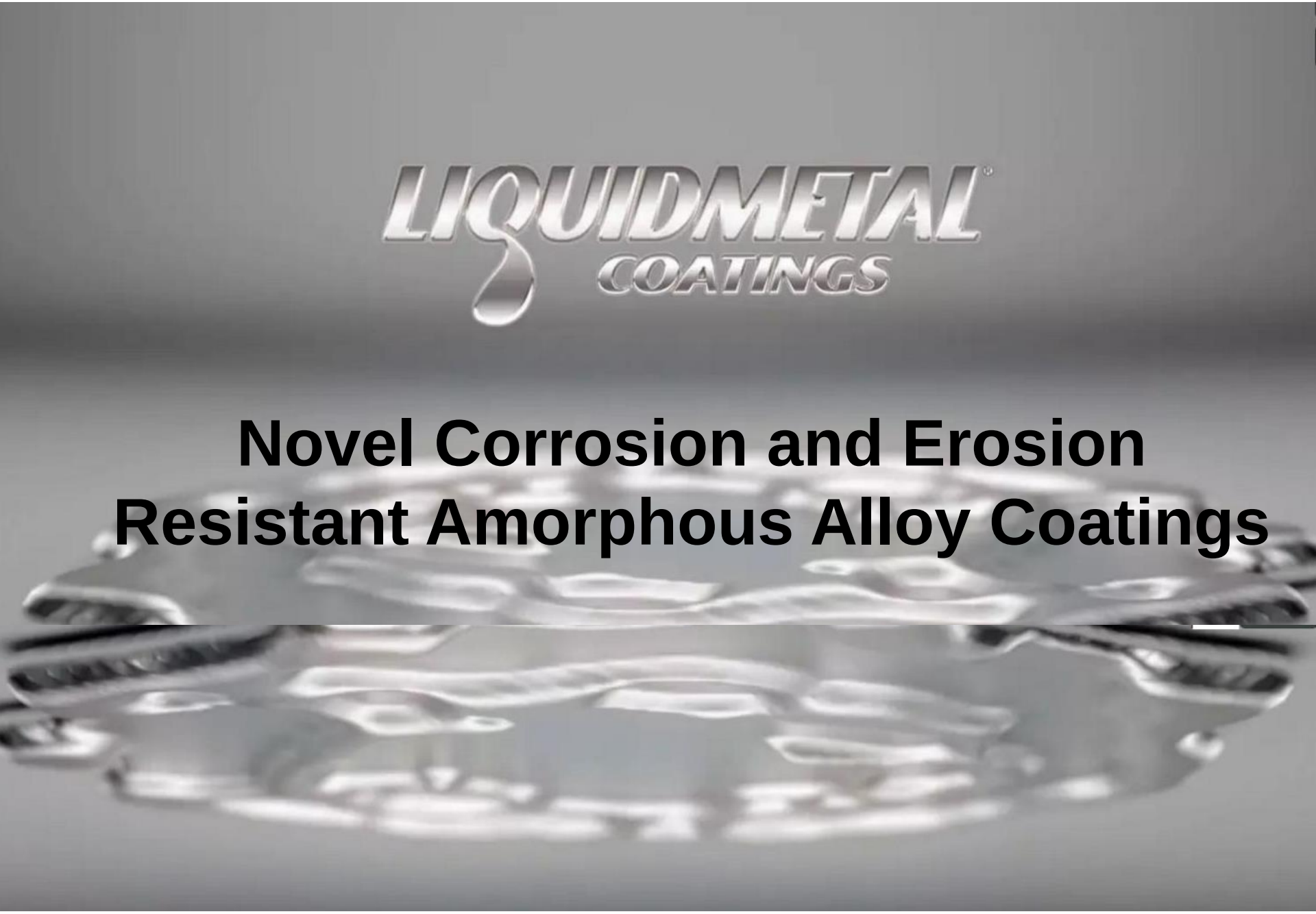
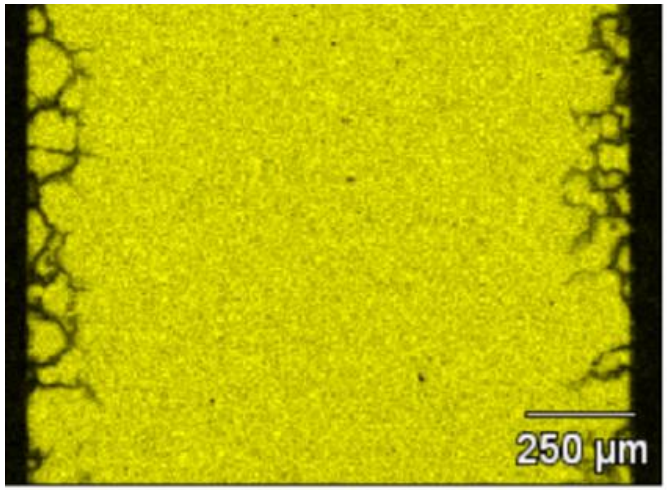


Novel Corrosion and Erosion Resistant Amorphous Alloy Coatings

Background

- LiquidMetal Coatings is the provider of choice for high performance coatings to prevent wear, corrosion and friction in extreme environments
- More than 30 years experience of spraying protective coatings in Power Generation and other Fields has lead to LiquidMetal Coatings – **Armacor** – that are most cost-effective and reliable solutions to some severe wear and corrosion problems
- Exclusive technology rights amorphous materials – 85 patents
- Purchased Foster Wheeler Division in 2007
- Based on successful applications approved by our clients, LMC can provide optimized solutions with a wide range of products and technologies to combat corrosion/erosion/wear in Refinery/Petrochemical, Coal Power Plants, Waste Incinerations, Pulp and Papers, Recovery Boilers, Fluidized Bed Boilers, Biomass Boilers and much more…

Materials with High Corrosion Resistance against Liquid Chloride Systems



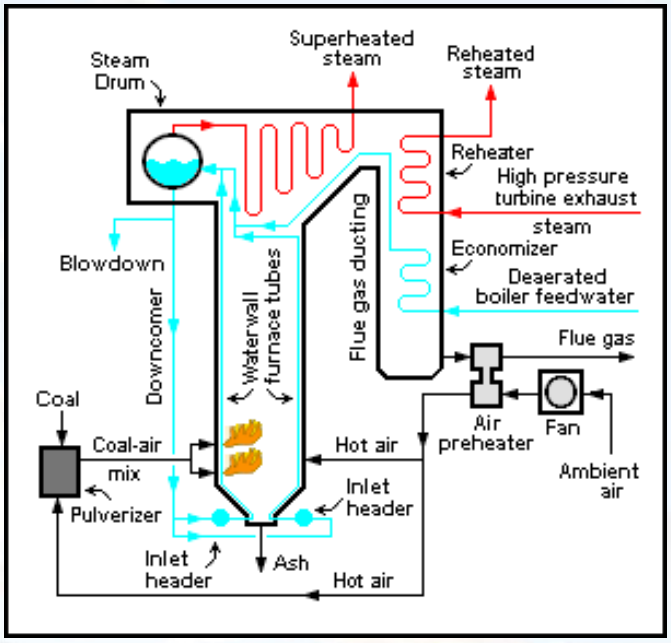
Cr depletion of Incoloy 800H exposed in KCl-$MgCl_2$

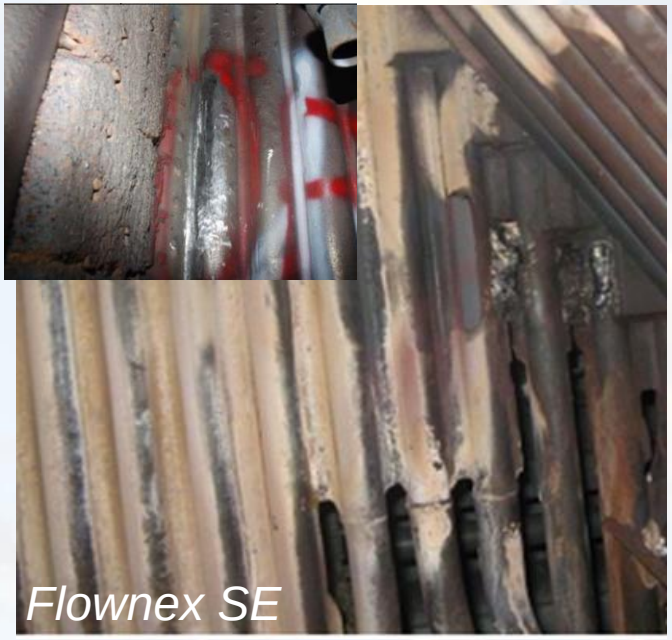
→ 316 stainless steel exhibited the worst grain boundary attack with chromium depletion to 300µm depth after 100hrs exposure

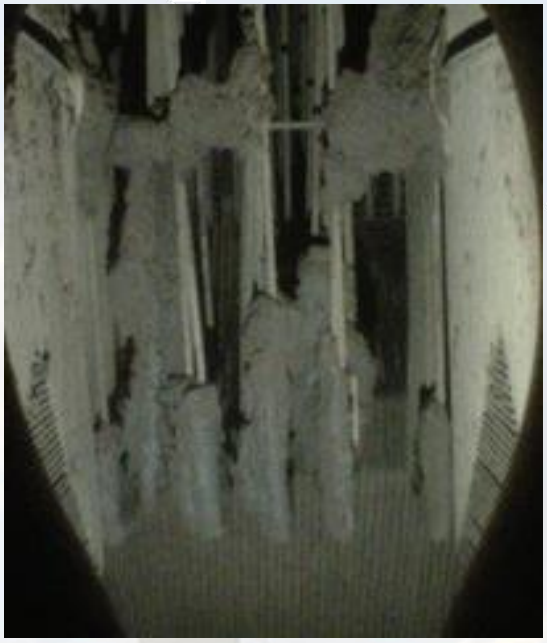
→ SunShot program has a target of a corrosion rate of less than 15 µm/yr to ensure a 30 years lifetime of the next generation of CSP (Concentrated Solar Power) systems

LMC is working on new coating solutions with high resistance against molten salt corrosion at temperatures over 700°C

Power Plants

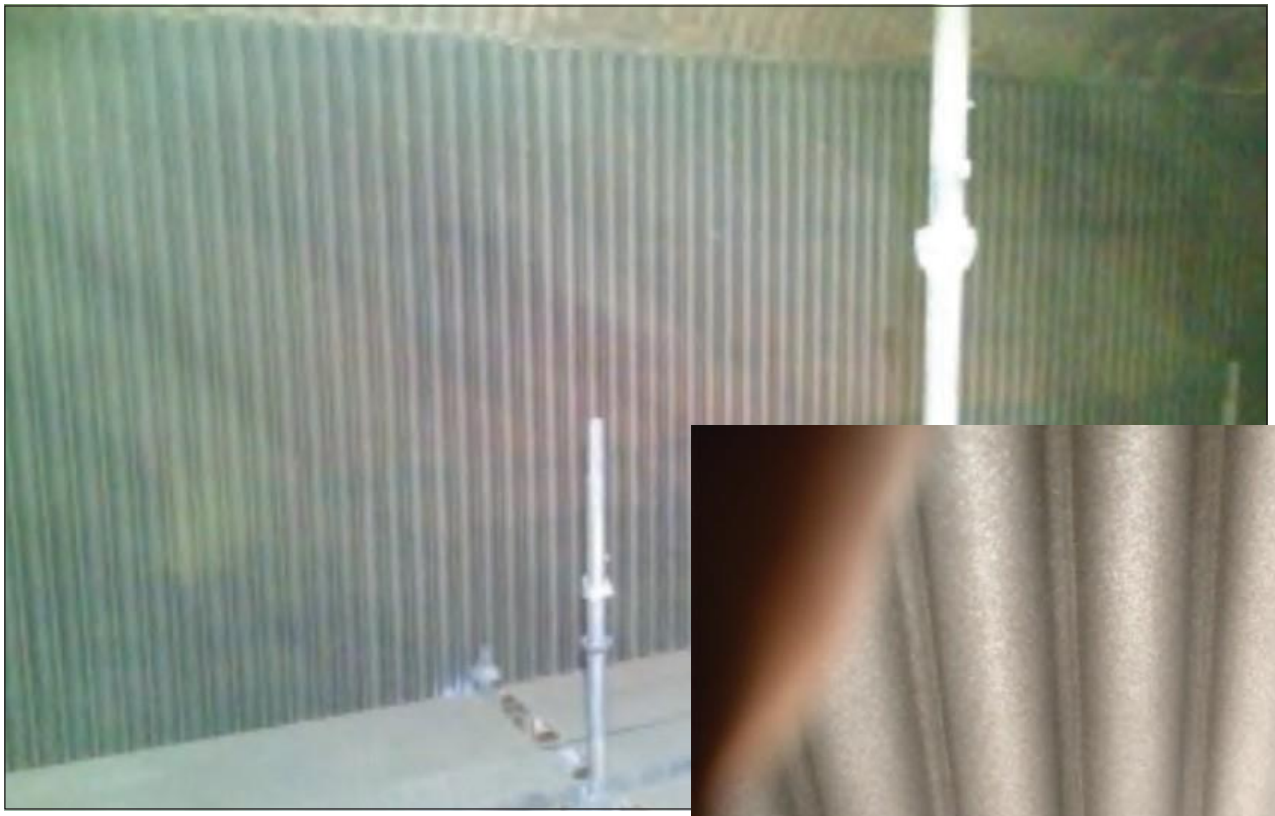






- Power plants experience major wear and corrosion problems, especially due to the high temperature environment and highly corrosive/erosive environment
- Boiler tube failures remain one of the leading causes for forced maintenance outages in the coal and biomass fueled power generation industries.
- Tube failures, unplanned outages, increased boiler down time and costs the power generation industry billions of dollars annually

Performance in-Field

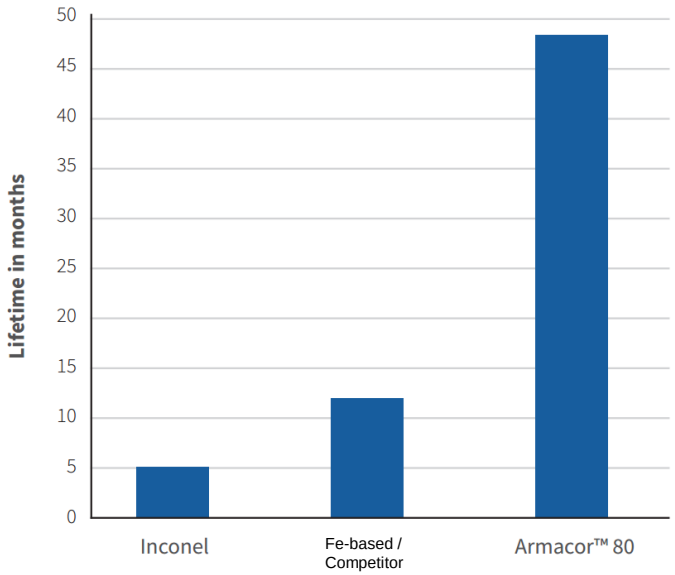


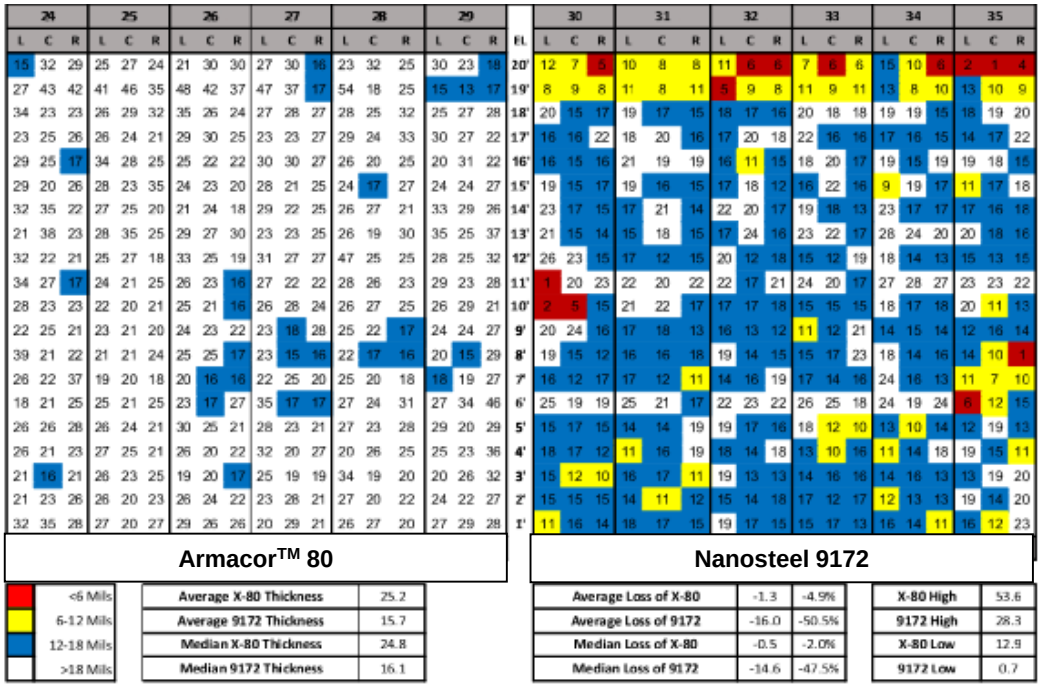
After 3 years in operations, X-80 coating needed minimal repairs due to gouging

After 2 years in operations, X-80 coating needed no repairs

Performance in-Field

Boiler-Tube Case Study – 4-year Evaluation of 3 Different Coatings at a Central California Power Plant





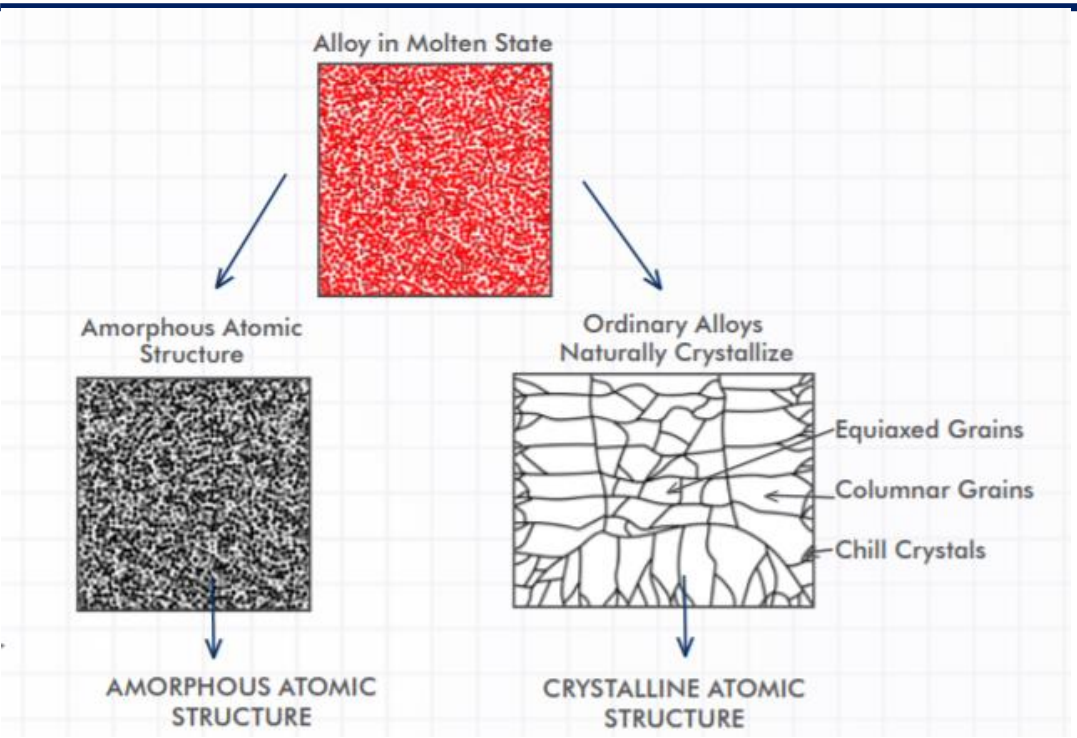
Coating thickness readings after three months in operation

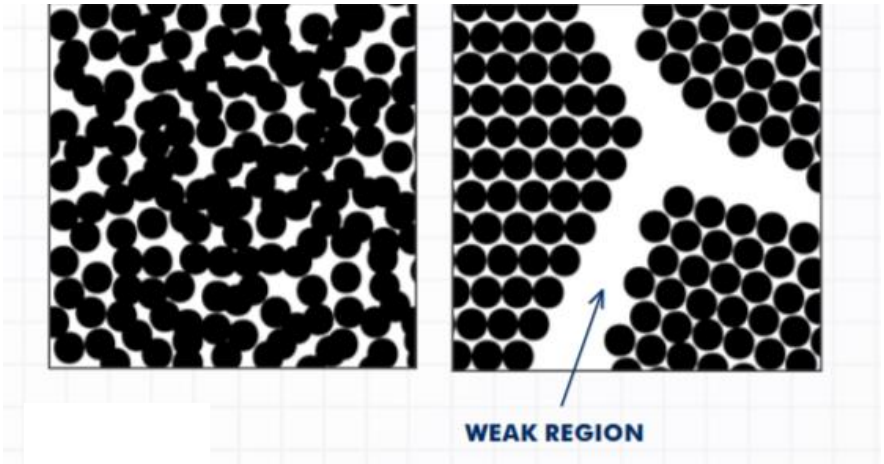
Savings of $10.8 Million

Technology

What makes it unique?

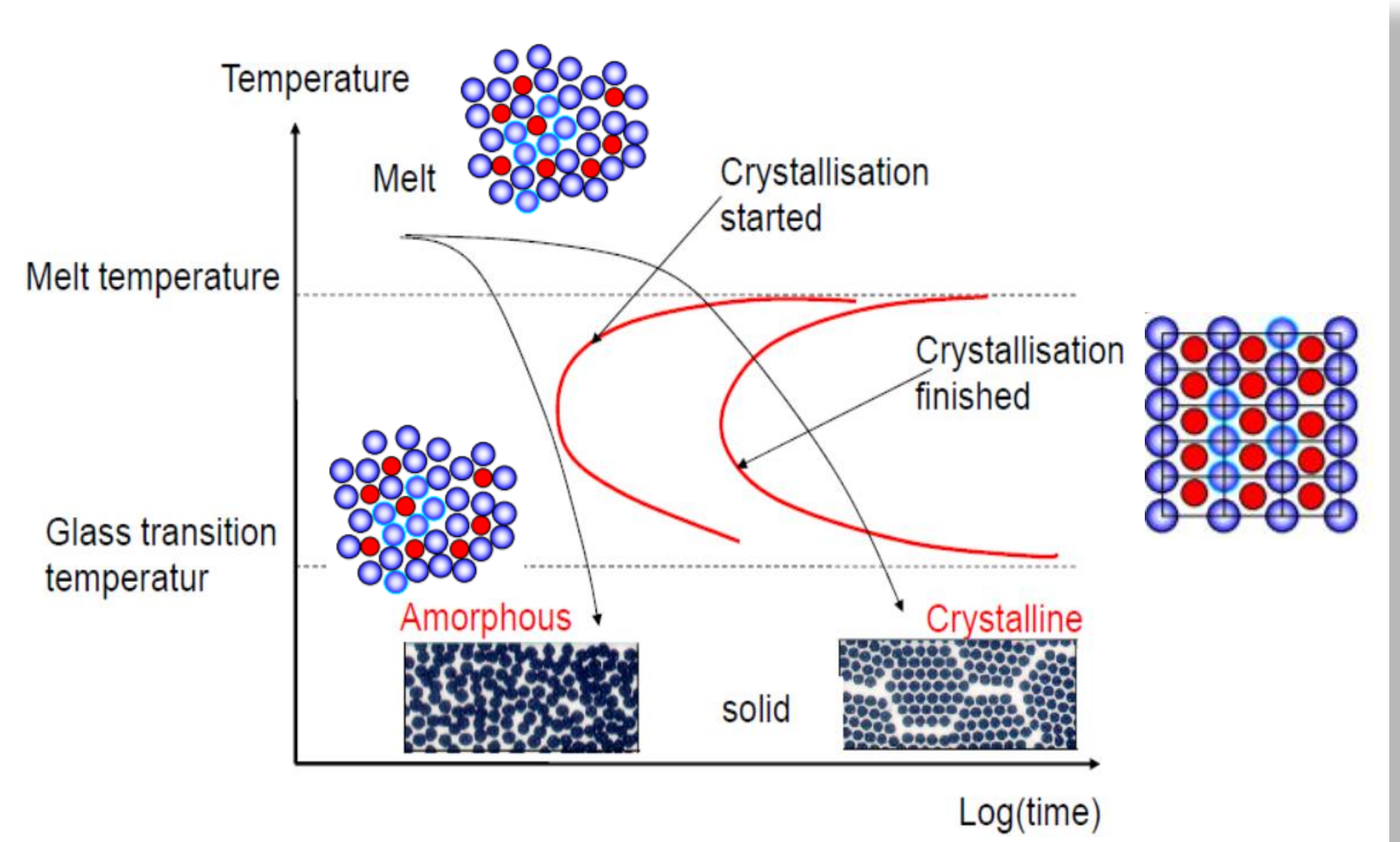
Amorphous Alloys



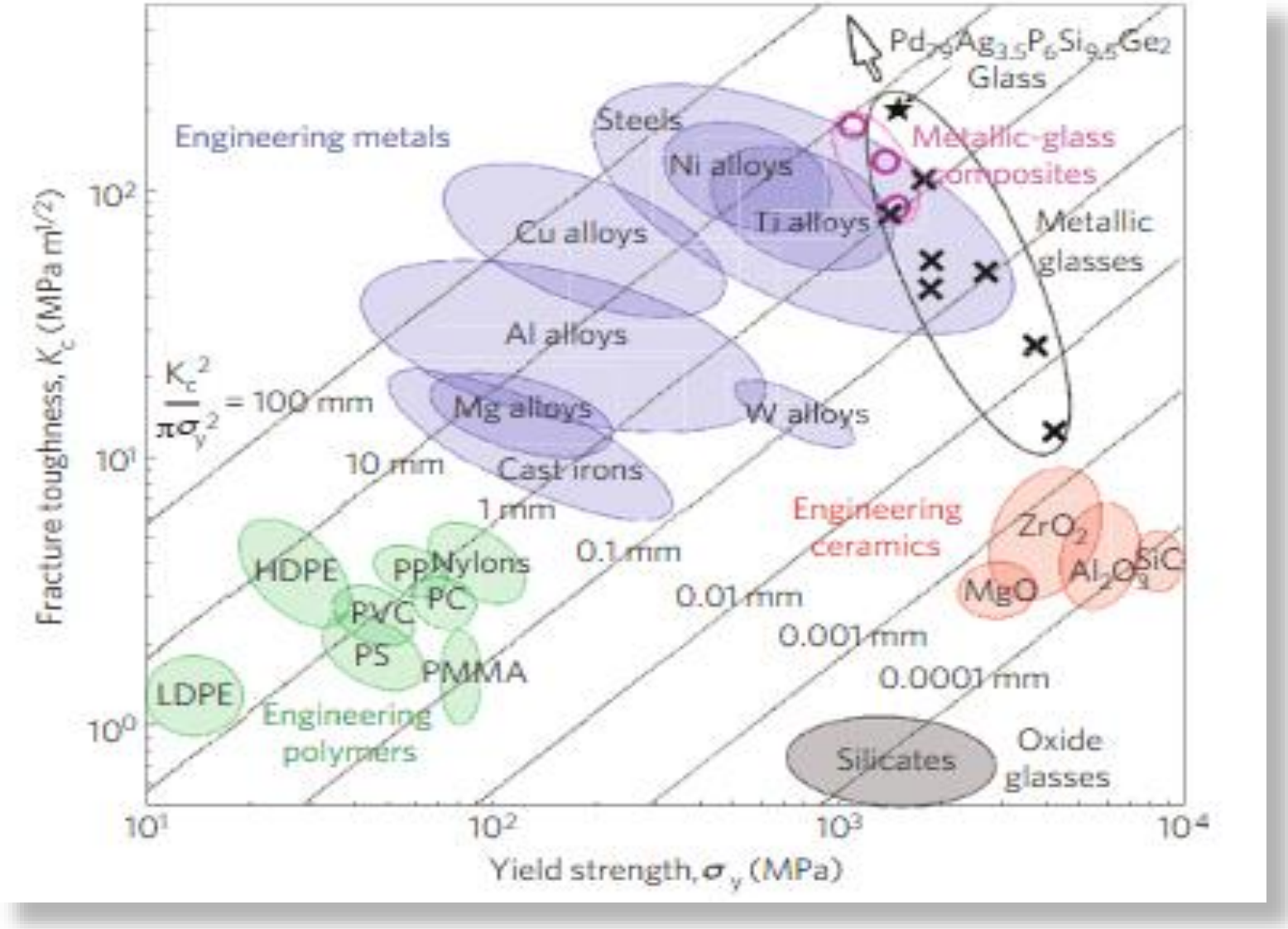


- The alloys contain atoms of significantly different sizes, which results in a higher viscosity when melted.
- There are no grain boundaries (defects) present in the metal.
- There is no shrinkage when cooled resulting in a resistance to plastic deformation.
- Amorphous metals have a high yield strength, higher hardness, and a higher strength/weight ratio than other metals.

Time-Temperature-Transformation diagram

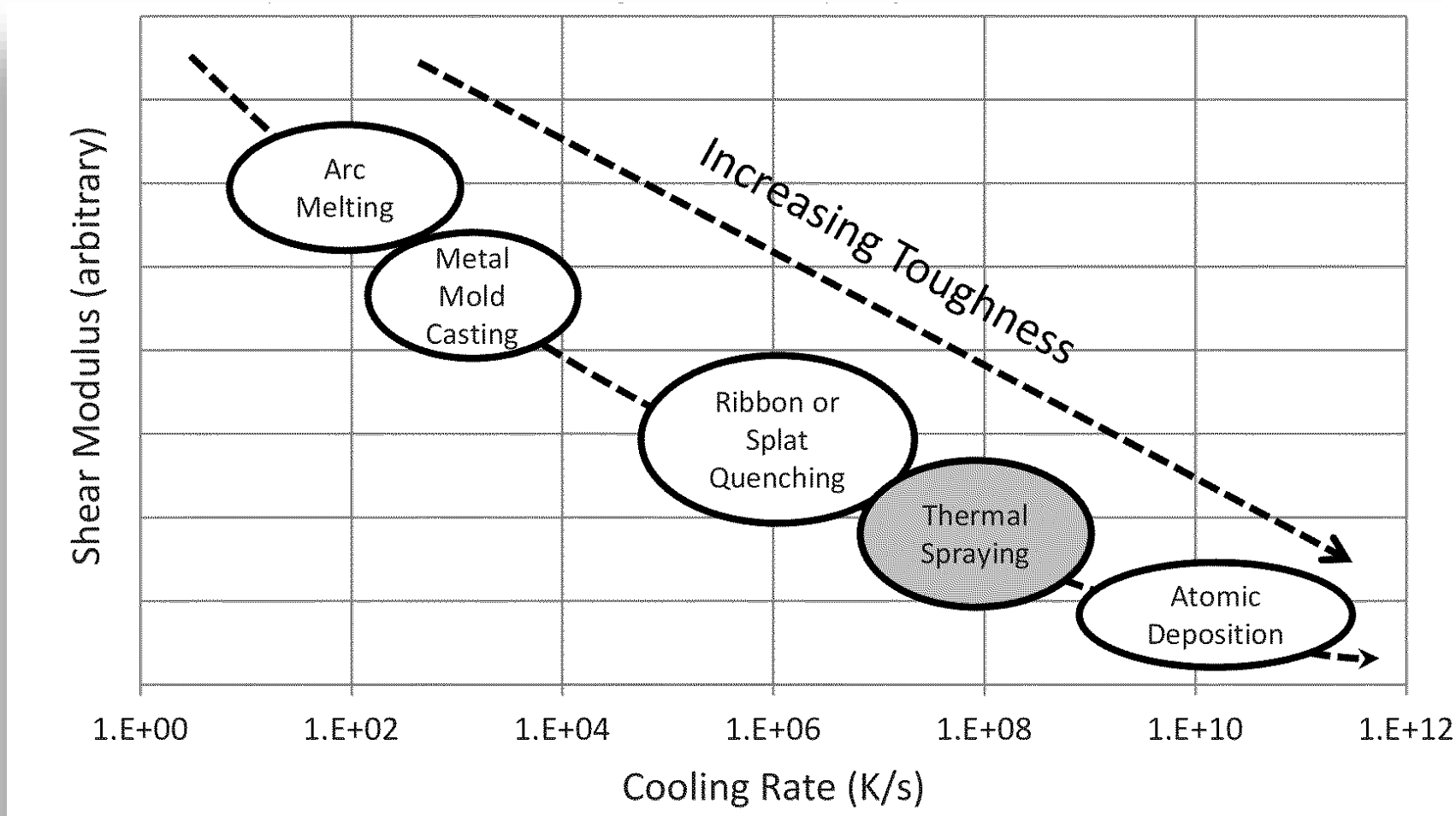


Ashby Map



Courtesy: Nature Mater. 10, 123 (2010)

Relationship between Cooling Rates and Properties for Metallic Glasses



Courtesy: D. Hoffmann / JPL

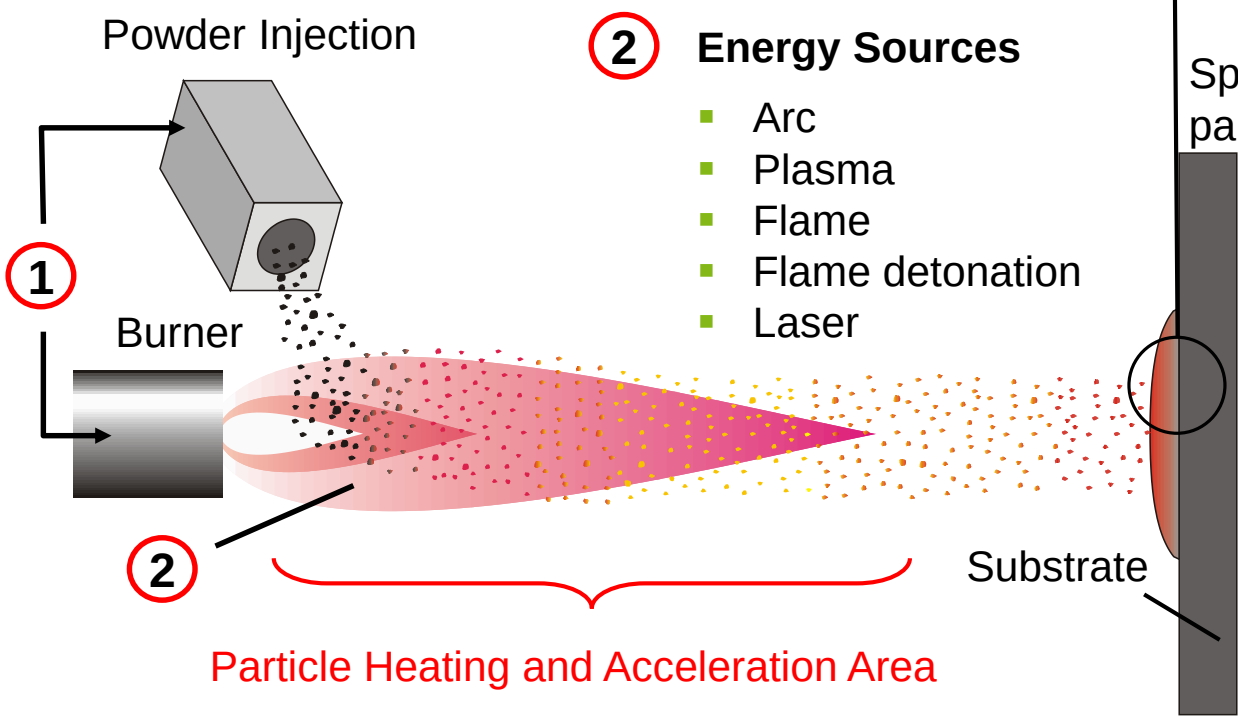
Thermal Spraying

1 Initial Materials:

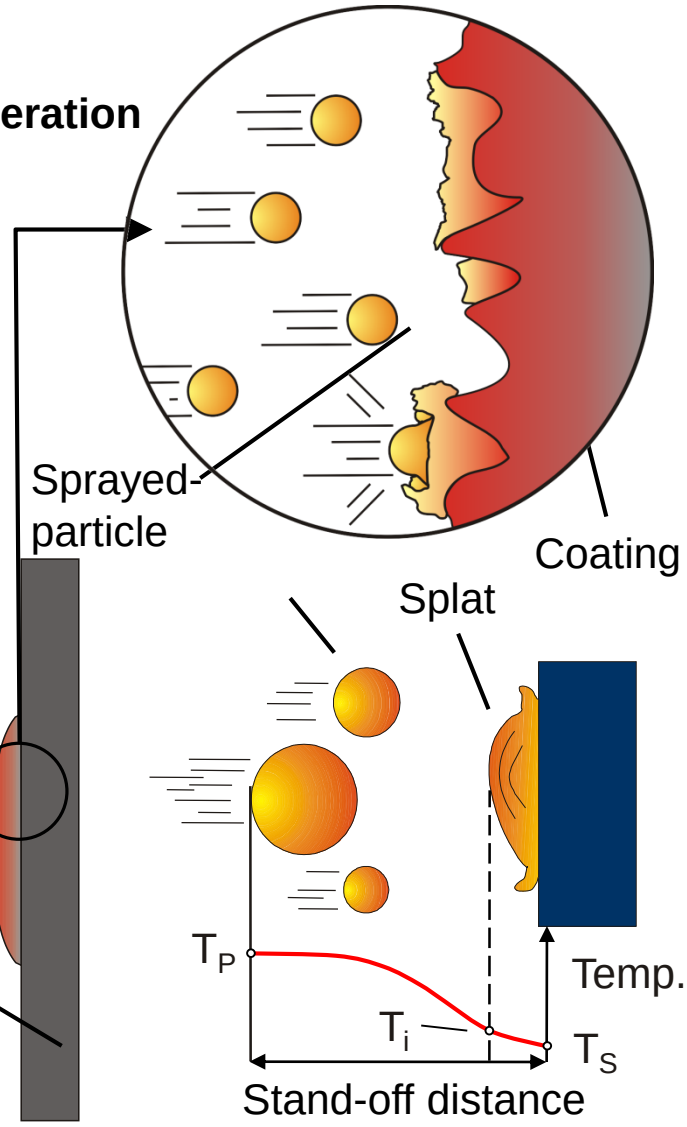
- Wire
- Rod
- Submicron- / Nanopowder
- Nanoparticle-suspension

2 Energy Sources

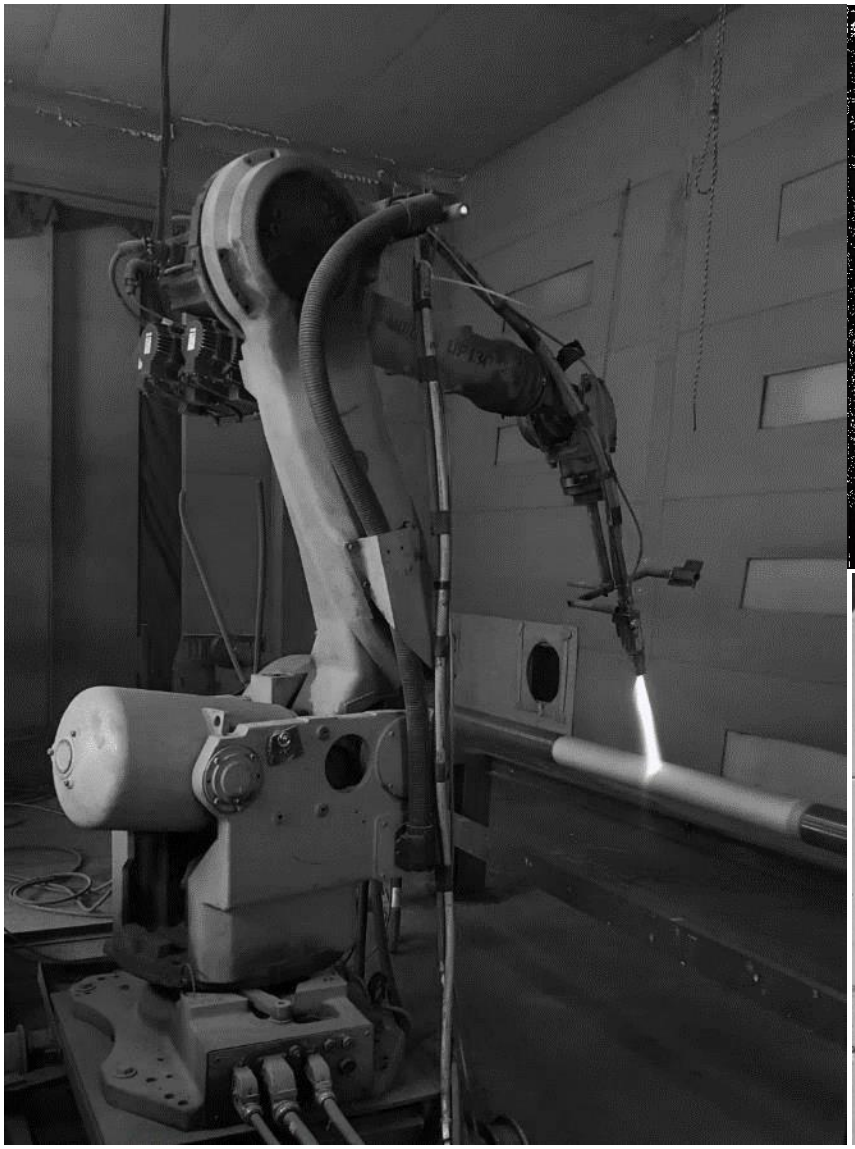
- Arc
- Plasma
- Flame
- Flame detonation
- Laser

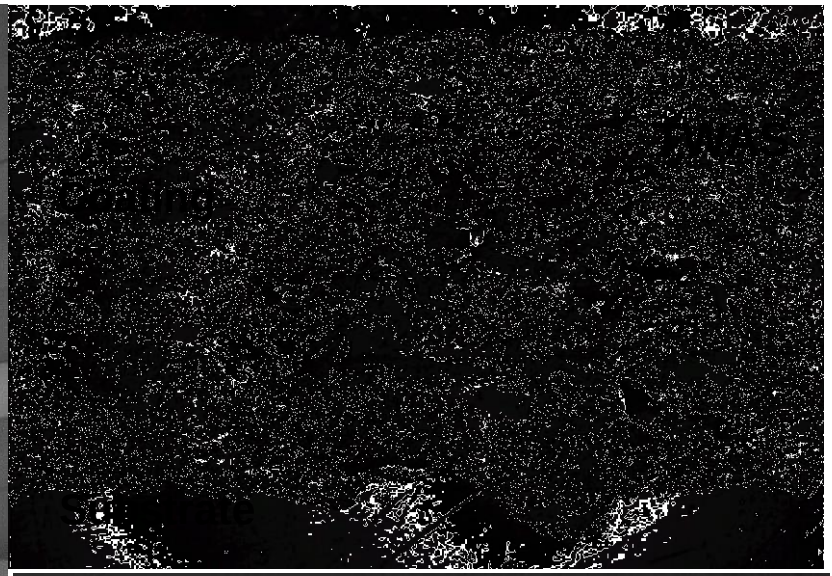


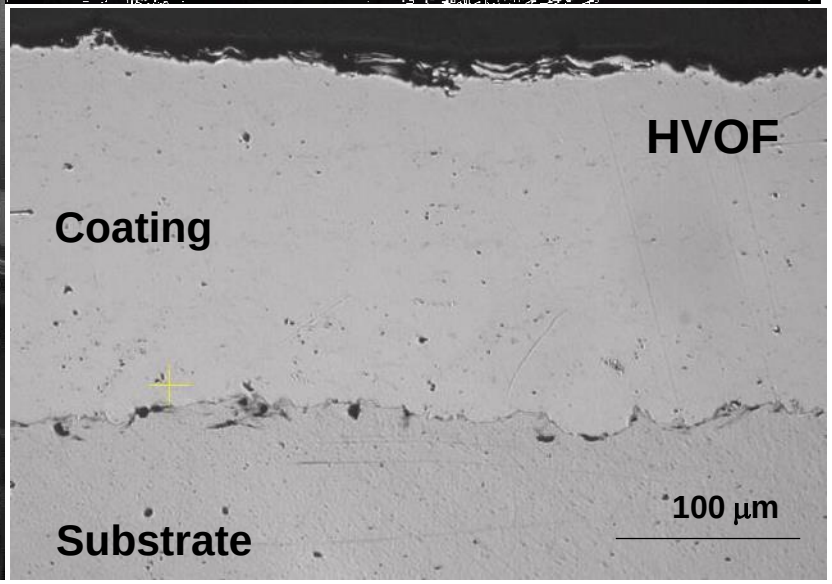
Coating generation



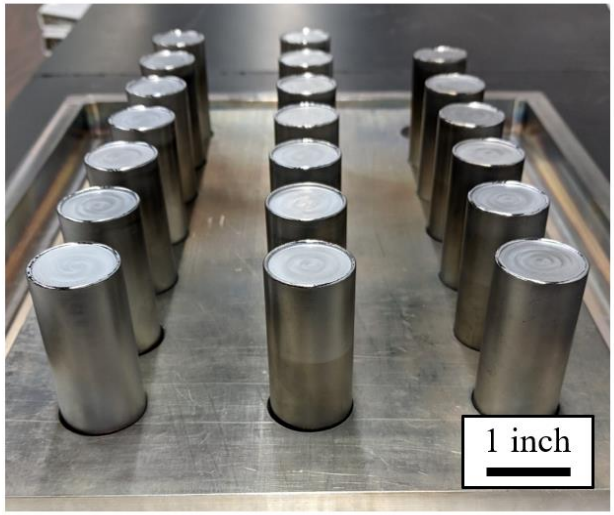
Spraying in-shop

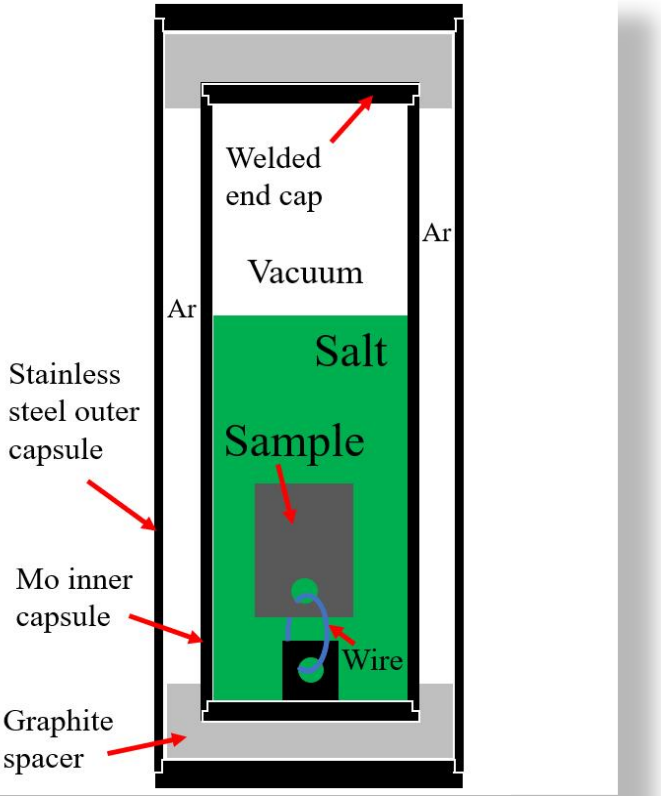






Testing Corrosion Resistance Testing at 750°C under Molten Salt (KCl-MgCl2)

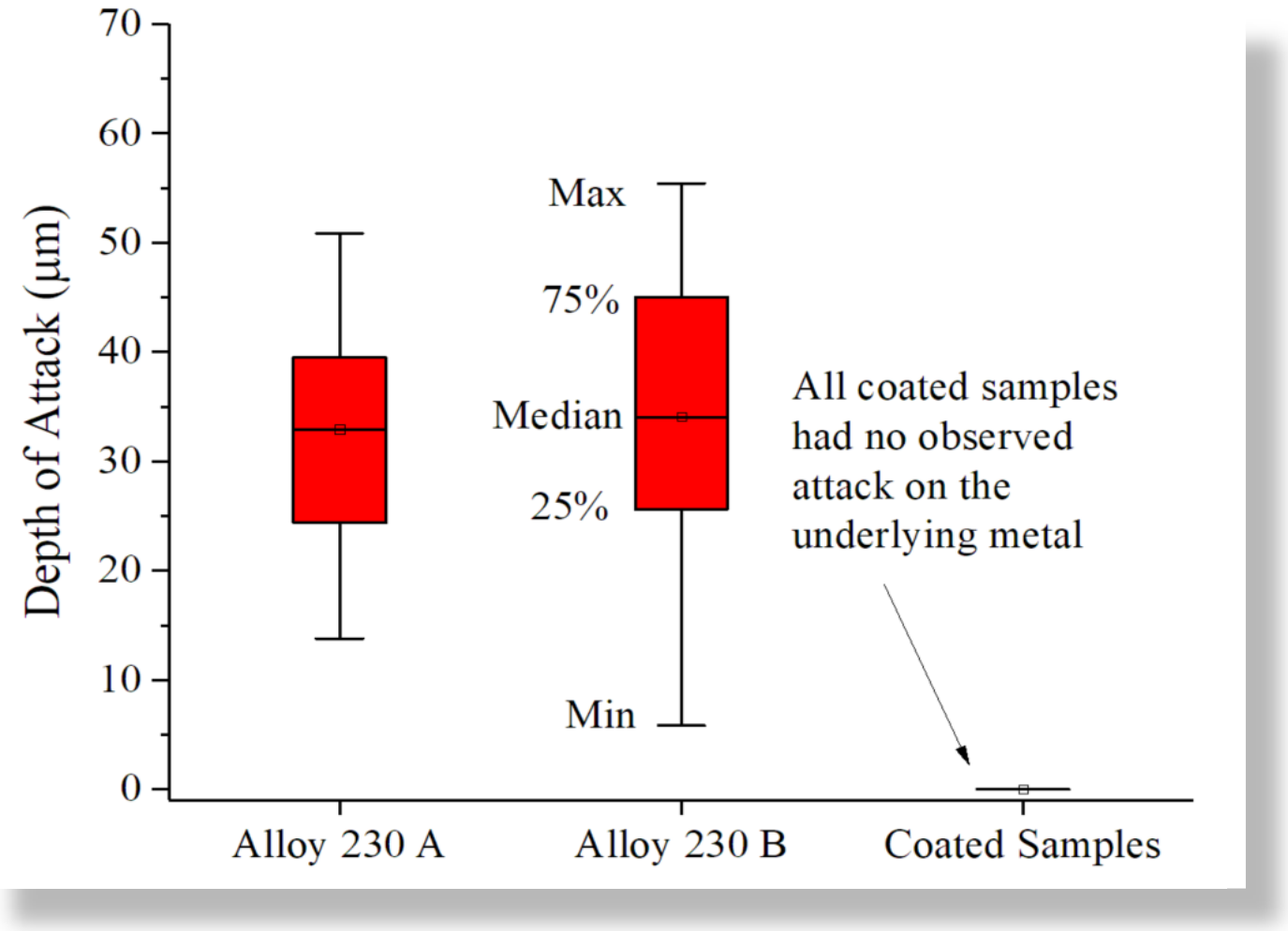




- 300hours at 750°C
- molten KCl-$MgCl_2$ in a 68/32 ratio

(work done in cooperation with ORNL)

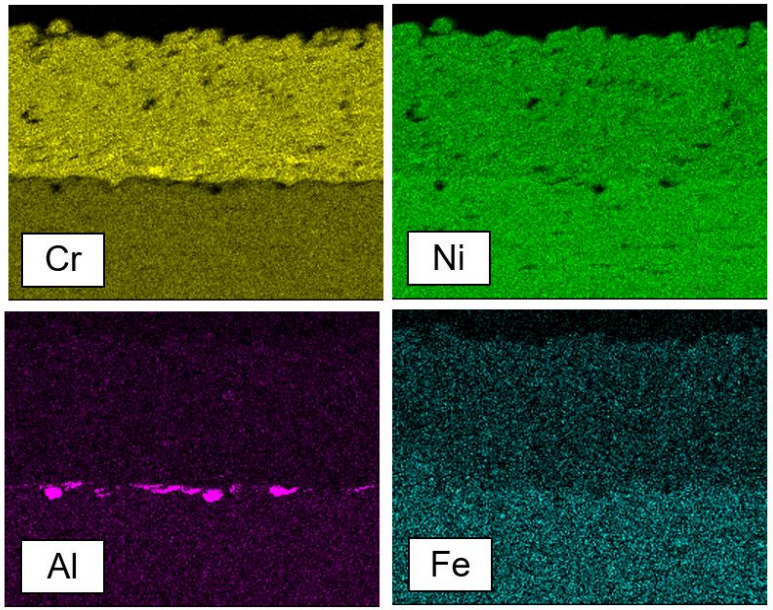
Depth of Corrosion Attack after Testing



Cr-depletion after Testing

DOE Award – DE-SC0017682

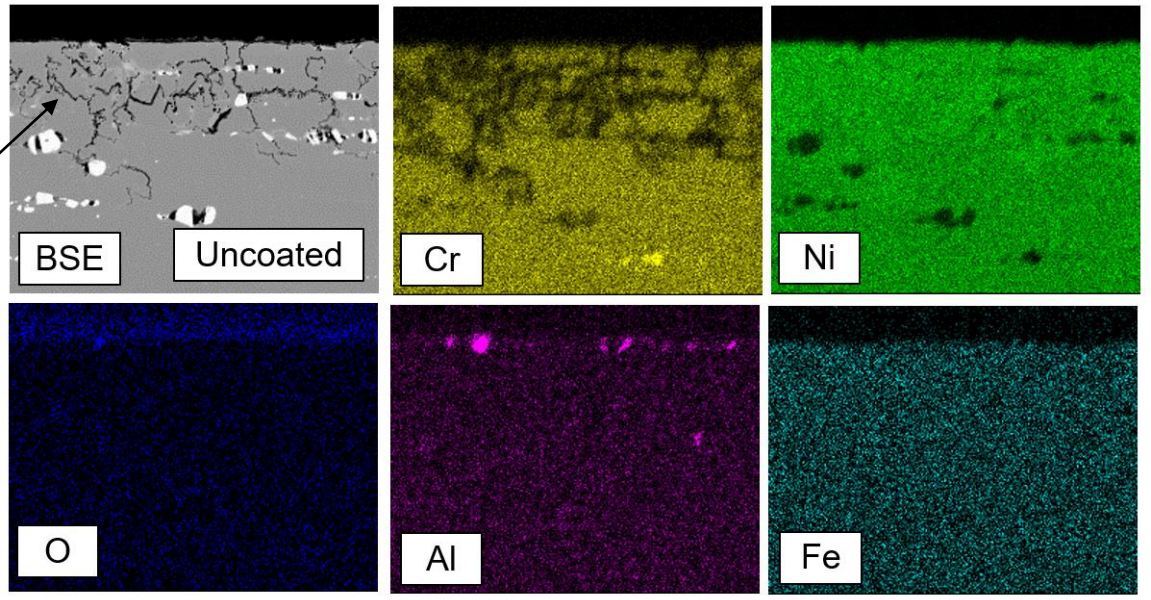
LM Ni-based coating



No Cr-depletion

Cr-depletion

Haynes 230

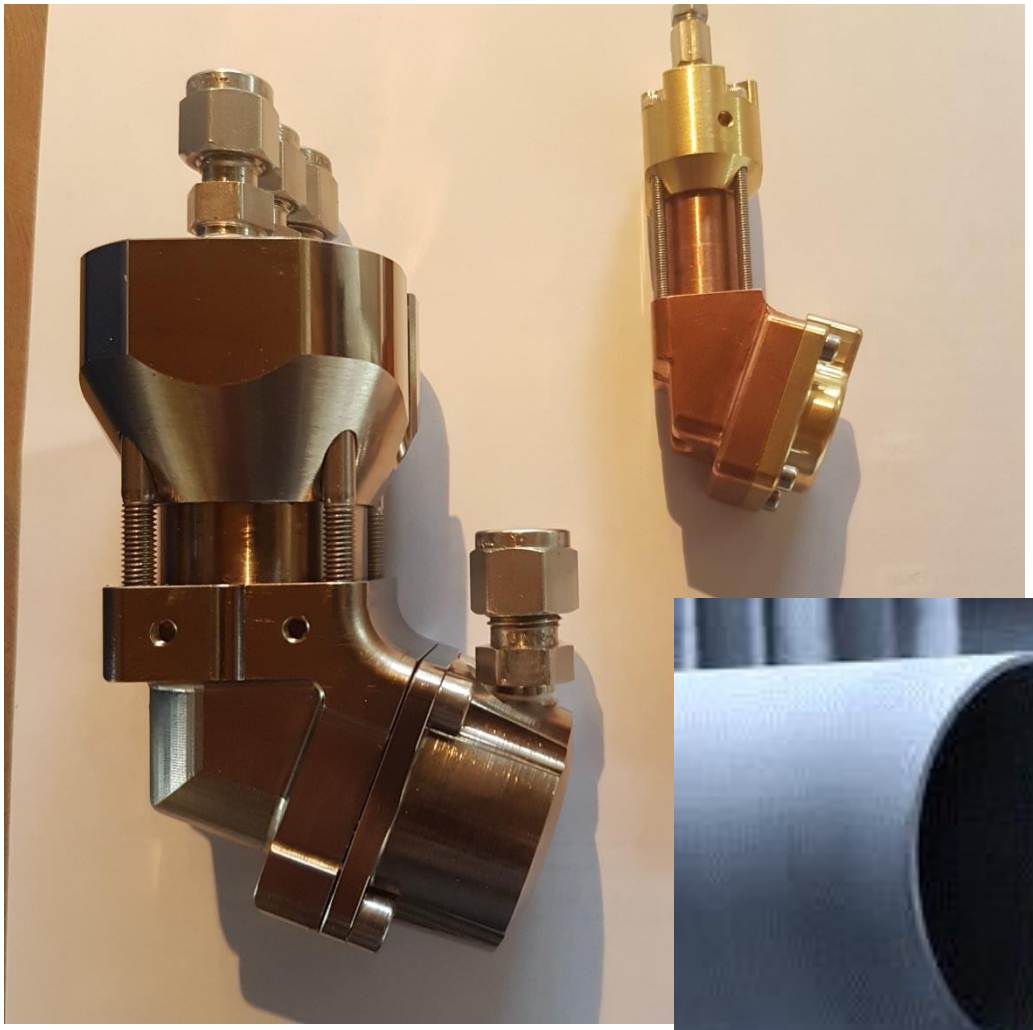


Technical Objectives

- Understand and explain the protection mechanism of the corrosion resistant amorphous alloys-based coatings
- Validate better performance over crystalline Ni-based alloys using not purified chloride molten salt
- Validate better performance over crystalline Ni-based alloys under near-real and real liquid chloride molten salt conditions at temperatures over 700°C (molten loop test)
- Evaluate erosion performance
  - Show low erosion rate and minimal material loss
- Evaluate mechanical properties of the amorphous coatings in the molten salt operating temperature range (600 to 800°C) before and after
- Demonstrate thermal spraying of amorphous metal-based alloy powders into different shapes (shafts, propeller and IDs of pipes):
  - Near-net shape grinding to show proof of concept production of components with specified surface characteristics
- Demonstrate a high adhesion of thermal sprayed coatings into complex shaped substrate materials (Haynes 230 and stainless steel). Achieve a bond strength greater than 10,000 ksi.

New Development ID- Mini

LM GROUP HOLDINGS



Impact

The amorphous metal coating solution developed by LMGH under this program would have applications primarily in the pump (impellers, bearings, shafts) and other components used in energy storage (concentrated solar power, solar thermal, batteries).

Other Applications:

- Concentrated Solar Power, molten-salt batteries, other energy storage solutions
- Desalination: Pumps, compressors, heat exchangers, valves
- Power Generation: Heat shields, boiler tubes, nozzles, seals, shields, etc.
- Chemical: Nozzles, casings, valves, pumps
- Oil & Gas: Impellers, centralizers, inserts
- Aerospace: Turbine blades, compressors, nozzles, gears, chambers

Thank you for your attention!

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