abrasive scratch tests, it was found that the ASTM International Standard G 171 specified a generic metric based only on visually determined scratch width as a way to compare abraded materials. A limitation to this method was identified in that the scratch width is based on optical surface measurements, manually defined by approximating the boundaries, but does not consider the three-dimensional volume of material that was displaced. With large, potentially irregular deformations occurring on softer materials, it becomes unclear where to systematically determine the scratch width. Specifically, surface scratches on different samples may look the same from a top view, resulting in an identical scratch width measurement, but may vary in actual penetration depth and/or plowing deformation. Therefore, two different scratch profiles would be measured as having identical abrasion properties, although they differ significantly.

With these refined measurements, a wider variety of testing needs can be addressed with greater resolution while using the most appropriate abrasive tip and test material combination for the intended application. The core of this innovation in two-body abrasion research involved scratch testing with ASTM G 171 used as a guideline for determining the number of tests to be conducted. The resultant profiles of each scratch were digitized using an optical interferometer and accompanying software. To accomplish this objective, software code was developed to produce a suite of metrics based on a zero line (ZL) through the scratch, which allowed quantitative definition of the scratch and associated wear metrics.

The computer code determines a ZL through individual cross-sections, then produces the following metrics: Negative Volume Displaced, Positive Volume Displaced, Net Volume Displaced, and Absolute Volume Displaced, along with a secondary set of metrics composed of six roughness parameters that allow definition of the ZL. From these metrics, a Zone of Interaction (ZOI) can be established.

This work was done by K. W. Street, Jr. of Glenn Research Center and R. L. Kobrick and D. M. Klaus of the University of Colorado – Boulder. 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: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18675-1.

Detection of Carbon Monoxide Using Polymer-Carbon Composite Films

NASA's Jet Propulsion Laboratory, Pasadena, California

A carbon monoxide (CO) sensor was developed that can be incorporated into an existing sensing array architecture. The CO sensor is a low-power chemiresistor that operates at room temperature, and the sensor fabrication techniques are compatible with ceramic substrates.

Sensors made from four different polymers were tested: poly (4-vinylpryridine), ethylene-propylene-diene-terpolymer, polyepichlorohydrin, and polyethylene oxide (PEO). The carbon black used for the composite films was Black Pearls 2000, a furnace black made by the Cabot Corporation. Polymers and carbon black were used as received. In fact, only two of these sensors showed a good response to CO. The poly (4-vinylpryridine) sensor is noisy, but it does respond to the CO above 200 ppm. The polyepichlorohydrin sensor is less noisy and shows good response down to 100 ppm.

This work was done by Margie L. Homer, Margaret A. Ryan, and Liana M. Lara of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47612

Substituted Quaternary Ammonium Salts Improve Low-Temperature Performance of Double-Layer Capacitors

Low cell resistances are observed when used with modified acetonitrile electrolyte blends.

NASA's Jet Propulsion Laboratory, Pasadena, California

Double-layer capacitors are unique energy storage devices, capable of supporting large current pulses as well as a very high number of charging and discharging cycles. The performance of double-layer capacitors is highly dependent on the nature of the electrolyte system used. Many applications, including for electric and fuel cell vehicles, back-up diesel generators, wind generator pitch control back-up power systems, environmental and structural distributed sensors, and spacecraft avionics, can potentially benefit from the use of double-layer capacitors with lower equivalent series resistances (ESRs) over wider temperature limits. Higher ESRs result in decreased power output, which is a particular problem at lower temperatures. Commercially available cells are typically rated for operation down to only –40 °C.

Previous briefs [for example, "Low Temperature Supercapacitors" (NPO-44386), *NASA Tech Briefs,* Vol. 32, No. 7 (July 2008), p. 32, and "Supercapacitor Electrolyte Solvents With Liquid Range Below –80 °C" (NPO-44855), *NASA Tech Briefs,* Vol. 34, No. 1 (January 2010), p. 44] discussed the use of electrolytes that employed low-melting-point co-solvents to depress the freezing point of traditional acetonitrile-based electrolytes. Using these modified electrolyte formulations can extend the low-temperature operational limit of double-layer capacitors beyond that of commercially available cells. This previous work has shown that although the measured capacitance is relatively insensitive to temperature, the ESR can rise rapidly at low temperatures, due to decreased electrolyte conductance within the pores of the high-surface-area carbon electrodes. Most of these advanced electrolyte systems featured tetraethylammonium tetrafluoroborate (TEATFB) as the salt. More recent work at JPL indicates the use of the asymmetric quaternary ammonium salt triethylmethylammonium tetrafluoroborate (TEMATFB) or spiro-(l,l')-bipyrrolidium tetrafluoroborate (SBPBF4) in a 1:1 by volume solvent mixture of acetonitrile (AN) and methyl formate (MF) enables double-layer capacitor cells to operate well below –40 °C with a relatively low ESR. Typically, a less than two-fold increase in ESR is observed at –65 °C relative to room-temperature values, when these modified electrolyte blends are used in prototype cells. Double-layer capacitor coin cells filled with these electrolytes have displayed the lowest measured ESR for an organic electrolyte to date at low temperature (based on a wide range of electrolyte screening studies at JPL). The cells featured high-surface-area (≈2,500 m/g) carbon electrodes that were 0.50 mm thick and 1.6 cm in diameter, and coated with a thin layer of platinum to reduce cell resistance. A polyethylene separator was used to electrically isolate the electrodes.

This work was done by Erik J. Brandon, Marshall C. Smart, and William C. West of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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:

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Refer to NPO-47327, volume and number of this NASA Tech Briefs *issue, and the page number.*

Sustainably Sourced, Thermally Resistant, Radiation Hard Biopolymer

A sustainably sourced biopolymer provides simultaneous thermal insulation and radiation protection.

Goddard Space Flight Center, Greenbelt, Maryland

This material represents a breakthrough in the production, manufacturing, and application of thermal protection system (TPS) materials and radiation shielding, as this represents the first effort to develop a non-metallic, non-ceramic, biomaterial-based, sustainable TPS with the capability to also act as radiation shielding. Until now, the standing philosophy for radiation shielding involved carrying the shielding at liftoff or utilizing onboard water sources. This shielding material could be grown onboard and applied as needed prior to different radiation landscapes (commonly seen during missions involving gravitational assists).

The material is a bioplastic material. Bioplastics are any combination of a biopolymer and a plasticizer. In this case, the biopolymer is a starch-based material and a commonly accessible plasticizer. Starch molecules are composed of two major polymers: amylase and amylopectin.

The biopolymer phenolic compounds are common to the ablative thermal protection system family of materials. With similar constituents come similar chemical ablation processes, with the potential to have comparable, if not better, ablation characteristics. It can also be used as a flame-resistant barrier for commercial applications in buildings, homes, cars, and heater firewall material.

The biopolymer is observed to undergo chemical transformations (oxidative and structural degradation) at radiation doses that are 1,000 times the maximum dose of an unmanned mission (10–25 Mrad), indicating that it would be a viable candidate for robust radiation shielding. As a comparison, the total integrated radiation dose for a three-year manned mission to Mars is 0.1 krad, far below the radiation limit at which starch molecules degrade. For electron radiation, the biopolymer starches show minimal deterioration when exposed to energies greater than 180 keV.

This flame-resistant, thermal-insulating material is non-hazardous and may be sustainably sourced. It poses no hazardous waste threats during its lifecycle. The material composition is radiation-tolerant up to megarad doses, indicating its use as a radiation shielding material. It is lightweight, non-metallic, and able to be mechanically densified, permitting a tunable gradient of thermal and radiation protection as needed. The dual-use (thermal and radiation shielding), sustainable nature of this material makes it suitable for both industrial applications as a sustainable/green building material, and for space applications as thermal protection material and radiation shield.

This work was done by Diane Pugel of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16177-1