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A Comparative Study on Tensile Properties of Additively Manufactured Nickel-based Superalloys at Different Temperatures: Inconel 718 vs. Haynes 282 vs. Hastelloy X

Seyed R Ghiaasiaan
1st November 2022 (Tuesday), 14:40 PM

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A Comparative Study on Tensile Properties of Additively Manufactured Nickel-based Superalloys at Different Temperatures: Inconel 718 vs. Haynes 282 vs. Hastelloy X

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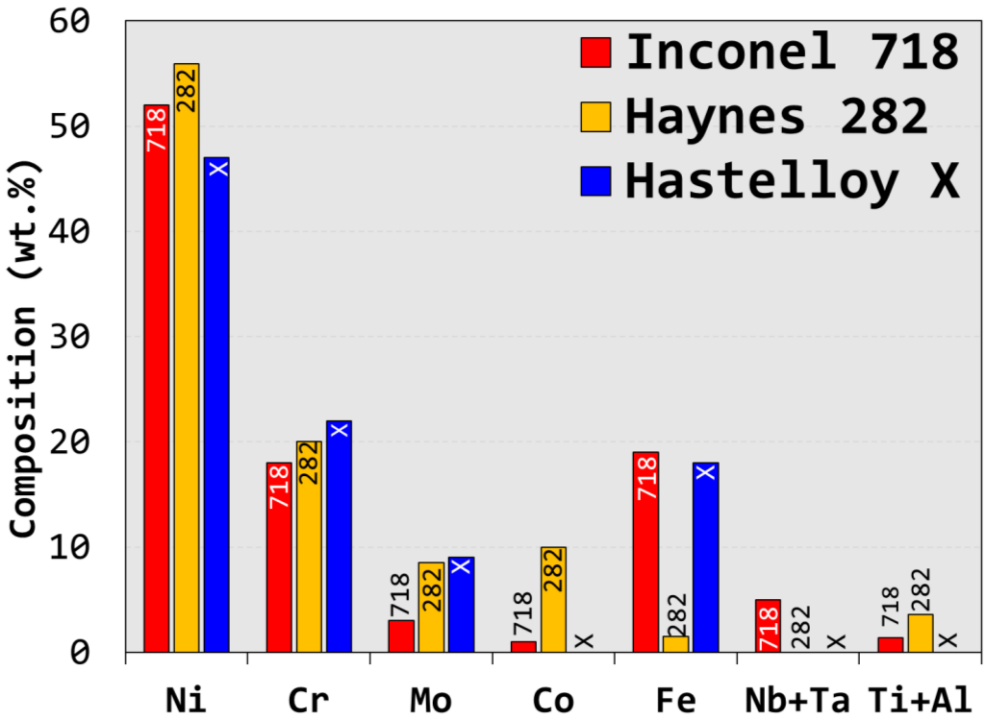
- Acknowledgment

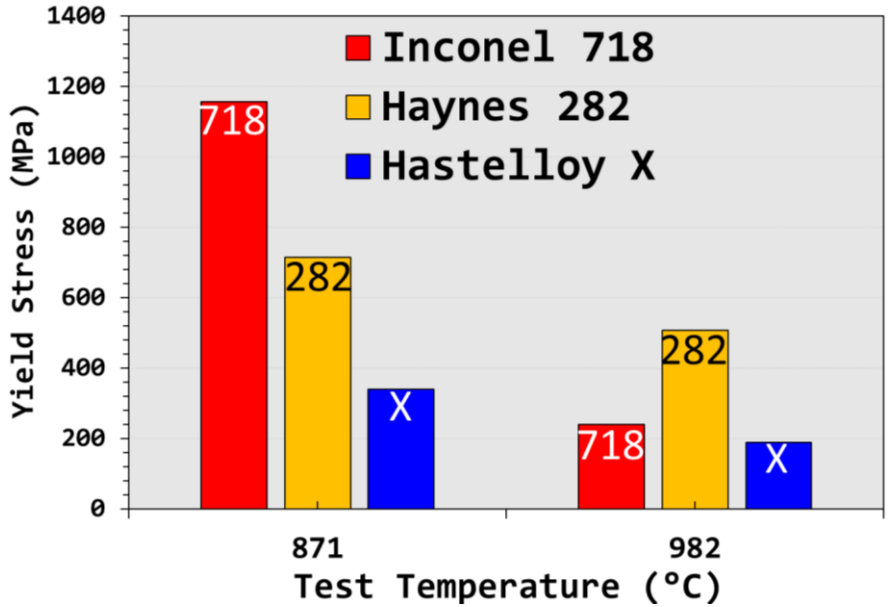
Introduction

Inconel 718 (γ”), Haynes 282 (γ’), and Hastelloy X (solid solution)



	Inconel 718	Haynes 282	Hastelloy X
Ni	52.5	55.885	49.05
Cr	19	20	21.75
Mo	3.05	8.5	9
Co	1	10	
Fe	16.8	1.5	18.5
Nb+Ta	5		
Ti+Al	1.5	3.6	

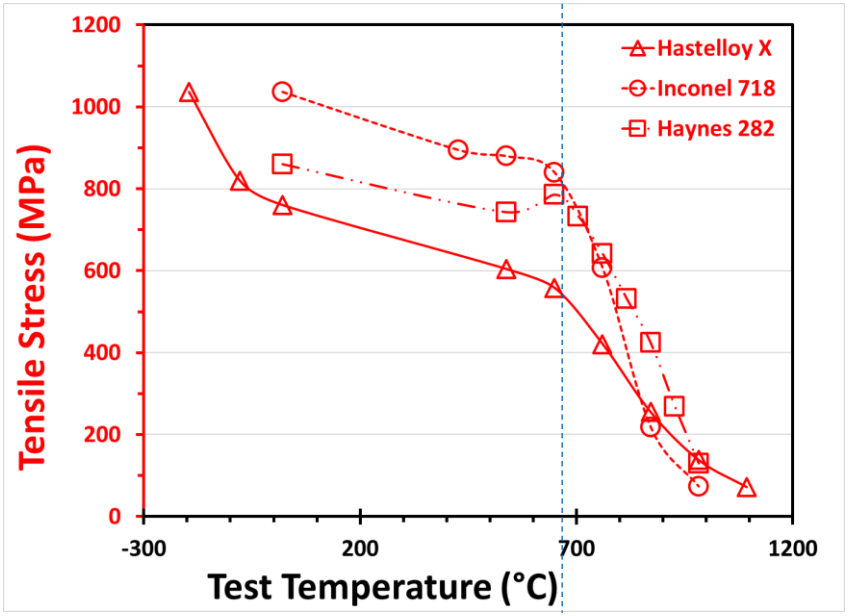
High Temperature Ni-base Superalloy:

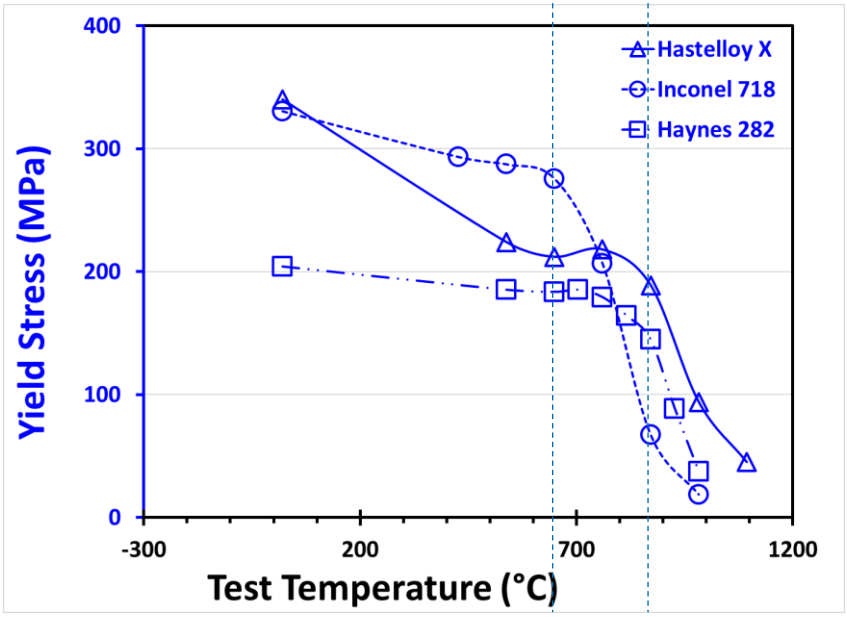


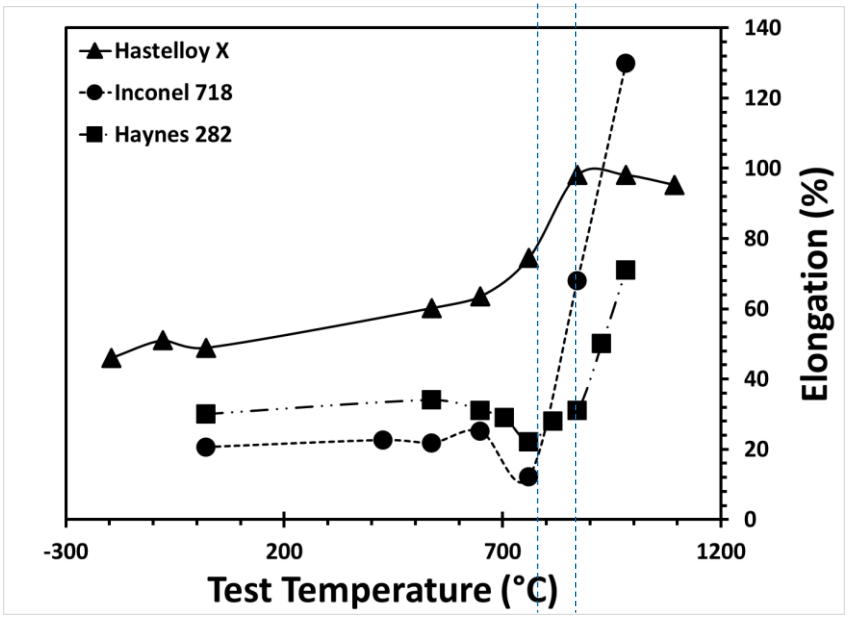
Haynes International: https://www.haynesintl.com/

Introduction

Tensile properties in wrought at different temperature (literature)







Problem statement, motivation, and objective

This study investigates **tensile** performance at different temperatures for LP-DED IN718, L-PBF HY282, and L-PBF HX.

Properties	Process	Test Temperature								
		°F	-320	70	400	800	1200	1400	1600	1800
		°C	-195	21	204	427	649	780	871	980

Wrought data: Haynes International: https://www.haynesintl.com/

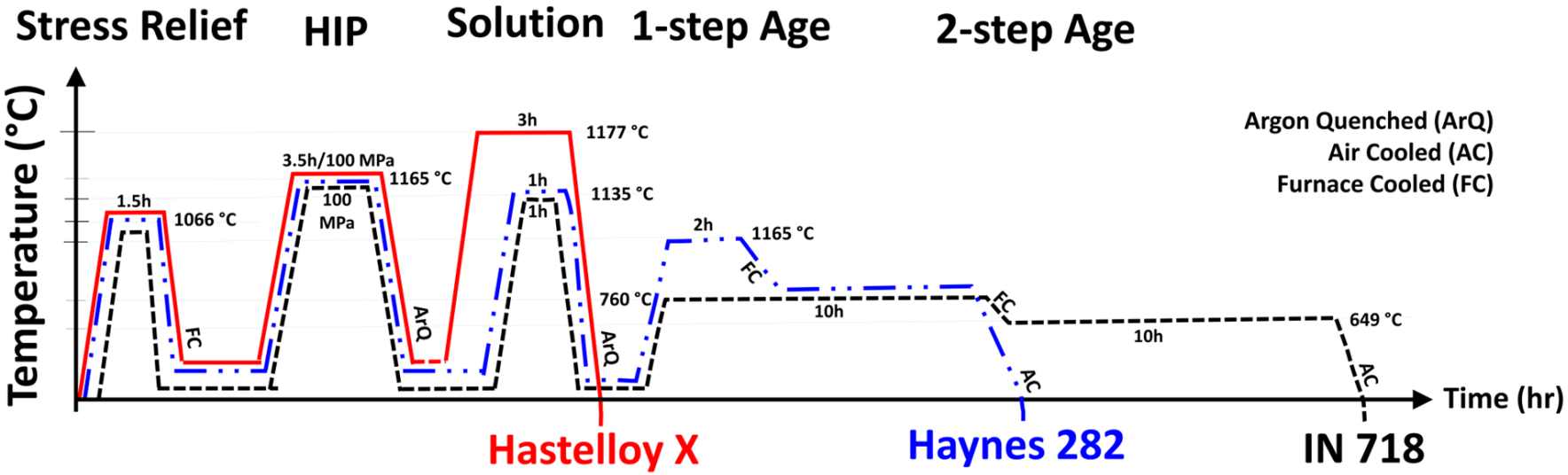
Experimental Procedures

fabrication, heat treatment, and tests

Experimental Procedure

Fabrication

Post-processing Heat Treatment



Process	Laser power (W)	Travel speed (mm/min)	Powder feed rate (g/min)	Scan speed (mm/s)	Layer height (μm)	Manufacturer
LP-DED IN718	1070	1016	16		381	RPM Innovations, Inc (www.rpm-innovations.com)
L-PBF HY282	285	-		960	40	KAM Solutions (http://www.kamsolutions.com)
L-PBF HX	200	-		1000	30	SLM Solutions (www.slm-solutions.com)

Experimental Procedure

Microstructural Characterizations

- Zeiss Crossbeam 550 Scanning Electron Microscope (SEM).
- Electron backscatter diffraction (EBSD).
- Energy dispersive spectroscopy (EDS).
- Electron channeling contrast imaging (ECCI).

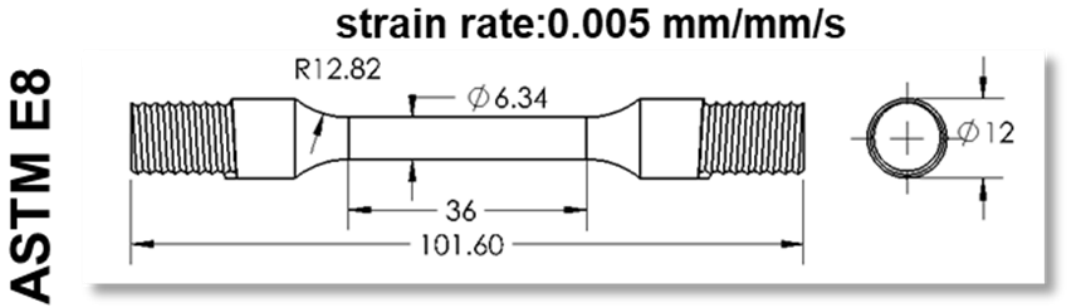
Fatigue/Tensile Tests

- All specimens were fully heat treated and then machined to ASTM E8 geometry size.
- Tensile tests were performed according to ASTM E8 & E21.

Prior to test:

- 5 min isothermal hold in N2 for cryogenic temperature tests.
- 30 min isothermal hold for elevated temperature tests.

- Test temperatures
  - Tensile:-195ºC, room, 204ºC, 427ºC, 649ºC, 870ºC, 980ºC.
  - 5-6 tests per temperature.



Experimental Results

initial microstructure
(undeformed)

Results: Initial Microstructure (BSE)

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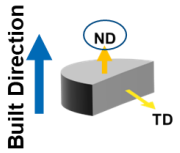
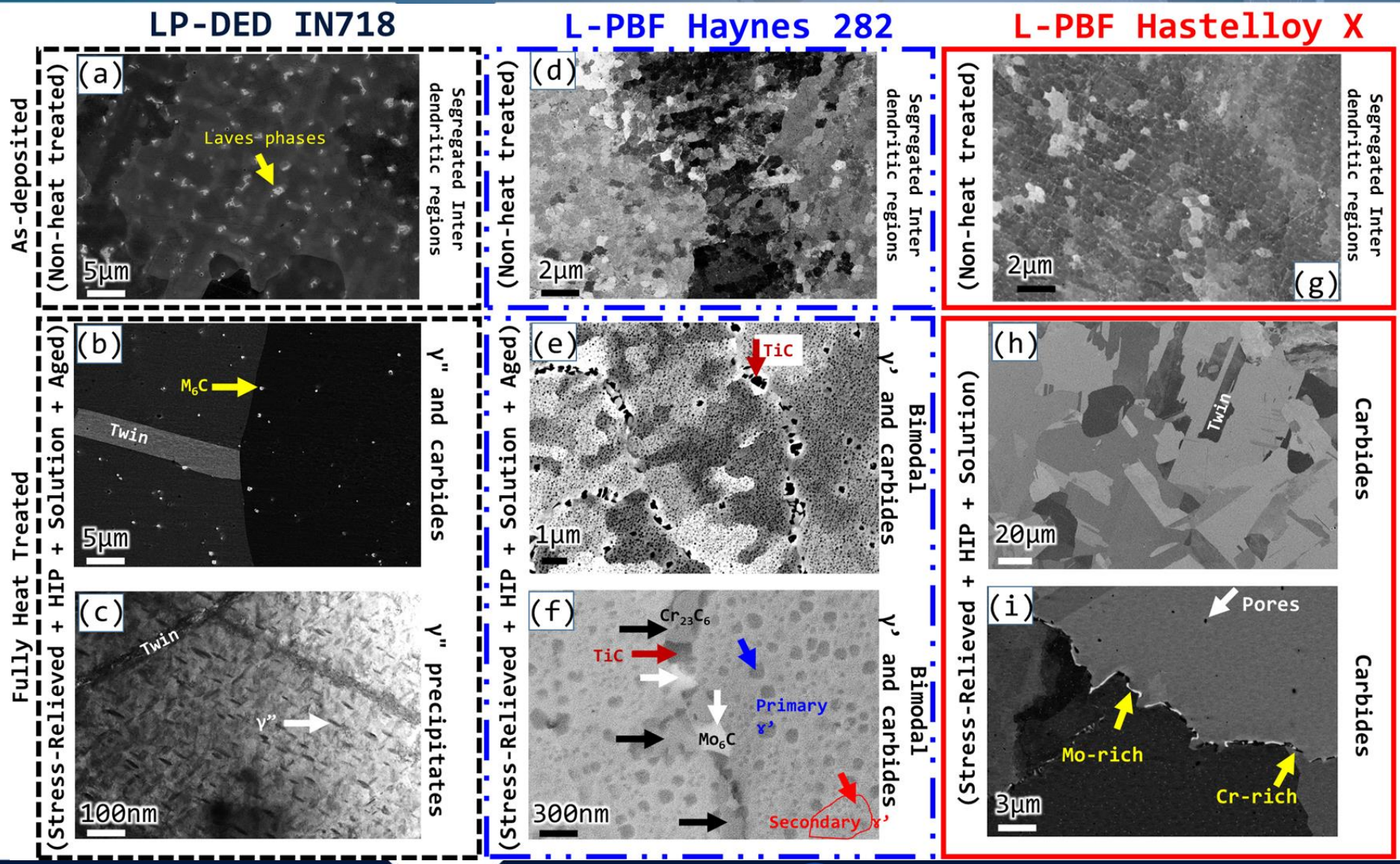
Non-Heat Treated vs. Fully Heat Treated:

- LP-DED Inconel 718:
  - NHT: Inter-dendritic micro-segregated cellular regions of Laves phase.
  - HT: γ-grains + micron-sized carbides + nano-sized γ" plate-like precipitates.
- L-PBF Haynes 282:
  - NHT: Inter-dendritic micro-segregated cellular regions.
  - HT: γ-grains + micron-sized GB carbides + nano-sized γ' spherical precipitates (~60 nm).
- L-PBF Hastelloy X:
  - NHT: Inter-dendritic micro-segregated cellular regions.
  - HT: γ-grains + micron-sized GB carbides.





Results: Initial Microstructure (EBDS)

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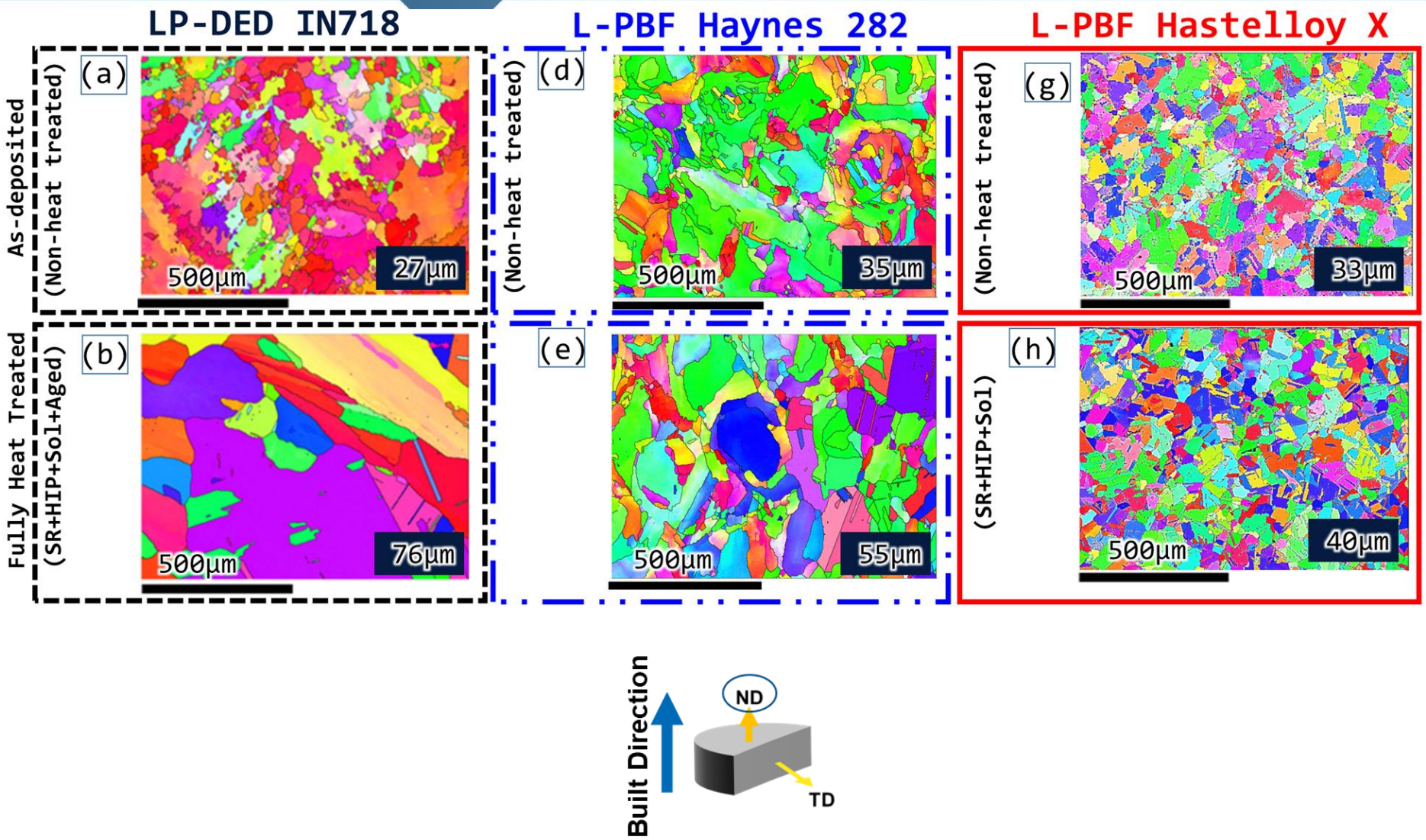
Non-Heat Treated vs. Fully Heat Treated:

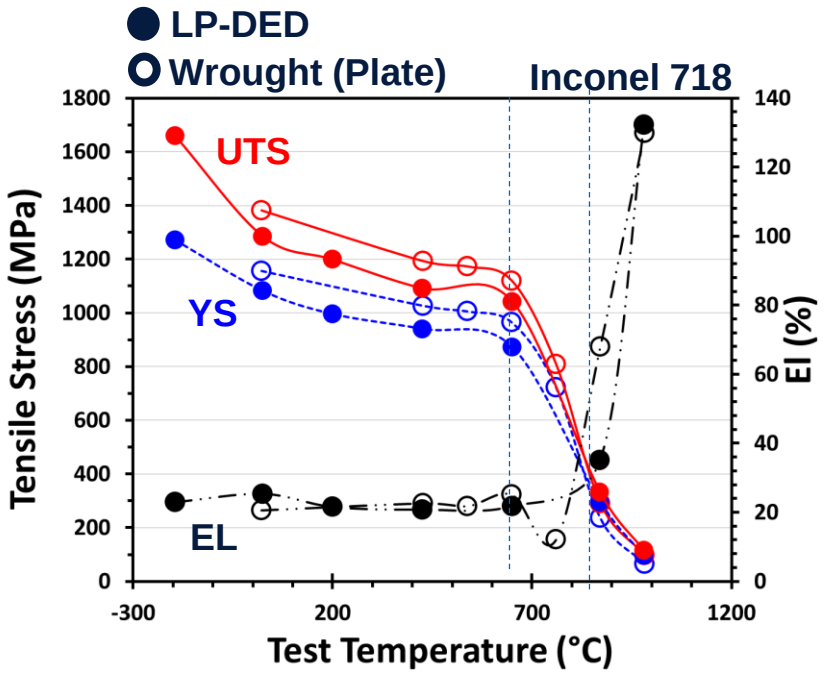
- LP-DED Inconel 718:
  - Coarser grain structure with shown recrystallization and grain growth.
- L-PBF Haynes 282:
  - Finer grain structure (due to higher cooling rate) however, sluggish in recrystallization and grain growth; most likely due to pinning effect of GB carbides.
- L-PBF Hastelloy X:
  - Finer grain structure (due to higher cooling rate); however, sluggish in recrystallization and grain growth; most likely due to pinning effect of GB carbides.

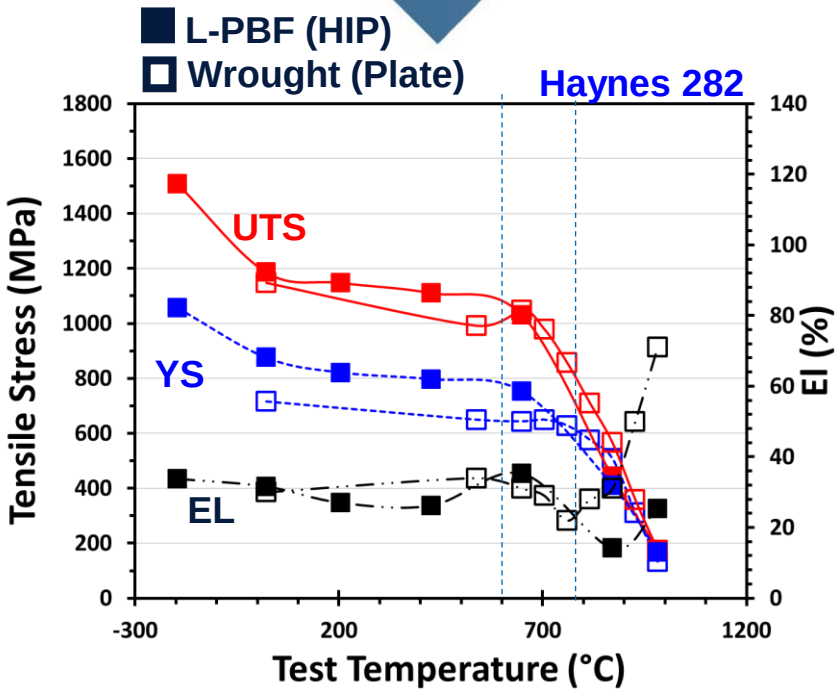


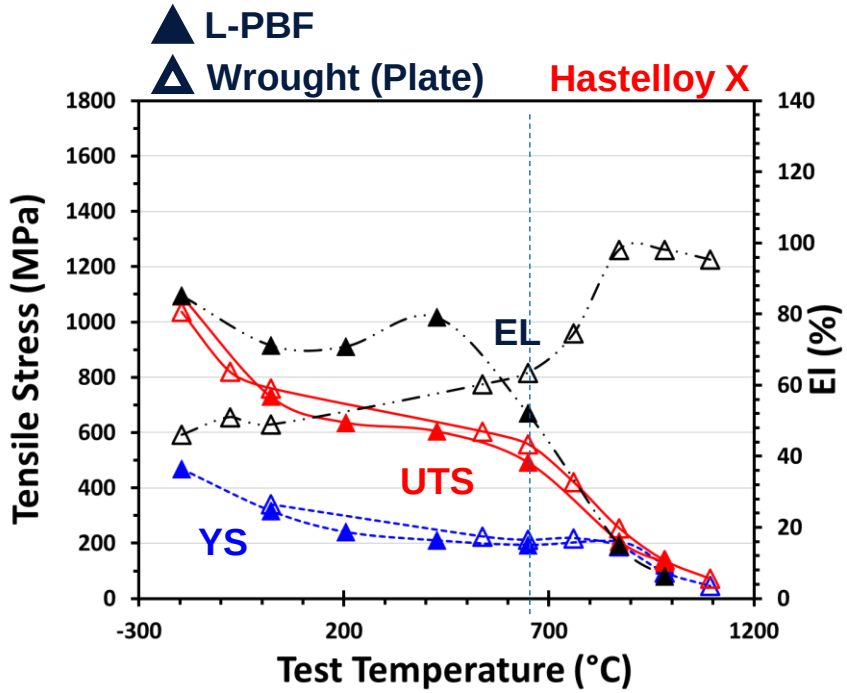
Experimental Results

tensile behavior at different temperatures;
fracture surfaces

Results: Tensile Properties vs. Temperature



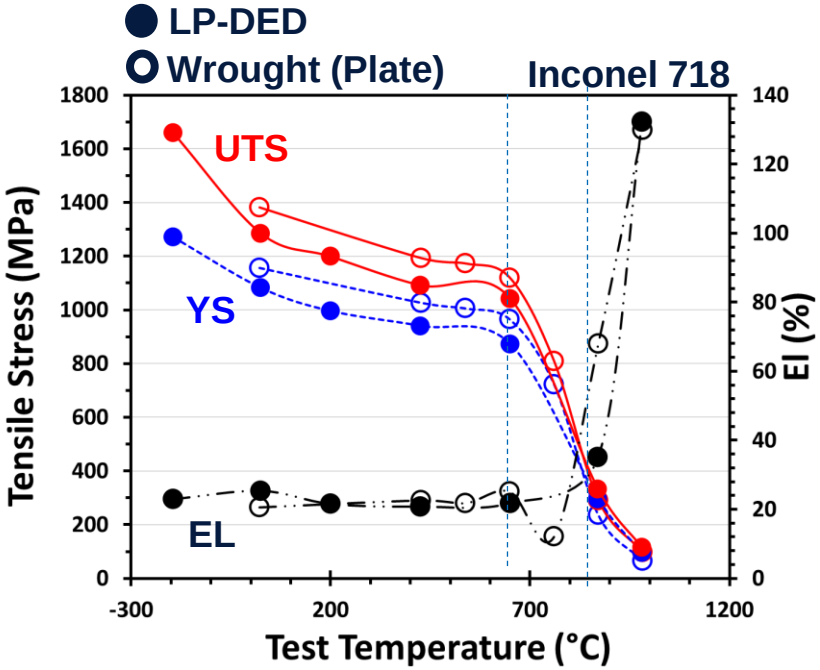




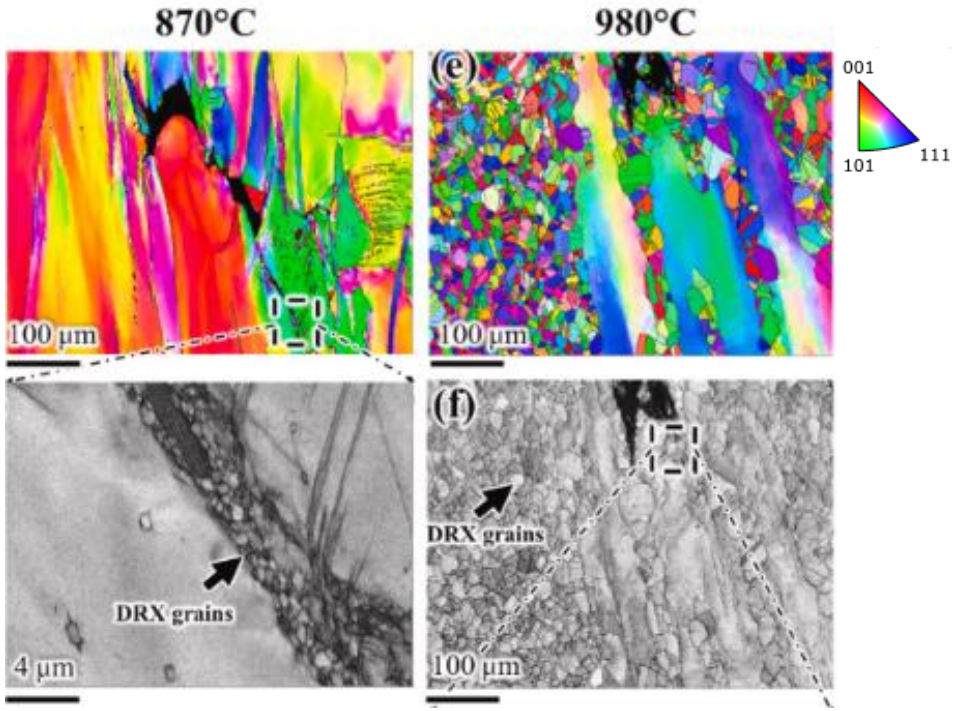
- Up to 650 °C:
  - All three showed stable behavior.
  - All three showed comparable strengths with wrought.
  - Precipitation hardened alloys (AM IN718/AM Haynes 282) showed comparable ductility with wrought while solid solutioned alloy (AM Hastelloy X) showed superior ductility than wrought; most likely due to pinning effect of GB carbides.
- Above 650 °C:
  - All three showed decreased strenths.
  - Precipitation hardened alloys (AM IN718/AM Haynes 282) showed increased ductility.
  - AM IN718 showed comparable ductility with wrought.
  - While AM HY282 and solid solutioned AM Hastelloy X showed inferior ductility to wrought.

Wrought data: Haynes International: https://www.haynesintl.com/
DED 718: Ahmad-Ghiaasiaan-Gradl-Shao-Shamsaei; MSE A 849 (2022) 143528

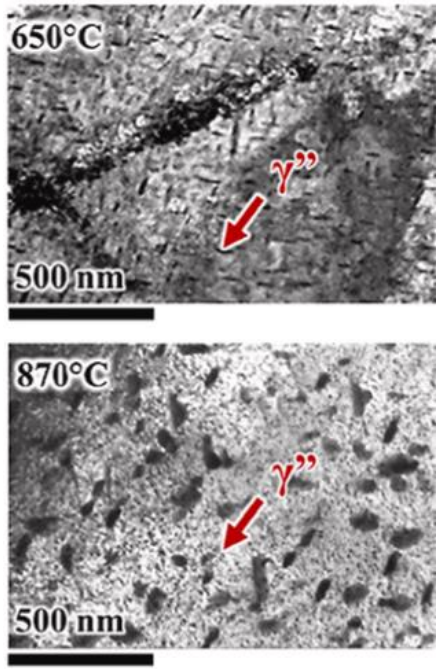
Results: Tensile Properties vs. Temperature



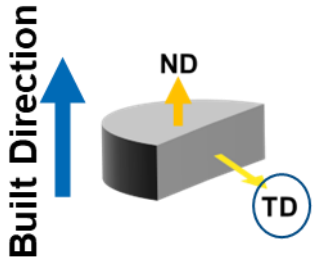
Carbide debonding/DRX/twining



Coarsening of γ” precipitate



- Up to 650 °C:
  - Stable strengths/ductility comparable with wrought.
- Above 650 °C:
  - Decreased strenths due to coarsening of γ” precipitates, dynamic recrystallization (DRX) and deformation twining.
  - While ductility increased due to carbide debonding.



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Results: Tensile Properties vs. Temperature

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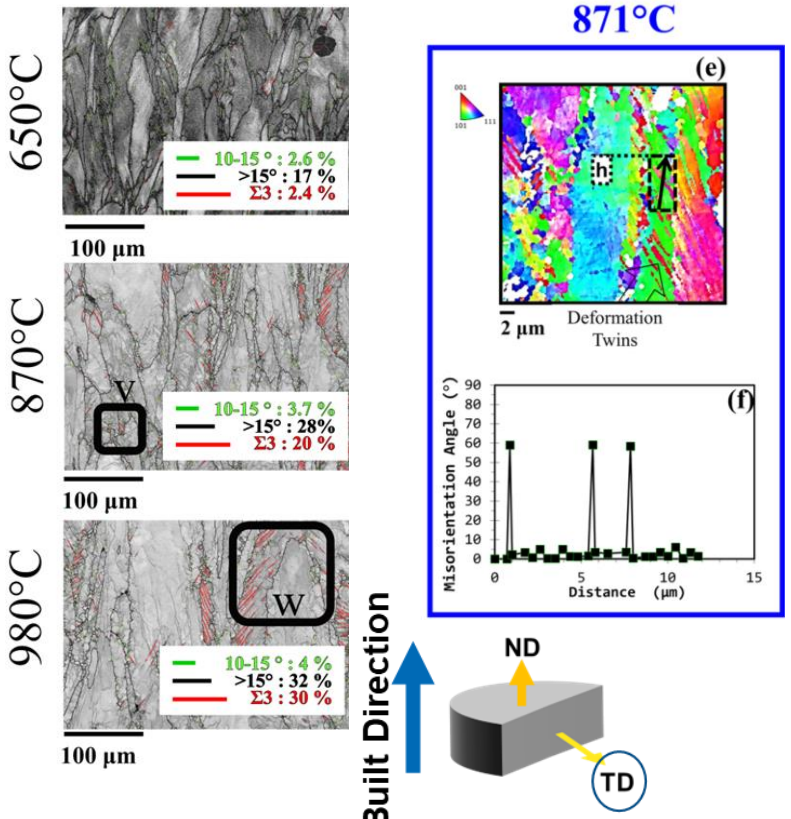
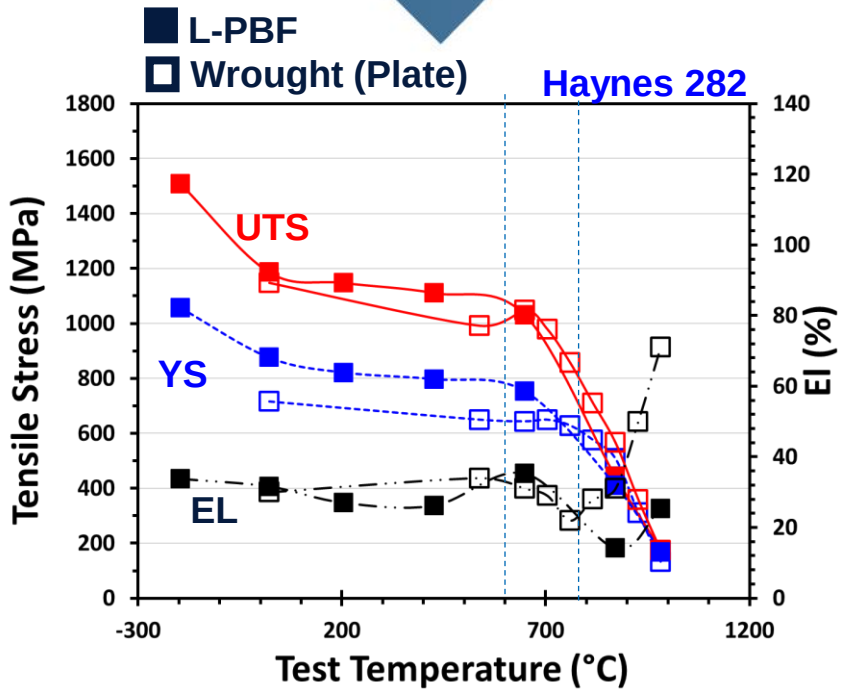
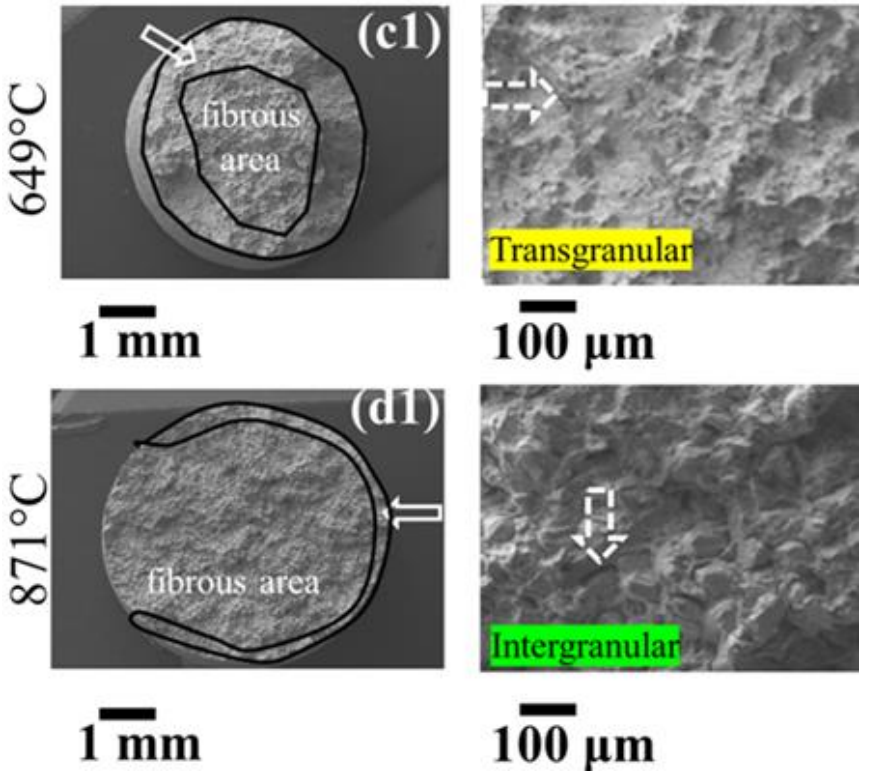
Deformation twins





Fracture Mode



- Up to 650 °C:
  - Stable strengths/ductility comparable with wrought.
- Above 650 °C:
  - Decreased strenths due to deformation twining.
  - Decreased ductility due to carbide debonding and fracture mode changed from transgranular to mixed mode.

Results: Tensile Properties vs. Temperature

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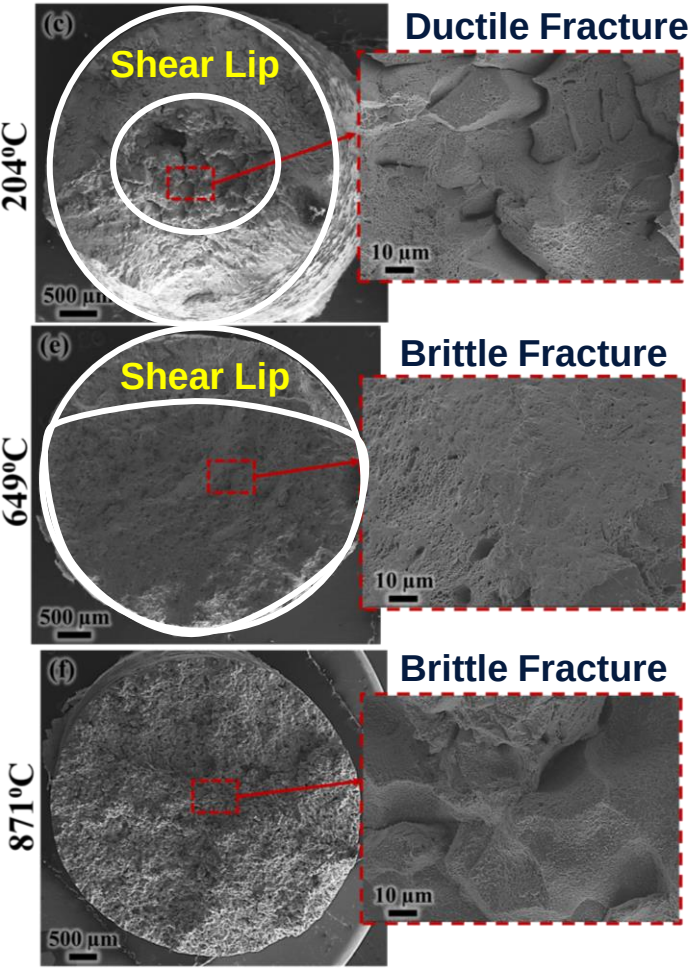
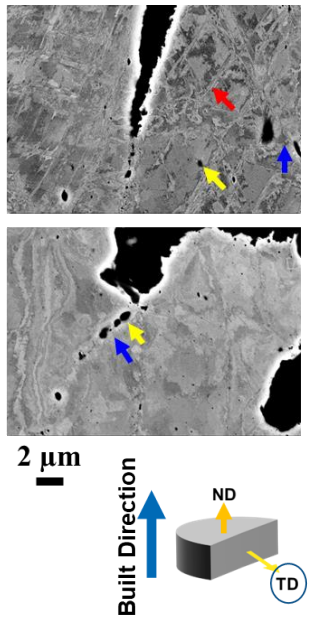
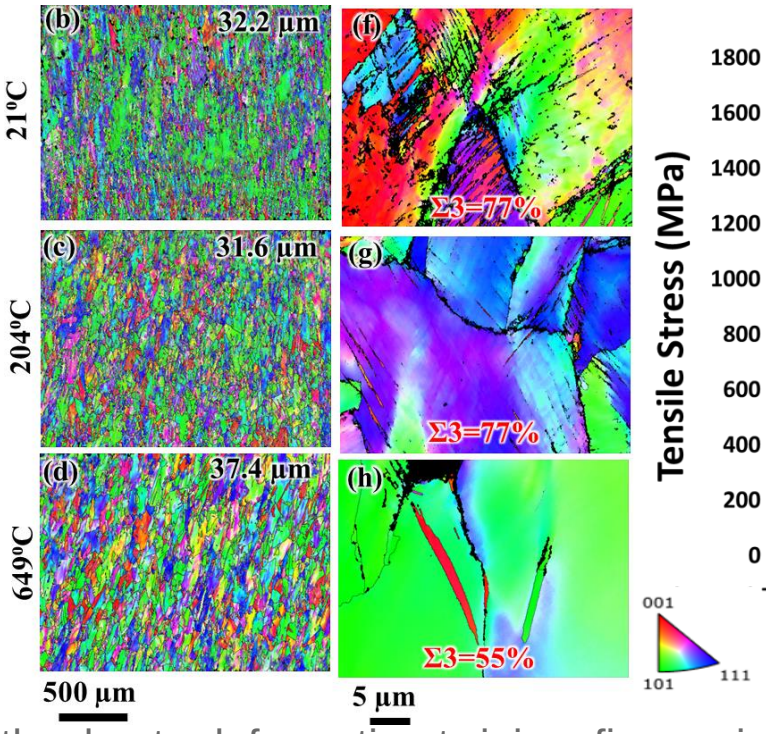
Fracture Mode

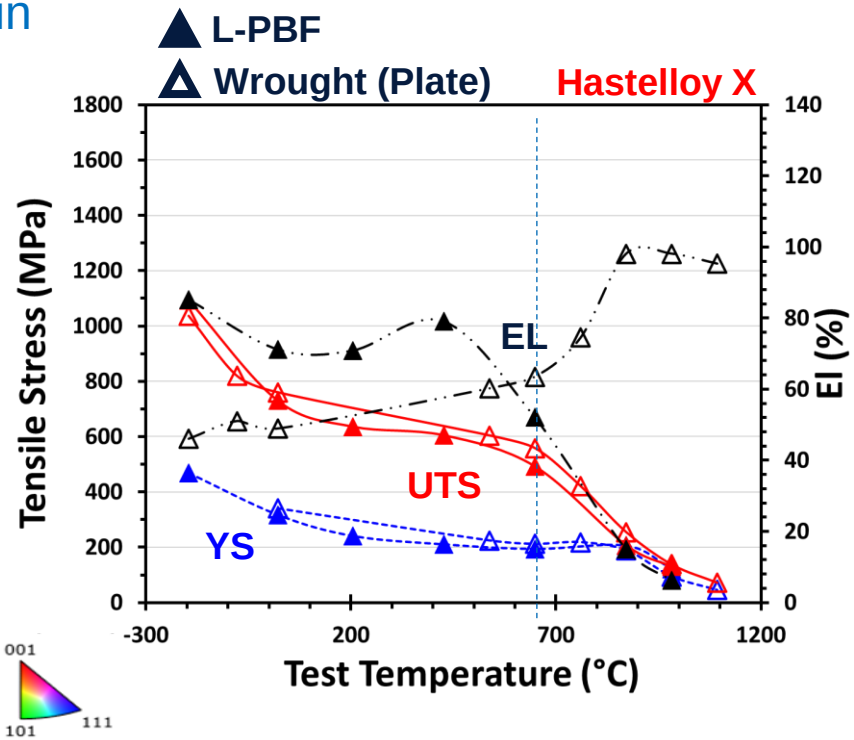


Carbide Debonding



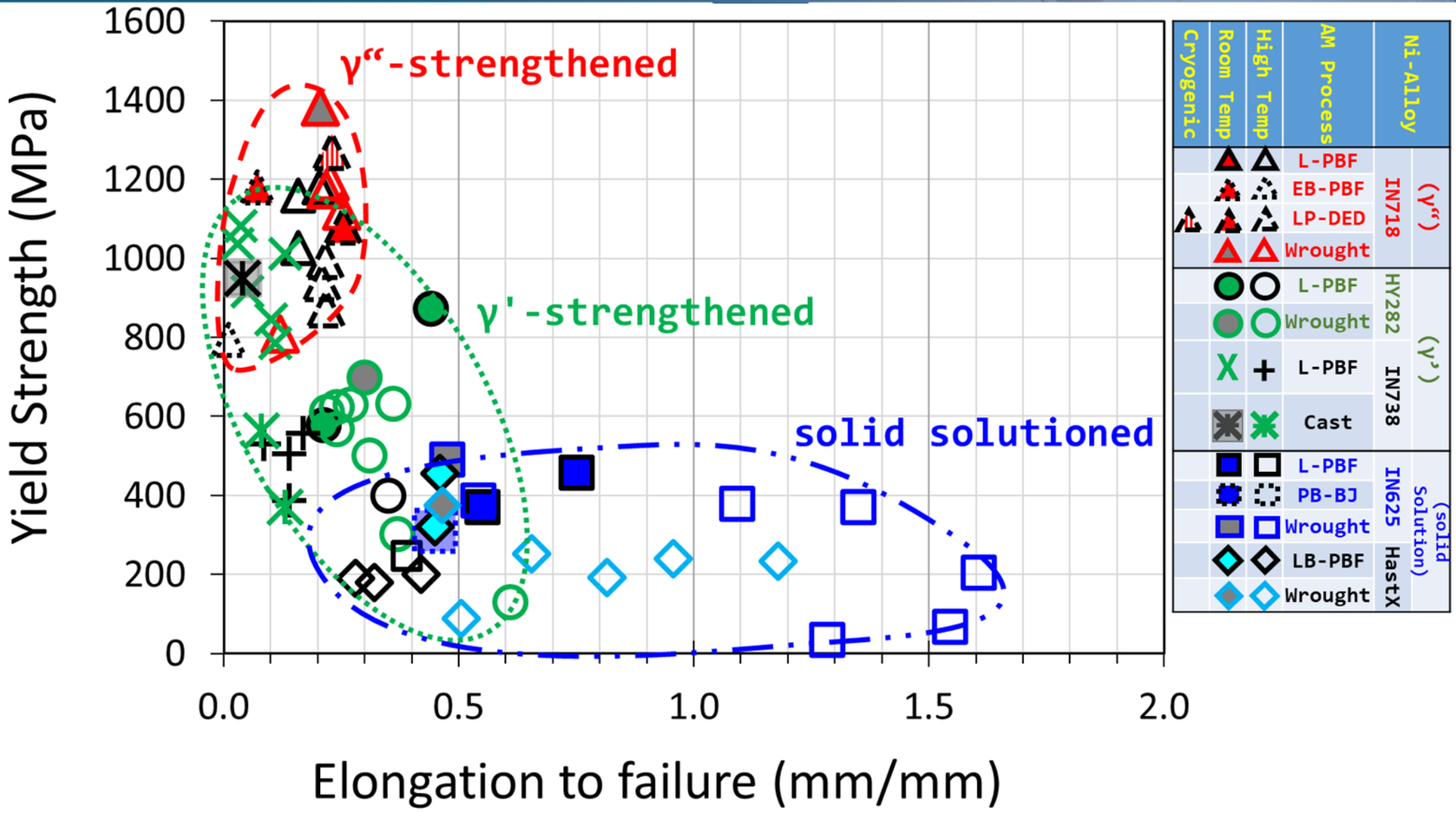
Deformation Twin





- Up to 650 °C:
  - Stable strengths due to deformation twining, fine grain structure and carbide strengthening; and comparable with wrought.
  - While superior ductility than wrought due to pinning of GB carbides and fine grains.
- Above 650 °C:
  - Slightly decreased strenths due to strengthening of carbides and deformation twining.
  - Decreased ductility due to carbide debonding and fracture mode change from ductile fracture to brittle fracture due to increased effect of carbide strengthening.

Results: Tensile Properties vs. Temperature



Conclusive Summary

- Tensile properties of three types of Ni-based superalloys manufactured with AM were compared (LP-DED IN718, L-PBF Haynes 282, and L-PBF Hastelloy X).
- Post-processing heat treatments:
  - LP-DED IN718/L-PBF Haynes 282: stress relieved + HIP + solutionized + 2-step aged.
  - L-PBF Hastelloy X: stress relieved + HIP + solutionized.
- Initial microstructure (HT):
  - LP-DED IN718: γ-grains + micron-sized carbides + nano-sized γ" plate-like precipitates.
  - L-PBF Haynes 282: γ-grains + micron-sized GB carbides + nano-sized γ' spherical precipitates (~60 nm).
  - L-PBF Hastelloy X: γ-grains + micron-sized GB carbides.
- Tensile properties:
  - Up to 650 °C:
    - All three showed stable behavior.
    - All three showed comparable strengths with wrought.
    - Precipitation hardened alloys (LP-DED IN718/L-PBF Haynes 282) showed comparable ductility with wrought while solid solutioned alloy (L-PBF Hastelloy X) showed superior ductility than wrought due to pinning effect of GB carbides.
  - Above 650 °C:

    Strenths:
    - LP-DED IN718 showed decreased strengths (comparable with wrought) due to coarsening of γ" precipitates, dynamic recrystallization (DRX) and deformation twining.
    - L-PBF Haynes 282 showed decreased strengths (comparable with wrought) due to due to deformation twining.
    - L-PBF Hastelloy X showed slightly decreased strengths (comparable with wrought) due to finer grains and strengthening effects of carbides and deformation twining.

    Ductility:
    - LP-DED IN718 showed increased ductility (comparable with wrought) due to debonding carbide.
    - L-PBF Haynes 282 showed decreased ductility (inferior to wrought) due to carbide debonding and fracture mode changed from transgranular to mixed mode.
    - L-PBF Hastelloy X showed decreased ductility (inferior to wrought) due carbide debonding and fracture mode changed from ductile to brittle (due to carbide strengthening).

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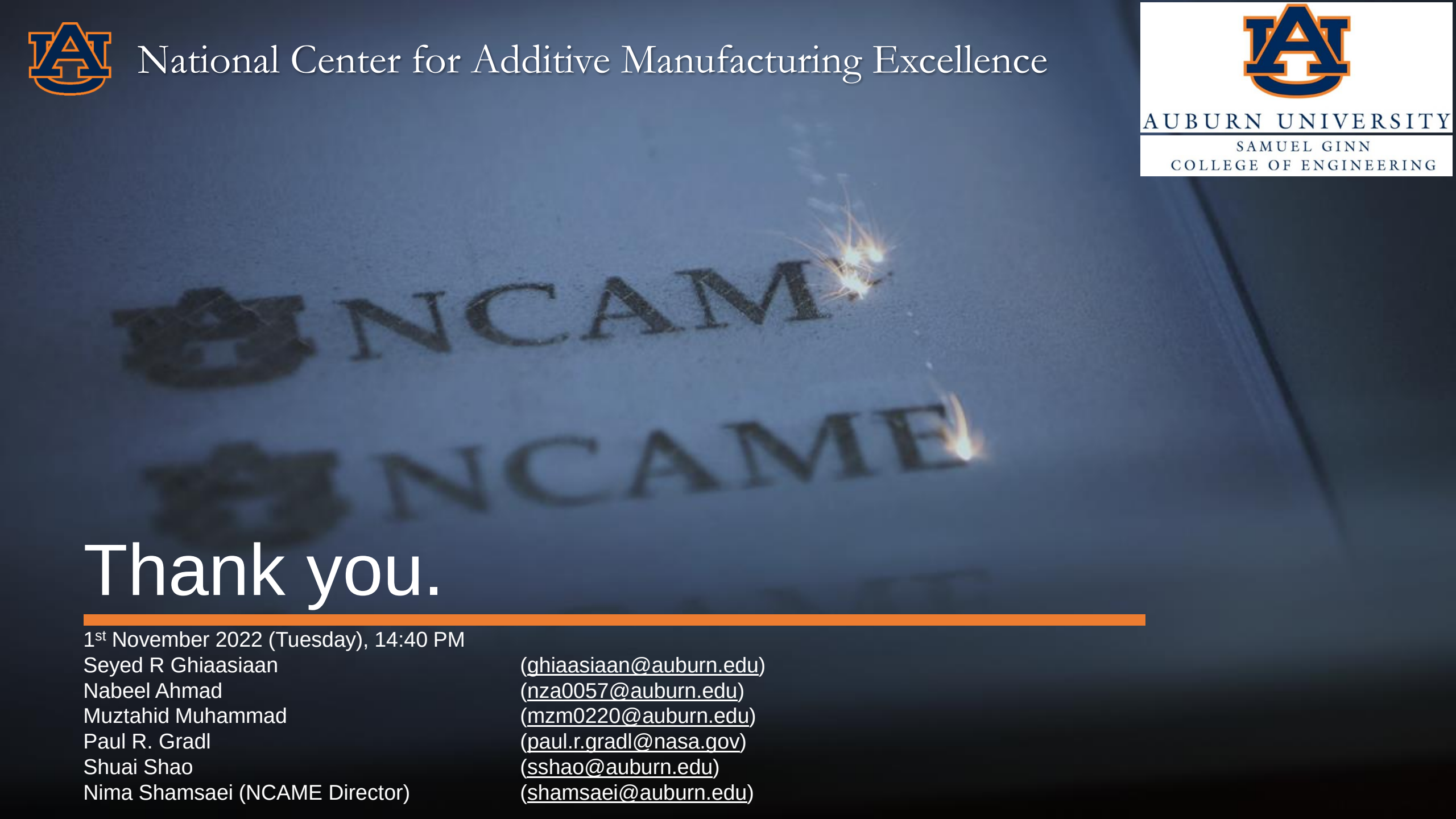

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