



Materials & Coatings

High-Temperature, Lightweight, Self-Healing Ceramic Composites for Aircraft Engine Applications

Applications include the nuclear power generation industry and military ships.

John H. Glenn Research Center, Cleveland, Ohio

The use of reliable, high-temperature, lightweight materials in the manufacture of aircraft engines is expected to result in lower fossil and biofuel consumption, thereby leading to cost savings and lower carbon emissions due to air travel. Although nickel-based superalloy blades and vanes have been successfully used in aircraft engines for several decades, there has been an increased effort to develop high-temperature, lightweight, creep-resistant substitute materials under various NASA programs over the last two decades. As a result, there has been a great deal of interest in developing SiC/SiC ceramic matrix composites (CMCs) due to their higher damage tolerance compared to monolithic ceramics. Current-generation SiC/SiC ceramic matrix composites rely almost entirely on the SiC fibers to carry the load, owing to the premature cracking of the matrix during loading. Thus, the high-temperature usefulness of these CMCs falls well below their theoretical capabilities.

The objective of this work is to develop a new class of high-temperature, lightweight, self-healing, SiC fiber-reinforced, engineered matrix ceramic composites. Several engineered matrices

were designed to be thermally compatible with SiC. Several different tests were conducted on these matrices, which helped to down-select suitable compositions. Engineered matrix composites (EMCs) designed to match the coefficient of thermal expansion (CTE) of the SiC fiber were fabricated by slurry casting and melt infiltration techniques. The matrix composition was designed to convert any ingressed oxygen into low-viscosity oxides or silicates so they can flow into the cracks due to capillary action and seal them, thereby activating its self-healing properties.

The present concept uses the fundamental principles of physics and materials science to develop a new class of self-healing ceramic composites (SHCCs). Unlike current SiC/SiC CMC technology, the present concept develops SiC fiber-reinforced SiC-Si₃N₄-silicide matrix composites with a composition formulated to match the CTE of the fibers, and with an ability to get ingressed oxygen and self-heal cracks by filling them with low-viscosity oxides.

The present concept provides considerable flexibility in designing the composite matrix for a wide variety of high-

temperature applications. Depending on the composition, silicides deform plastically at high temperatures, unlike SiC and Si₃N₄. Thus, the matrix is likely to be compliant to the applied loading conditions at high temperatures rather than develop cracks. This important feature allows the matrix to carry some load before transferring to the reinforcing SiC fibers, extending the life of the composite. The ability of these matrices to self-heal fine cracks is also expected to increase composite life. For matrices containing (Cr,Mo)₃Si, the expected amount of free silicon after melt infiltration is expected to be low, which would allow composites made with this engineered matrix to be used in applications at or above 1,755 K.

This work was done by Sai V. Raj of Glenn Research Center, and Mrityunjay Singh and Ramkrishna Bhatt of the Ohio Aerospace Institute. 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-18964-1.

Treatment to Control Adhesion of Silicone-Based Elastomers

Ultraviolet radiation is used to control and decrease the level of adhesion.

John H. Glenn Research Center, Cleveland, Ohio

Seals are used to facilitate the joining of two items, usually temporarily. At some point in the future, it is expected that the items will need to be separated. This innovation enables control of the adhesive properties of silicone-based elastomers. The innovation may also be effective on elastomers other than the silicone-based ones. A technique has been discovered that decreases the level of adhesion of silicone-based elastomers to negligible levels. The new technique causes less dam-

age to the material compared to alternative adhesion mitigation techniques.

Silicone-based elastomers are the only class of "rubber-like" materials that currently meet NASA's needs for various seal applications. However, silicone-based elastomers have natural inherent adhesive properties. This stickiness can be helpful, but it can frequently cause problems as well, such as when trying to get items apart.

In the past, seal adhesion was not always adequately addressed, and has

caused in-flight failures where seals were actually pulled from their grooves, preventing subsequent spacecraft docking until the seal was physically removed from the flange via an extravehicular activity (EVA). The primary method used in the past to lower elastomer seal adhesion has been the application of some type of lubricant or grease to the surface of the seal. A newer method uses ultraviolet (UV) radiation — a mixture of UV wavelengths in the range of near ultravi-

olet (NUV) and vacuum ultraviolet (VUV) wavelengths. UV radiation also causes damage to the seal, with different wavelengths causing different levels of damage.

Low-wavelength VUV radiation attenuates rapidly; it is absorbed quickly and does not penetrate deeply into solids or gases. VUV is absorbed by air, thus does not reach the surface of Earth. Seals exposed to near-VUV radiation achieve the desired level of adhesion reduction without raising the seal leakage level. The radiation likely breaks weaker atomic bonds on long polymer molecules near the sur-

face, which can then cross-link with other molecules, thereby absorbing the weaker bonds and preventing adhesive bonds.

The novel feature of the innovation is that it uses near-VUV wavelength radiation to control and decrease the level of adhesion of silicone-based elastomers without significantly damaging the elastomer. It is expected that the innovation can be implemented using handheld radiation sources, thereby enabling the technique to be used on odd-shaped and very large parts.

The innovation has the potential to use off-the-shelf radiation sources in air,

thus circumventing the need for a vacuum chamber. Exposures could be done, for example, using a radiation “oven” through which a conveyor belt passes.

This work was done by Henry C. de Groh III, Bernadette J. Puleo, and Deborah L. Waters 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: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18948-1.

High-Temperature Adhesives for Thermally Stable Aero-Assist Technologies

These adhesives feature high thermal conductivity and increased thermal decomposition temperature.

Marshall Space Flight Center, Alabama

Aero-assist technologies are used to control the velocity of exploration vehicles (EVs) when entering Earth or other planetary atmospheres. Since entry of EVs in planetary atmospheres results in significant heating, thermally stable aero-assist technologies are required to avoid the high heating rates while maintaining low mass. Polymer adhesives are used in aero-assist structures because of the need for high flexibility and good bonding between layers of polymer films or fabrics. However, current polymer adhesives cannot withstand temperatures above 400 °C.

This innovation utilizes nanotechnology capabilities to address this need, leading to the development of high-temperature adhesives that exhibit high thermal conductivity in addition to increased thermal decomposition temperature. Enhanced thermal conductivity will help to dissipate heat quickly and effectively to avoid temperature rising to harmful levels. This, together with increased thermal decomposition temperature, will enable the adhesives to sustain transient high-temperature conditions.

A first principle analysis showed that enhancing the thermal conductivity of

the adhesive can have a beneficial impact on the high-temperature stability of aeroshells and inflatable structures. Silicones and polyimides are used as high-temperature adhesives, and prior efforts have been made to incorporate thermally conductive ceramic powders such as aluminum oxide and boron nitride into silicone formulations to increase thermal conductivity. These high loading levels of ceramic particles present several problems. Viscosity rises, necessitating the use of a solvent, which then needs to be removed at a later stage. Adhesive and mechanical properties deteriorate. A way to decrease the additive loading level while achieving the desired thermal performance was needed.

For conventional composite structures, a three-dimensional percolative network is required to achieve significant performance enhancement, which typically results in a high-volume loading of particles. In contrast, advances were made in creating a new paradigm in non-three-dimensional percolative composites. The emphasis is on nanoparticulate composites, but the concept applies equally well to all particulate composites

(i.e., both nanoscale and microscale). As a result, the desired thermal properties can be obtained at relatively low loading levels of nanoparticles, without the detrimental effect on processing and other properties, such as mechanical strength and bonding.

The thermal conductivity of silicone material can be significantly enhanced by adding high-aspect-ratio nanoparticles at relatively low levels. For example, the thermal conductivity is drastically increased by a factor of 3.7 when 10 wt % of high-aspect-ratio nanoparticles is added to a commercial silicone adhesive. In addition, it was shown that there is a synergistic effect when spherical nanoparticles and high-aspect-ratio particles are present. An array of samples that had unique nanoparticle characteristics and nanocomposite morphology was fabricated, and a set of characterization protocols was developed.

This work was done by Kenneth Eberts and Runqing Ou of NEI Corp. for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32899-1.