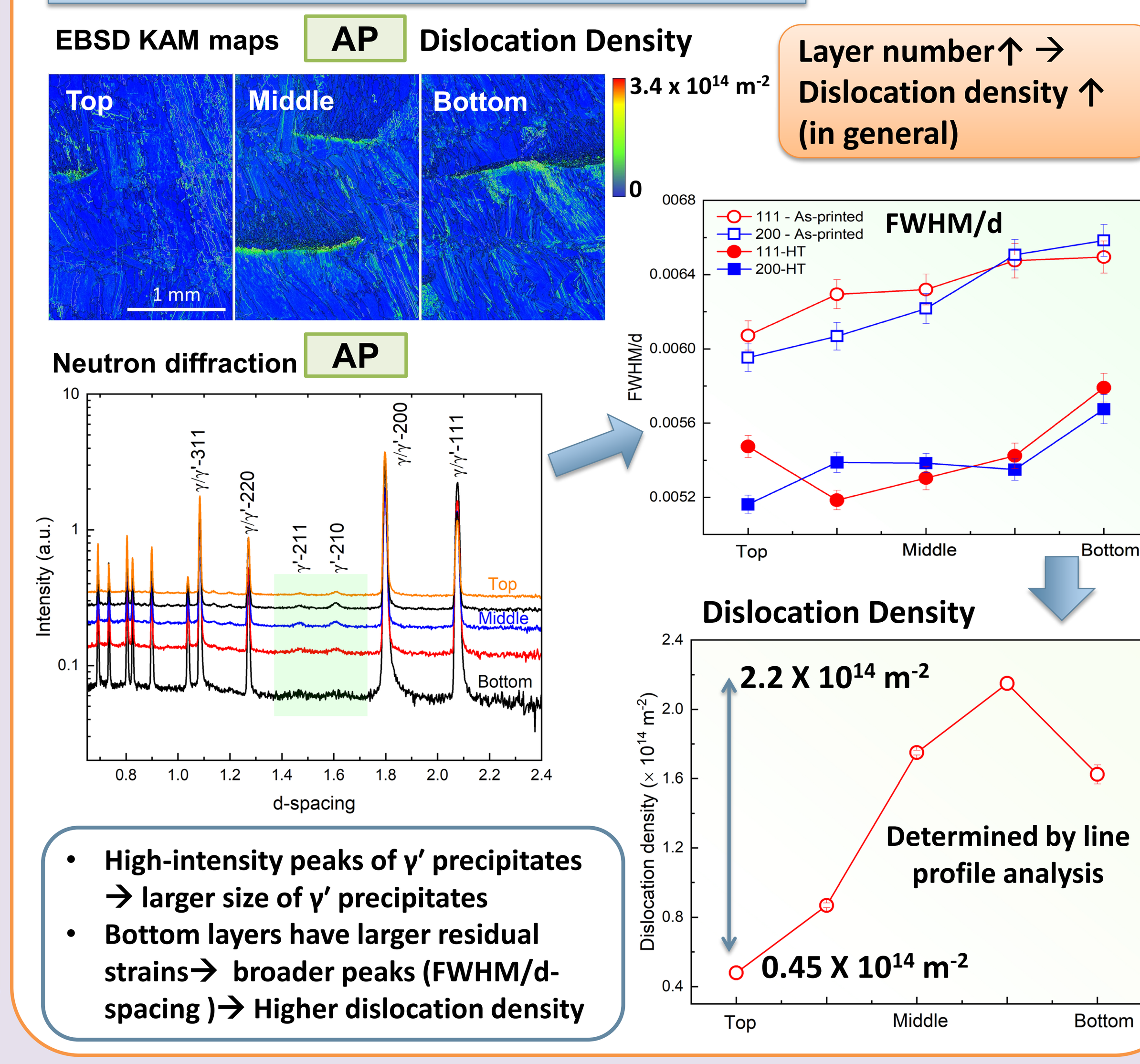
Carbides evidenced by TEM

Variability in γ' precipitate distribution w/processing parameters & layer height



- ✓ Linear heat input ↑ → Size of γ' precipitates ↑
- ✓ Smaller γ' precipitates at bottom layers
- ✓ Gradient size of γ' precipitates disappeared after HT

Location-specific dislocation density

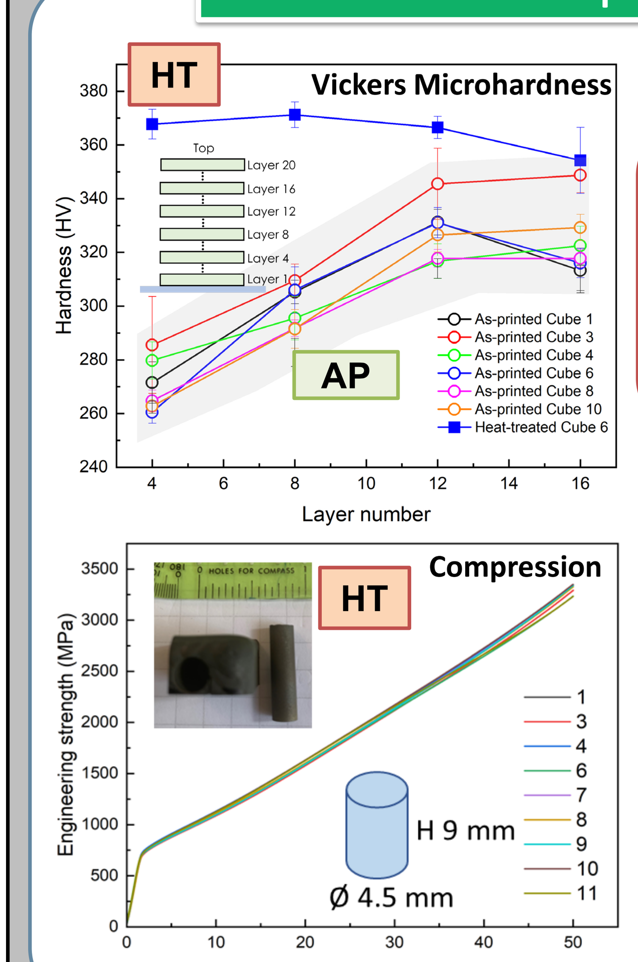


- High-intensity peaks of γ' precipitates → larger size of γ' precipitates
- Bottom layers have larger residual strains→ broader peaks (FWHM/d-spacing)→ Higher dislocation density

Conclusions & Summary

- Optimized LW-DED Haynes 282 printing achieves ~99.98% density for 1.67-1.83 W·min/mm
- Bimodal grain distribution: Fewer fine grain colonies with increasing heat input: 12% → 2%
- γ'-precipitate size: Mid-height shows the size triples with increasing heat input: 3 → 10 nm; Top layers have the size triples the bottom layers': 2 → 6 nm, due to the faster cooling rate at the bottom
- Mo-rich M_6C and Ti/-rich MC carbides prefer to the interlayer regions in AP and HT conditions
- Location-specific dislocation density: Five times higher at bottom layers than that at top layers: $0.45 \times 10^{14} \rightarrow 2.2 \times 10^{14}$ m^{-2}
- Hall-Petch effect resulted in the small deviation in yield strength in HT samples
- Gradient γ'-precipitate size distribution in AP condition leads to gradient hardness distribution

Mechanical properties



Variability with layer height

- ✓ Gradient hardness from the bottom to the top layers
- ✓ No gradient hardness distribution after heat treatment

- ✓ Small deviation in stress-strain response between all conditions
- ✓ Note: Comparable yield strength (695~728 MPa) to that of conventional-processed 282 alloy (~ 715 MPa)

Discussion

- Strengthening mechanism → Gradient hardness values

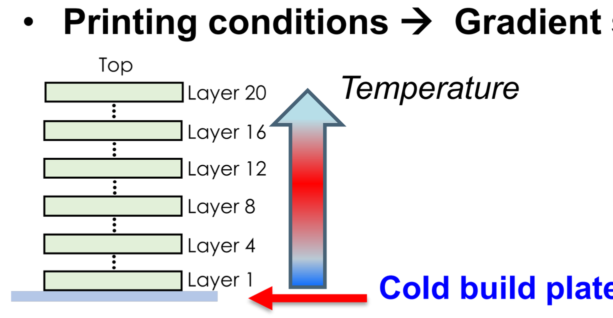
Middle & Top: $\sigma_y = \sigma_0 + \sigma_{dis}\ (\text{small}) + \sigma_{P\text{-}L12}\ (\text{large})$ — Hardness: **Large**

Bottom: $\sigma_y = \sigma_0 + \sigma_{dis}\ (\text{large}) + \sigma_{P\text{-}L12}\ (\text{small})$ — Hardness: **Small**

σ_0: Intrinsic strengthening; σ_{dis}: Dislocation strengthening; $\sigma_{P\text{-}L12}$: Precipitation strengthening

- ✓ Larger γ' precipitates → more significant strengthening (particle shearing) → larger hardness values at bottom layers

- Printing conditions → Gradient sizes of γ' precipitates due to thermal history

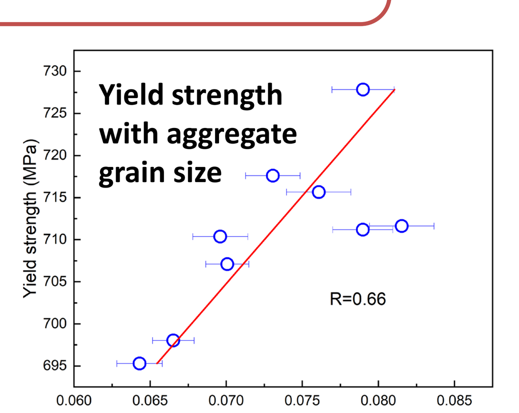


- ✓ Cold build plate → Gradient temperature distribution from the bottom to the top layers
- ✓ The fastest cooling rate at the bottom layers → the smallest γ' precipitates

- Hall-Petch effect → Yield strength deviations correlated to aggregate grain size

$$\sigma_y = \sigma_{y,FGs} f_{FGs} + \sigma_{y,LGs} f_{LGs}$$

$$\sigma_y = \sigma_0 + \sigma_{P\text{-}L12} + k\,(f_{FGs}\, d_{FGs}^{-1/2} + f_{LGs}\, d_{LGs}^{-1/2})$$



Acknowledgements: This work was performed in support of the US DOE's NETL Advanced Materials Development under FWP-1022406. The authors would like to thank **P. Wang** from **Haynes International** for supplying the wire; **Staff** at **OSU ATAMI** for DED deposition assistance; **M.B. Fortner** and **D. Harvey** for metallographic preparation; **C. Powell** for compression testing, and **T.A. Godell** for sample machining. This research used resources at the Spallation Neutron Source (SNS) and Center for Nanophases Materials Sciences (CNMS), DOE Office of Science User Facilities operated by the Oak Ridge National Laboratory (ORNL).

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