Materials

Damage Detection and Self-Repair in Inflatable / Deployable Structures

Integrated sensors and self-repairing materials provide structural health management.

NASA's Jet Propulsion Laboratory, Pasadena, California

Inflatable / deployable structures are under consideration for applications as varied as expansion modules for the International Space Station to destinations for space tourism to habitats for the lunar surface. Monitoring and maintaining the integrity of the physical structure is critical, particularly since these structures rely on non-traditional engineering materials such as fabrics, foams, and elastomeric polymers to provide the primary protection for the human crew. The closely related prior concept of monitoring structural integrity by use of built-in or permanently attached sensors has been applied to structures made of such standard engineering materials as metals, alloys, and rigid composites. To effect monitoring of flexible structures comprised mainly of soft goods, however, it will be necessary to solve a different set of problems — especially those of integrating power and data-transfer cabling that can withstand, and not unduly interfere with, stowage and subsequent deployment of the structures. By incorporating capabilities for self-repair along with capabilities for structural health monitoring, successful implementation of these technologies would be a significant step toward semi-autonomous structures, which need little human intervention to maintain. This would not only increase the safety of these structures, but also reduce the inspection and maintenance costs associated with more conventional structures.

A series of proof-of-concept technology sensing and self-repair technologies have recently been developed and tested individually, for future integration into a full health management system for inflatable / deployable structures. With further development, these technologies could be applied individually or as part of an entire system, depending on the particular architecture of the structure or on the specific mission needs. The technologies include:

- Arrays of thin-film capacitive or inductive sensors, made of a flexible circuit material that can be integrated into an inflatable / deployable structure for use in detecting the location and extent of damage. Damage manifests itself as changes in inductance or capacitance in elements of the sensor array.
- Strain gauges made from thin films of amorphous silicon for monitoring the integrity of thin, flexible structures. To reduce the amount of wiring required, thin-film transistors are used to construct an addressable, matrixed array of sensors allowing selection and readout of specific sensors in the array.
- Wireless sensors and passive (no-power) radio-frequency identification sensor tags to provide additional sensing capabilities such as strain sensing, temperature sensing, and impact or leak detection, without the need for data and power cables.
- Self-repairing elastomeric materials (such as those used to construct the bladder of a habitat), which incorporate microcapsules filled with a monomer resin and a small amount of a polymerization catalyst. Upon damage to the material, some of the capsules burst and release the monomer, becoming polymerized after making contact with the embedded catalyst and thus effecting repair of the damage.
- Sensory and self-repair features will eventually be combined into the structure to effect a unified structural health maintenance system. Sensors will alert humans to initial damage and will monitor the self-repair process, to indicate whether there is a need for human intervention for inspection and / or repair.

This work was done by Erik Brandon of Caltech, George Studor of NASA Johnson Space Center, David Banks and Mark Curry of Boeing Phantom Works, Robert Broccato of Sandia National Laboratories, Tom Jackson of Penn State University, Kevin Champaigne of Invocon, Stan Woodard of NASA Langley Research Center, and Nancy Sottos of the University of Illinois at Urbana-Champaign for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-44519

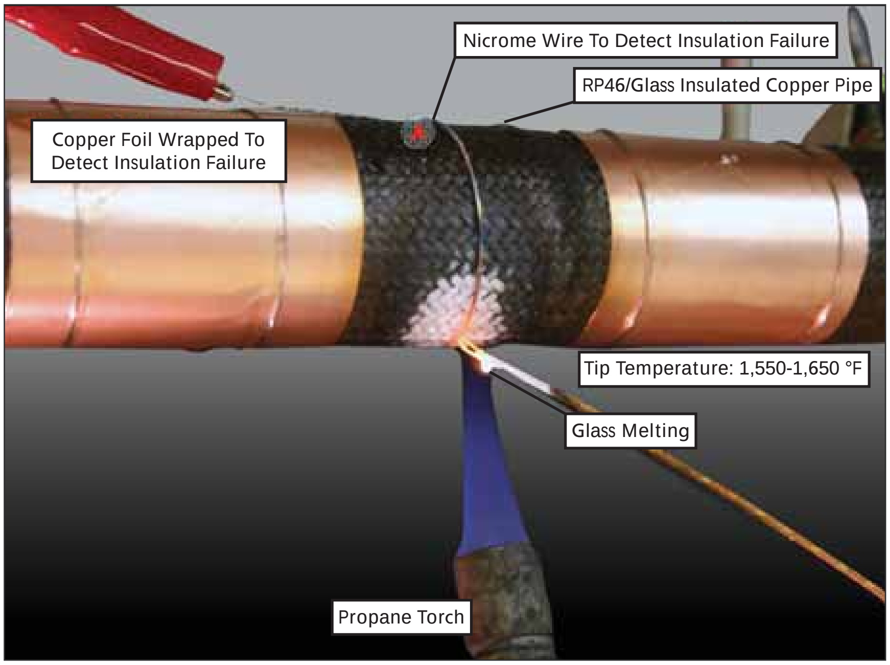
Polyimide / Glass Composite High-Temperature Insulation

This composite was found to exhibit an unexpectedly high degree of fire resistance.

Langley Research Center, Hampton, Virginia

Lightweight composites of RP46 polyimide and glass fibers have been found to be useful as extraordinarily fire-resistant electrical-insulation materials. RP46 is a polyimide of the polymerization of monomeric reactants (PMR) type, developed by NASA Langley Research Center. RP46 has properties that make it attractive for use in electrical insulation at high temperatures. These properties include high-temperature resistance, low relative permittivity, low dissipation factor, outstanding mechanical properties, and excellent resistance to moisture and chemicals. Moreover, RP46 contains no halogen or other toxic materials and when burned it does not produce toxic fume or gaseous materials.

The U. S. Navy has been seeking lightweight, high-temperature-resistant elec-



A **Gas Flame** at 1,600°F (about 871°C) was applied for 3 hours to a layer of RP46/glass composite 0.15 in. (about 3.8 mm) thick on a 1.62-in. (≈41.2-mm)-diameter copper pipe while a 60-Hz, 110-V alternating potential was applied across the layer. Electrical-insulation failure, effectively defined for the purpose of the test as being manifested by a current ≥0.25 A through the insulation, was not observed.

trical-insulation materials in a program directed toward reducing fire hazards and weights in ship electrical systems. To satisfy the requirements of this program, an electrical-insulation material must withstand a 3-hour gas-flame test at 1,600°F (about 871°C). Prior to the development reported here, RP46 was rated for use at temperatures from –150 to +700°F (about –101 to 371°C), and no polymeric product — not even RP46 — was expected to withstand the Navy 3-hour gas-flame test.

A typical process for applying RP46/glass-fiber composite to a wire, pipe, or other electrically conductive object that one seeks to insulate consists of the following steps:

1. The surface to be coated with the composite is prepared by roughening it, then cleaning it using methanol and acetone.
2. The roughened, cleaned surface is wrapped with either a prepreg [glass fabric or one or more layer(s) of glass fibers pre-impregnated with RP46] or a dry fabric or fiber sleeve or preform to a desired thickness.
3. If a dry sleeve has been wrapped, then at this point, it is infused with a resin solution having a suitable viscosity, by use of a vacuum-assisted resin-transfer molding (VARTM) technique. The VARTM step can be performed at either room temperature or an elevated temperature, depending on the specific resin solution used.
4. The workpiece as processed thus far is placed in an autoclave, wherein the resin is cured at an appropriate elevated temperature and pressure. If the resin has a low and stable melt viscosity, then the cure can be performed in a vacuum bag in an oven.

The figure depicts the Navy gas-flame test being performed on a copper pipe insulated with an RP46/glass-fiber composite. The same test was also performed on a similarly insulated aluminum pipe. The RP46/glass-fiber composite layers unexpectedly passed the tests, retaining their electrical-insulation integrity for more than 3 hours at 1,600±50°F (about 871±28°C). Furthermore, the composite showed remarkably high insulating capability. This was evident from the observation that while the RP46 was exposed to a temperature of 1,667°F (908°C), the temperature of the insulated conductor was only 229°F (109°C).

This work was done by Ruth H. Pater, Peter Vasquez, Richard L. Chattin, Donald L. Smith, Thomas J. Skalski, and Gary S. Johnson of Langley Research Center and Sang-Hyon Chu of the National Institute of Aerospace. Further information is contained in a TSP (see page 1). *LAR-17321-1*

Nanocomposite Strain Gauges Having Small TCRs

Usefully large gauge factors and acceptably small drifts should also be attainable.

John H. Glenn Research Center, Cleveland, Ohio

Ceramic strain gauges in which the strain-sensitive electrically conductive strips made from nanocomposites of noble metal and indium tin oxide (ITO) are being developed for use in gas turbine engines and other power-generation systems in which gas temperatures can exceed 1,500°F (about 816°C). In general, strain gauges exhibit spurious thermally induced components of response denoted apparent strain. When temperature varies, a strain-gauge material that has a nonzero temperature coefficient of resistance (TCR) exhibits an undesired change in electrical resistance that can be mistaken for the change in resistance caused by a change in strain. It would be desirable to formulate strain-gauge materials having TCRs as small as possible so as to minimize apparent strain.

Most metals exhibit positive TCRs, while most semiconductors, including ITO, exhibit negative TCRs. The present development is based on the idea of using the negative TCR of ITO to counter the positive TCRs of noble metals and of obtaining the benefit of the ability of both ITO and noble metals to endure high temperatures. The noble metal used in this development thus far has been platinum. Combinatorial libraries of many ceramic strain gauges containing nanocomposites of various proportions of ITO and platinum were fabricated by reactive co-sputtering from ITO and platinum targets onto alumina- and zirconia-based substrates mounted at various positions between the targets. TCR values of the sensors were determined from measurements made in thermal cycling between room