Cyclic Oxidation Behavior of CuCrAl Cold-Sprayed Coatings for Reusable Launch Vehicles

John H. Glenn Research Center, Cleveland, Ohio

The next generation of reusable launch vehicles is likely to use GRCop-84 [Cu-8(at.%)Cr-4%Nb] copper alloy combustion liners. The application of protective coatings on GRCop-84 liners can minimize or eliminate many of the environmental problems experienced by uncoated liners and significantly extend their operational lives and lower operational cost. A newly developed Cu-23 (wt.%) Cr-5% Al (CuCrAl) coating, shown to resist hydrogen attack and oxidation in an as-cast form, is currently being considered as a protective coating for GRCop-84. The coating was deposited on GRCop-84 substrates by the cold spray deposition technique, where the CuCrAl was procured as gas-atomized powders. Cyclic oxidation tests were conducted between 773 and 1,073 K to characterize the coated substrates. The coating proved to be effective in preventing the cyclic oxidation of the substrate for up to 1,000 cycles. The coated substrates showed no significant weight loss in comparison to uncoated specimens, which lost between 60 to 80 percent of its original weight with much lower lives. The coating was adherent to the substrate at all temperatures, whereas the uncoated GRCop-84 showed excessive spallation of the oxide scale. It is anticipated that the use of this alloy can extend the operational life of the liner, which translates to increased component reliability, shorter depot maintenance turnaround time, and lower operational cost. Additionally, engines using CuCrAl-coated GRCop-84 combustion liners could operate at higher temperatures, thereby resulting in its increased thermal efficiency.

This work was done by Sai Raj of Glenn Research Center and J. Karthikeyan of ASB Industries. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18330-1.

Ceramic Fiber Structures for Cryogenic Load-Bearing Applications

Woven or braided fibers resist embrittlement under cryogenic conditions, enabling ultralow-temperature applications.

John H. Glenn Research Center, Cleveland, Ohio

This invention is intended for use as a load-bearing device under cryogenic temperatures and/or abrasive conditions (i.e., during missions to the Moon). The innovation consists of small-diameter, ceramic fibers that are woven or braided into devices like ropes, belts, tracks, or cables. The fibers can be formed from a variety of ceramic materials like silicon carbide, carbon, aluminosilicate, or aluminum oxide. The fiber architecture of the weave or braid is determined by both the fiber properties and the mechanical requirements of the application. A variety of weave or braid...
architectures is possible for this application. Thickness of load-bearing devices can be achieved by using either a 3D woven structure, or a layered, 2D structure. For the prototype device, a belt approximately 0.10 in. (0.25 cm) thick, and 3.0 in. (7.6 cm) wide was formed by layering and stitching a 2D aluminosilicate fiber weave. The circumferential length of the 2D, layered belt was approximately 36 in. (91 cm).

To demonstrate the resistance to abrasion while under load, the ceramic fiber belt was installed on two aluminum spools that were mounted in an Instron load frame. Both spools were completely enclosed in a Lexan box within the load frame. Bearings were used at each end of the spool shafts to allow the spools to spin freely while a load was applied. The lower spool, which was secured to the stationary head of the load frame, was also attached to a small motor to drive the rollers. The upper spool was attached to the movable crosshead of the Instron frame to apply a load to the belt while it was rolling. JSC-1a, a highly abrasive lunar regolith simulant, was added to the Lexan box. Enough JSC-1a was placed in the bottom of the box to allow the belt to contact and pick up the dust as it traveled around the lower spool. The track was exposed to the dust while rolling under load for several hours to simulate relevant rover mission duration. After 12.5 hours of exposure to the lunar simulant, under loads varying between 50 and 100 N, no elongation or mechanical creep of the belt was measured. Under these loads, which were estimated to be comparable to those required for tracks on the lunar rover, there was no deformation or loss of load carrying ability.

To demonstrate flexibility under cryogenic conditions, individual fibers and fiber tows were exposed to cryogenic temperatures by being submerged in liquid nitrogen for 4 minutes, and then were flexure tested. Immediately upon removal from the liquid nitrogen, the fibers and tows were wrapped around mandrels of progressively smaller diameters. Both the fibers and the tows were successfully wrapped around wire mandrels with a diameter of approximately 0.02 in. (0.5 mm) without any breakage. The continuous ceramic belt that is envisioned for the lunar rover would be a closed-edge, multilayer weave with through thickness holes woven in place. The holes in the weave would engage the sprockets on the drive mechanism of the track device.

This work was done by Martha H. Jaskowiak and Andrew J. Echel of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18364-1.

### Elastomer Reinforced With Carbon Nanotubes

Lyndon B. Johnson Space Center, Houston, Texas

Elastomers are reinforced with functionalized, single-walled carbon nanotubes (SWNTs) giving them high-breaking strain levels and low densities. Cross-linked elastomers are prepared using amine-terminated, poly(dimethylsiloxane) (PDMS), with an average molecular weight of 5,000 daltons, and a functionalized SWNT. Cross-link densities, estimated on the basis of swelling data in toluene (a dispersing solvent) indicated that the polymeric elastomer occurring at a strain of 6.5. Tensile properties examined at room temperature indicate a three-fold increase in the tensile modulus of the elastomer, with rupture and failure of the elastomer occurring at a strain of 6.5.

This work was done by James M. Tour and Jared L. Hudson of Rice University and Ramanan Krishnamoorti of University of Houston for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

- William M. Rice University
  - Office of Technology Transfer
  - 6100 Main Street
  - Houston, TX 77005
  - Phone No.: (713) 348-6188
  - Refer to MSC-24071-1, volume and number of this NASA Tech Briefs issue, and the page number.

### Biologically Inspired Purification and Dispersion of SWCNTs

Lyndon B. Johnson Space Center, Houston, Texas

A biologically inspired method has been developed for (1) separating single-wall carbon nanotubes (SWCNTs) from other materials (principally, amorphous carbon and metal catalysts) in raw production batches and (2) dispersing the SWCNTs as individual particles (in contradistinction to ropes and bundles) in suspension, as required for a number of applications.

Prior methods of purification and dispersal of SWCNTs involve, variously, harsh physical processes (e.g., sonication) or harsh chemical processes (e.g., acid reflux). These processes do not completely remove the undesired materials and do not disperse bundles and ropes into individual suspended SWCNTs. Moreover, these processes cut long SWCNTs into shorter pieces, yielding typical nanotube lengths between 150 and 250 nm.

In contrast, the present method does not involve harsh physical or chemical processes. The method involves the use of biologically derived dispersal agents (BDDAs) in an aqueous solution that is mechanically homogenized (but not sonicated) and centrifuged. The dense solid material remaining after centrifuga-