Conducting Materials Research During and After a Global Pandemic

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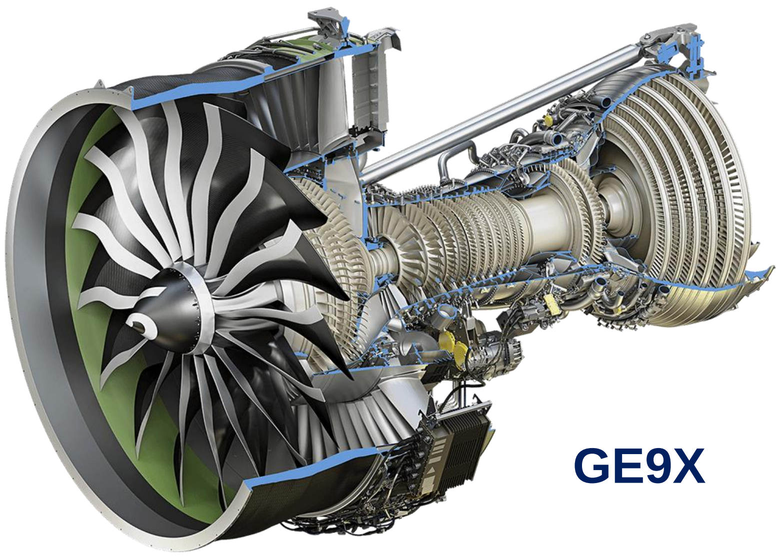
NASA Research



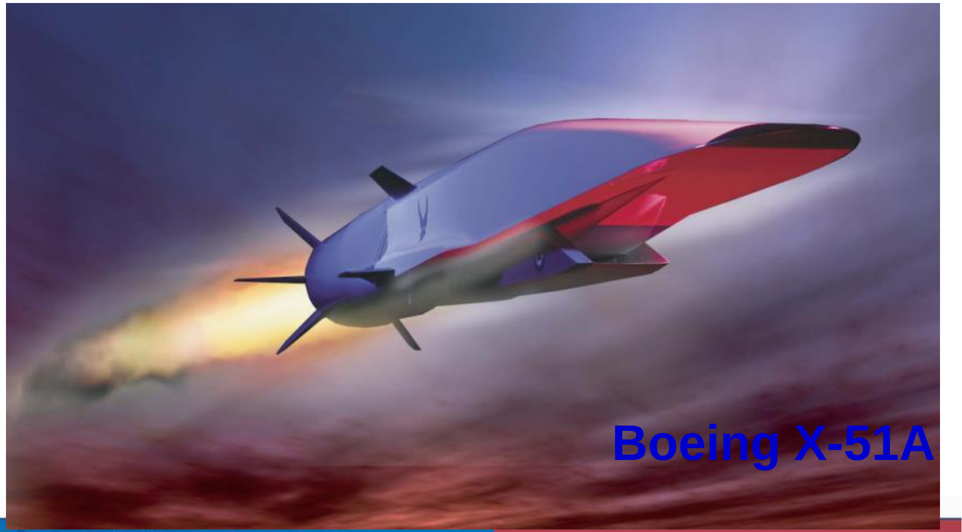
GE9X

I. Employ cutting edge experimental and modelling tools to significantly improve aero materials for more efficient Propulsion technologies.

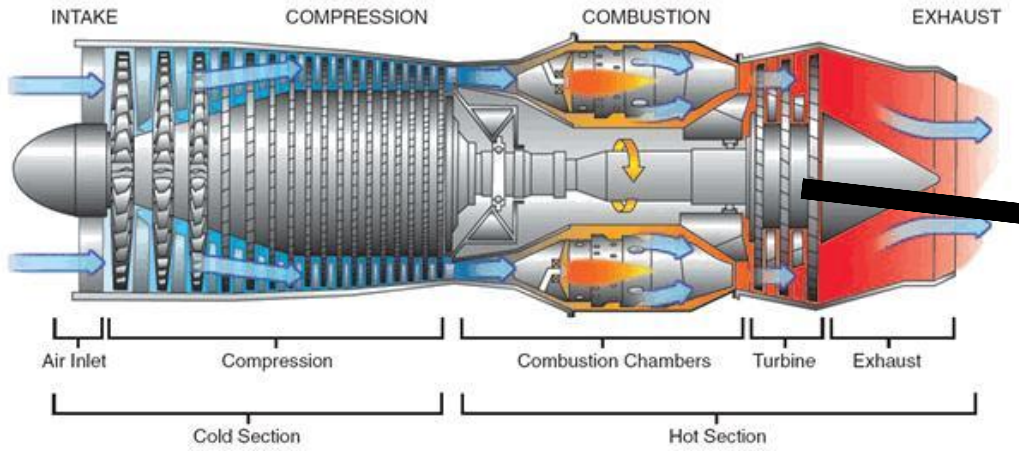
- Commercial Ni-base superalloys
- Atomic resolution analysis and modeling
- Designing new disk to blade joining methods.

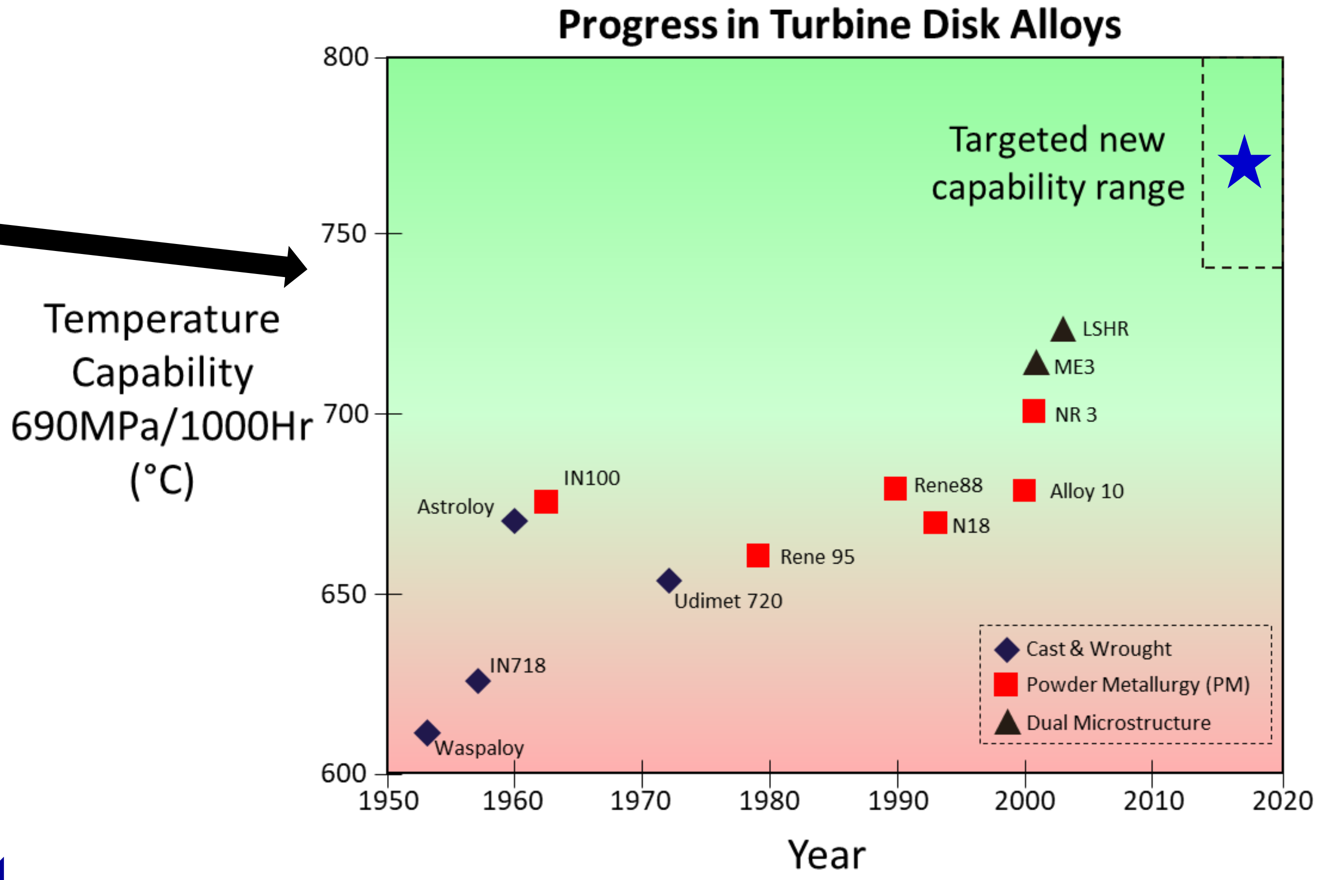
II. Develop new alloy systems and manufacturing techniques to help realize aero technologies that are currently not possible with today's materials.

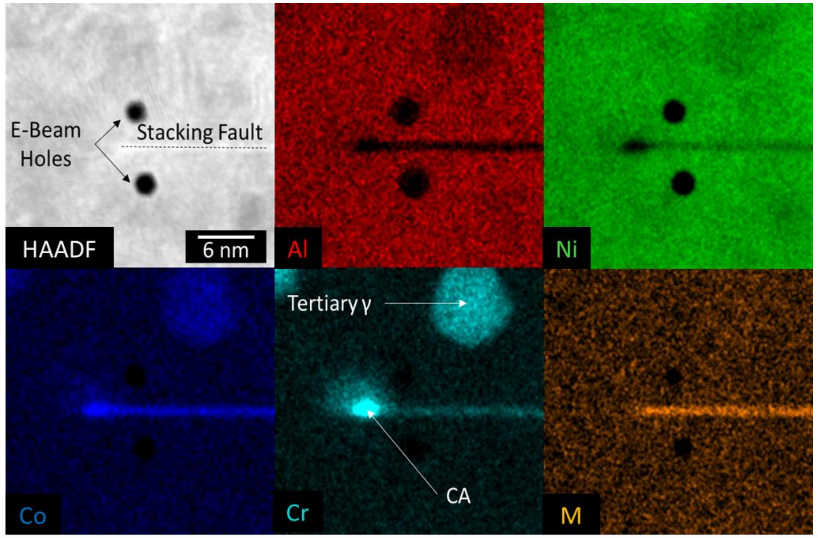
- ODS alloys
- Additive manufacturing
- Refractory alloys



Project 1: New Alloy Class Created - Transformation Strengthened NASA Alloy







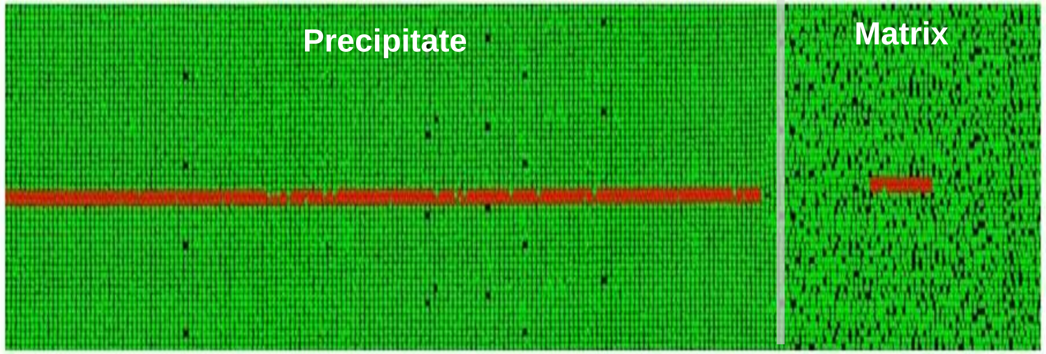
Atomic resolution analysis has identified segregation mechanisms that limit high temperature strength

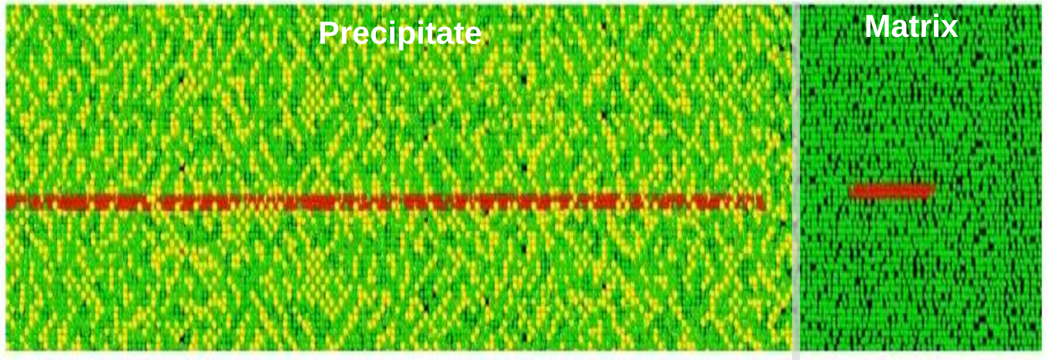
Project 1: New Alloy Class Created - Transformation Strengthened NASA Alloy

Atomistic Models of Phase Transformations

Low Nb

High Creep

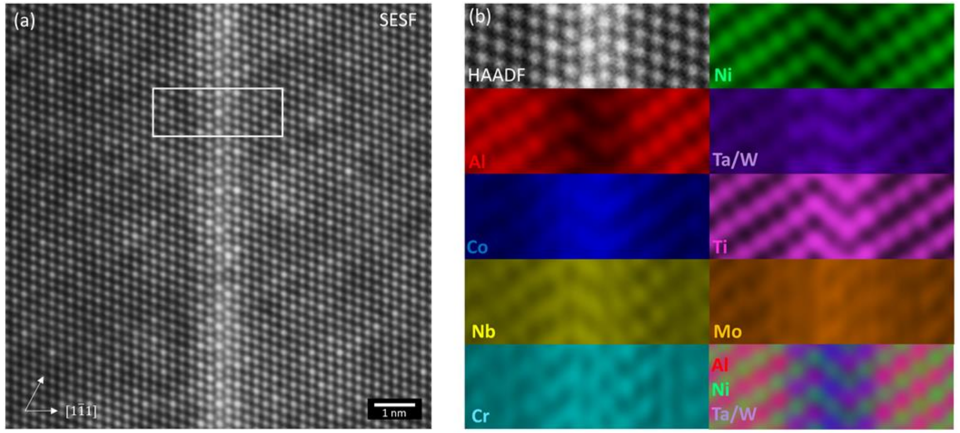




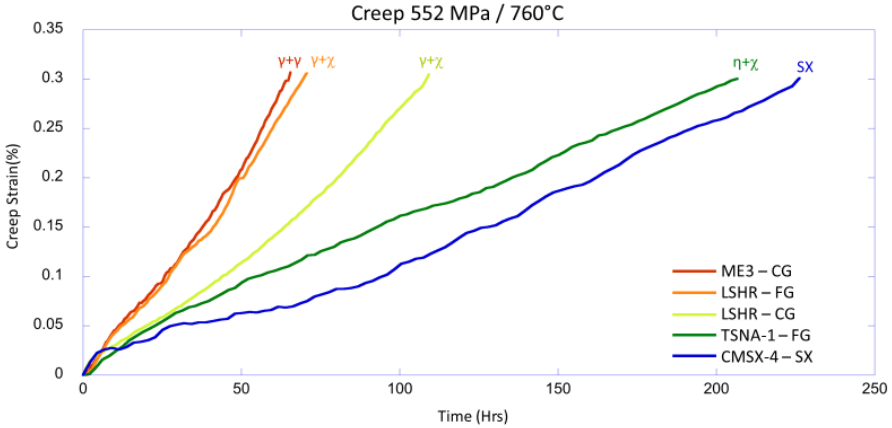
High Nb

Low Creep

Atomic-scale Characterization of Strengthened Defects



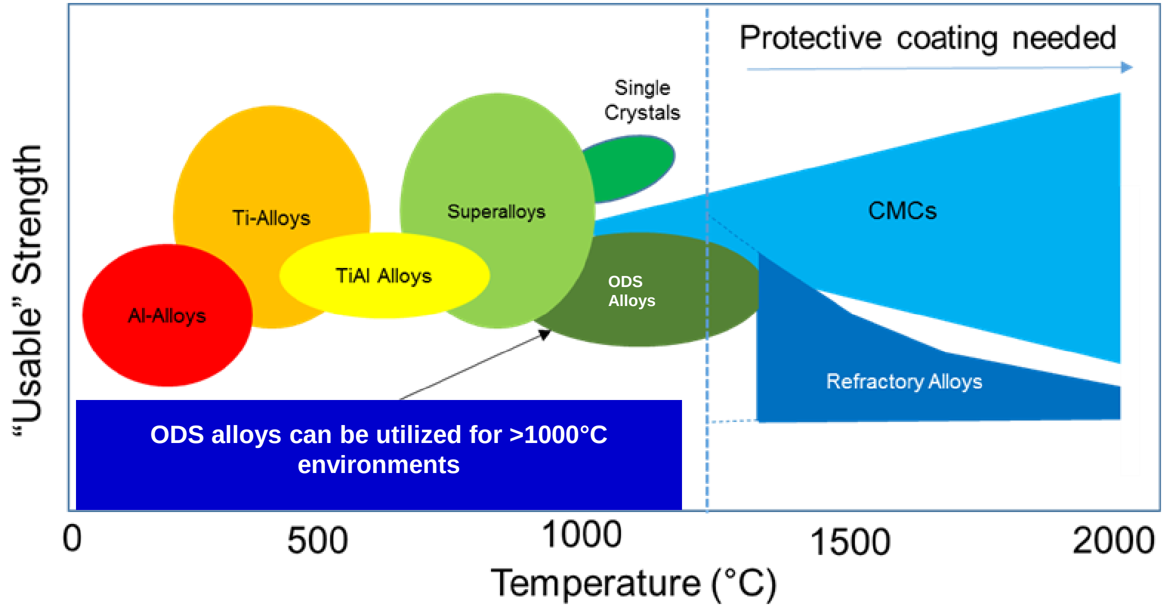
3X Improvement in High Temperature Properties

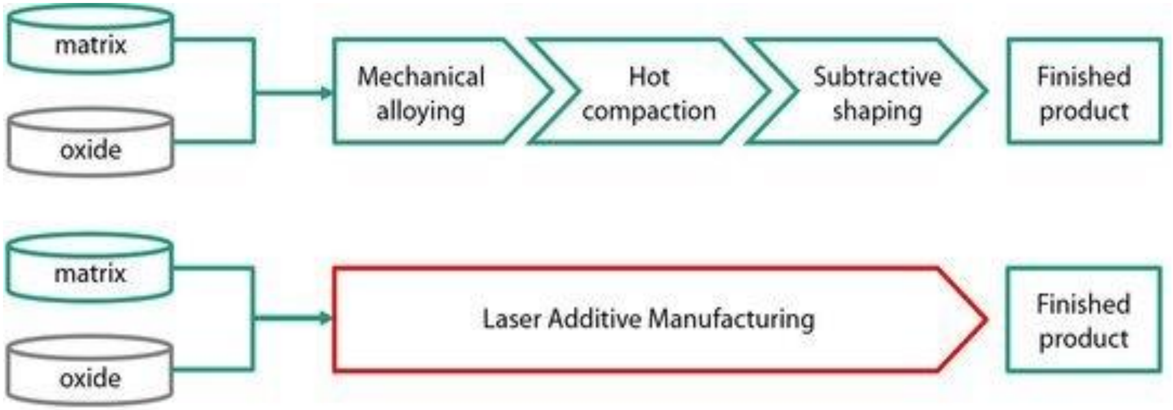


Smith et al. Nature Communications Materials 2021

Project 2: Additive Manufacturing of Revolutionary Dispersion Strengthened Alloys

Oxide dispersion strengthened (ODS) alloys exhibit superior high temperature properties but are prohibitively expensive.

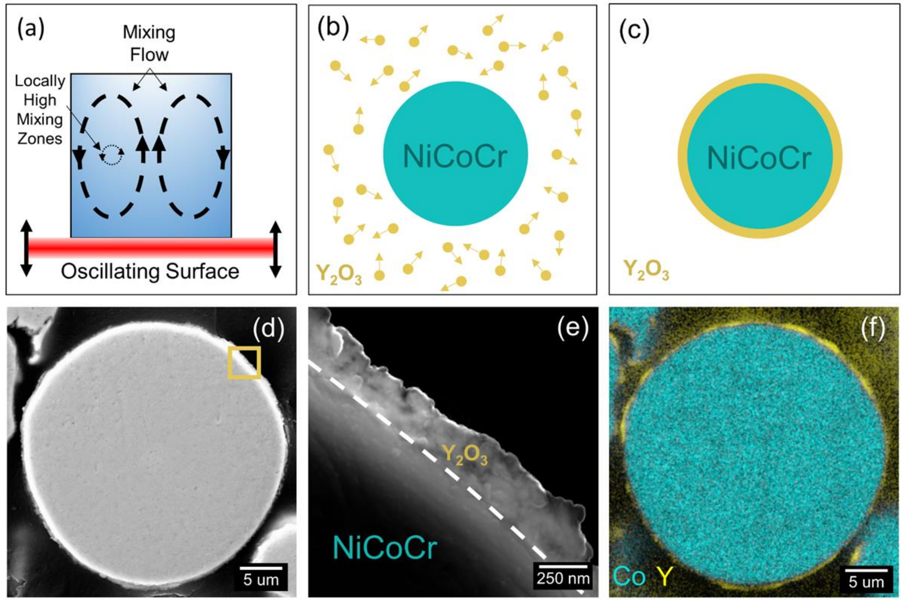




Additive manufacturing can help realize next-generation ODS alloys.

Project 2: Additive Manufacturing of Revolutionary Dispersion Strengthened Alloys

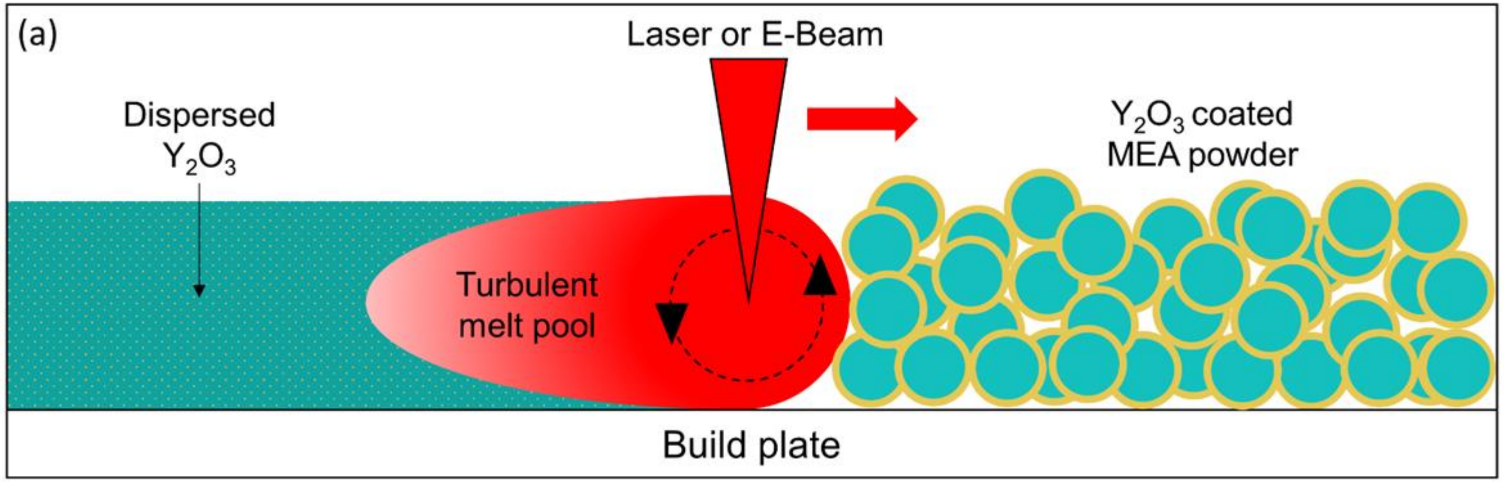
Novel Powder Coating Technique



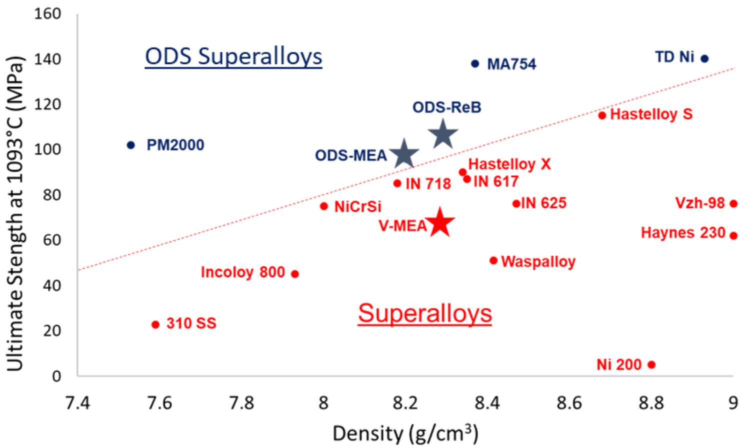
The powder coating technique has been successfully employed for numerous alloys and dispersoids

AM successfully produces ODS alloys opening the design space for future alloy development!

3D Printed ODS Entropy Alloys



3D Printed ODS Combustor Dome



Smith et al. Scientific Reports 2020

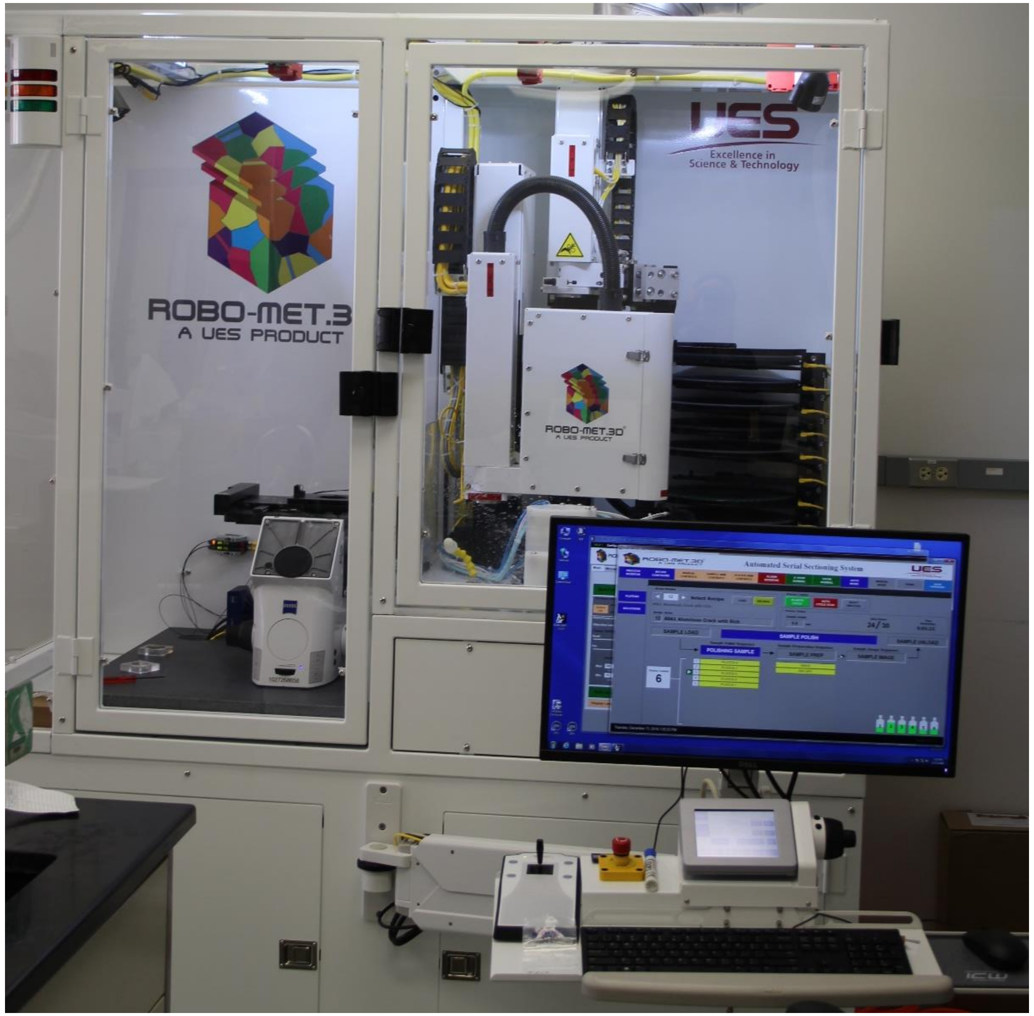
Covid-19 Pandemic Challenges

NASA GRC Covid Framework

	Stage 4	Stage 3	Stage 2	Stage 1
Center Access	- Mandatory telework - Facility is closed, except to mission-essential³ personnel	- Mandatory telework - On-site work is limited to mission-essential³ and approved mission-critical² work.	- Employees who must be on-site to perform their work may return on-site with center/supervisor approval. - All other employees will continue to telework. - Mission-critical² visitors only and with approval.	- Full access. - Telework is encouraged for employees who can accomplish their work remotely, with supervisor approval.
Health & Safety	- All facilities closed	- On-center food service open for take-out only. - Daycare centers may reopen. Fitness centers remain closed. - Clinics open to support mission-essential and mission-critical personnel only. - Follow all center/facility safety protocols.	- Daycare centers may open. - Fitness centers may re-open only if enhanced hygiene procedures, physical distancing, and sanitation can be maintained. - Clinics defer physicals. - Follow all center/facility safety protocols.	- Follow all center/facility safety protocols.
Meetings & Events	- Conduct virtual meetings and participate remotely only in events	- Conduct virtual meetings with remote participation only	- Social settings or meetings of more than 50 people (conferences, large gatherings), where physical distancing may not be practical, should be avoided unless precautionary measures are observed.	- Conduct virtual meetings and participate remotely, when possible. - Reduce in-person meetings and large gatherings.
Travel	- All travel suspended	- Mission-critical² travel only	- Non-essential travel may resume, with the exception that travel to an area that has not progressed in its gates or experiences a rebound of cases should not be approved.	- Minimize travel that is not mission-critical².

https://www.grc.nasa.gov/smad/wp-content/uploads/sites/59/NASA_RTOW_Framework.pdf

Covid-19 Pandemic Solution: Automation



UES RoboMet.3D Serial Polishing System

- Sequentially, and repeatably, grinds and polishes samples
- Multiple grinding/polishing steps can be programmed into a polishing recipe
- Dip wells for chemical etching
- Built-in ultrasonic cleaner
- Post-processing to reassemble 2D optical images into 3D microstructural models

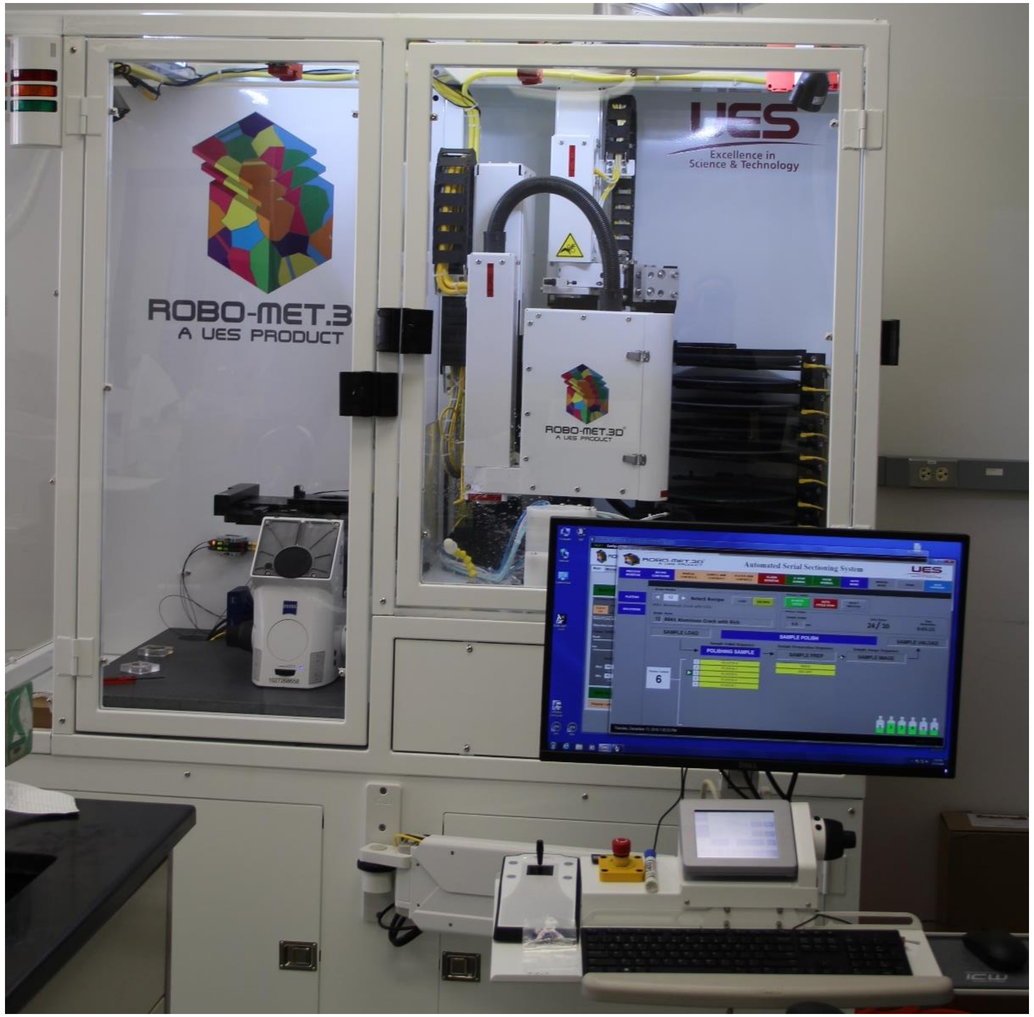
Applications

- Material Characterization
- Assessing influence of AM process variables
- Input to material models

Materials

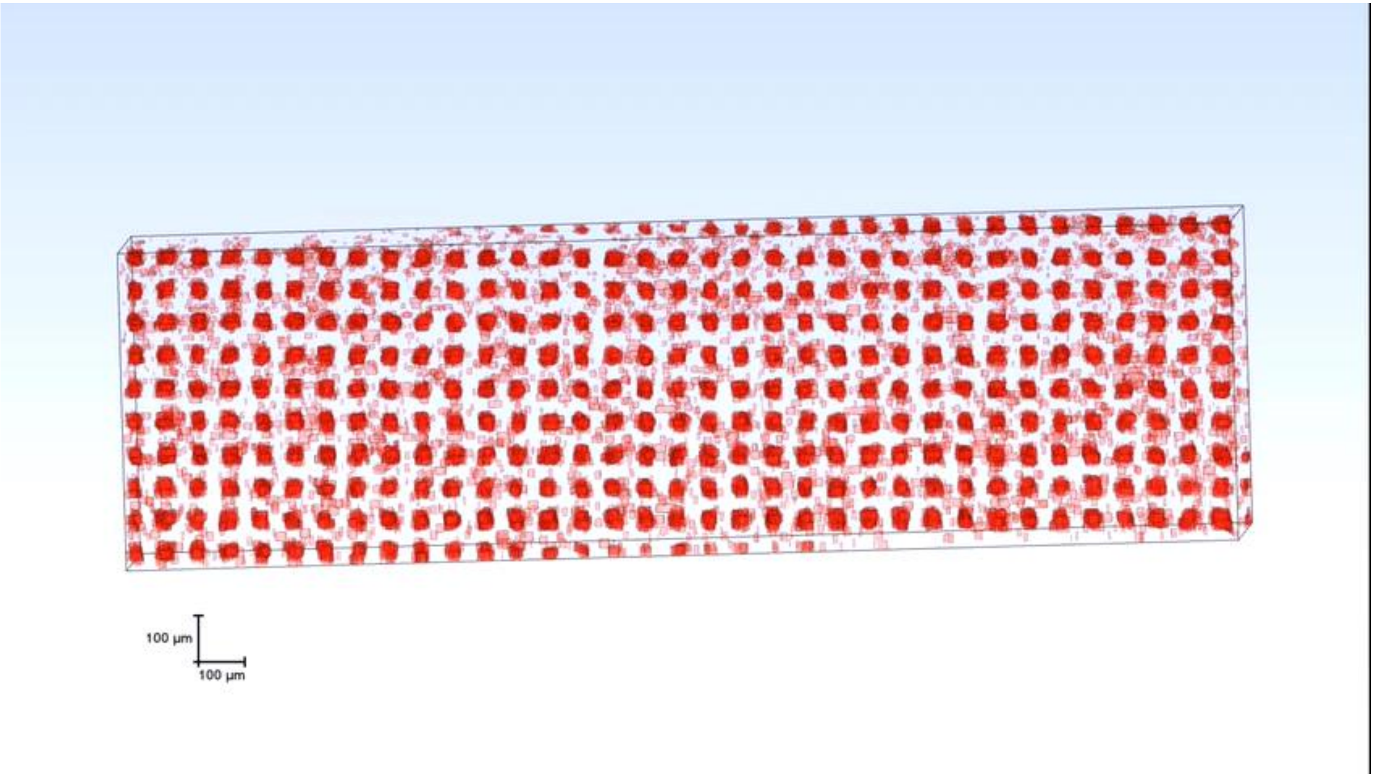
- Polymer and Ceramic Composites
- Metallic Materials (traditional and AM)
- EBC/TBC coatings

Covid-19 Pandemic Solution: Automation



UES RoboMet.3D Serial Polishing System

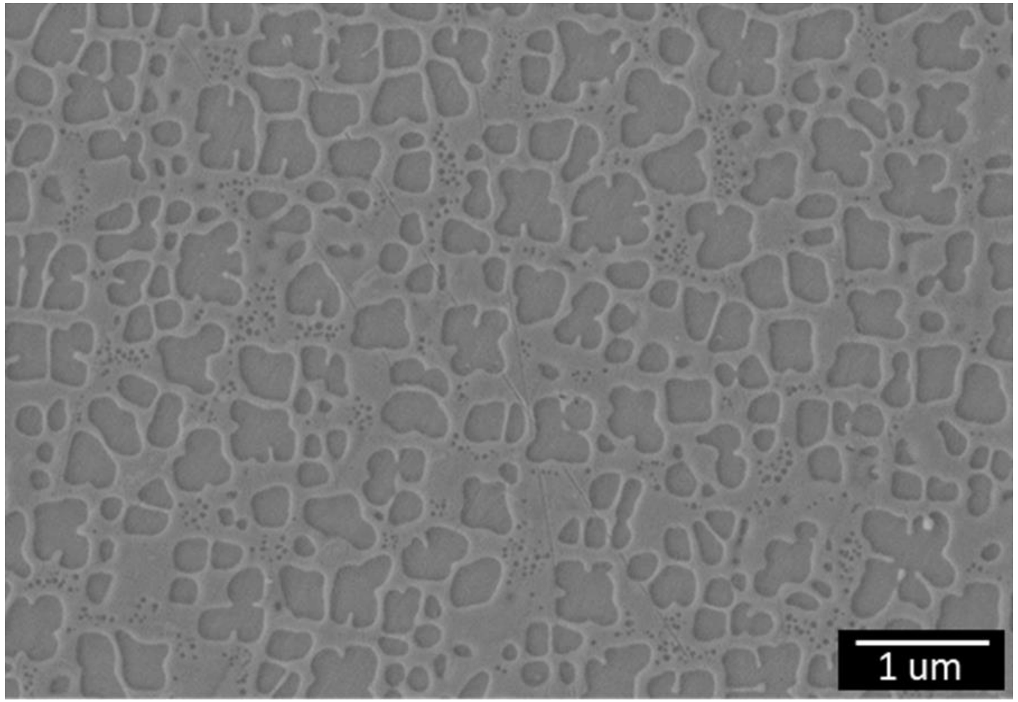
Defects in 3D printed Alloy

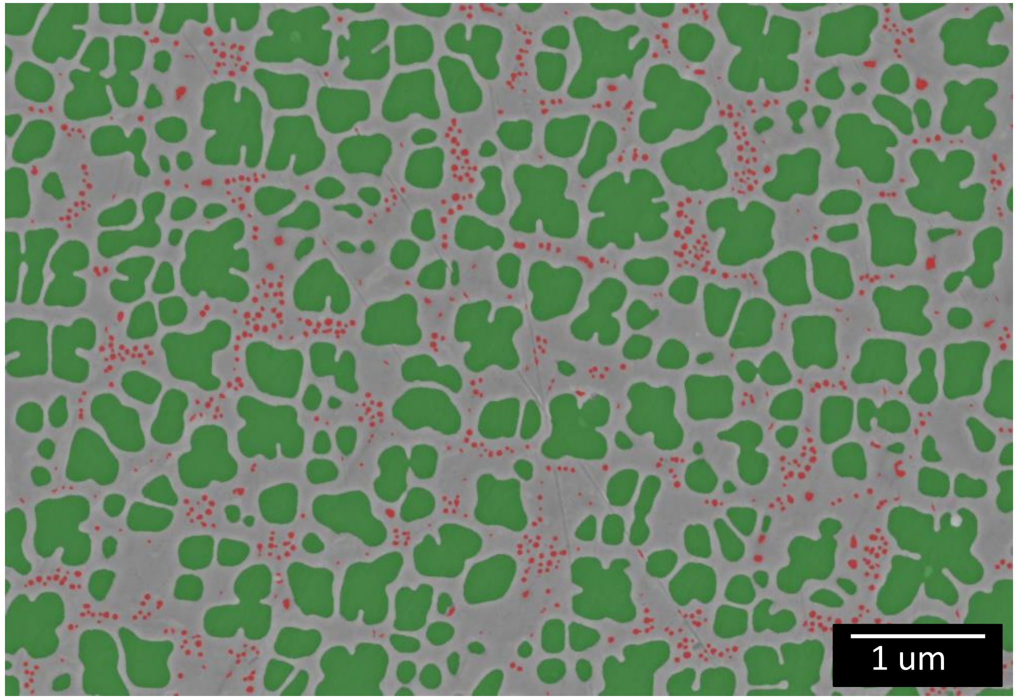


Covid-19 Pandemic Solution: Remote Characterization

- Ultra-High Resolution SEM
  - Field emission electron source
  - Advanced TriLens electron optics
  - Large sample chamber capacity
  - Low kV operation – 1nm resolution at 1kV
- Imaging modes:
  - Ultra-High Resolution
  - Extended depth of field
  - Overview
  - Analysis
  - UHR-Cross-Free for low kV imaging
  - Automated montage
  - Low Vacuum/Variable Pressure Mode
- Oxford Analytical Tools
  - Large (50mm) EDS detector
  - EBSD
  - Aztec integrated phase analysis software

Covid-19 Pandemic Solution: Advanced Modeling





Machine learning can successfully and accurately segment micrographs of superalloy precipitate structures that were either difficult or impossible to process through conventional segmentation techniques.

ML has increased the accuracy and efficiency of our microstructure analysis.

Covid-19 Pandemic Solution: Advanced Modeling

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 phases

Over 50 simulations provided an optimized composition named Alloy X

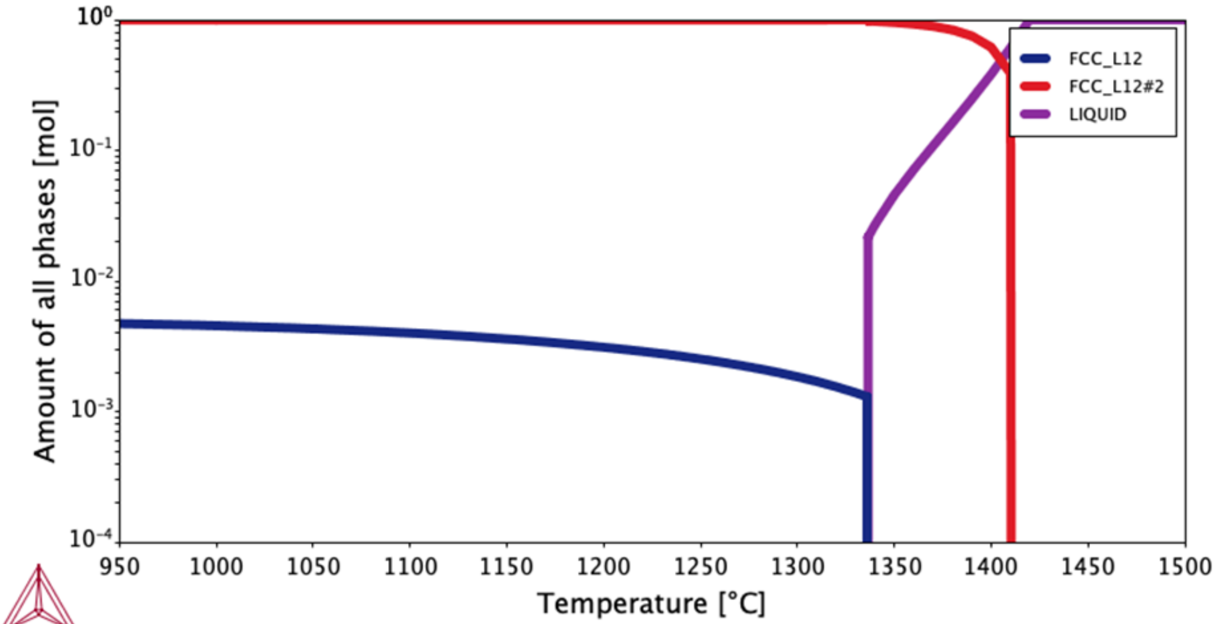


Figure: CALPHAD simulation of phase formation in new composition. No intermetallic or TCP phases are predicted.

Models calculated by C. Kantzos

	Ni	Co	Cr	Re	Al	Ti	Nb	Mo	W	Zr	C	B
Old Composition	Bal.	32	30	1.5								.003
New Composition (Alloy X)	Bal.	33	29	1.5	x	x	x	x	x	x	x	x

Covid-19 Pandemic Solution: Collaboration

Article | Open Access | Published: 14 October 2021

Utilizing local phase transformation strengthening for nickel-base superalloys

Timothy M. Smith, Nikolai A. Zarkevich, Ashton J. Egan, Joshua Stuckner, Timothy P. Gabb, John W. Lawson & Michael J. Mills

Communications Materials **2**, Article number: 106 (2021) | Cite this article

Abstract

Almost 75 years of research has been devoted to producing superalloys capable of higher operating temperatures in jet turbine engines, and there is an ongoing need to increase operating temperature further. Here, a new disk Nickel-base superalloy is designed to take advantage of strengthening atomic-scale dynamic complexions. This local phase transformation strengthening provides the alloy with a three times improvement in creep strength over similar disk superalloys and comparable strength to a single crystal blade alloy at 760 °C. Ultra-high-resolution chemical mapping reveals that the improvement in creep strength is a result of atomic-scale η ($D0_{24}$) and χ ($D0_{19}$) formation along superlattice stacking faults. To understand these results, the energy differences between the $L1_2$ and competing $D0_{24}$ and $D0_{19}$ stacking fault structures and their dependence on composition are computed by density functional theory. This study can help guide researchers to further optimize local phase transformation strengthening mechanisms for alloy development.

Manuscript written during the height of pandemic restrictions was achieved through collaboration:

NASA GRC: Lead project: procured material, performed characterization, machine learning
AFRL: Thermodynamic Modeling
ATI: Produced Material
Metcut: Performed mechanical tests
OSU: Performed characterization
NASA Ames: Performed DFT Modeling

This collaboration was enhanced by the implementation of video conferencing.

Conclusions

The Covid-19 pandemic presented challenges that were non-existent just a few years prior:

- **Restricted lab access**
- **Travel restrictions**
- **Supply chain issues**
- **Delayed milestones**

However, this was also a period where new advanced solutions could help improve materials research moving forward:

- **Automation**
- **Remote working**
- **Advanced modeling techniques**
- **Faster collaboration / video conferences**

When the challenges from Covid-19 subside these new solutions/techniques are poised to help advance materials science beyond where it was before the pandemic.

Questions?