Materials & Coatings

Fiber-Reinforced Reactive Nano-Epoxy Composites

Marshall Space Flight Center, Alabama

An ultra-high-molecular-weight polyethylene/matrix interface based on the fabrication of a reactive nano-epoxy matrix with lower surface energy has been improved. Enhanced mechanical properties versus pure epoxy on a three-point bend test include: strength (25 percent), modulus (20 percent), and toughness (30 percent). Increased thermal properties include higher Tg (glass transition temperature) and stable CTE (coefficient of thermal expansion). Improved processability for manufacturing composites includes faster wetting rates on macro-fiber surfaces, lower viscosity, better resin infusion rates, and improved rheological properties. Improved interfacial adhesion properties with Spectra fibers by pullout tests include initial debonding force of 35 percent, a maximum pullout force of 25 percent, and energy to debond at 65 percent. Improved mechanical properties of Spectra fiber composites (tensile) aging resistance properties include hygrothermal effects.

With this innovation, high-performance composites have been created, including carbon fibers/nano-epoxy, glass fibers/nano-epoxy, aramid fibers/nano-epoxy, and ultra-high-molecular-weight polyethylene fiber (UHMWPE).

This work was done by Wei-Hong (Katie) Zhong of North Dakota State University for Marshall Space Flight Center. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32666-1.

Polymerization Initiated at the Sidewalls of Carbon Nanotubes

Lyndon B. Johnson Space Center, Houston, Texas

A process has been developed for growing polymer chains via anionic, cationic, or radical polymerization from the side walls of functionalized carbon nanotubes, which will facilitate greater dispersion in polymer matrices, and will greatly enhance reinforcement ability in polymeric material.

Aryl bromide functionalized carbon nanotubes are dispersed in 5-mL tetrahydrofuran (THF), and a solution of n-butyllithium (5 mL, 2.19 M in hexane) was added at 23 °C, and the solution stirred for 10 min. The stirring was then turned off, and the nanotubes were allowed to settle out of solution. After settling, the excess n-butyllithium solution was removed from the reaction vessel via cannula, and the nanotubes were washed three times with dry THF (10 mL) to remove traces of n-butyllithium.

The flask was then charged with dry THF (10 mL), and the tubes were dispersed in solution with rapid stirring. Styrene (1.7 mL, 15 mmol) was added to the reaction vessel, and the mixture was stirred for 180 min before adding ethanol (1 mL) or a function terminator of choice such as trimethylsilyl chloride. The mixture was then diluted with 100 mL dichloromethane, and filtered through Fisherbrand P8 filter paper to remove any large particulates. The filtrate was concentrated under reduced pressure and precipitated into methanol. The resulting gray powder was then collected by filtration, using Whatman 451 filter paper and dried under vacuum (0.1 mm) to a constant weight (typically 0.100–1.00 g, depending on the precise amount of styrene added). This material can then be blended with other polymers, or can be molded and used by itself as a specialty material.

This work was done by James M. Tour and Jared L. Hudson of Rice University 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:

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Refer to MSC-24065-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Metal-Matrix/Hollow-Ceramic-Sphere Composites

These materials are relatively inexpensive, lightweight, stiff, tailorable, and machinable.

Goddard Space Flight Center, Greenbelt, Maryland

A family of metal/ceramic composite materials has been developed that are relatively inexpensive, lightweight alternatives to structural materials that are typified by beryllium, aluminum, and graphite/epoxy composites. These metal/ceramic composites were originally intended to replace beryllium (which is toxic and expensive) as a structural material for lightweight mirrors for aerospace applications. These materials also have potential utility in automotive and many other terrestrial applications in which there are requirements for lightweight mate-

rials that have high strengths and other tailorable properties as described below.

The ceramic component of a material in this family consists of hollow ceramic spheres that have been formulated to be lightweight (0.5 g/cm^3) and have high crush strength [40–80 ksi (≈276–552 MPa)]. The hollow spheres are coated with a metal to enhance a specific performance — such as shielding against radiation (cosmic rays or x rays) or against electromagnetic interference at radio and lower frequencies, or a material to reduce the coefficient of thermal expansion (CTE) of the final composite material, and/or materials to mitigate any mismatch between the spheres and the matrix metal. Because of the high crush strength of the spheres, the initial composite workpiece can be forged or extruded into a high-strength part. The total time taken in processing from the raw ingredients to a finished part is typically 10 to 14 days depending on machining required.

For purposes of further processing, the material behaves like a metal: It can be processed by conventional machining (including formation of threads) or electrical-discharge machining, and pieces of the material can be joined by techniques commonly used to join metal pieces. The material is also receptive to coating materials and exhibits highly variable thermal conductivity from metal to ceramic depending on loading.

Typical mechanical properties of such a material include a density less than that of beryllium (ranging from 1.2–17 g/cm^3 while the density of beryllium is 1.85 g/cm^3) and modulus as high as 25 Msi (≈170 GPa). In contrast, the modulus of aluminum is generally 14 Msi (≈97 GPa). The CTE, the thermal conductivity, and the specific heat can be tailored, through the formulation of the ceramic and metal matrix ingredients of the composite.

Piezoelectrically Enhanced Photocathodes

Attributes would include stability, high efficiency, and relative ease of fabrication.

NASA's Jet Propulsion Laboratory, Pasadena, California

Doping of photocathodes with materials that have large piezoelectric coefficients has been proposed as an alternative means of increasing the desired photoemission of electrons. Treating cathode materials to increase emission of electrons is called "activation" in the art. It has been common practice to activate photocathodes by depositing thin layers of suitable metals (usually, cesium). Because cesium is unstable in air, fabrication of cesiated photocathodes and devices that contain them must be performed in sealed tubes under vacuum. It is difficult and costly to perform fabrication processes in enclosed, evacuated spaces. The proposed piezoelectrically enhanced photocathodes would have electron-emission properties similar to those of cesiated photocathodes but would be stable in air, and therefore could be fabricated more easily and at lower cost.

Candidate photocathodes include nitrides of elements in column III of the periodic table — especially compounds of the general formula $Al_xGa_{1-x}N$ (where $0 \leq x \leq 1$). These compounds have high piezoelectric coefficients and are suitable for obtaining response to ultraviolet light. Fabrication of a photocathode according to the proposal would include inducement of strain in cathode layers during growth of the layers on a substrate. The strain would be induced by exploiting structural mismatches among the various constituent materials of the cathode. Because of the piezoelectric effect in this material, the strain would give rise to strong electric fields that, in turn, would give rise to a high concentration of charge near the surface.

Examples of devices in which piezoelectrically enhanced photocathodes could be used include microchannel plates, electron-bombarded charge-coupled devices, image tubes, and night-vision goggles. Piezoelectrically enhanced photocathode materials could also be used in making highly efficient monolithic photodetectors. Highly efficient and stable piezoelectrically enhanced, ultraviolet-sensitive photocathodes and photodetectors could be fabricated by use of novel techniques for growing piezoelectrically enhanced layers, in conjunction with thinning and dopant-selective etching techniques.

Iridium-Doped Ruthenium Oxide Catalyst for Oxygen Evolution

Possible applications of this catalyst include fabrication of water electrolysis units in hydrogen generators.

NASA's Jet Propulsion Laboratory, Pasadena, California

NASA requires a durable and efficient catalyst for the electrolysis of water in a polymer-electrolyte-membrane (PEM) cell. Ruthenium oxide in a slightly reduced form is known to be a very efficient catalyst for the anodic oxidation of water to oxygen, but it degrades rapidly, reducing efficiency. To combat this tendency of ruthenium oxide to change oxidation states, it is combined with iridium, which has a tendency to stabilize ruthenium oxide at oxygen evolution potentials. The novel oxygen evolution catalyst was fabricated under flowing argon in order to allow the iridium to