Fabrication of GRCop-84 Rocket Thrust Chambers

William S. Loewenthal\textsuperscript{1} and David L. Ellis\textsuperscript{2}

\textsuperscript{1} Ohio Aerospace Institute, NASA Glenn Research Center, MS 49-1, Cleveland OH 441335
\textsuperscript{2} NASA Glenn Research Center, MS 49-1, Cleveland OH 441335
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Abstract

GRCop-84, a copper alloy, Cu-8 at% Cr-4 at% Nb developed at NASA Glenn Research Center for regeneratively cooled rocket engine liners has excellent combinations of elevated temperature strength, creep resistance, thermal conductivity and low cycle fatigue. GRCop-84 is produced from pre-alloyed atomized powder and has been fabricated into plate, sheet and tube forms as well as near net shapes. Fabrication processes to produce demonstration rocket combustion chambers will be presented and includes powder production, extruding, rolling, forming, friction stir welding, and metal spinning. GRCop-84 has excellent workability and can be readily fabricated into complex components using conventional powder and wrought metallurgy processes. Rolling was examined in detail for process sensitivity at various levels of total reduction, rolling speed and rolling temperature representing extremes of commercial processing conditions. Results indicate that process conditions can range over reasonable levels without any negative impact to properties.
Fabrication of GRCop-84 Rocket Thrust Chambers

Outline
- Rocket Thrust Chambers
- GRCop-84 Properties
- Thrust Chamber Fabrication Steps
- Conclusions
Rocket Thrust Chambers

Combustion Chamber

Shuttle Main Engine

Liquid Propellant Rocket Engine

GRCop-84 Liner

Ref: www.islandone.org/LEOBiblioSPBI101.HTM
Why GRCop-84 for Rocket Thrust Chambers?

**GRCop-84** (Cu-6.5 Cr 5.8 Nb)
Stable dispersion of Cr$_2$Nb

**Competitive Alloys**
- OFHC Cu (Cu) - Can be work hardened
- AMZIRC (Cu-0.15Zr) - Precipitation and work hardened alloy
- GLIDCOP (Cu-0.15 to 0.60 Al2O3) Dispersion strengthened alloys
- NARloy-Z (Cu-3 Ag-0.5 Zr) - Precipitation strengthened alloy, Current Space Shuttle Main Engine (SSME) liner material

![Typical rolled microstructure](image)

![Excellent elevated temp strength](image)

Retains strength after 935°C (1715°F) simulated braze cycle

Superior creep strength
# Major Fabricating Steps
## Rocket Thrust Chamber

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Production Of GRCop-84 Powder
(Crucible Research, Pittsburgh, PA)

- Laboratory Gas Atomizer
  50 pound capacity

- Pilot Gas Atomizer
  300 pound capacity

- Typical Powder
  -140 mesh (<106 μm)
  Average diameter 35-40 μm
Canning and Extrusion
(Crucible Research, Pittsburgh, PA and HC Starck, Coldwater, MI)

15.1” Diameter Copper Can
800-1,200 pounds
of GRCop-84 powder

Hot Extrusion
2.9” x 9.9”

GRCop-84 can be extruded at low (7:1) to high (60:1) reductions in area
Billet Sawing, Flattening and Decaning
(Lunar Tool and Mold, Cleveland, OH)

As-extruded with copper can

After Milling top and bottom surfaces to remove copper can
Plate Rolling
(HC Starck, Euclid, OH)

GRCop-84 can be warm rolled or cold rolled. Cold reductions to 90% demonstrated.

GRCop-84 Plate
Rolled to approximately 0.525” x 20” x 54”
Each plate makes 1.5 to 2 liners

After rolling, annealing and cleaning

Entering rolling mill
Half Cylinder Forming
(Spin Tech, Paso Robles, CA)

Forming plate into a half cylinder

GRCop-84 Half Cylinders
Nominally 5.5” id x 18” long
Friction Stir Welding
(NASA Marshall Space Flight Center, Huntsville, AL)

- Solid state process – does not melt base metal
  - Frictional heating from rotating pin locally plasticizes material at the joint
  - Applied load reacted by an anvil forges the material creating a weld
  - Three process parameters – rotation, load, and travel

GRCop-84 cylinder weld tooling

Pin tool design and material selected for specific application

Photos courtesy of NASA MSFC
Metal Spinning
(Spin Tech, Paso Robles, CA)

Hot metal spinning over shaped mandrel

Liners were annealed to relieve residual stresses

Photos courtesy of Spin Tech

Glenn Research Center at Lewis Field
Machining, Plasma Spray Coating
(Starwin Industries, Dayton, OH and Plasma Processes, Huntsville, AL)

Coated Cu demonstration liners
(Cu-8Cr-1Al bond coat, NiCrAlY top coat)

Machined preform

Completed liner assembly.

Closeout applied and machined

Completed machined liner
Effect of Processing on Room Temperature Tensile Properties

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<tr>
<th>Treatment</th>
<th>Yield Strength (MPa)</th>
<th>UTS (MPa)</th>
<th>Elongation (%)</th>
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<td>Baseline Specimen</td>
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<td>Large Extrusions</td>
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<td>HIPed Billet</td>
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<td>Vacuum Plasma</td>
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Hot Fire Testing
(NASA Marshall Space Flight Center, Huntsville, AL)

GRCop-84 Hot Fire Test
NASA MSFC produced 5,000 pound thrust cell with GRCop-84 liner/NiCrAlY FGM

108 hot fire tests conducted at O:F from 6:1 to 8:1
Two injectors failed during testing
No visible signs of degradation
Uncoated NARloy-Z liners tested earlier showed cracking and other problems
Conclusions

- GRCop-84 has a good combination of mechanical properties making it well suited for rocket thrust chambers.
- GRCop-84 can be readily formed, joined and machined using conventional techniques for copper-based alloys.
- GRCop-84 fabrication processes can be easily scaled to produce large components.
- GRCop-84 can be fabricated into other high temperature, high heat flux components besides rocket engine liners.