Novel Corrosion and Erosion Resistant Amorphous Alloy Coatings
Materials with High Corrosion Resistance against Liquid Chloride Systems

Cr depletion of Incoloy 800H exposed in KCl-MgCl₂

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

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

- Melt
- Crystallisation started
- Crystallisation finished

- Melt temperature
- Glass transition temperature

- Amorphous
- Crystalline

Log(time)
Ashby Map

Fracture toughness, $K_c$ (MPa m$^1/2$)

$\frac{K_c^2}{\pi \sigma_y^2} = 100 \text{ mm}$

10 mm, 1 mm, 0.1 mm, 0.01 mm, 0.001 mm, 0.0001 mm

Engineering metals
Stainless steels
Ni alloys
Ti alloys
Metallic-glass composites
Metallic glasses
Cu alloys
Al alloys
Mg alloys
W alloys
Cast irons
Engineering ceramics
Silicates
Oxide glasses

Yield strength, $\sigma_y$ (MPa)

LDPE, HDPE, ppNylons, PVC, PC, PS, PMMA

Relationship between Cooling Rates and Properties for Metallic Glasses

Shear Modulus (arbitrary)

Increasing Toughness

Arc Melting

Metal Mold Casting

Ribbon or Splat Quenching

Thermal Spraying

Atomic Deposition

Cooling Rate (K/s)


Courtesy: D. Hoffmann / JPL
Thermal Spraying

1. Initial Materials:
   - Wire
   - Rod
   - Submicron- / Nanopowder
   - Nanoparticle-suspension

2. Energy Sources
   - Arc
   - Plasma
   - Flame
   - Flame detonation
   - Laser

Powder Injection

Energy Sources

Particle Heating and Acceleration Area

Coating generation

Sprayed particle

Substrate

Splat

Temp.

Stand-off distance

TP

Ti

TS
Build-up of a Thermal Sprayed Coating

**Build-up of a Thermal Sprayed Coating**

- **Coating Substrate**
  - Dense
  - Homogeneous
  - Good cohesion and adhesion

- **Coating**
  - WC-Co-coating (HVOF)
  - Embedding resin
  - Void
  - Oxidized particle
  - Unmelted particle

**Image**

- Embedding resin
- Wool
- Anisotropic
- Lamellar
- Porous
- Heterogeneous

**Scale**

- 200 µm

**Image Annotation**

- 1 µs

**Note**

- Proprietary and Confidential
Spraying in-shop
Testing Corrosion Resistance Testing at 750°C under Molten Salt (KCl-MgCl₂)

- 300 hours at 750°C
- molten KCl-MgCl₂ in a 68/32 ratio
(work done in cooperation with ORNL)
Depth of Corrosion Attack after Testing

- Alloy 230 A
- Alloy 230 B
- Coated Samples

All coated samples had no observed attack on the underlying metal.
Cr-depletion after Testing

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
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
Coating on our Shop
Coating on Site

Armacor 80 sprayed on water wall
Application Capabilities

- Six operation facilities (TX, TN, AL, PA, CA, Canada)
  - Over 150,000 sq. ft. of space for shop applications
  - Ability to mobilize for field work from all 6 locations

- Thermal Spray including Spray and Fuse
  - 45 Twin wire systems
  - 15 HVOF systems

- Weld Overlay
  - 22 Fully automatic systems
  - 36 Semi automatic systems

- Mechanical Services

- Heat Treatment
  - Multiple ovens with capability of handling size range up to 10’ wide × 12’ high × 35’ long
Thank you for your attention!

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With hardness from 900 to 1500 HV, Liquidmetal coatings are 3 to 5 times harder than the other materials like steel and Ni-based alloys.

Products protected by Liquidmetal coatings are lasting 2 to 10 times longer in actual field applications.
XRD Thermally Sprayed Fe-Based Coatings

Coating

Powder

Two Theta

0 20 40 60 80 100

0 5,000 10,000 15,000 20,000 25,000

Two Theta
Other Oil & Gas Applications

- **Pump Plunger Rods**
  - Field wear results show that Liquidmetal solutions lasts 3 times longer than the current solutions
- **Internal Pump Components**
- **Sucker Rods & Couplings**
- **Sleeves**
- **Valves & Seats**
- **Extension Rods**
- ....

**Mandrel**

**Sucker Rod Coupling**

Coated two sections for wear protection
The use of coatings to enhance performance is growing among leading automakers.

Liquidmetal Coatings have been tested on gears in 7 speed DCT transmission as replacement of the existing self lubricating, high performance coating, molybdenum:
- 35% improvement in coefficient of friction and over a 1% improvement in fuel efficiency utilizing Liquidmetal Coatings.

Coating application inside diameter of cylinder to reduce wear.
Proprietary and Confidential

**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…