



## High-Temperature Shape Memory Polymers

The shape memory behavior is provided by a non-polymer additive.

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Shape memory materials undergo physical conformation changes when exposed to an external stimulus, such as a change in temperature. Such materials have a permanent shape, but can be reshaped above a critical temperature and fixed into a temporary shape when cooled under stress to below the critical temperature. When reheated above the critical temperature ( $T_c$ , also sometimes called the triggering or switching temperature), the materials revert to the permanent shape.

The current innovation involves a chemically treated (sulfonated, carboxylated, phosphonated, or other polar function group), high-temperature, semicrystalline thermoplastic poly(ether ether ketone) ( $T_g \approx 140^\circ\text{C}$ ,  $T_m = 340^\circ\text{C}$ ) mix containing organometallic complexes ( $\text{Zn}^{++}$ ,  $\text{Li}^+$ , or other metal, ammonium, or phosphonium salts), or high-temperature ionic liquids (e.g. hexafluorosilicate salt with 1-propyl-3-methyl imidazolium,  $T_m = 210^\circ\text{C}$ ) to form a network where dipolar or ionic

interactions between the polymer and the low-molecular-weight or inorganic compound forms a complex that provides a physical crosslink. Hereafter, these compounds will be referred to as “additives.” The polymer is semicrystalline, and the high-melt-point crystals provide a temporary crosslink that acts as a permanent crosslink just so long as the melting temperature is not exceeded. In this example case, the melting point is  $\approx 340^\circ\text{C}$ , and the shape memory critical temperature is between  $150$  and  $250^\circ\text{C}$ . PEEK is an engineering thermoplastic with a high Young’s modulus, nominally  $3.6\text{ GPa}$ .

An important aspect of the invention is the control of the PEEK functionalization (in this example, the sulfonation degree), and the thermal properties (i.e. melting point) of the additive, which determines the switching temperature. Because the compound is thermoplastic, it can be formed into the “permanent” shape by conventional plastics processing operations. In addition, the

compound may be covalently crosslinked after forming the permanent shape by S-PEEK by applying ionizing radiation ( $\gamma$  radiation, neutrons), or by chemical crosslinking to form a covalent permanent network.

With respect to other shape memory polymers, this invention is novel in that it describes the use of a thermoplastic composition that can be thermally molded or solution-cast into complex “permanent” shapes, and then reheated or redissolved and recast from solution to prepare another shape. It is also unique in that the shape memory behavior is provided by a non-polymer additive.

*This work was done by Mitra Yoonessi of Glenn Research Center and Robert A. Weiss of the University of Akron. 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-18756-1.*

## Modular Flooring System

Lighter material is easier to transport and assemble.

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The modular flooring system (MFS) was developed to provide a portable, modular, durable carpeting solution for NASA’s Robotics Alliance Project’s (RAP) outreach efforts. It was also designed to improve and replace a modular flooring system that was too heavy for safe use and transportation. The MFS was developed for use as the flooring for various robotics competitions that RAP utilizes to meet its mission goals. One of these competitions, the FIRST Robotics Competition (FRC), currently uses two massive rolls of broadloom carpet for the foundation of the arena in which the robots are contained during the competition. The area of the arena is approximately  $30$  by

$72\text{ ft}$  ( $\approx 9$  by  $22\text{ m}$ ). This carpet is very cumbersome and requires large-capacity vehicles, and handling equipment and personnel to transport and deploy. The broadloom carpet sustains severe abuse from the robots during a regular three-day competition, and as a result, the carpet is not used again for competition. Similarly, broadloom carpets used for trade shows at convention centers around the world are typically discarded after only one use. This innovation provides a green solution to this wasteful practice.

Each of the flooring modules in the previous system weighed  $44\text{ lb}$  ( $\approx 20\text{ kg}$ ). The improvements in the overall design of the system reduce the weight

of each module by approximately  $22\text{ lb}$  ( $\approx 10\text{ kg}$ ) ( $50\%$ ), and utilize an improved “module-to-module” connection method that is superior to the previous system.

The MFS comprises  $4\text{-by-4-ft}$  ( $\approx 1.2\text{-by-1.2-m}$ ) carpet module assemblies that utilize commercially available carpet tiles that are bonded to a lightweight substrate. The substrate surface opposite from the carpeted surface has a module-to-module connecting interface that allows for the modules to be connected, one to the other, as the modules are constructed. This connection is hidden underneath the modules, creating a smooth, co-planar flooring surface. The modules are stacked and strapped