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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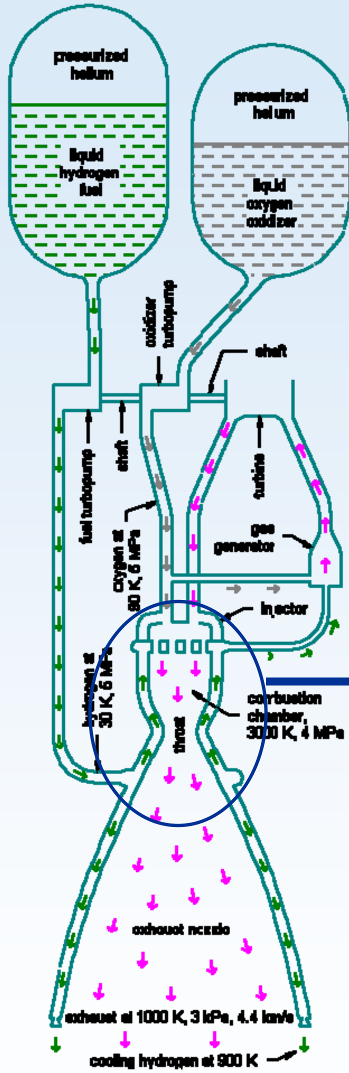
Outline

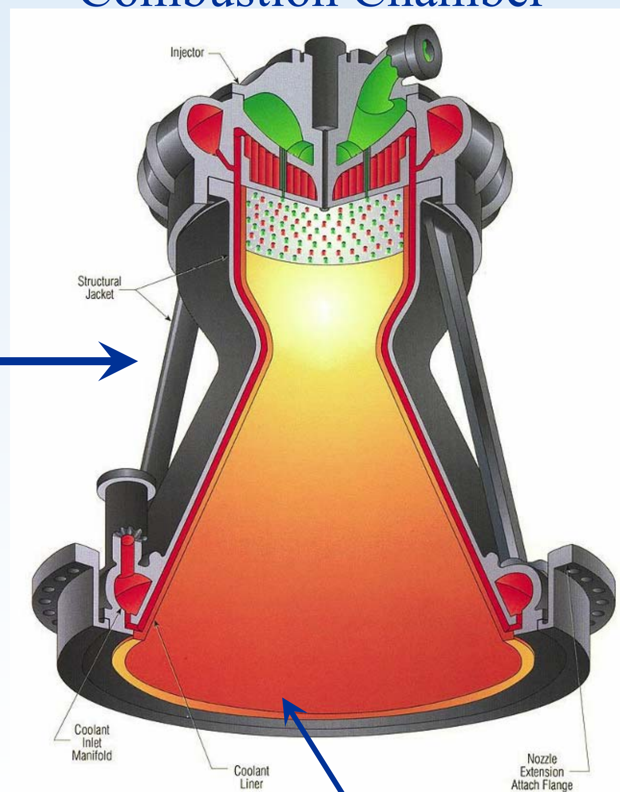
- Rocket Thrust Chambers
- GRCop 84 Properties
- Thrust Chamber Fabrication Steps
- Warm Rolling Optimization
- Conclusions

Rocket Thrust Chambers



Regen Cool Rocket Engine

Combustion Chamber



GRCop-84 Liner

Shuttle Main Engine

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

Why GRCop84 for Rocket Thrust Chambers?

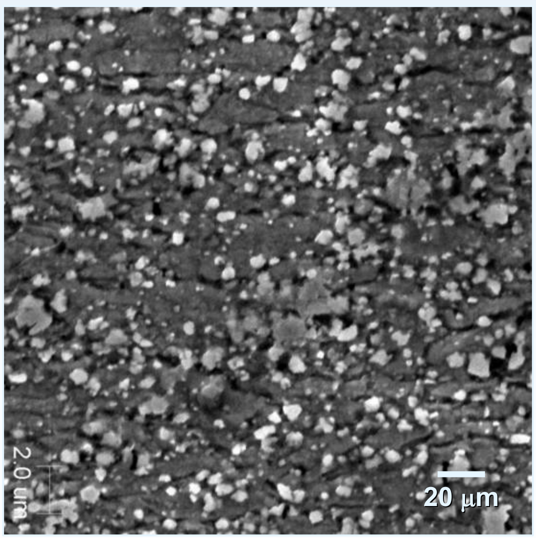
GRCop-84 (Cu-6.5 Cr 5.8 Nb)
Stable dispersion of Cr_2Nb

Competitive Alloys
OFHC Cu (Cu) - Can be work hardened

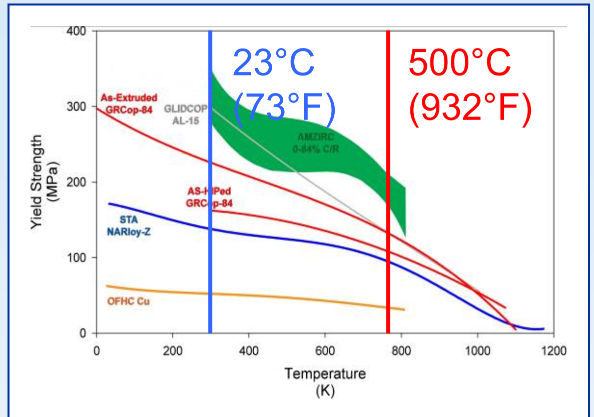
AMZIRC (Cu-0.15Zr) - Precipitation and work hardened alloy

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

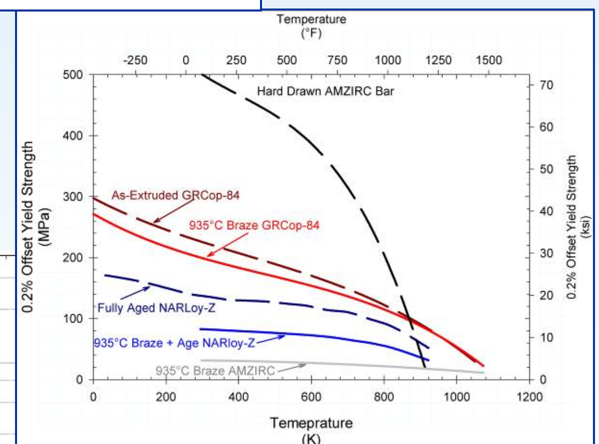


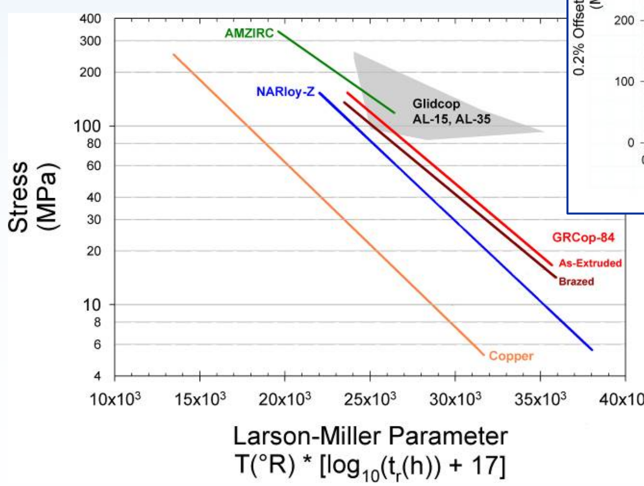
Typical rolled microstructure



Excellent elevated temp strength

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





Superior creep strength

Major Fabricating Steps
Rocket Thrust Chamber

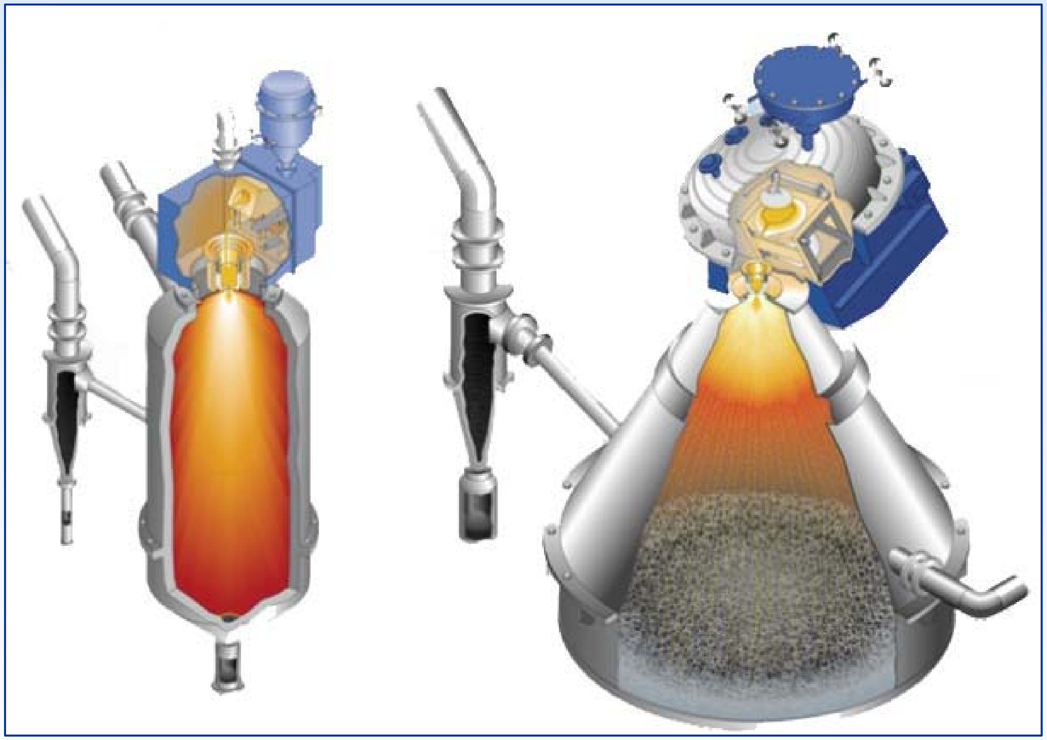
Demonstrated Processes

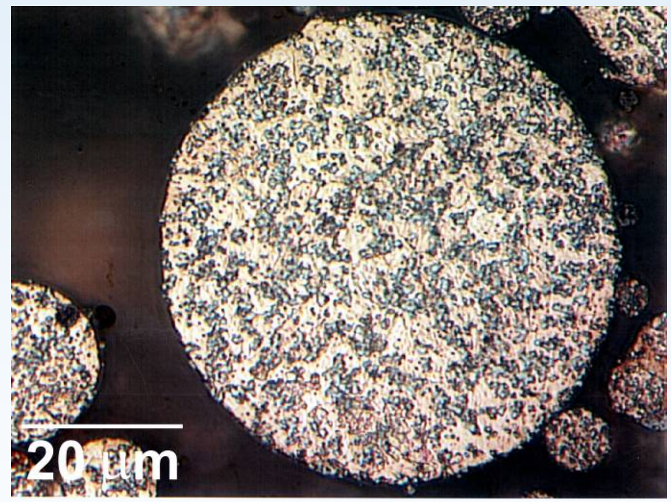
1. Powder Production
2. Canning
3. Extrusion
4. De-can and Billet Prep
5. Roll/Anneal/Clean
6. Form Half Cylinders
7. Friction Stir Weld
8. Metal Spin
9. Anneal
10. Machine ID, rough OD
11. Coat Liner w/ NiCrAlY and HIP
12. Machine ID + OD Cooling Channels

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)

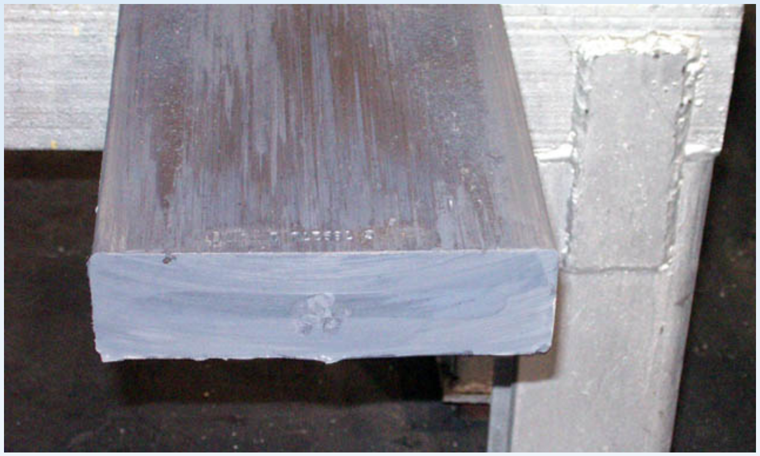
15.1" Diameter Copper Can
800-1,200 pounds
of GRCop-84 powder

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)

After rolling, annealing and cleaning

GRCop-84 can be warm rolled or cold rolled.

Cold reductions to 90% demonstrated.

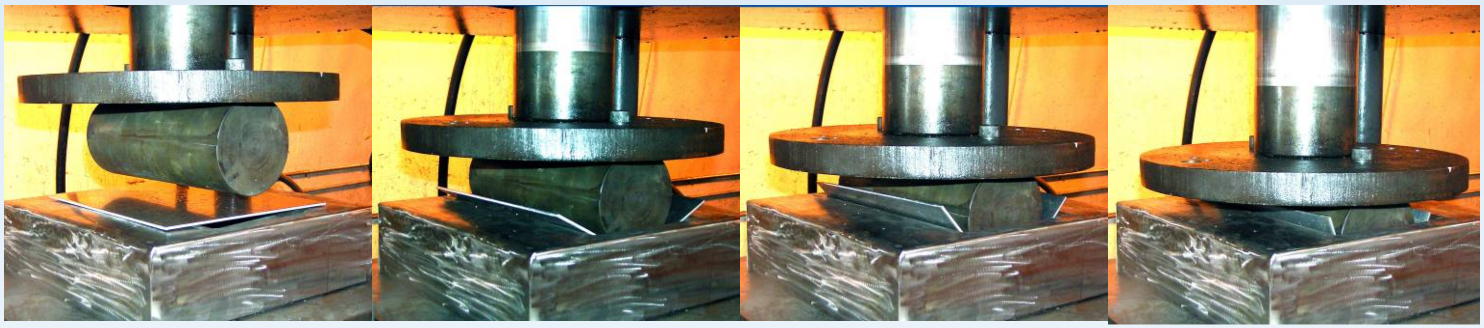
GRCop-84 Plate

Rolled to approximately 0.525” x 20” x 54”

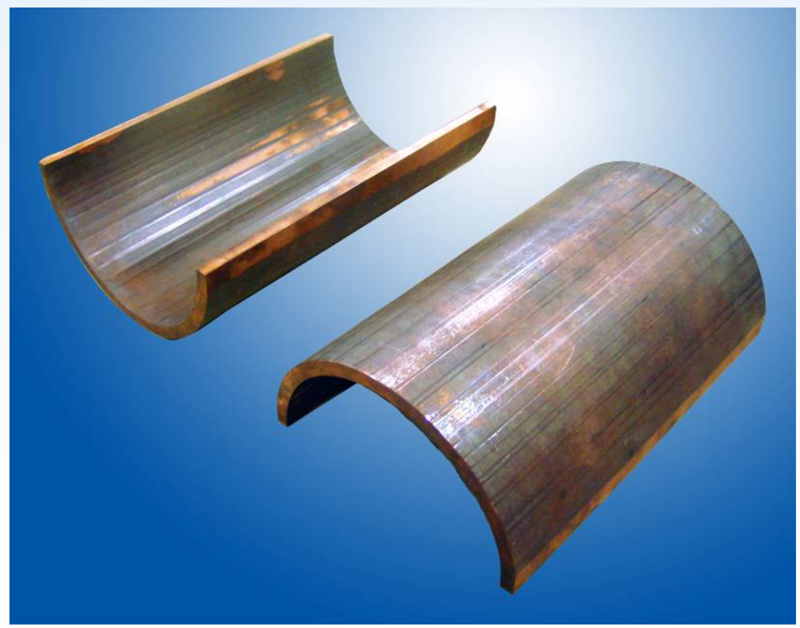
Each plate makes 1.5 to 2 liners

Entering rolling mill

Half Cylinder Forming
(Spin Tech, Paso Robles, CA)

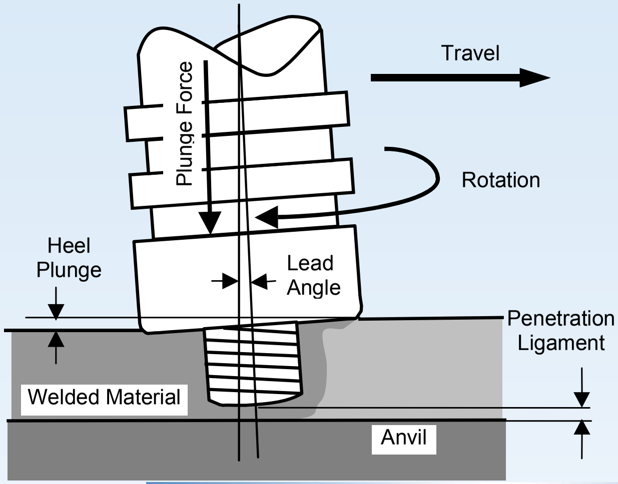


Forming plate into a half cylinder

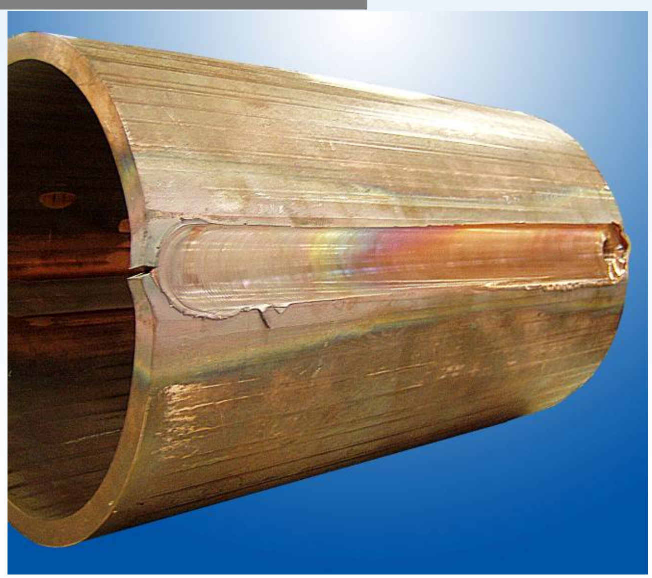


GRCop-84 Half Cylinders
Nominally 5.5” id x 18” long

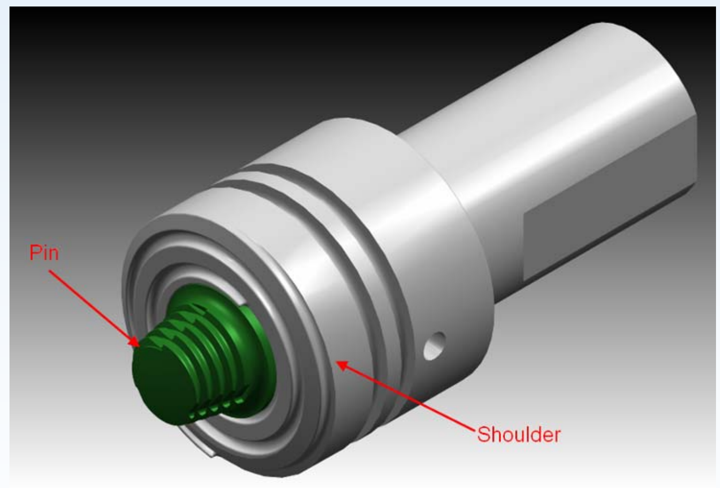
Friction Stir Welding
(NASA Marshall Space Flight Center, Huntsville, AL)



- **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



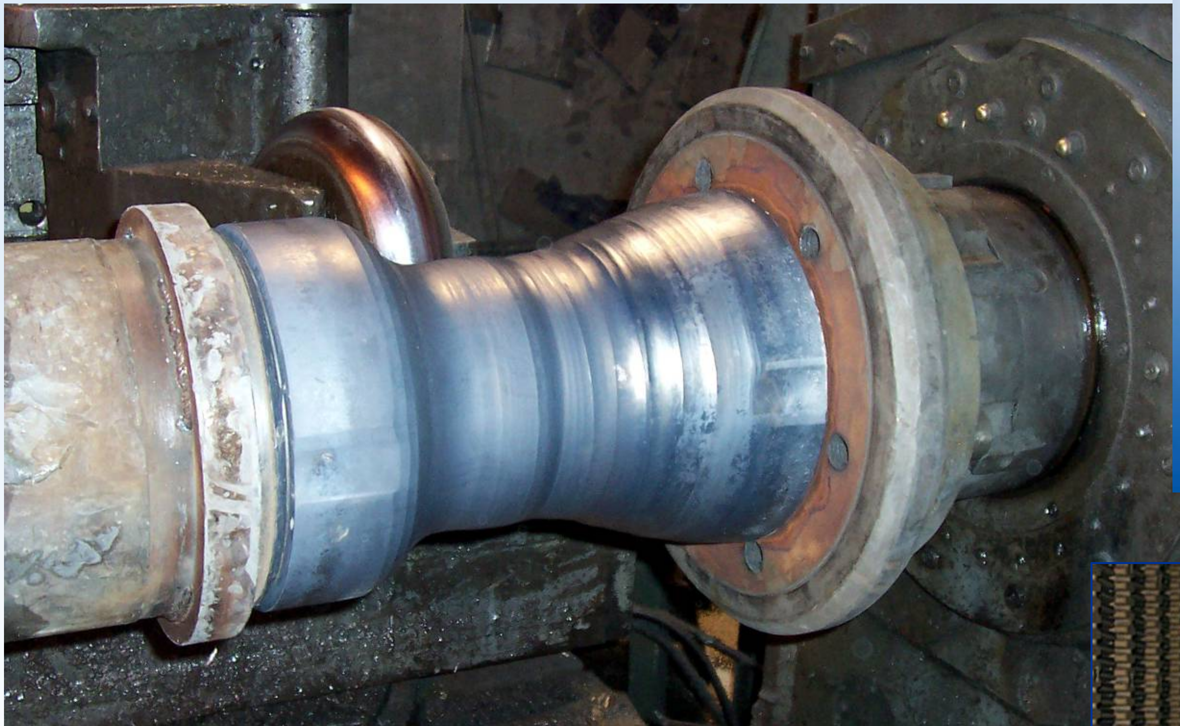
GRCop-84 Welded Cylinder



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

Before and after spinning

Liners were annealed at 600°C
to relieve residual stresses

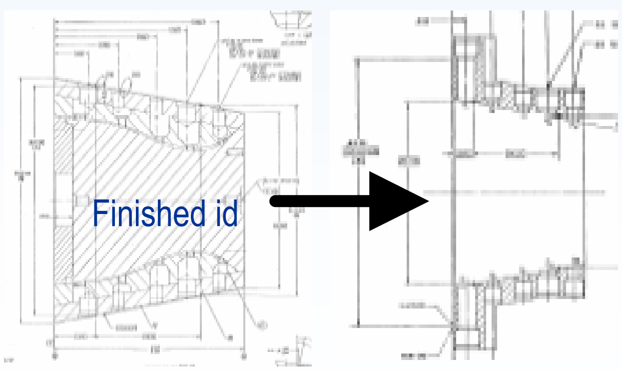
Photos courtesy of Spin Tech

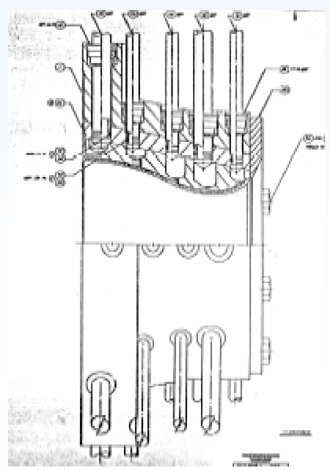
Machining, Plasma Spray Coating

(Starwin Industries, Dayton, OH; Plasma Processes Inc., Huntsville, AL)

Machined Preform ready for coating

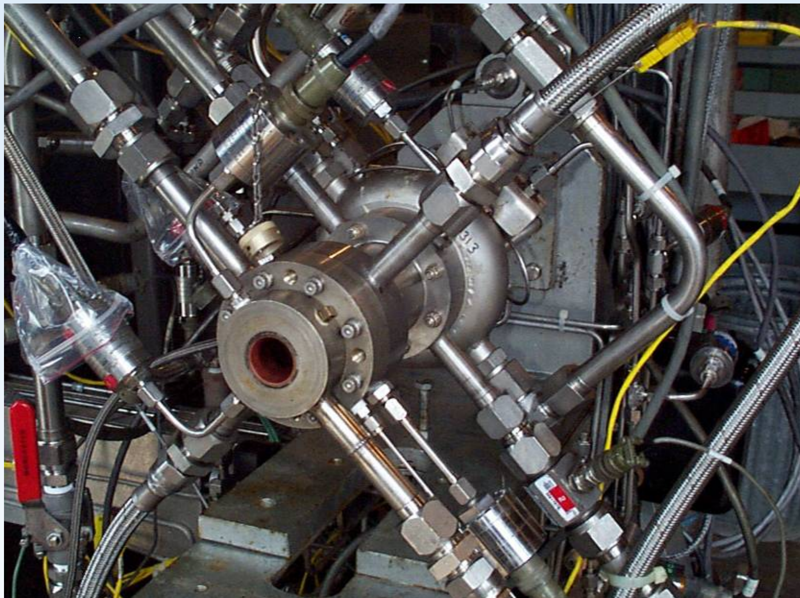
Coated copper mock-up liner
Coating: Cu-8Cr-1Al Bond coat and NiCrAlY top coat



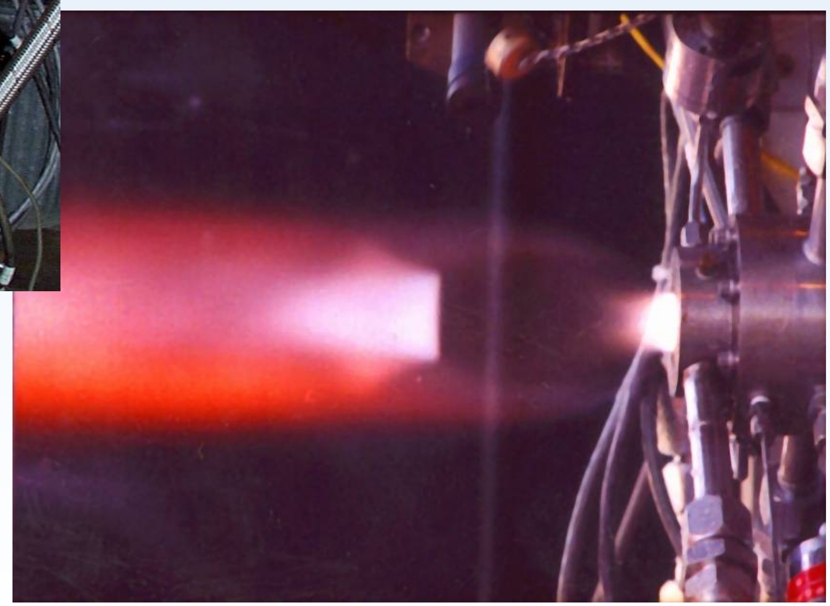


Final machining, closeout and installation into calorimeter hardware for hot fire testing.

Hot Fire Testing
(NASA Marshall Space Flight Center, Huntsville, AL)



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

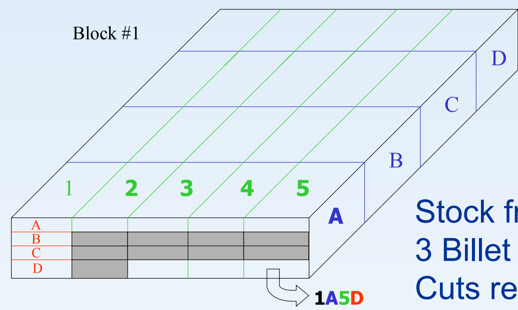


Warm Rolling Optimization

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 f/min.
Heat Treatment (anneal) after Rolling:
none, 450C, selected 350 and 250C

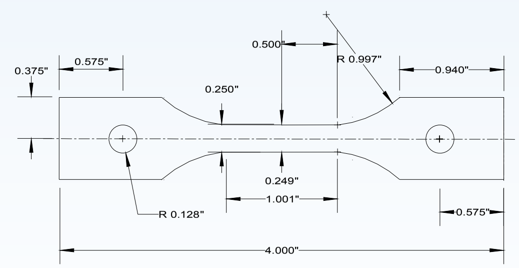


Block Preparation

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

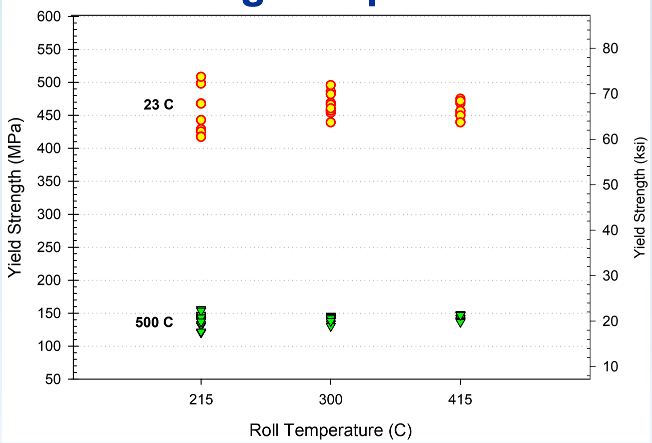
Rolled at HC Stark - Small Lab Mill
Reheat after every roll pass
approx 20 min
Post rolling heat treatment on selected specimens at 250, 350, 450 C



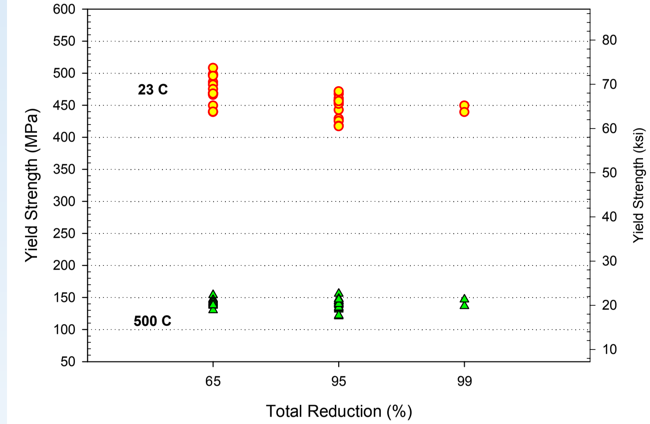
Test Specimens Per ASTM E8

Warm Rolling Optimization

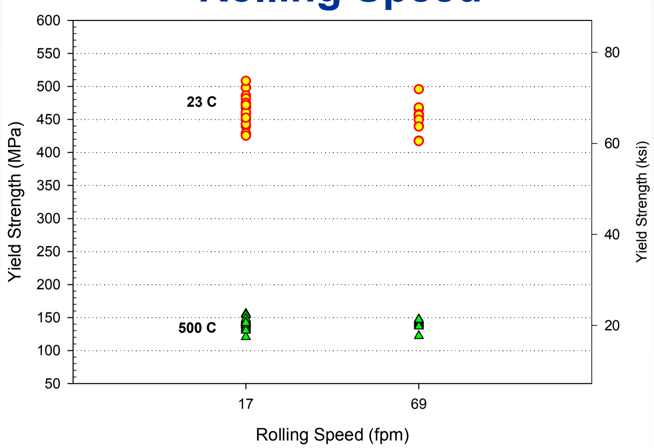
Rolling Temperature



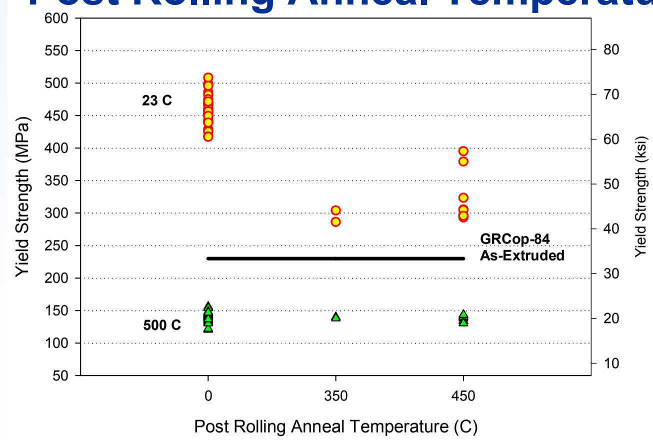
Total Reduction



Rolling Speed



Post Rolling Anneal Temperature



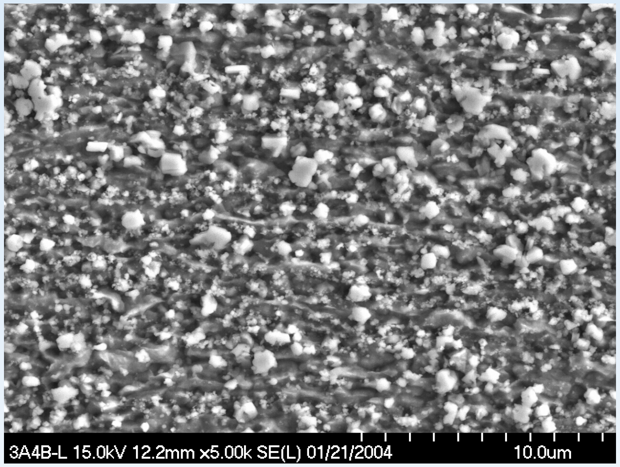
Warm Rolling Optimization

Metallography

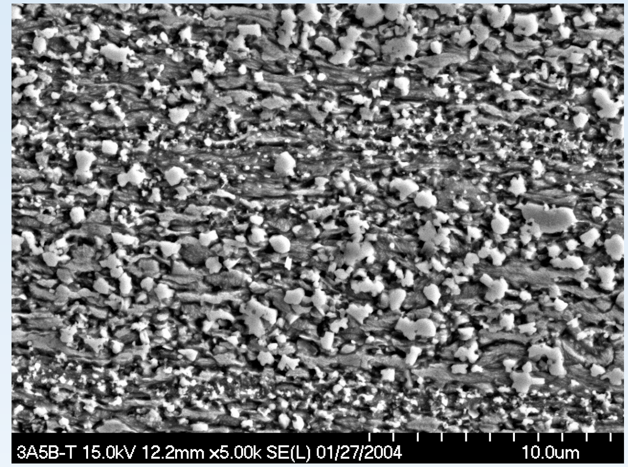
Roll Temp

Total Reduction

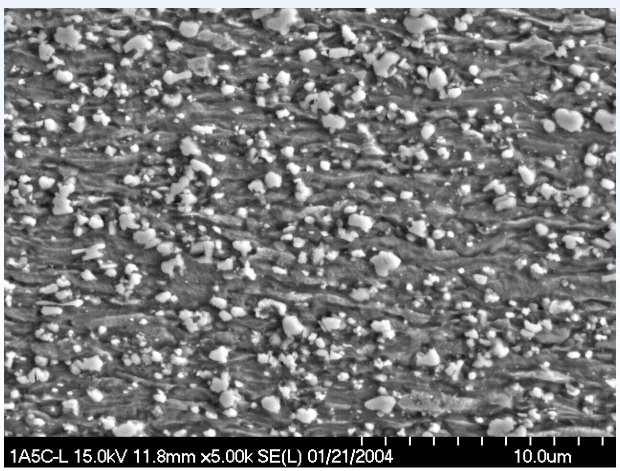
Roll Speed



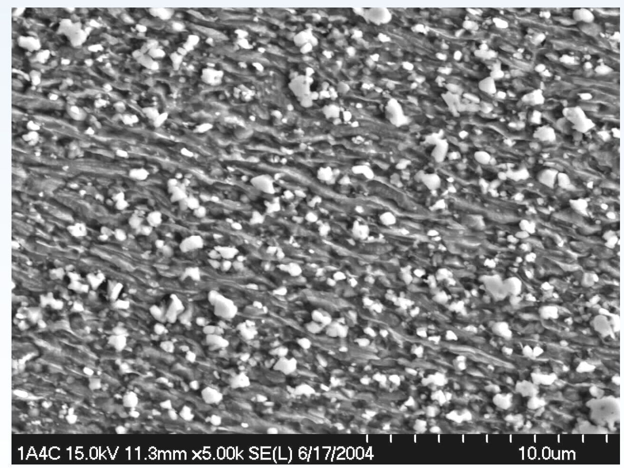
Sample 3a4b
Roll Temp = 215 C, Total Red = 95 % , Roll Spd = 17 fpm



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



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

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