



## Refractory Ceramic Foams for Novel Applications

Properties could be tailored for specific uses as insulators, filters, or catalyst supports.

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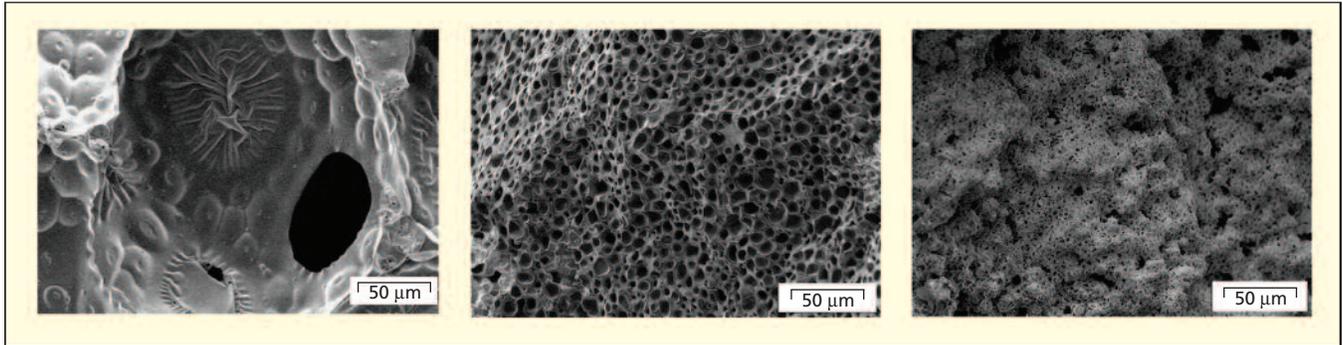


Figure 1. These Microstructures Are Typical of ceramic foams made by pyrolysis of preceramic polymers with sacrificial blowing agents and/or sacrificial fillers.

Workers at NASA Ames Research center are endeavoring to develop durable, oxidation-resistant, foam thermal protection systems (TPSs) that would be suitable for covering large exterior spacecraft surfaces, would have low to moderate densities, and would have temperature capabilities comparable to those of carbon-based TPSs [reusable at 3,000 °F ( $\approx 1,650$  °C)] with application of suitable coatings. These foams may also be useful for repairing TPSs while in orbit. Moreover, on Earth as well as in outer space, these foams might be useful as catalyst supports and filters.

Preceramic polymers are obvious candidates for use in making the foams in question. The use of these polymers offers advantages over processing routes followed in making conventional ceramics. Among the advantages are the ability to plastically form parts, the ability to form pyrolyzed ceramic materials at lower temperatures, and the ability to form high-purity microstructures having properties that can be tailored to satisfy requirements.

Heretofore, preceramic polymers have been used mostly in the production of such low-dimensional products as fibers because the loss of volatiles during pyrolysis of the polymers leads to porosity and large shrinkage (in excess of 30 percent). In addition, efforts to form bulk structures from preceramic polymers have resulted in severe cracking during pyrolysis. However, because the foams in question would consist of networks of thin struts (in contradistinction

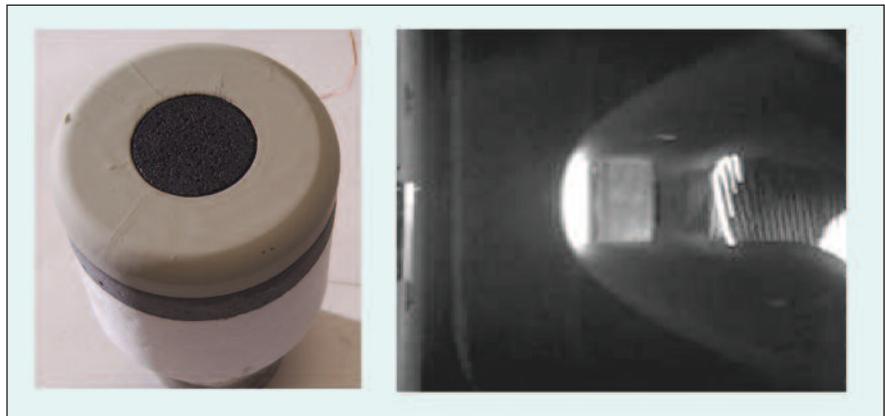


Figure 2. An Arc Jet Test Model is shown before and during testing. The material specimen to be tested is the black disk in the center.

to nonporous dense solids), these foams are ideal candidates for processing along a preceramic-polymer route.

The present research explores the feasibility of forming ceramic foams using sacrificial blowing agents and/or sacrificial fillers in combination with preceramic polymers. The possibility of using reactive fillers in combination with the aforementioned ingredients is also investigated. The use of such reactive fillers as Ti or Si reduces the large shrinkage observed in pyrolysis of polymers. The fillers also react with excess carbon that, in the absence of such reaction, would be present in the foam pyrolysis products. A reactive filler becomes converted to a ceramic material with an expansion that reduces overall shrinkage in the pyrolyzed part. The expansion of the reac-

tive filler thus compensates for the shrinkage of the polymer if the appropriate volume fraction of filler is present in a reactive atmosphere (e.g.,  $N_2$  or  $NH_3$ ).

Previously, this reactive-filler approach yielded limited success in efforts to make fully dense structural composite materials (in contradistinction to foams). However, in the present research, this reactive-filler approach has been modified to enable processing of foams with minimal shrinkage.

Figure 1 shows representative foam microstructures. In all cases, the foams are isotropic, open-celled structures. Foams processed by use of a polyurethane blowing agent have large cell sizes (50 to 500  $\mu m$ ), whereas foams processed by incorporating sacrificial fillers (e.g., polymer microspheres) generally have much

smaller cell sizes (as low as 3  $\mu\text{m}$ , depending on the diameter of the starting sacrificial filler particles). In all three micrographs of Figure 1, it is evident that the original unpyrolyzed structure is retained after pyrolysis, without loss of spherical cell shape.

In preliminary tests, specimens of SiC foams made by processing from pre-ceramic polymers were exposed to arc jets, which are traditionally used to simulate the aerothermal heating environments experienced by spacecraft entering or re-entering a planetary atmosphere. These tests were con-

ducted in the NASA Ames 60-MW Interaction Heating Facility (IHF), wherein flowing air is heated by an electric discharge. In these tests, disk specimens of 1.5-in. (3.81-cm) diameter and 0.5-in. (1.27-cm) thickness were mounted in an SiC-coated graphite holder and exposed to a temperature of 1,650  $^{\circ}\text{C}$  for 90 seconds (see Figure 2). The specimens showed minimal degradation after exposure.

In summary, the use of pre-ceramic polymers with the addition of sacrificial blowing agents and sacrificial and/or reactive fillers offers a feasible approach to

forming open-cell ceramic foams. Moreover, it has been found that refractory ceramic foams having properties that are encouraging for further development can be made using processing temperatures that, for ceramics, are relatively low ( $\approx 1,200$   $^{\circ}\text{C}$ ). This approach enables tailoring of such foam properties as composition, pore size, and strength by varying the processing conditions.

*This work was done by M. Stackpoole of ELORET for Ames Research Center. Further information is contained in a TSP (see page 1). ARC-15260-1*

## Self-Deploying Trusses Containing Shape-Memory Polymers

Compacted structures can be used in shelters for hostile environments.

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Composite truss structures are being developed that can be compacted for stowage and later deploy themselves to full size and shape. In the target applications, these “smart” structures will precisely self-deploy and support a large, lightweight space-based antenna. Self-deploying trusses offer a simple, light, and affordable alternative to articulated mechanisms or inflatable structures. The trusses may also be useful in such terrestrial applications as variable-geometry aircraft components or shelters that can be compacted, transported, and deployed quickly in hostile environments.

The truss technology uses high-performance shape-memory-polymer (SMP) thermoset resin reinforced with fibers to form a helical composite structure. At normal operating temperatures, the truss material has the structural properties of a conventional composite. This enables truss designs with required torsion, bending, and compression stiffness. However, when heated to its designed glass transition temperature ( $T_g$ ), the SMP matrix acquires the flexibility of an elastomer. In this state, the truss can be compressed telescopically to a configuration encompassing a fraction of its original volume.

When cooled below  $T_g$ , the SMP reverts to a rigid state and holds the truss in the stowed configuration without external constraint. Heating the materials above  $T_g$  activates truss deployment as the composite material releases strain energy, driving the truss to its original “memorized” configuration without the



**Activation Sequence** of an early prototype self-deploying truss shows one one-minute duration from compressed [2.5 in. (6.4 cm)] to deployed [28.5 in. (72.4 cm)].

need for further actuation. Laboratory prototype trusses have demonstrated repeatable self-deployment cycles following linear compaction exceeding an 11:1 ratio (see figure).

While this new truss technology exhibits some functionality similar to that of cold hibernated elastic memory (CHEM) structures developed in other NASA-sponsored research (previously reported in *NASA Tech Briefs*), there are important distinctions. First, the CHEM SMP is based on a thermoplastic resin, while the new truss material's high-performance SMP is a fully cured thermoset resin. The high-perform-

ance SMP molecular design has been implemented in a variety of resin systems, enabling resin selection for desired structural properties while enabling selection of a required  $T_g$  (e.g., 25–225  $^{\circ}\text{C}$  achievable in high-performance SMPs based on cyanate ester). Also, CHEM-based structures use unreinforced foam as the active component. In the new composite truss design, the high-performance SMP is integral to the structure, simplifying the design and increasing the savings in mass, cost, and system complexity. Structures employing high-performance SMP are fabricated using the