Robust Low-Cost (RLV) Aerospike Combustion Chamber

Project Number: 97-08

Investigators: **R.R. Holmes/EJ71**
F.R. Zimmerman/EH23

Purpose

The primary objective of this program is to combine new technologies for forming a low cost, robust liner for the X–33/RLV combustion chambers, utilizing a stronger liner material and oxidation protection coating. The result will be the development and demonstration of lower cost combustion chambers with increased durability, reliability, and safety, manufactured in reduced time for U.S. reusable and expendable launch vehicles.

Background

Next generation, regeneratively cooled rocket engines will require materials that can withstand high temperatures while retaining high thermal conductivity. At the same time, fabrication techniques must be cost efficient so that engine components can be manufactured within the constraints of a shrinking NASA budget. In recent years, combustion chambers of equivalent size to the Aerospike chamber have been fabricated at NASA–MSFC using innovative, relatively low-cost, vacuum plasma spray (VPS) techniques. Additionally, current research and development conducted by NASA–LeRC has identified a Cu–8Cr–4Nb alloy which possesses excellent high temperature strength, creep resistance, and low cycle fatigue behavior combined with exceptional thermal stability.[1] Utilization of functional gradient coating techniques, developed in the MSFC Microgravity Program will further enhance the operating life of high-performance liquid rocket engines by reducing the operating temperature of the combustion chamber liner 200 °F.

Approach

Parameters were developed to vacuum plasma spray (VPS) Cu–8Cr–4Nb material to demonstrate the benefit of fabricating high-performance, robust, inexpensive rocket engine combustion chambers using this alloy and process. Bulk Cu–8Cr–4Nb material was deposited onto cylindrical mandrels, and properties specimens were machined from this to assess the density and hardness of the VPSed material. Test specimens were heat treated vacuum annealing followed by hot isotactic pressure (HIP). Tensile and low cycle fatigue (LCF) specimens were machined from the same VPS-formed cylindrical mandrel shells, and heat treated by the processes developed using the properties specimens, i.e., vacuum annealing for 4 hours with 1 hour of HIPing at 1750 °F. One set of tensile and LCF test specimens was HIPed 4 hours only at 1750 °F to compare with powder metallurgy (PM) work with Cu–8Cr–4Nb at Rocketdyne.

Accomplishments

A vacuum plasma process was developed and demonstrated producing a Cu–8Cr–4Nb shell with density and Rockwell B hardness values exceeding those reported by Case Western Reserve University and NASA Lewis, the developers of the alloy. Table 1 shows as-sprayed, Cu–8Cr–4Nb had a hardness of 62.6 (Rockwell B scale) and a density of 8.480 g/cm^3 which is 96.4 percent of theoretical. Heat treating the Cu–8Cr–4Nb after VPS deposition improved the density and hardness, and the combination of vacuum annealing for 4 hours with 1 hour of HIPing at 1750 °F produced the best properties with 76.8

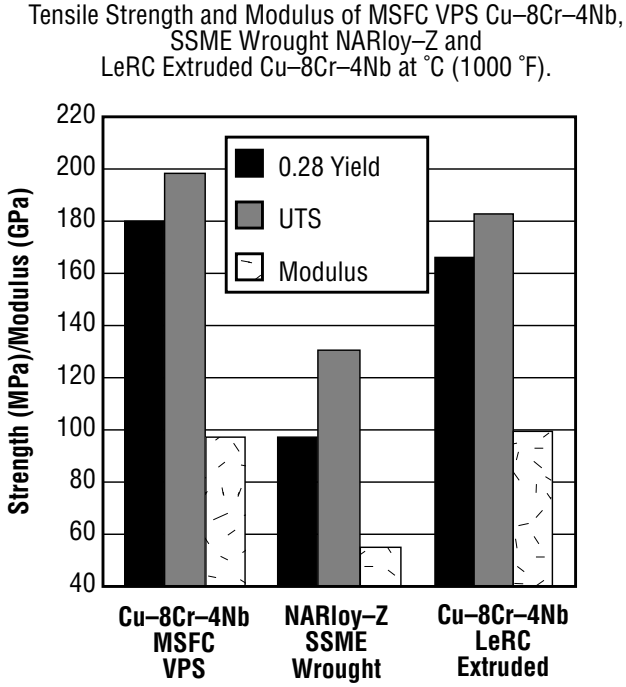

TABLE 1.—Shows the improvement in Cu–8Cr–4Nb physical properties with different heat treatments.

(Rockwell B scale) and 8.730 g/cm^3 (99.2 percent of theoretical), respectively. Extruded Cu–8Cr–4Nb has a density of 8.66 g/cm^3 and a Rockwell B hardness of 70.9; therefore, the tests demonstrated that VPSed Cu–8Cr–4Nb, vacuum annealed for 4 hours with 1 hour of HIPing, has preferable density and hardness characteristics. The improved properties of the VPSed material were expected to translate to superior tensile and low-cycle fatigue characteristics.

Cu–8Cr–4Nb Results

Sample	Density (g/cm^3)	Hardness	Electrical Conduc.
As Sprayed	8.48 96.4%	62.6	70.19
Vacuum Anneal	8.60 97.7%	72.3	70.59
HIP Only	8.73 99.2%	69.3	Not Available
Vac. Anneal + HIP	8.73 99.2%	76.8	Not Available
Extruded	8.66 98.4%	70.9	Not Available

FIGURE 18.—Shows the superiority (50-84%) of VPS Cu–8Cr–4Nb in tensile strength over NARloy–Z, currently used in SSME and X–33/RLV combustion chamber liners.

Tensile specimens were tested at RT, 1,000 °F and 1,200 °F with the results at 1,000 °F, the operating temperature of the combustion chamber liner, shown in figure 18. The VPS Cu–8Cr–4Nb ultimate tensile strength (UTS) was 197 MPa (mega pascal) compared to 183 MPa for the LeRC extruded specimen versus 131 MPa for NARloy-Z. The VPS Cu–8Cr–4Nb is 50 percent stronger at operating temperature than X–33 and SSME baseline alloy NARloy-Z. The VPS and extruded data are an average of three test specimens, while the NARloy-Z data are historical. Heat treating the VPS specimens by 4 hours vacuum annealing and 1 hour HIPing or 4 hours HIPing only (not shown) were statistically the same when testing at 1,000 °F. Yield strengths were 179 MPa, 166 MPa and 97 MPa for the VPS, extruded and NARloy-Z specimens respectively. In yield strength the VPS Cu–8Cr–4Nb is 84 percent stronger at operating temperature than X–33 and SSME baseline alloy NARloy-Z. The low cycle fatigue specimens have not been tested because of high priority work on the SSME/ATD Program.

Thermal analysis by ED64 has found that a 0.0035-inch NiCrAlY coating applied to NARloy-Z or Cu–8Cr–4Nb will lower the operating temperature of the liner by 200 °F. Using functional gradient formation, the coating is integrally formed into the liner, providing oxidation and thermal protection.

Planned Future Work

For phase II, a Spoolpiece support jacket has been obtained from NASA Lewis. A VPS Cu–8Cr–4Nb liner has been sprayed, and will be heat treated by EH22, machined by EH51 and HIP brazed into the NASA Lewis support jacket. Two weeks hot fire testing at NASA Lewis have been scheduled for the VPS Cu–8Cr–4Nb liner beginning May 4, 1998. The Cu–8Cr–4Nb liner will be tested under the extreme 7:1 oxidizer to fuel ratio required of the X–33/RLV thrust cells. (The 7:1 ratio makes it even more imperative to qualify an improved, more robust liner.) Phase II will be completed with VPS spraying two X–33 thrust cell liners to demonstrate the simplicity and viability of the VPS Cu–8Cr–4Nb process/product and to calculate manufacturing costs.

Publications and Patent Applications

Article written, not yet submitted for publication.

Funding Summary ($k)

All program funding has been spent for FY97 with funding approved for FY98.

FY97	FY98	Total
75	158.65	233.65

Status of Investigation

Project approved—October 1, 1996

It is requested that the RLCACC CDDF be continued into FY98 with an estimated completion date of November 21, 1998.

References

[1] Ellis, D. L.; Dreshfield, R. L.; Verrilli, M. J.; and Ulmer, D. G.: "Mechanical Properties of a Cu–8Cr–4Nb Alloy," Earth to Orbit Conference Proceedings, pp. 32–38, June 1994.