

Development of GRCop-84 for Rocket Engine Applications

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GRCop-84 (Cu-8 at.% Cr-4 at.% Nb) has been under development at the NASA Glenn Research Center for several years. The alloy possesses a unique combination of good thermal conductivity, high elevated temperature strength, long creep lives and long low cycle fatigue lives. The alloy is also more oxidation resistant than pure copper and most competitive alloys. The combination of properties has attracted attention from major rocket engine manufacturers who are interested in the alloy for the combustion chamber liner in their next generation of regeneratively cooled engines. It is also a strong candidate for various components in hypersonic vehicles, which also experience very high heat flux conditions. This presentation will discuss the alloy design strategies used to develop GRCop-84 and the various processing routes available for manufacturing components. The microstructure and mechanical properties of the alloy will be reviewed, as well as the results of actual hot fire testing of subscale rocket combustion chambers. The use of environmental and thermal barrier coatings to extend the performance to even higher levels will also be discussed.

Keywords: GRCop-84; copper; rocket engines; high conductivity;

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Development of GRCop-84 for Rocket Engine Applications

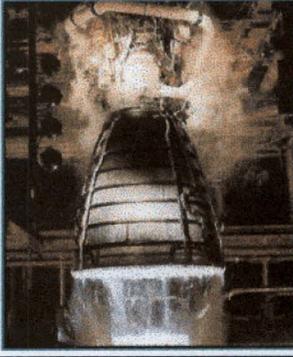
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Composites At Lake Louise
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Space Shuttle Main Engine



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“Dog House” Cooling Channel Failure



- During operation the hot wall over a cooling channel will bulge outwards until thinning and pressure results in crack
- Caused by combination of creep from thermally induced stresses and thermal ratcheting
- **Blanching exacerbates problem**
 - Blanching caused by rapid cycling between oxidizing and reducing environments
 - Results in development of low conductivity copper “sponge” on hot wall
 - Low thermal conductivity gives rise to hot spots

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General Design Requirements For Regeneratively Cooled Rocket Engine Liners

- **Engine conditions**
 - Cold side – Cryogenic hydrogen to -253°C (-423°F)
 - Hot side – Hydrogen-oxygen flame to 3315°C (6000°F)
 - Heat flux - $\gg 1 \text{ MW/m}^2$
 - Chamber pressure – Up to 34.5 MPa (5,000 psi)
 - Coolant pressure – Up to 48.3 MPa (7,000 psi)
 - Wall thickness - $\leq 1 \text{ mm}$ (0.040")
 - Anticipated hot wall temperature – 300°C to 700°C (572°F to 1292°F)
- **Thermophysical properties**
 - High thermal conductivity to minimize thermal gradient
 - Low thermal expansion to minimize thermally induced stress
- **Mechanical properties**
 - High elevated temperature strength for pressure
 - Long creep lives/high creep strength for long life
 - Long LCF lives for long life

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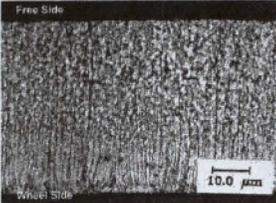
Cu-Cr-Nb Alloy System

- **Cu as base for high conductivity**
 - Second highest thermal conductivity (~400 W/mK)
 - Second highest melting point (1085°C)
- **Cr and Nb for strengthening**
 - Forms Cr₂Nb
 - High melting point Laves phase
 - Very hard precipitate / particle
 - Minimal solid solubility to retain conductivity
 - Very high liquid solubility to allow powder metallurgy (P/M) processing
 - Maximize volume fraction
 - Attempted unsuccessfully to form highly supersaturated solid solution

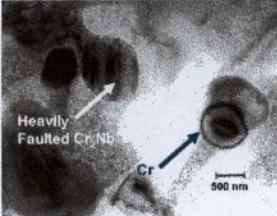
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Chill Block Melt Spun Cu-Cr-Nb Ribbons



Through thickness microstructure



TEM micrograph showing precipitates

Despite cooling rates >10⁶ K/s and solidification rates >10 m/s, precipitates form in the ribbon during cooling

- Observations indicate Cr₂Nb precipitates in liquid copper as soon as cooling begins

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Implication

While GRCop-84 is produced and processed like other conventional P/M monolithic copper alloys, it is a particulate reinforced copper metal matrix composite with 14 volume percent of submicron Cr₂Nb particles

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Production Of GRCop-84 And Rocket Engine Components

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GRCo-84 Powder Production

Rotary Lined 50 lb. (23 kg) Vacuum Induction Furnace

Cyclone Separator

Powder Collection Canister

Graphite Hopper

Tundish for Powder Atomization, or MGS Location for Small Ingots

Inert Gas (20-25 kg) Hot Atomization Die

Cooling Tower All Interior Surfaces and Polished Stainless Steel

Cumulative Frequency

Powder Particle Diameter (µm)

CRNiCo

20 µm

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Vacuum Plasma Spraying (VPS)

As-sprayed liner

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Hot Isostatic Pressing (HIPing)

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Extrusion

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Rolling

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Platelet Technology

Stacking Etched Platelets

Diffusion-Bonded Panels With and Without Stainless Steel Blanch Shield on Hot Gas Wall.

Cold-Formed Panels

Uniform Water Flow Yields Functional Internal Channels

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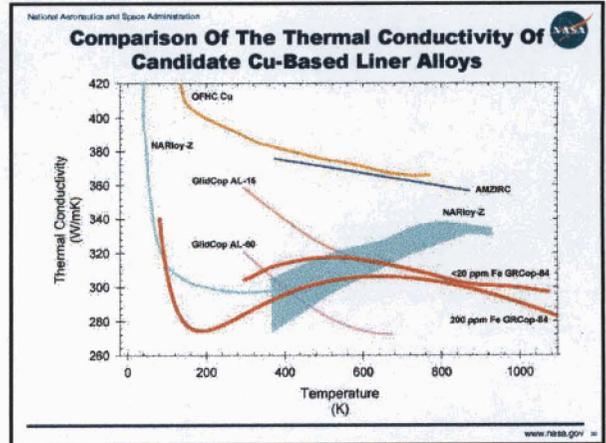
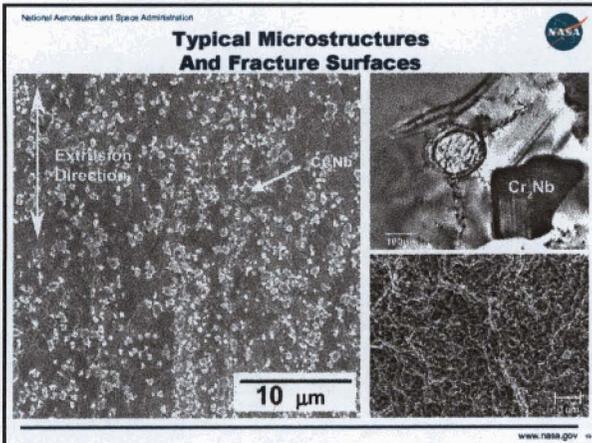
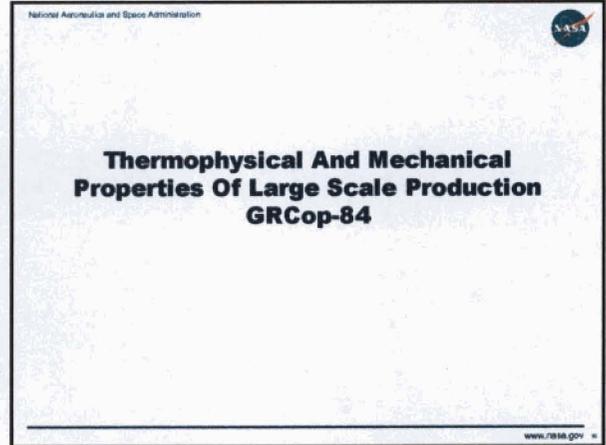
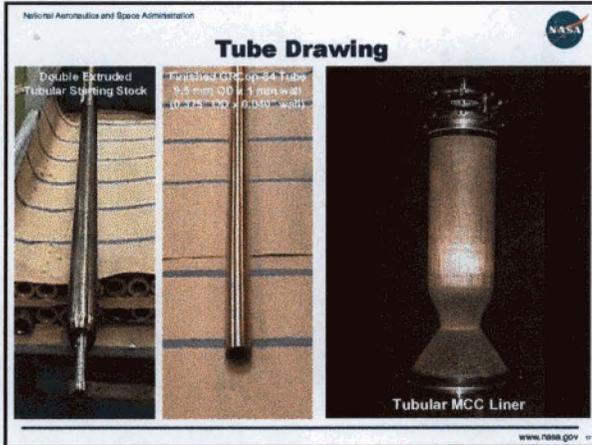
Stamping / Forming

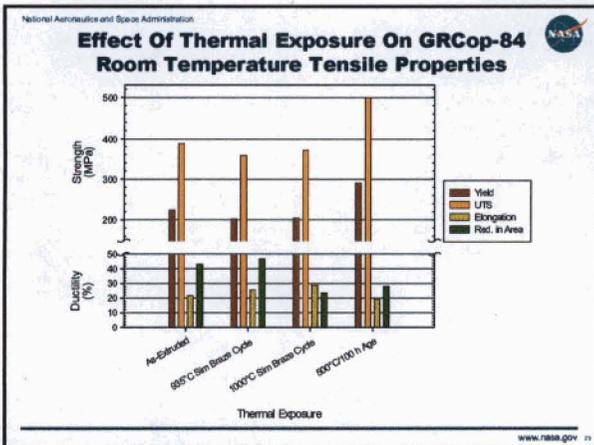
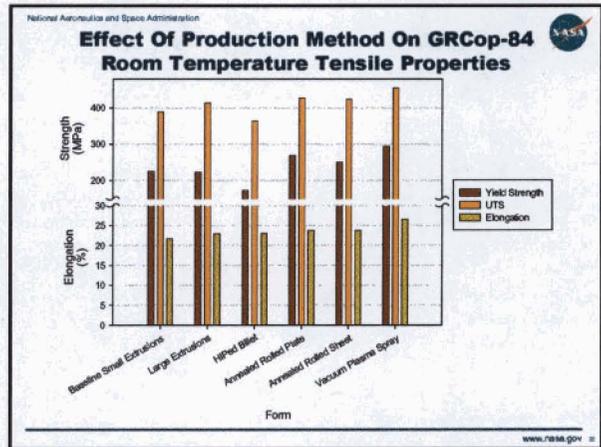
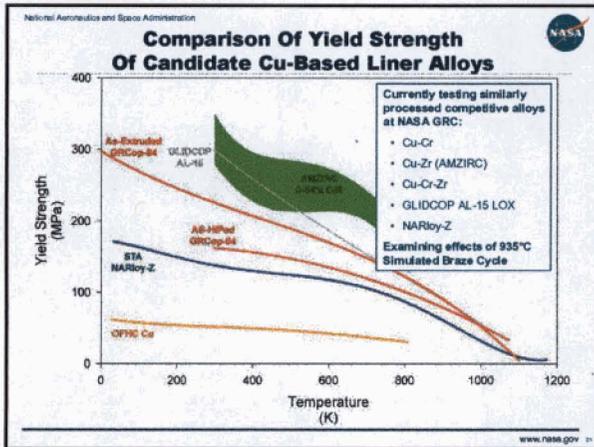
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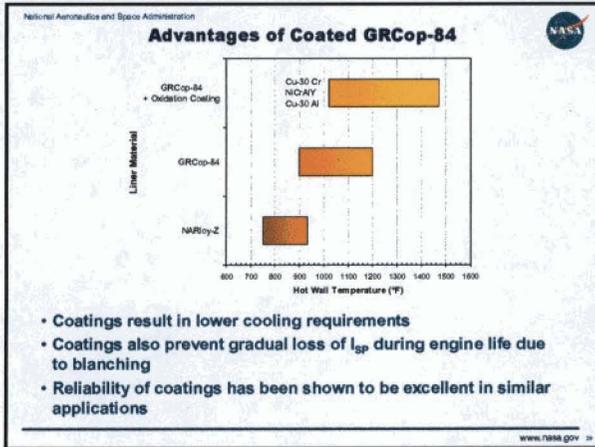
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Metal Spinning

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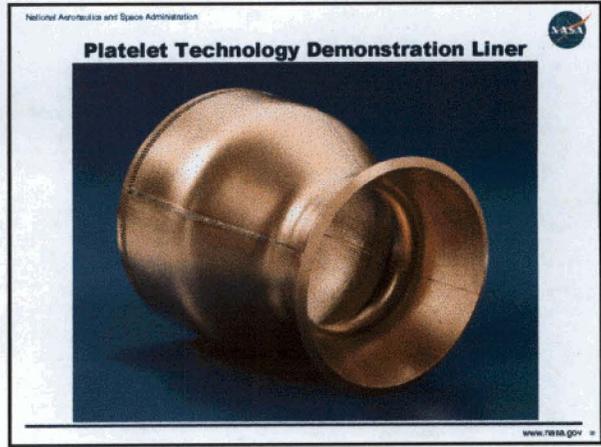


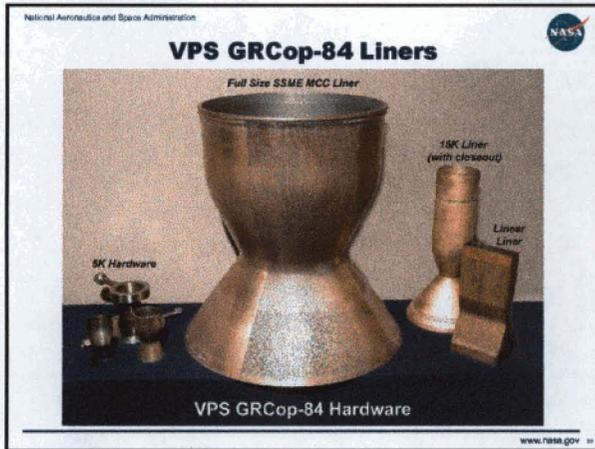


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GRCop-84 Main Combustion Chamber Liners

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Hot Fire Testing Of 5,000 lb, Thrust Cell

- VPS GRCoP-84 liner with a NiCrAlY coating on the hot wall
- Liquid oxygen – gaseous hydrogen combination used for all testing
- Testing includes several tests at O:F ratios of 8
 - Stoichiometric burning
 - Would destroy uncoated NARloy-Z liner in seconds
- Two injectors have failed and sent parts through liner during firing
- To date no damage or degradation to liner observed in 150 firings

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Summary

- GRCoP-84 has property advantages over existing alloys used in high heat flux applications such as rocket engines.
- GRCoP-84 has a suite of supporting technologies available for manufacturing into actual components.
- GRCoP-84 has demonstrated exceptional performance under the severe conditions of ground-based rocket hot fire testing.

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