NASA High Temperature Alloy Development – GRX-810

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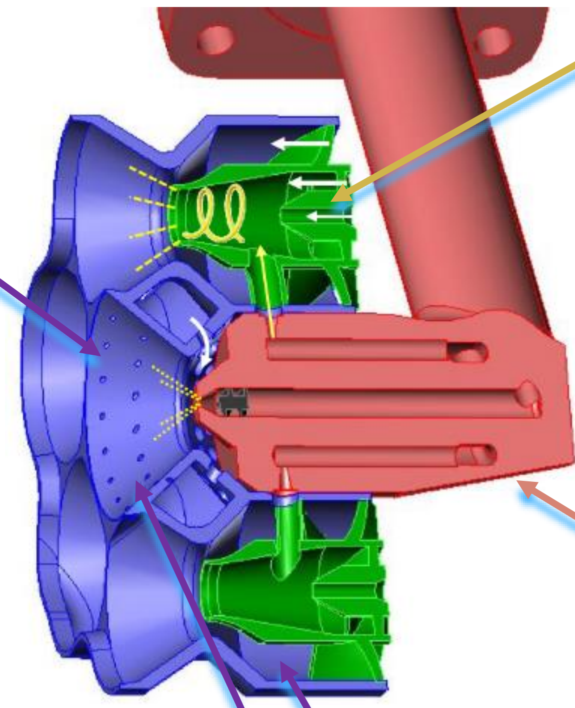
Background – NASA Application

Problem: Conventional materials and processing techniques limit the design of combustor domes used in jet turbine engines.

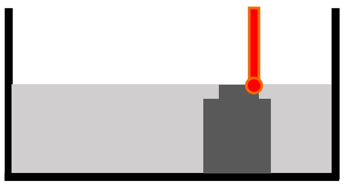
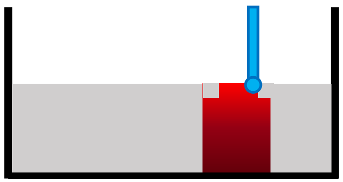
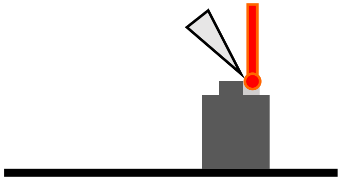
Proposed Solution: Develop a high ductility, high temperature material for an additively-manufactured (AM) combustor fuel nozzle and dome for supersonic aircraft (>1093°C (2000°F) operating temperature).

- Lead to several improvements to the turbine combustor design ultimately reducing NOx pollution and lowering weight.
- May enable lean-front-end small-core combustors.



Schematic of AM produced fuel injector/combustor dome

Metallic Additive Manufacturing

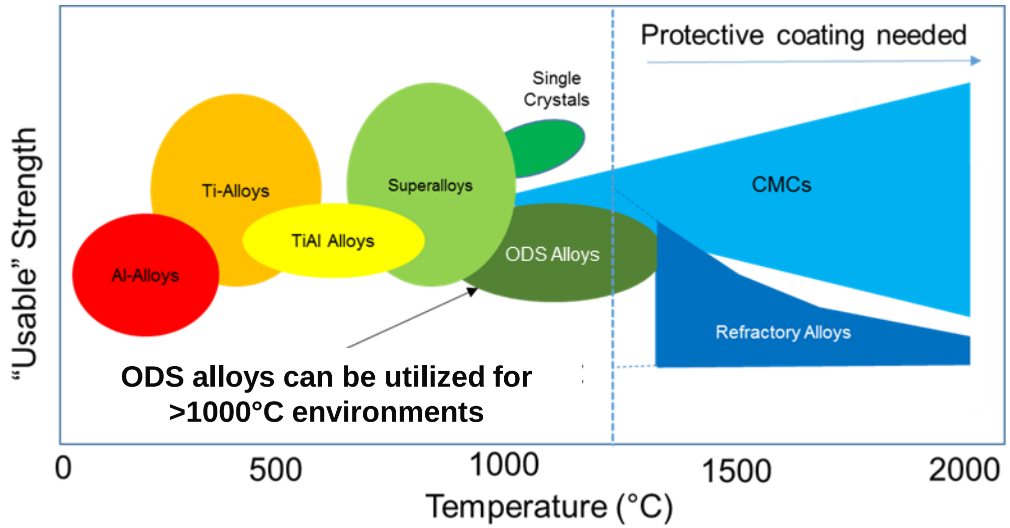
Process	Laser Powder Bed Fusion (L-PBF) 	Electron Beam Powder Bed Fusion 	Direct Energy Deposition (DED) 
Energy Source	Laser	E-Beam	Laser or E-Beam
Powder Bed	Yes	Yes	No
Power (W or kV)	50-1000 W	**30-60kV**	100-2000 W
Max Build Size (mm)	500 x 280 x 320	500 x 280 x 320	**2000 x 1500 x 750**
Material	Metallic Powder	Metallic Powder	Metallic Powder or Wire
Dimensional Accuracy	**<0.04 mm**	0.04-0.2 mm	0.5 mm (powder) 1.0 mm (wire)

- 3D printing or additive manufacturing (AM) has shown promise in realizing a new design space for aerospace applications.
- Each AM technique has a set of pros and cons associated with them.
- Instead of producing well known cast and wrought alloys with AM. We should look at AM as a new opportunity to produce materials that are currently difficult to create.
- For this study, L-PBF is used due to its superior dimensional accuracy.

High Temperature AM Compatible Materials

High Temperature Materials:

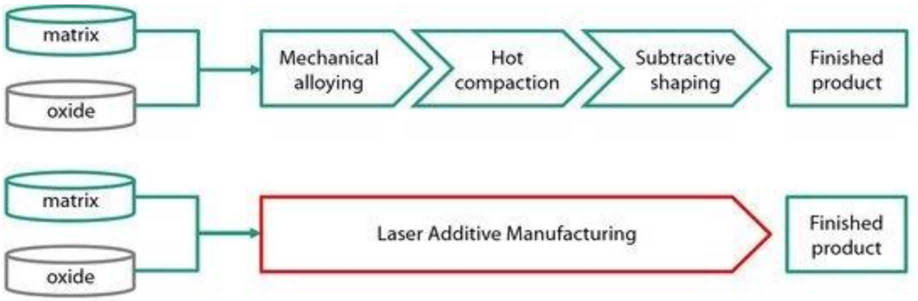
- Refractory metals
- Carbon-Carbon composites
- CMC's
- Ni-base superalloys
- **Oxide Dispersion strengthened (ODS) alloys**



Inspired by Andy Jones. ODS alloy Development.

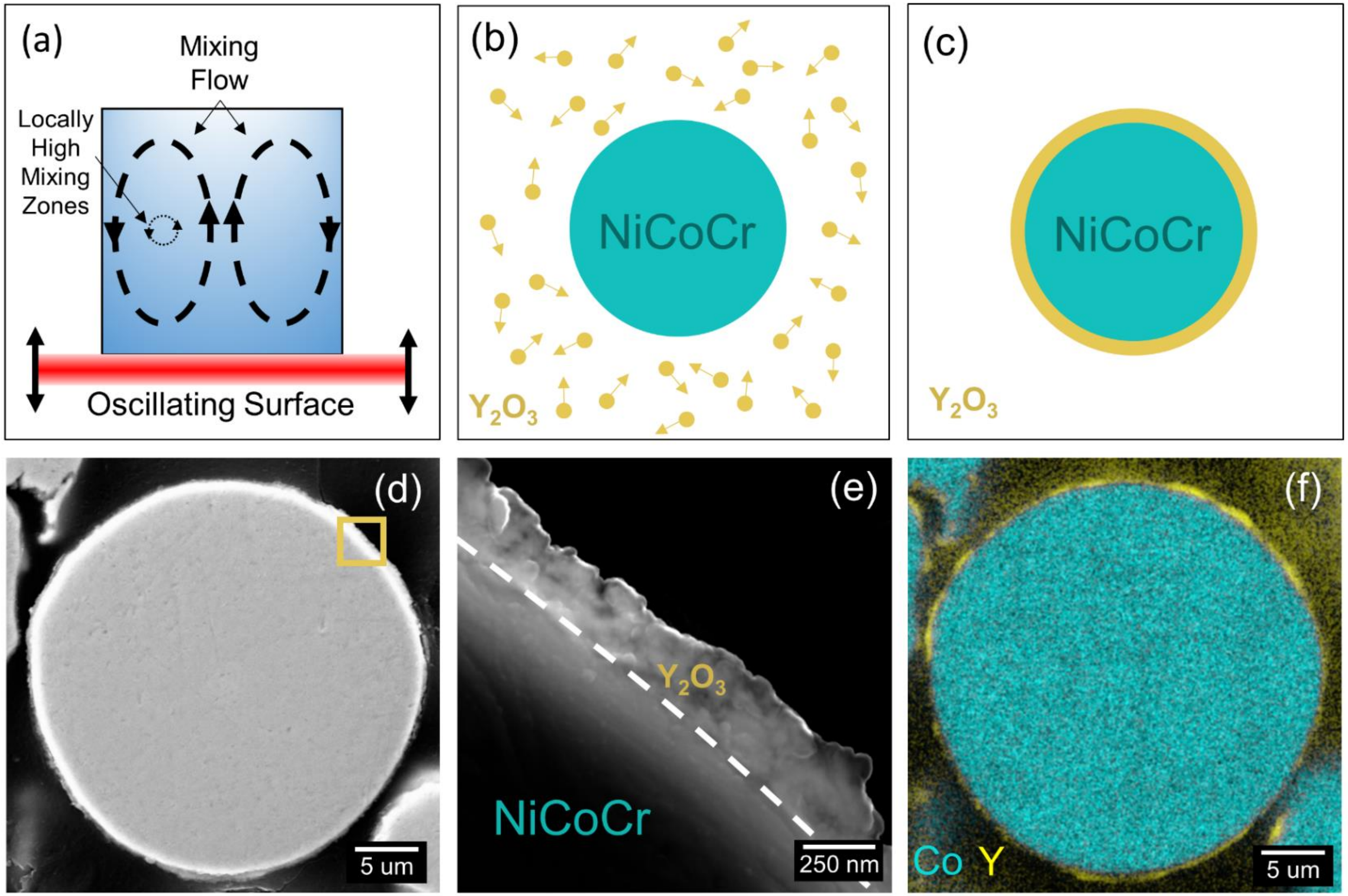
(ODS) alloys offer higher temperature capabilities compared to Ni-base superalloys. However, it has been a challenge to produce ODS alloys through conventional manufacturing methods.

Conventional Manufacturing vs AM



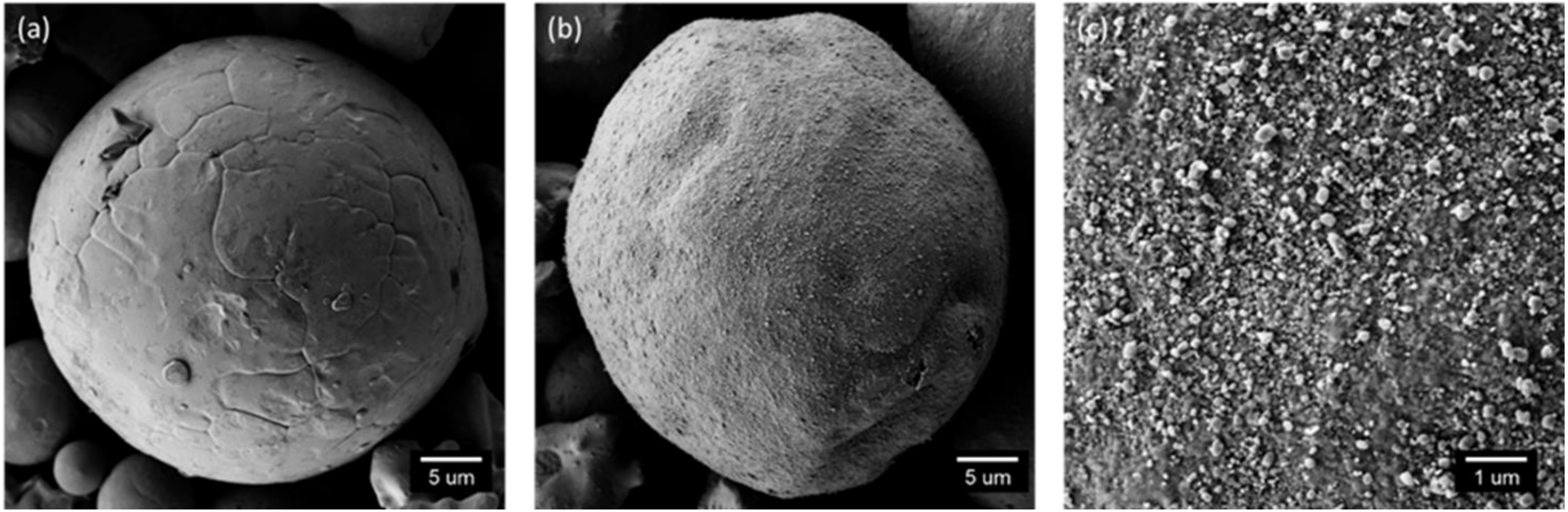
Can AM improve ODS alloy manufacturability?

Novel Fabrication Technique for Oxide Dispersion Strengthened (ODS) Alloys



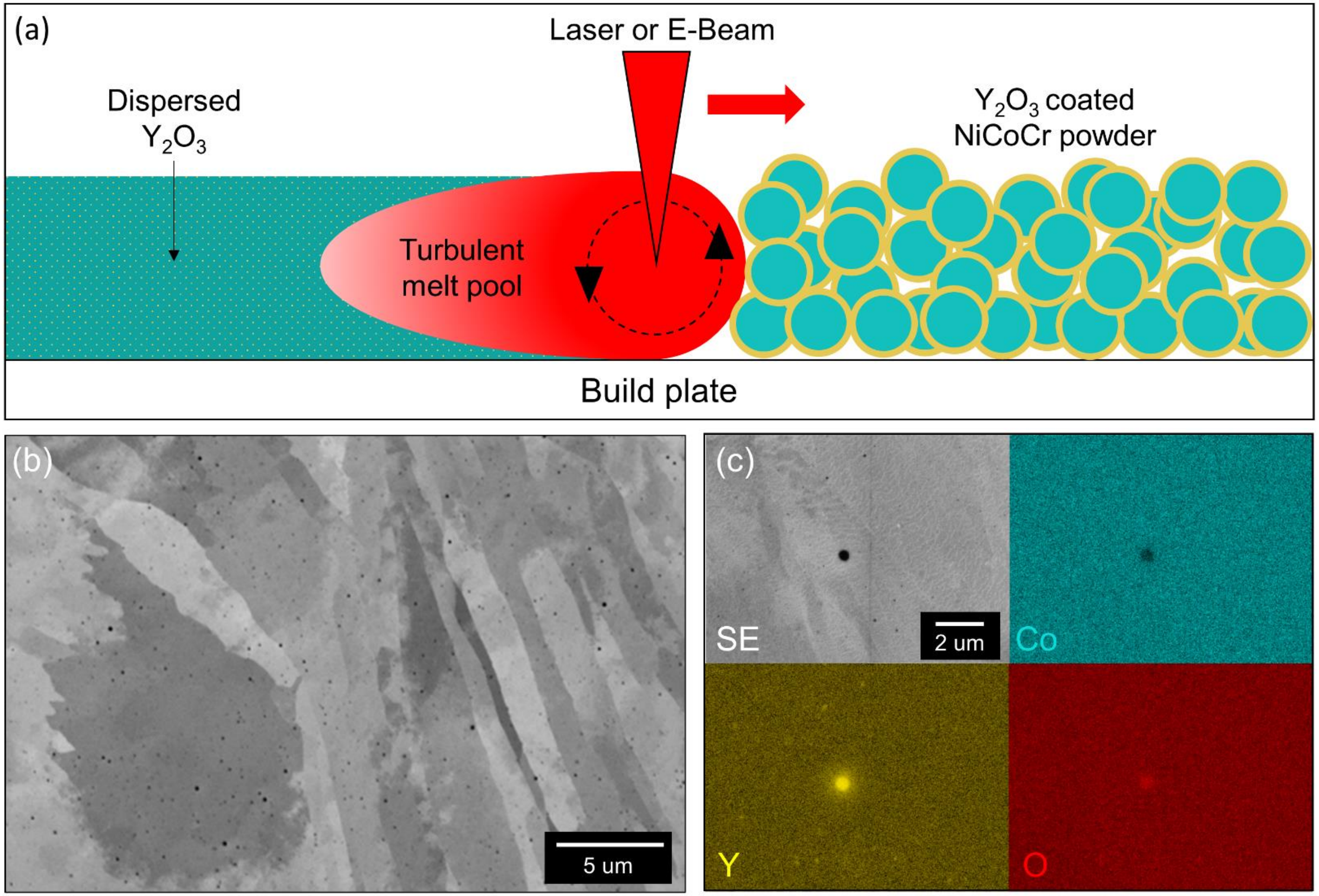
New high energy mixing technique successfully coats NiCoCr-base powders with 1 wt.% Y_2O_3.

Novel Powder Coating Technique



- The advanced dispersion coating (ADC) technique did not deform the metallic powder.
- The ADC technique fully coats the metallic powders with nano-scale oxides
- Both uncoated and coated powders qualitatively passed the Hall flow test.
- The technique does not affect the printability of the powder lot.

Leveraging L-PBF to Produce Oxide Dispersion Strengthened Alloys



L-PBF successfully disperses the nano-scale Y_2O_3 particles throughout the AM build

Development of GRX-810 Composition

Model Driven MPEA Design

Goals to improve on previous NiCoCr Entropy Alloy:

1.) Maximize solid solution strengthening
2.) Maintain solid solution matrix
3.) Add grain boundary carbides
4.) Reduce freezing range to under 100°C for printability
5.) Avoid TCP and intermetallic grain boundary phases

>10^7 equilibrium calculations provided an optimized composition named GRX-810

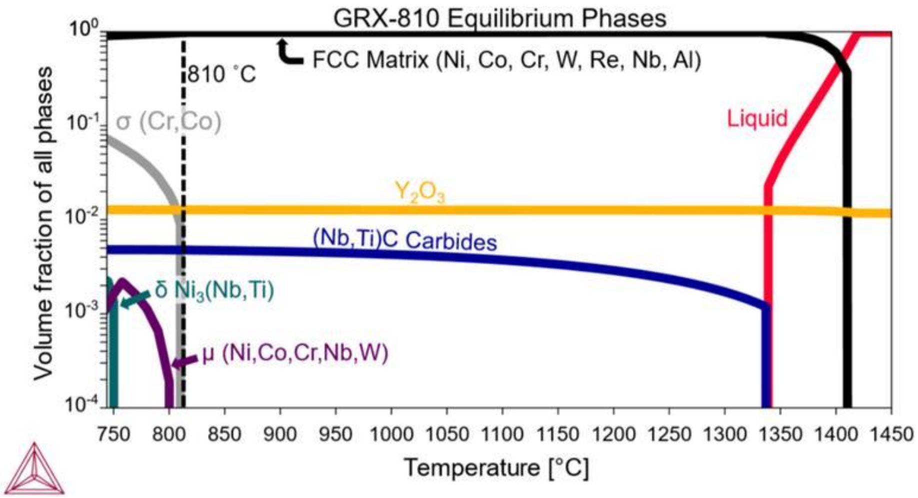
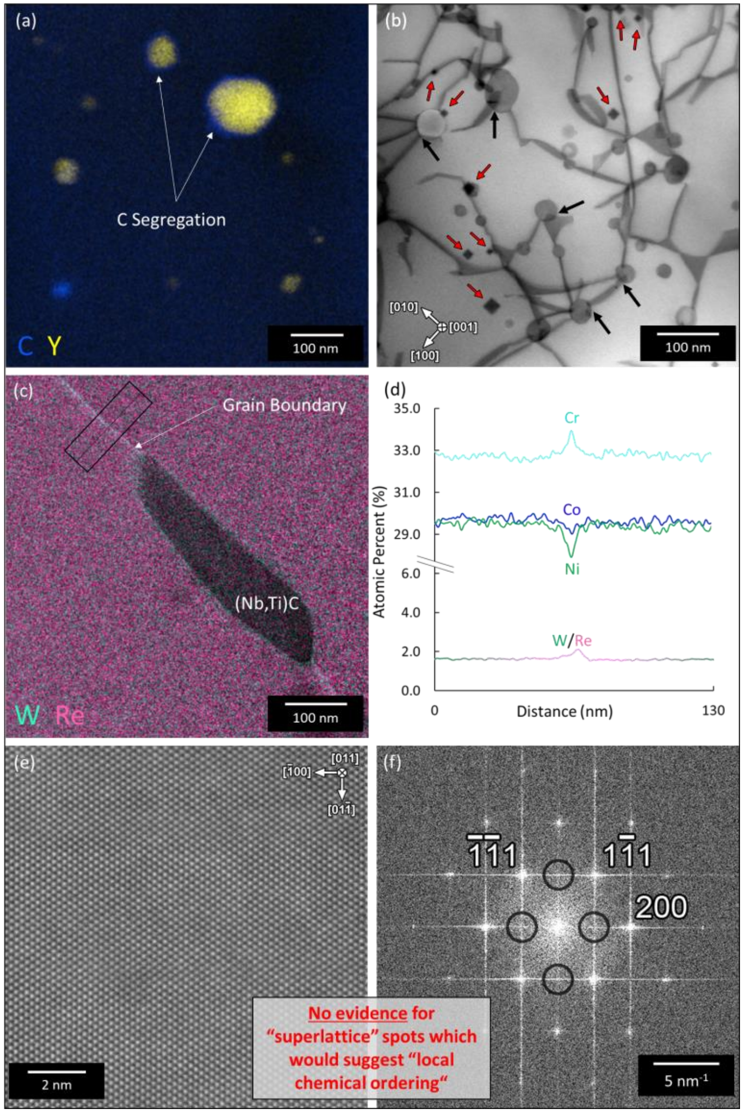


Figure: CALPHAD simulation of phase formation in new composition. No intermetallic or TCP phases are predicted.

Models calculated by C. Kantzos

	Ni	Co	Cr	Re	Al	Ti	Nb	Mo	W	Zr	C	B
Nominal Composition (GRX-810)	Bal.	33	29	1.5	**0.3**	**0.25**	**0.75**	**0**	**3**	**0**	**0.05**	0

STEM Analysis



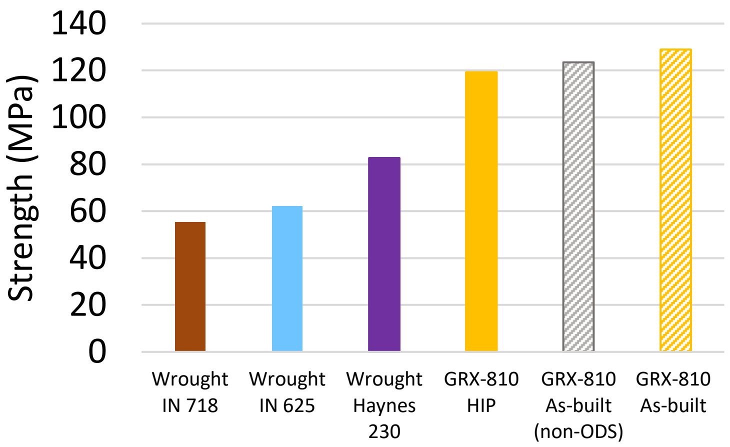
Top: STEM analysis revealed Carbon segregation at the oxide matrix interface. Top Right: Reveals dislocation oxide interactions.

Middle: Solute segregation of W/Re/Cr along Grain Boundaries

Bottom: Diffraction from the [001] zone axis STEM image reveals that there is no local elemental ordering at the atomic level.

GRX-810 Tensile Overview

Tensile Strength Comparison 1093°C



- GRX-810 begins to perform better than conventional alloys (625/718) around 850°C
- GRX-810 possesses good ductility at all temperatures tested – including cryogenic temperatures.

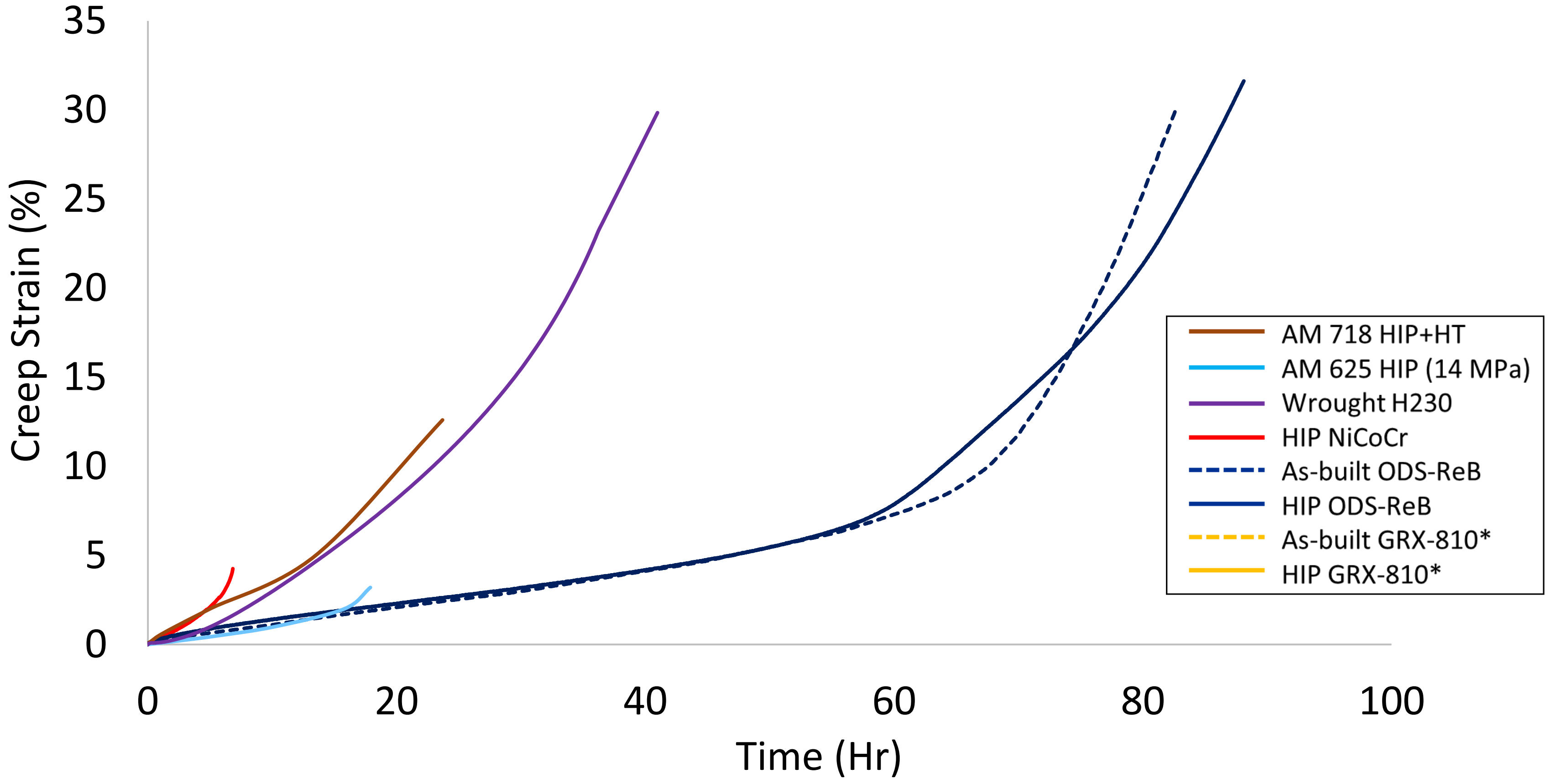
As-built GRX-810 Tensile Properties

Temperature (C)	Tensile Strength (Mpa)	Yield Strength (Mpa)	Elongation
-195.6	1303.1	910.1	39.6
21.1	882.5	641.2	33
426.7	710.2	527.4	33.3
648.9	675.7	479.2	32.1
871.1	292.3	249.6	56.1
1093.3	128.9	127.6	22

HIPed GRX-810 Tensile Properties

Temperature (C)	Tensile Strength (Mpa)	Yield Strength (Mpa)	Elongation
-195.6	1227.3	723.9	49
21.1	848.1	515.0	43
426.7	655.0	410.2	40
648.9	630.9	368.9	43
871.1	262.7	206.2	62
1000.0	164.1	161.3	44
1093.3	119.3	115.8	32

Mechanical Results – 1093°C/20MPa Creep Rupture



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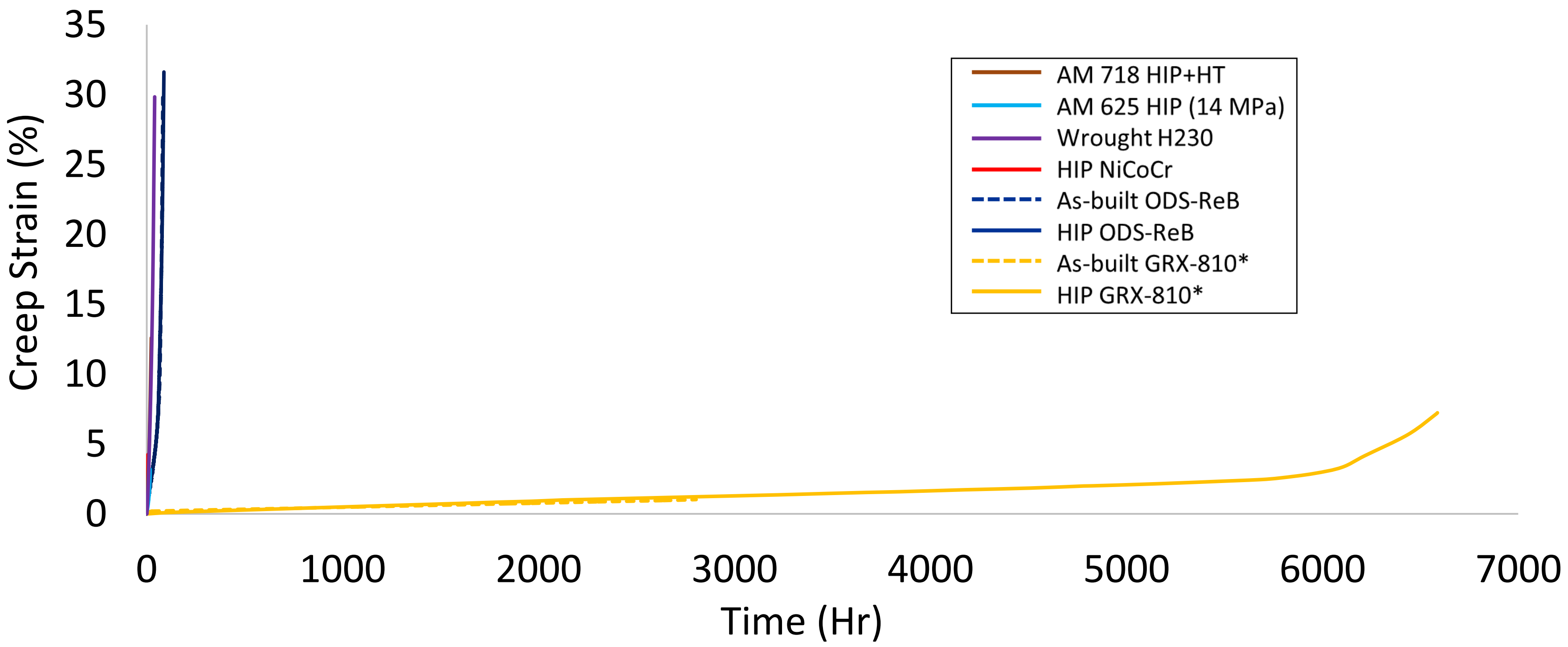
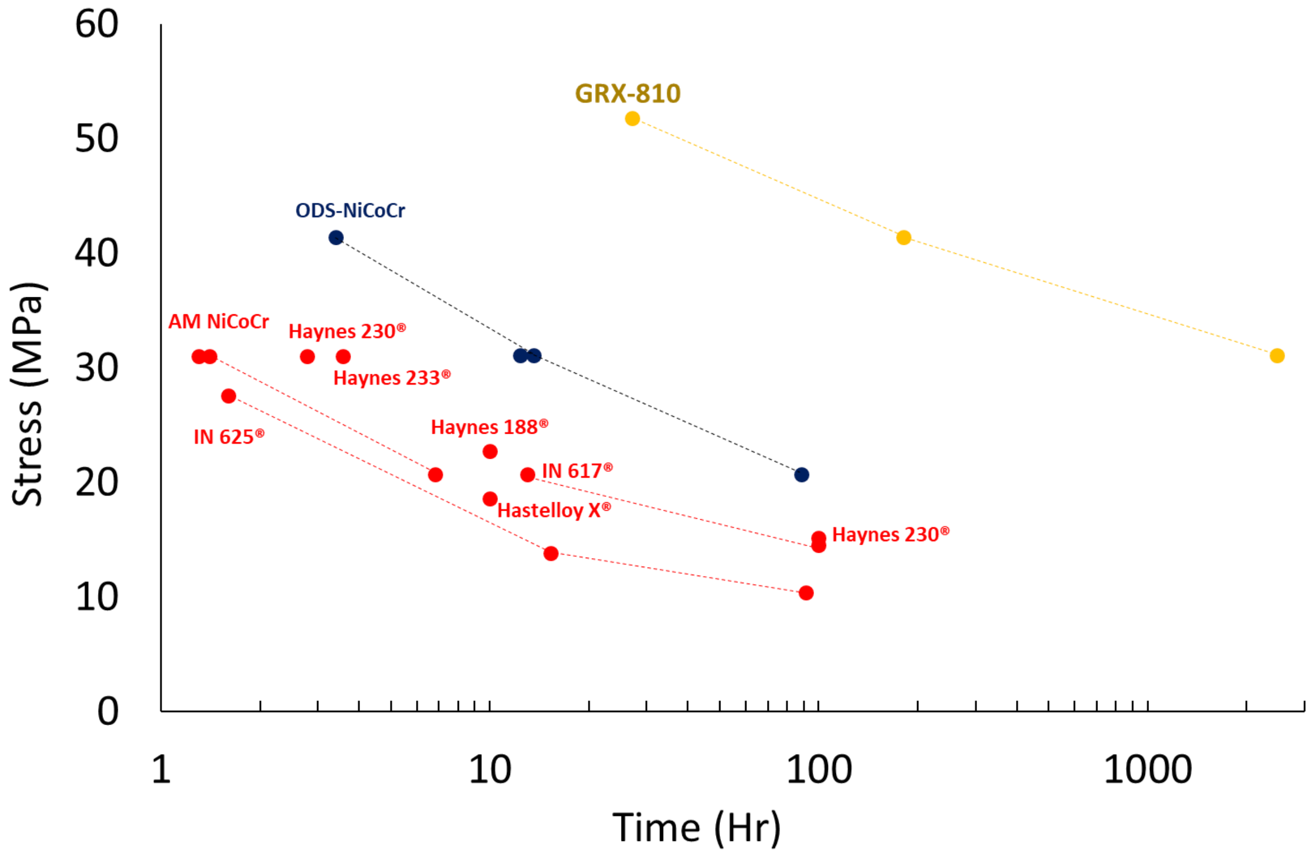


GRX-810 provides orders of magnitude improvements in creep rupture life at 1093°C compared to conventional superalloys 718 and 625.

Creep Rupture Lives Comparison- 1093°C

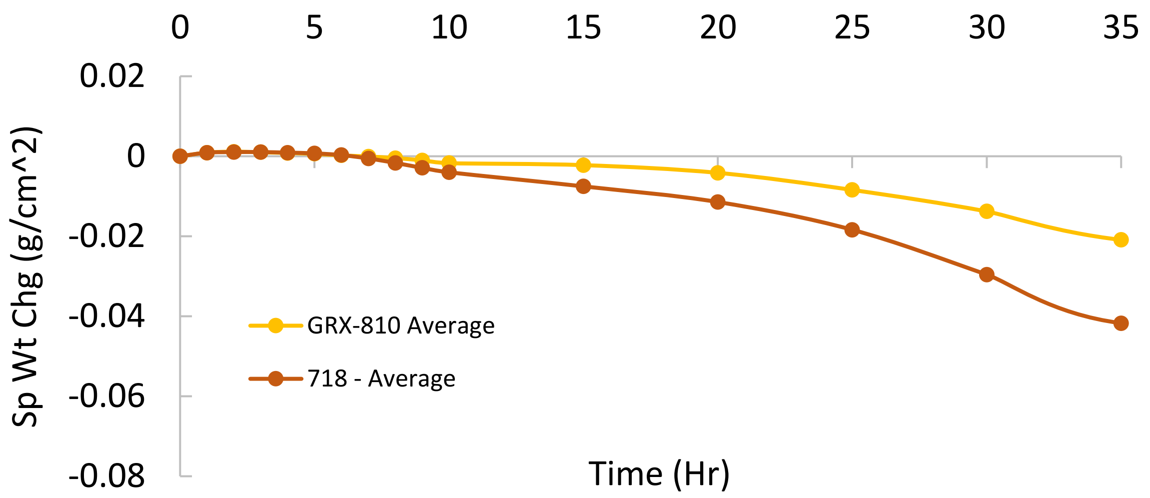


Alloy	NiCoCr	AM 718	AM 625*	Haynes 230	ODS-ReB	C-103 (Vacuum)	As-built GRX-810	HIP GRX-810
Time (Hr)	0.35	2.2	10	5	9	1170	2804	2122

Table: Time to reach 1 % Creep Strain at 20MPa. Note: Superalloy 625 test was performed at 14 MPa.

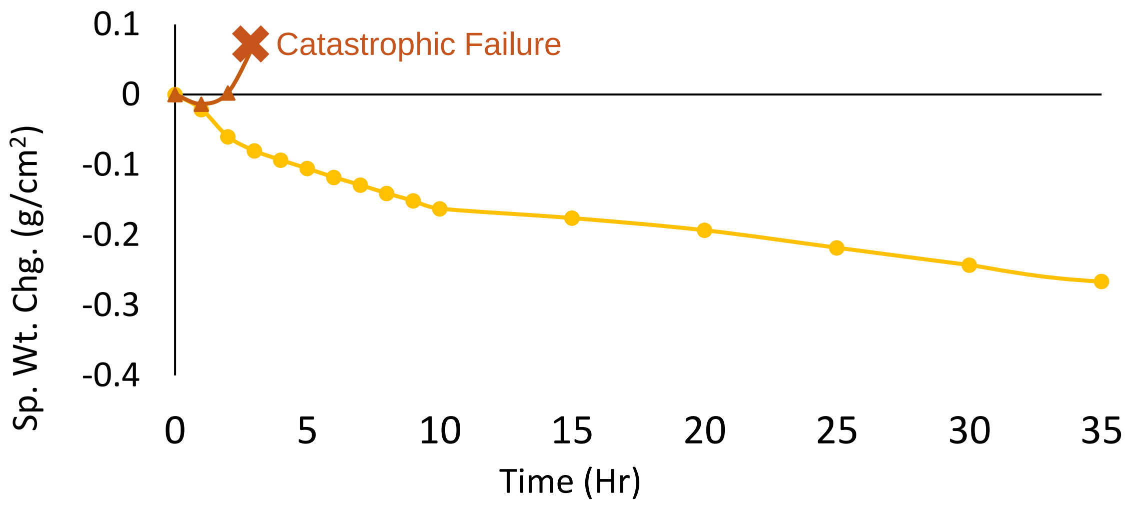
Oxidation

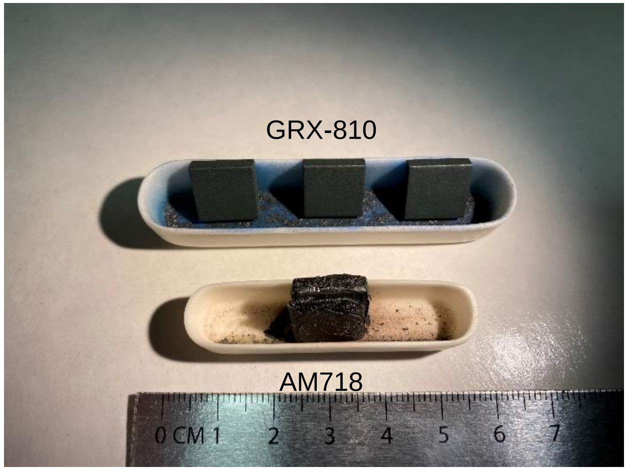
Oxidation – 1100°C



GRX-810 Provides better oxidation properties at 1100°C and 1200°C compared to 718.

Oxidation – 1200°C





GRX-810 and 718 after 100 hrs at 1100°C and 3 hours at 1200°C

GRX-810 - Scale Up and Hot-fire Test

- Most work presented was coated with a coating rate of 1Kg per hour using two in-house lab-scale mixers.
- We have optimized the mixing parameters and improved the coating rate to 18kg per hour using the same machines.
- Successfully printed GRX-810 on larger EOS M280 and DED machines. Have begun component testing at MSFC (see below).

Left: Successful hot-fire test of a liquid oxygen/methane (LOX/LCH4) GRX-810 injector and nozzle.

Oxide Dispersion Strengthened Combustor Dome

Questions?