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Low Cost Corrosion and Oxidation Resistance Coatings for Improved System Reliability

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Challenge

Problem

Current coating processes are costly or incompatible with coating complex shape components and currently can not maintain performance required at the next generation operating temperatures

Turbine Disks / Blades

Goal/Objective

- Develop a **scalable cost effective process** to produce coatings that can enhance high temperature reliability and corrosion/oxidation resistance.
- Evaluate the potential of designing new state of the art coatings, based on our scalable approach, to further improve resistance to operating temperatures in **excess of 760°C**.

Technical Approach

- Design a custom bench-scale system to electrochemical codeposition NiCo with CrAlY powder
- Heat treat and evaluate the coating for potential high temperature corrosion and oxidation resistance
- Estimate the scalability and potential cost savings
- Design an alpha scale apparatus

Material and Testing

- ***Turbine Disk Material, Shape, and Composition***

Ideally ME3, LSHR, or Alloy10

- Used Inconel (IN718) due to availability

Alloy	Note	Cr	Co	Mo	W	Ta	Nb	Al	Ti	Fe	C	B	Zr	Re	Hf	Others
Inconel 718	wrought	18.6		3.1			5	0.4	0.9	18.5	0.04					0.2Mn, 0.3Si

- ***Coating Deposition and Characterization***

- Analyzed the coating via **XRF** and **SEM-EDX** to measure composition and **cross-sectional uniformity** in the as-plated and post heat treatment orientations

- ***Coating Consolidation and Mixing***

- After plating high temperature anneal

- ***Critical Tests***

- High Temperature Corrosion
- Low Cycle Fatigue (LCF)
 - Plated bar and demonstrated coating

Experimental setup and Materials

- Substrate
 - IN718 Tubes
- Base electrolyte components
 - NiSO_4 , CoSO_4 , $5\text{ }\mu\text{m}$ CrAlY powder
- Designed and built reactor

Materials (CrAlY & Cr powders)

- 5 μm [Cr, 29-31% Al, 1.4-2% Y, 0.4% max O, 0.3% max Fe, 0.1% max Si, 0.06% max C, 0.05% max N] powder from Sandvik

Mean:	4.376 μm	S.D.:	1.685		
Median:	4.659 μm	Variance:	2.839		
Mode:	4.878 μm	Skewness:	-1.259 Left skewed		
Specific Surf. Area:	16,367 cm^2/mL	Kurtosis:	3.019 Leptokurtic		
d ₁₀ :	2.389 μm	d ₅₀ :	4.659 μm	d ₉₀ :	7.892 μm
<10%	<25%	<50%	<75%	<90%	
2.389 μm	3.319 μm	4.659 μm	6.318 μm	7.892 μm	

Coating Compositional Development

- Substrate and Materials

- Inconel 718 and Nimonic 105 disc samples (~16 mm in diameter and 2 mm thick)
- CrAlY powder
- Ni/Co electrolyte containing 100 g/L powder
- Heat treatment: 6h at 1000°C

- Analysis

- The NiCoCrAlY coating appears very uniform
- EDS analysis indicates the coatings contain approximately 8-10 wt.% Al and 12-15 wt.% Cr after heat treatment.

Alloy	Note	Cr	Co	Mo	W	Ta	Nb	Al	Ti	Fe	C	B	Zr	Re	Hf	Others
Inconel 718	wrought	18.6		3.1			5	0.4	0.9	18.5	0.04					0.2Mn, 0.3Si
Nimonic 105	wrought	14.5	20	5					1.2	4.5		0.2				

Experiment – Tank Trials (CrAlY powder)

- Plated up to 12 wt% CrAlY powder within the NiCo (78% Ni/ 10% Co) matrix
- pH control is crucial for a uniform and adherent coatings

Effect of CrAlY Concentration

Effect of pH

Cross Section (CrAlY powder)

Effect of pH on the coating before annealing

Effect of coating thickness

Coating Separation due to pH

Effect of plating waveform

Annealing Development

- Annealing Treatment (Using Tube Furnace at TTU)
 - 8 h at 760°C in Ar performed on LCF bars
 - 6 h at 800, 850 and 1000°C in vacuum
 - Found a **minimum of 850°C** required to fully anneal

800°C for 6 h

850°C for 6 h

Corrosion Testing

- Oxidation trials at 800°C in air (after 3 100-h)
- All specimens showed very low mass gains after oxidation (0.1-0.32 mg/cm²)

IN 718 Uncoated

IN 718 with NiCoCrAlY Coating

Corrosion Testing

- 50h at 760°C in static air ; 55% Na₂SO₄-45% MgSO₄, Salt deposit: 2.6-2.7 mg/cm²

IN718 Uncoated

Cr₂O₃ (with Ti)

IN718 with NiCoCrAlY Coating

Cr-Al-O

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Corrosion Testing

- 50h at 760°C in static air ; 55% Na₂SO₄-45% MgSO₄, Salt deposit: 2.6-2.7 mg/cm²

NM105 Uncoated

Mass change: -2.244 mg/cm²

NM105 with NiCoCrAlY Coating

Mass change: -2.296 mg/cm²

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LCF Bar plating

As Plated

Post Annealed
@ 760°C 8 h

Cross Section SEM-EDX

760 °C 8h Heat Treatment is not sufficient to fully anneal

Scale up Design

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Summary

- Designed, built, and optimized a scalable electrochemical codeposition system
- Demonstrated the potential to achieve 30 vol% CrAlY inclusions within the NiCo
- Optimized annealing protocols to dissolve CrAlY particle into NiCo matrix
- Identified potential elemental additions of Hf, Si, and Cr could improve hot corrosion resistance
- Demonstrated the potential to improve both hot and accelerated corrosion resistance
- Uniformly coated and annealed conventional low cycle fatigue (LCF) bars
- Designed tooling to enable uniform coating on conventional turbine disk teeth

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**THANK YOU FOR YOUR ATTENTION!
QUESTIONS?**

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