

lower temperatures can be used in the heat treatment process, less energy will be consumed, and there will be less dimensional distortion and quench cracking. This results in fewer scrap parts, less material waste from large amounts of material removal, and fewer machining steps to rework parts that are out of specification.

This material has a combination of properties that have been previously un-

obtainable. The material has a Young's modulus of approximately 95 GPa (about half that of conventional steels), moderate density (10 to 15% lower than conventional steels), excellent corrosion resistance, and high hardness (58 to 62 HRC). These properties make this material uniquely suited for advanced bearings.

*This work was done by Malcolm Stanford, Ronald Noebe, Christopher Dellacorte, Glen*

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*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19029-1. t*

## Cu-Cr-Nb-Zr Alloy for Rocket Engines and Other High-Heat-Flux Applications

**Applications include high-temperature, high-efficiency industrial heat exchangers, welding electrodes, and head gaskets for automobile racing engines.**

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Rocket-engine main combustion chamber liners are used to contain the burning of fuel and oxidizer and provide a stream of high-velocity gas for propulsion. The liners in engines such as the Space Shuttle Main Engine are regeneratively cooled by flowing fuel, e.g., cryogenic hydrogen, through cooling channels in the back side of the liner. The heat gained by the liner from the flame and compression of the gas in the throat section is transferred to the fuel by the liner. As a result, the liner must either have a very high thermal conductivity or a very high operating temperature.

In addition to the large heat flux (>10 MW/m<sup>2</sup>), the liners experience a very large thermal gradient, typically more than 500 °C over 1 mm. The gradient produces thermally induced stresses and strains that cause low cycle fatigue (LCF). Typically, a liner will experience a strain differential in excess of 1% between the cooling channel and the hot wall. Each time the engine is fired, the liner undergoes an LCF cycle. The number of cycles can be as few as one for an expendable booster engine, to as

many as several thousand for a reusable launch vehicle or reaction control system. Finally, the liners undergo creep and a form of mechanical degradation called thermal ratcheting that results in the bowing out of the cooling channel into the combustion chamber, and eventual failure of the liner.

GRCop-84, a Cu-Cr-Nb alloy, is generally recognized as the best liner material available at the time of this reporting. The alloy consists of 14% Cr<sub>2</sub>Nb precipitates in a pure copper matrix. Through experimental work, it has been established that the Zr will not participate in the formation of Laves phase precipitates with Cr and Nb, but will instead react with Cu to form the desired Cu-Zr compounds. It is believed that significant improvements in the mechanical properties of GRCop-84 will be realized by adding Zr. The innovation is a Cu-Cr-Nb-Zr alloy covering the composition range of 0.8 to 8.1 weight percent Cr, 0.7 to 7.2 weight percent Nb, 0.1 to 1.5 weight percent Zr, and balance Cu.

The alloy combines two known strengthening mechanisms — dispersion strengthening by Cr<sub>2</sub>Nb precipitates (GRCop-84), and precipitation strengthening by Cu<sub>x</sub>Zr (AMZIRC) — to produce a synergistic increase in the capabilities of the alloy with the goal of achieving properties greater than either of the methods could achieve alone. The anticipated advantages of the alloy are higher strength at temperatures up to 700 °C, improved creep strength, and significantly higher LCF lives relative to GRCop-84. The thermal expansion, thermal conductivity, and processing of the alloy are anticipated to remain largely unchanged relative to GRCop-84.

*This work was done by David L. Ellis of Glenn Research Center. Further information is contained in a TSP (see page 1).*

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## Microgravity Storage Vessels and Conveying-Line Feeders for Cohesive Regolith

**This design may provide a reliable, robust method for filling pharmaceutical capsules with fine, dry powders.**

*John H. Glenn Research Center, Cleveland, Ohio*

Under microgravity, the usual methods of placing granular solids into, or extracting them from, containers or storage vessels will not function. Alternative

methods are required to provide a motive force to move the material. New configurations for microgravity regolith storage vessels that do not resemble ter-

restrial silos, hoppers, or tanks are proposed. The microgravity-compatible bulk-material storage vessels and exit-feed configurations are designed to reli-