Characterization of Cold Sprayed CuCrAl-Coated and Uncoated GRCop-84 Substrates for Space Launch Vehicles

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Abstract

A newly developed Cu-23(wt.%)-Cr-5%Al (CuCrAl) alloy is currently being considered as a protective coating for GRCop-84 (Cu-8(at.%)-Cr-4%Nb). The coating was deposited on GRCop-84 substrates by the cold spray deposition technique. Cyclic oxidation tests conducted in air on both coated and uncoated substrates between 773 and 1073 K revealed that the coating remained intact and protected the substrate up to 1073 K. No significant weight loss of the coated specimens were observed at 773 and 873 K even after a cumulative cyclic time of 500 h. In contrast, the uncoated substrate lost as much as 80% of its original weight under similar test conditions. Low cycle fatigue tests revealed that the fatigue lives of thinly coated GRCop-84 specimens were similar to the uncoated specimens within the limits of experimental scatter. It is concluded that the cold sprayed CuCrAl coating is suitable for protecting GRCop-84 substrates.
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@ Retired # Deceased

TMS Annual Meeting, Orlando, FL
Schematic of a LH₂/LOX Rocket Engine

Operating Environment

- **Combustion flame** - 2760 to 3315°C (5000 to 6000°F)
- **Cooling channel** - Cryogenic hydrogen (LH₂) (-253°C)
- **Heat Flux** - Typically 40 MW/m² or greater heat flux
- **Environment** - Reducing (overall) but locally oxidizing
“Dog House” Failure of Combustion Chamber Liners

- Failure of the liner occurs by a complex combination of creep, low cycle fatigue, thermal ratcheting and environmental interaction ("blanching")

- Flame Temp: > 3000°C
- Heat flux: > 40 MW/m²
- LH₂ Temp.: -253°C
- 1 mm

Diagram showing a Copper Alloy Thrust Chamber with images of cooling channel and hot wall.
GRCop-84 (Cu-8%Cr-4%Nb) Microstructures and Potential Applications

- Excellent mechanical properties
- Good oxidation resistance relative to most commercial copper alloys

Reusable Launch Vehicles (RLVs) - Combustor liners and nozzles

Microstructure of Extruded GRCop-84

10 μm

Courtesy Dr. D. Ellis, GRC
Oxide Scale Spallation in Cyclically Oxidized GRCop-84 in Air at 773 K After 1000 Cycles

- GRCop-84 forms a non-adherent oxide scale which limits engine operating temperatures and complicates engine design.

Optical Micrograph

Back Scattered Electron Image

30 minutes at temperature followed by a 5 minute cool down.
<table>
<thead>
<tr>
<th>Material</th>
<th>Cu-26%Cr (Rocketdyne – NASP)</th>
<th>Cu-23%Cr-5%Al (NASA – Third Generation Reusable Launch Vehicle)</th>
<th>NiAl (Aeronautics)</th>
<th>NiCrAlY (Aeronautics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRCop-84 (Substrate)</td>
<td>315</td>
<td>285</td>
<td>170</td>
<td>55</td>
</tr>
<tr>
<td>NiCrAlY (Aeronautics)</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Material**: GRCop-84 (Substrate)
- **Cu-26%Cr (Rocketdyne – NASP)**
- **Cu-23%Cr-5%Al (NASA – Third Generation Reusable Launch Vehicle)**
- **NiAl (Aeronautics)**
- **NiCrAlY (Aeronautics)**
Objectives

Preliminary evaluation of the thermal cyclic and low cycle fatigue behavior of newly developed Cu-23%Cr-5%Al overlay coatings for GRCop-84 substrates
Powder Particle Size Distribution

Frequency (%)

Particle diameter (μm)

Cu-23%Cr-5%Al Gas Atomized Powder

Particles 30 to 90 μm
Cold Spray Process

Substrate motion during spraying

de Laval spray nozzle

Gas jet with sprayed particles

Coating

Powder hopper

Gas heater

Preheated pressurized working gas

Carrier He gas

Pressurized He gas
- Dense coatings generally free of cracks and voids
Processing Defects

- Embedded grit particles were commonly observed.
- Cracks and porosity in the coating were observed in some instances.
- Non-uniform coating thickness (e.g. LCF specimens).

CuCrAl

GRCop-84
Thermal Cycling of Cold-Sprayed CuCrAl Coated and Uncoated GRCop-84 Specimens in Air at 773 K

- 30 minutes at temperature followed by a 5 minute natural cool down
Thermal Cycling of Cold-Sprayed CuCrAl Coated and Uncoated GRCop-84 Specimens in Air at 973 K

- 30 minutes at temperature followed by a 5 minute natural cool down

![Graph showing weight change over time for GRCop-84 and CuCrAl-coated GRCop-84 specimens.]

- 70% weight change at T = 973 K

- 150 cycles and 1000 cycles shown with corresponding images.

Advanced RLV Shuttle
Cross-Sectional Microstructures

- Cu$_2$O & CuO
- T = 773 K
- 1000 cycles
- GRCop-84

- CuCrAl
- T = 773 K
- 1000 cycles
- GRCop-84

- Cu$_2$O & CuO
- T = 873 K
- 500 cycles
- GRCop-84

- CuCrAl
- T = 973 K
- 1000 cycles
- GRCop-84

100 µm, 1250 µm, 40 µm
X-ray dot maps of oxidized Cu-23%Cr-5%Al coating

Cycled at 773 K for 1000 cycles
Low Cycle Fatigue Properties of Coated and Uncoated Extruded GRCop-84

- Coated specimens exhibit either comparable or lower fatigue lives than uncoated specimens within factors of 2 to 5.
- LCF life appears to decrease with increasing coating thickness.
Fractograph of a CuCrAl-Coated GRCop-84 LCF Specimen

Test conditions:
- Specimen: 2T-10
- Air, 300 K
- Coating thickness = 100 μm
- Strain range = 1.2%
- Life = 910 cycles

3.2 mm
Fractograph of a CuCrAl-Coated GRCop-84 LCF Specimen

Test conditions
Specimen: 2T-15
Coating thickness = 55 μm
Strain range = 0.7%
Life = 2042 cycles

- No coating delamination was observed in the observed specimens
- All cracks initiated either at the free surface or in the GRCop-84 matrix
Fractographs of a CuCrAl-Coated GRCop-84 LCF Specimen

**Test conditions**
- **Specimen**: 2T-3
- **Coating thickness** = 685 μm
- **Air, 300 K**
- **Strain range** = 1.2%
- **Life** = 178 cycles
Summary and Conclusions

- A new CuCrAl coating alloy was successfully cold spray deposited on GRCop-84 substrates.
- Thermal cyclic tests were conducted between 773 and 973 K
  - Coated specimens exhibited negligible loss in weight compared to the uncoated specimens
- Low cycle fatigue (LCF) tests were conducted between 300 and 873 K
  - Fatigue lives of the coated specimens were comparable to the uncoated specimens within the limits of experimental scatter
  - No coating delamination.