Fabrication of GRCop-84 Rocket Thrust Chambers

by

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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.
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Outline

• Rocket Thrust Chambers
• GRCop 84 Properties
• Thrust Chamber Fabrication Steps
• Warm Rolling Optimization
• Conclusions
Rocket Thrust Chambers

Combustion Chamber

Regen Cool Rocket Engine

GRCop-84 Liner

Shuttle Main Engine

Ref: www.islandone.org/LEOBiblio/SPBI101.HTM

Glenn Research Center at Lewis Field
Why GRCop84 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**

- **20 μm**

**Excellent elevated temp strength**
- Retains strength after 935°C (1715°F) simulated braze cycle

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

### Demonstrated Processes
1. Powder Production
2. Canning
3. Extrusion
4. De-can and Billet Prep
5. Roll/Anneal/Clean
6. Form Half Cylinders
7. Friction Stir Weld
8. Metal Spin
9. Anneal
10. Machine ID, rough OD
11. Coat Liner w/ NiCrAlY and HIP
12. Machine ID + OD Cooling Channels

### Future Work
2006
13. Closeout (Ni) and Machine
14. Assemble MSFC Jacket and Manifolds
15. Hot Fire Testing
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 Plate
Rolled to approximately 0.525” x 20” x 54”
Each plate makes 1.5 to 2 liners

After rolling, annealing and cleaning

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

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 Welded Cylinder

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

Photos courtesy of Spin Tech

Liners were annealed at 600°C to relieve residual stresses.
Machining, Plasma Spray Coating
(Starwin Industries, Dayton, OH; Plasma Processes Inc., Huntsville, AL)

Machined Preform ready for coating

Coated copper mock-up liner
Coating: Cu-8Cr-1Al Bond coat and NiCrAlY top coat

Finished id

Final machining, closeout and installation into calorimeter hardware for hot fire testing.
Hot Fire Testing

GRCop-84 Hot Fire Test
in GRC Tests Cell 22
MSFC test configuration
will look very similar
Warm Rolling Optimization

Examined the influence of total reduction, rolling speed, rolling temperature and a post-rolling annealing heat treatment of GRCop-84 on mechanical properties. The interrelationships of these variables defines boundaries for a robust commercial rolling process.

**Experimental Design**

- **Rolling Temperature**
  - 215, 300 and 415°C
- **Rolling Reduction**
  - 65, 95 and selected 99%
- **Rolling Speed**
  - 69 and 217 ft/min.
- **Heat Treatment (anneal) after Rolling:**
  - none, 450°C, selected 350 and 250°C

**Block Preparation**

Stock from HC Stark Extrusion Runs #1 and #2

3 Billet ends were cut into small plates

Cuts removed copper extrusion can

Identified per schematic

**Strip Rolling Procedure**

Rolled at HC Stark - Small Lab Mill

Reheat after every roll pass

approx 20 min

Post rolling heat treatment on selected specimens at 250, 350, 450°C

**Test Specimens Per ASTM E8**
Warm Rolling Optimization

**Rolling Temperature**

- Roll Temperature (C)
  - 215 300 415
- Yield Strength (MPa)
  - 50 100 150 200 250 300 350 400 450 500 550 600
- Yield Strength (ksi)
  - 10 20 30 40 50 60 70 80

**Total Reduction**

- Total Reduction (%)
  - 65 95 99
- Yield Strength (MPa)
  - 50 100 150 200 250 300 350 400 450 500 550 600
- Yield Strength (ksi)
  - 10 20 30 40 50 60 70 80

**Rolling Speed**

- Rolling Speed (fpm)
  - 17 69
- Yield Strength (MPa)
  - 50 100 150 200 250 300 350 400 450 500 550 600
- Yield Strength (ksi)
  - 10 20 30 40 50 60 70 80

**Post Rolling Anneal Temperature**

- Post Rolling Anneal Temperature (C)
  - 0 350 450
- Yield Strength (MPa)
  - 50 100 150 200 250 300 350 400 450 500 550 600
- Yield Strength (ksi)
  - 10 20 30 40 50 60 70 80

- GRCop-84
- As-Extruded
Warm Rolling Optimization
Metallography

Roll Temp

Total Reduction

Roll Speed

Sample 1a5c
Roll Temp = 300 C, Total Red = 95 %, Roll Spd = 17 fpm

Sample 1a4c
Roll Temp = 300 C, Total Red = 95 %, Roll Spd = 69 fpm

Sample 3a4b
Roll Temp = 215 C, Total Red = 95 %, Roll Spd = 17 fpm

Sample 3a5b
Roll Temp = 215 C, Total Red = 65 %, Roll Spd = 17 fpm
Summary

Warm Rolling Optimization Conclusions
• For the various levels of total reduction, rolling speed and strip rolling temperature representing boundaries of commercial processing, have slight to no influence on tensile properties.
• No second order effects were noted.
• Results indicate that the process conditions to roll strip for these variables can range over reasonable levels without any negative impact to performance.
• Incorporating broader process ranges in future rolling campaigns should lower commercial strip rolling costs by improving productivity.

Fabrication Summary
• GRCop-84 has a good combination of mechanical properties and exhibits exceptional stability when subjected to high temperature thermal cycles
• GRCop-84 can be easily formed and joined using conventional techniques for copper-based alloys
• GRCop-84 has the potential for many high temperature, high heat flux uses besides rocket engine liners