



## Composite Elastic Skins for Shape-Changing Structures

Anisotropic stiffness properties can be tailored for specific applications.

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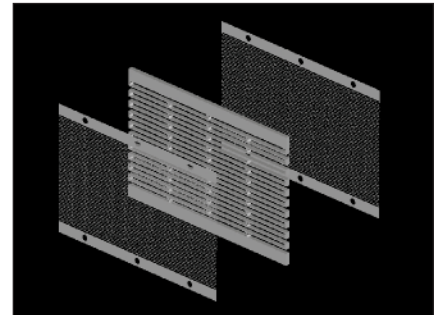
Composite elastic skins having tailorable mechanical properties have been invented for covering shape-changing (“morphable”) structures. These skins are intended especially for use on advanced aircraft that change shapes in order to assume different aerodynamic properties.

Many of the proposals for aircraft that could perform large aerodynamic shape changes require flexible skins that could follow shape changes of internal structures driven by actuators. Examples of such shape changes can include growth or shrinkage of bumps, conformal changes in wing planforms, cambers, twists, and bending of integrated leading- and trailing-edge flaps. Prior to this invention, there was no way of providing smooth aerodynamic surfaces capable of large deflections while maintaining smoothness and sufficient rigidity. Although latex rubber, silicone rubber, and similar conventional materials can be made into smooth coverings, they are not suitable for this purpose because, in order to impart required stiffness against out-of-plane bending, it would be necessary to make the coverings excessively thick, thereby necessitating the use of impractically large actuation forces.

The basic idea of the invention is that of smoothly wrapping an underlying variable structure with a smooth skin that

can be stretched or otherwise warped with low actuation force in one or both in-plane direction(s) and is relatively stiff against out-of-plane bending. It is envisioned that a skin according to the invention could be stretched as much as 20 percent in a desired direction. Because this basic idea admits of numerous variations, the following description is necessarily oversimplified for the sake of brevity.

A skin according to the invention can include one or more internal skeletal layer(s) made of a metal or a suitably stiff composite. By use of water-jet cutting, laser cutting, photolithography, or some other suitable technique, regular patterns of holes are cut into the skeletal layers (see figure). The skeletal layers are thereby made into planar springs. The skeletal layers are embedded in a castable elastomer. The anisotropic stiffness of the skin can be tailored through choice of the materials, the thicknesses of the skeletal and elastomeric layers, and the sizes and shapes of the cutouts. Moreover, by introducing local variations of thicknesses and/or cutout geometry, one can obtain local variations in the anisotropic stiffness. Threaded fasteners for attachment to actuators and/or the underlying structure are inserted in the internal skeleton at required locations.



**Metal Skeletal Layers Are Patterned** to obtain desired properties — in this case, to make them easily stretchable in the vertical direction but not in the horizontal direction. To complete the fabrication of a composite skin according to the invention, these metal skeletal layers would be embedded in an elastomeric sheet.

In one example typical of an important class of potential applications, the internal skeleton would be made less stiff in one in-plane direction. Such a skeleton would be desirable in an application in which the skin would be part of a hinge-like structure like a flap. In another example, the internal skeleton would be equally stiff in both in-plane directions, as would be desirable in application involving a planform change or a bump.

*This work was done by Christopher M. Cagle and Robin W. Schlecht of Langley Research Center. Further information is contained in a TSP (see page 1). LAR-16599-1*

## Glass/Ceramic Composites for Sealing Solid Oxide Fuel Cells

Ceramic fillers in a glass contribute to strength and fracture toughness.

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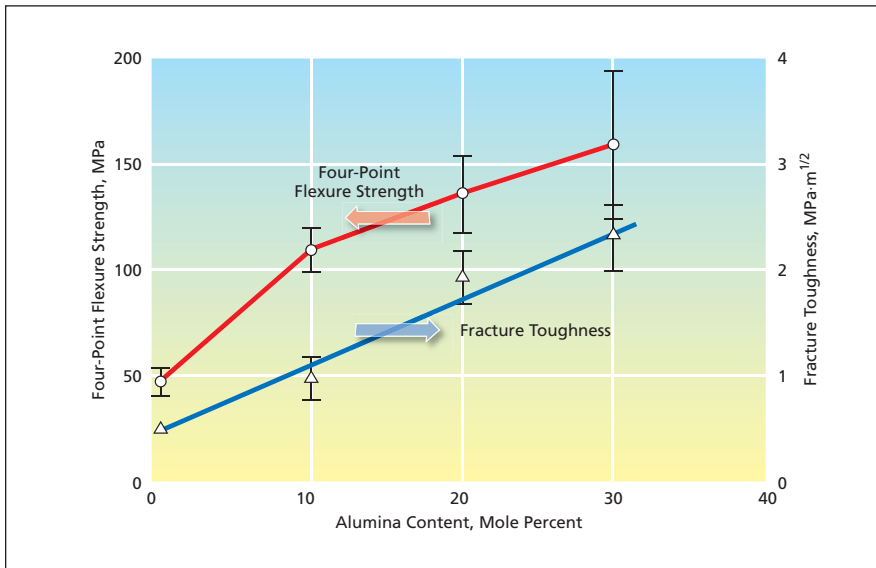
A family of glass/ceramic composite materials has been investigated for use as sealants in planar solid oxide fuel cells. These materials are modified versions of a barium calcium aluminosilicate glass developed previously for the same purpose. The composition of the glass in mole percentages is  $35\text{BaO} + 15\text{CaO} + 5\text{Al}_2\text{O}_3 + 10\text{B}_2\text{O}_3 + 35\text{SiO}_2$ . The glass seal was found to be susceptible to cracking during ther-

mal cycling of the fuel cells.

The goal in formulating the glass/ceramic composite materials was to (1) retain the physical and chemical advantages that led to the prior selection of the barium calcium aluminosilicate glass as the sealant while (2) increasing strength and fracture toughness so as to reduce the tendency toward cracking. Each of the composite formulations consists of the glass plus either

of two ceramic reinforcements in a proportion between 0 and 30 mole percent. One of the ceramic reinforcements consists of alumina platelets; the other one consists of particles of yttria-stabilized zirconia wherein the yttria content is 3 mole percent (3YSZ).

In preparation for experiments, panels of the glass/ceramic composites were hot-pressed and machined into test bars.



Four-Point Flexure Strength and Fracture Toughness were found to increase by factors of 2.3 and 3.5, respectively, with incorporation of 30 mole percent of alumina platelets.

Properties of the test bars, including four-point flexure strength, fracture toughness, modulus of elasticity, and density were determined. Four-point flexure strength and fracture toughness were found to increase with alumina or 3YSZ content (see figure). For the same mole percentage of ceramic, the increases in strength and fracture toughness were greater in the composites containing alumina than in the composites containing 3YSZ.

*This work was done by Narottam P. Bansal of Glenn Research Center and Sung R. Choi of the University of Toledo. 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-17905-1.*