Fabrication of GRCop-84 Rocket Thrust Chambers

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Abstract

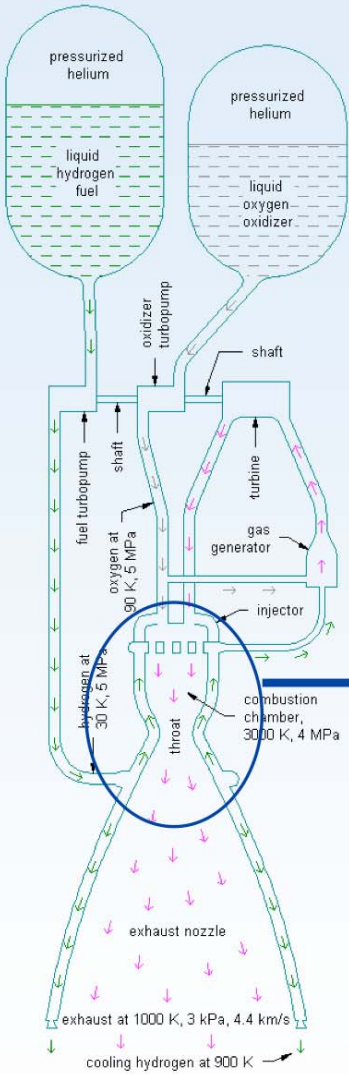
GRCop-84, a copper alloy, Cu-8 at% Cr-4 at% Nb developed at NASA Glenn Research Center for regeneratively cooled rocket engine liners has excellent combinations of elevated temperature strength, creep resistance, thermal conductivity and low cycle fatigue. GRCop-84 is produced from pre-alloyed atomized 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

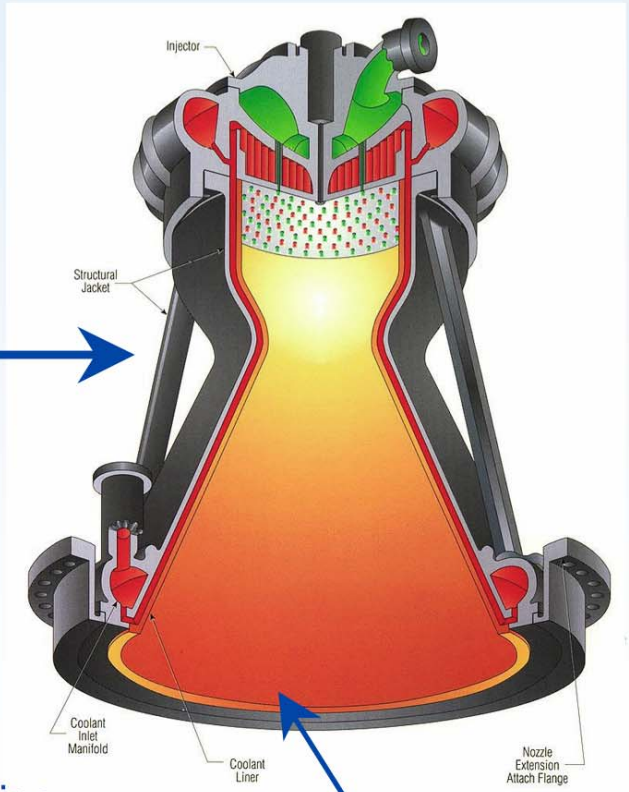
- Rocket Thrust Chambers
- GRCop-84 Properties
- Thrust Chamber Fabrication Steps
- Conclusions

Rocket Thrust Chambers



Liquid Propellant Rocket Engine

Combustion Chamber



GRCop-84 Liner

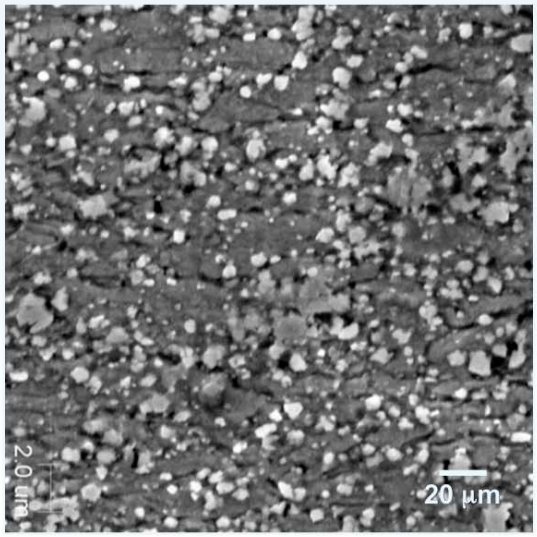
Shuttle Main Engine

Ref: www.islandone.org/LEOBibliøSPBI101.HTM

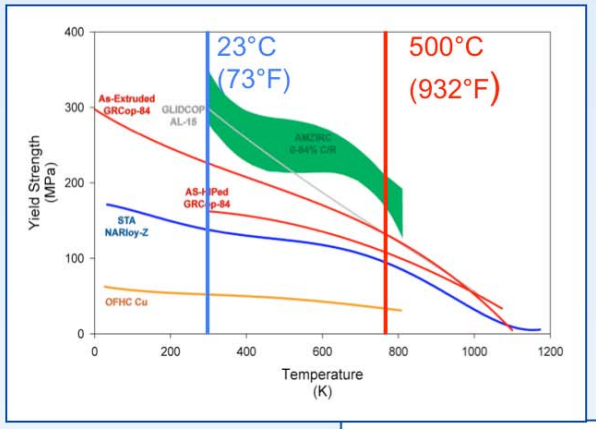
Why GRCop-84 for Rocket Thrust Chambers?

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

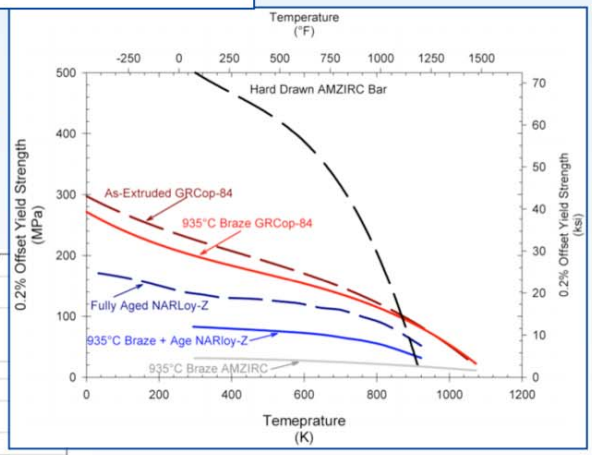


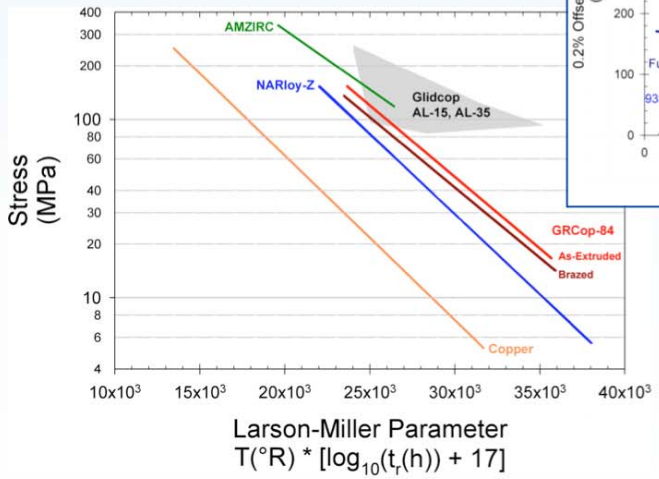
Typical rolled microstructure



Excellent elevated temp strength

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





Superior creep strength

Major Fabricating Steps
Rocket Thrust Chamber

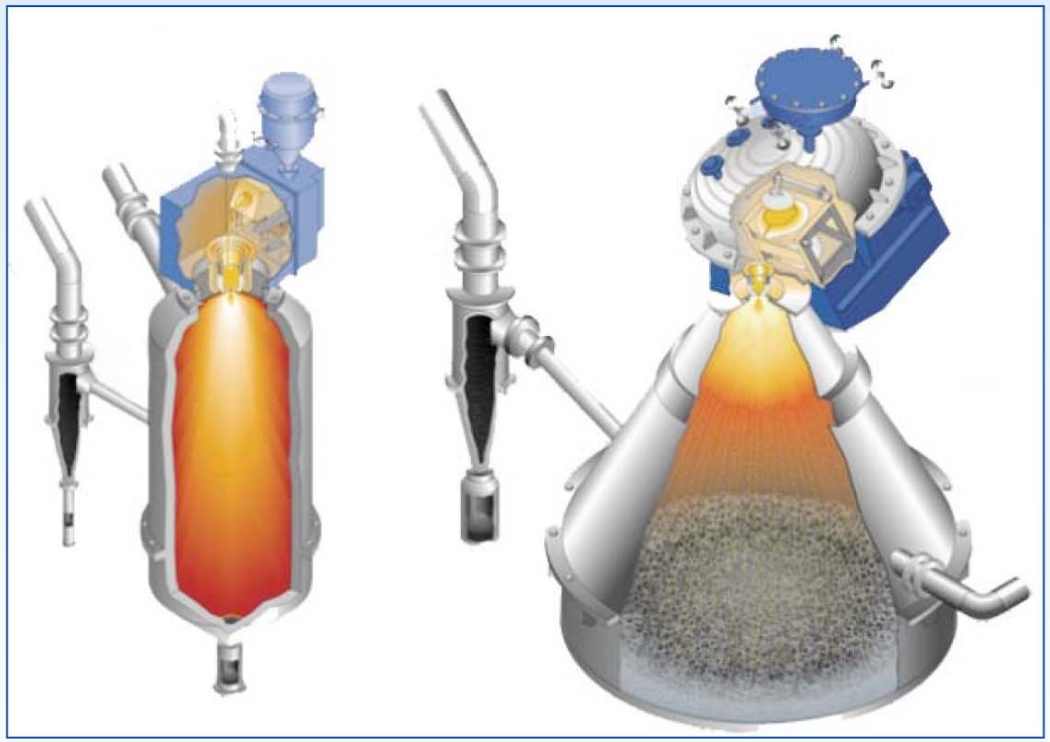
Demonstrated Processes

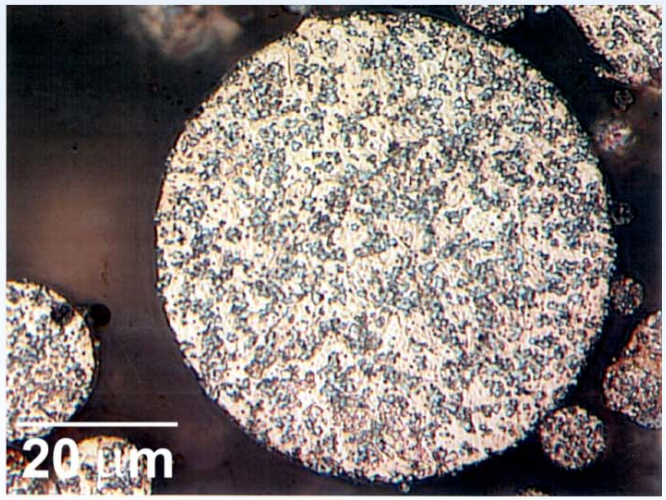
1. Powder Production
2. Canning
3. Extrusion
4. De-can and Billet Prep
5. Roll/Anneal/Clean
6. Form Half Cylinders
7. Friction Stir Weld
8. Metal Spin
9. Anneal
10. Machine ID, rough OD
11. Coat Liner w/ NiCrAlY and HIP
12. Machine ID + OD Cooling Channels

Future Work →

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

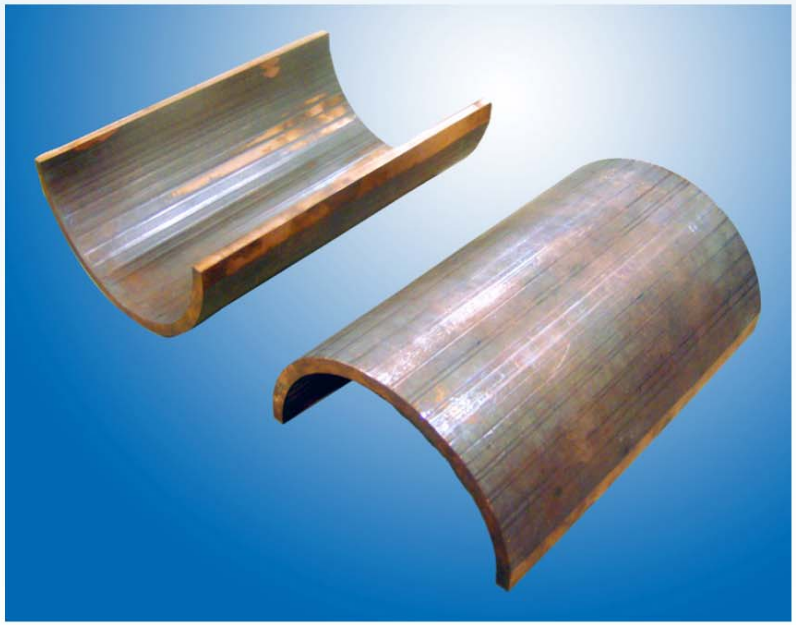
GRCop-84 Plate
Rolled to approximately 0.525” x 20” x 54”
Each plate makes 1.5 to 2 liners

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

Entering rolling mill

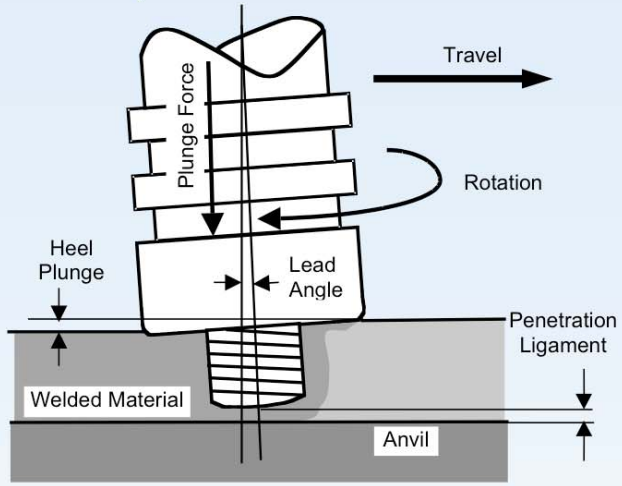
Half Cylinder Forming
(Spin Tech, Paso Robles, CA)

Forming plate into a half cylinder



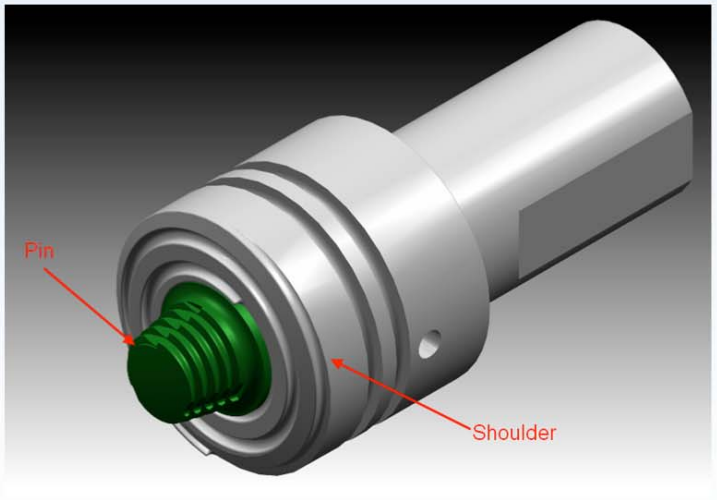
GRCop-84 Half Cylinders
Nominally 5.5” id x 18” long

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

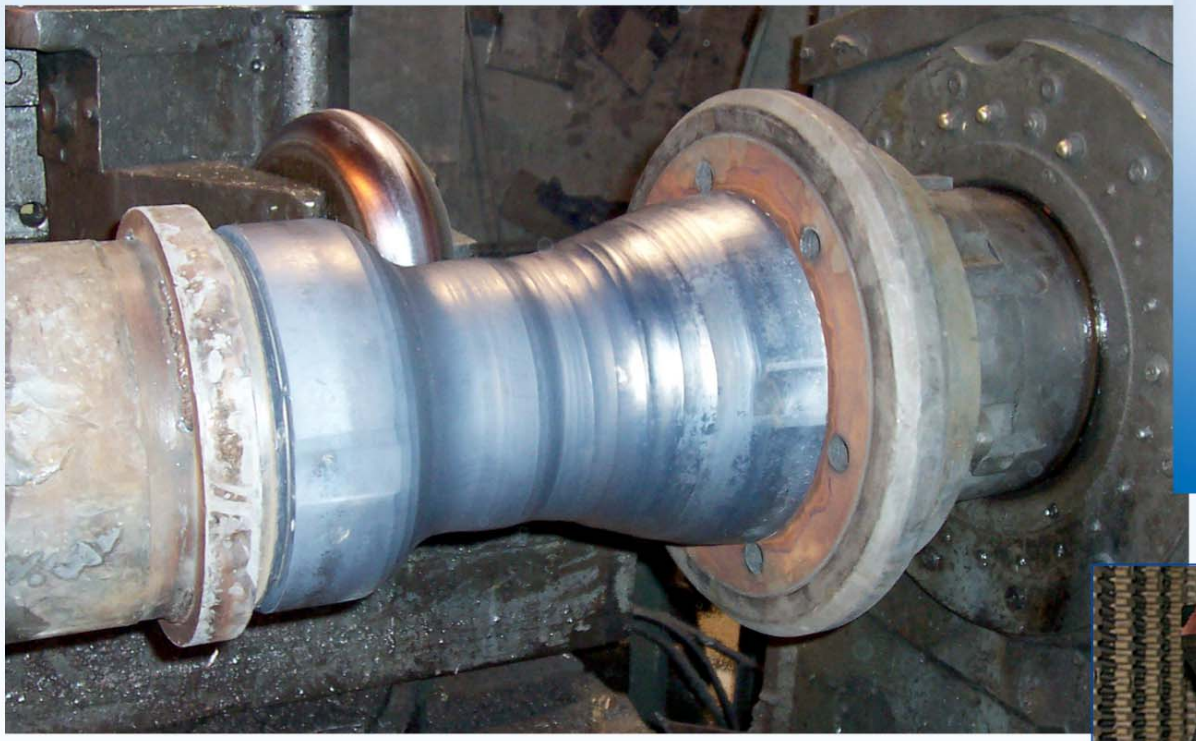
GRCop-84 cylinder weld tooling



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

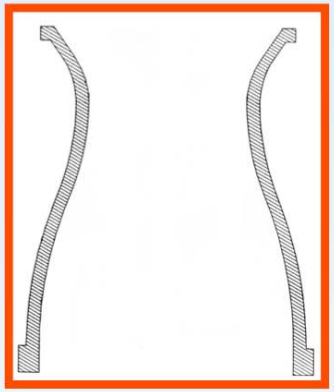
Before and after spinning

Liners were annealed to relieve residual stresses

Photos courtesy of Spin Tech

Machining, Plasma Spray Coating

(Starwin Industries, Dayton, OH and Plasma Processes, Huntsville, AL)



Machined preform

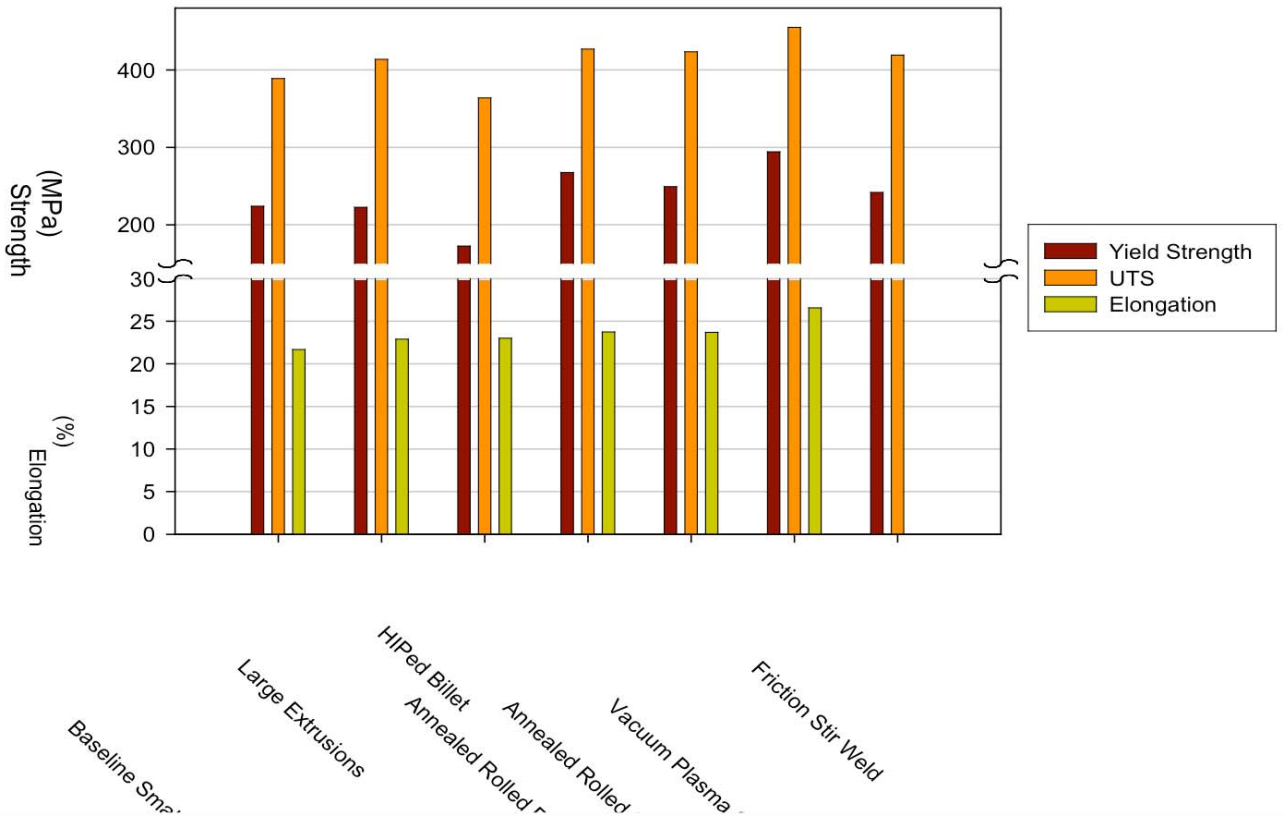
Coated Cu demonstration liners
(Cu-8Cr-1Al bond coat, NiCrAlY top coat)

Completed liner assembly.

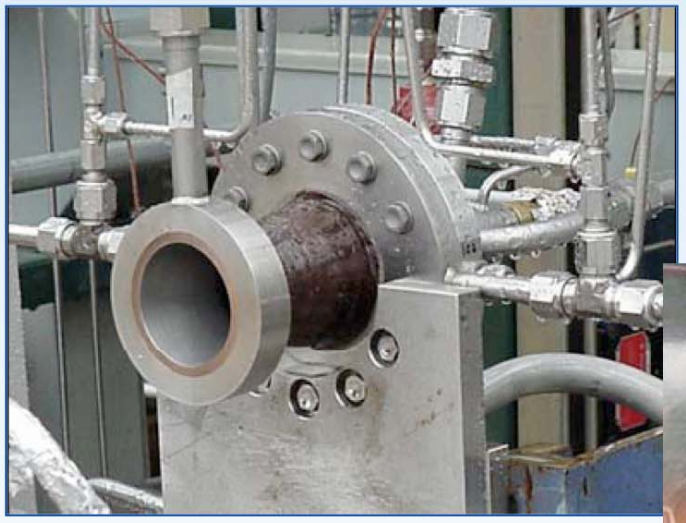
Closeout applied and machined

Completed machined liner

Effect of Processing on Room Temperature Tensile Properties



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