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Shape memory epoxy foams and composites: ribes_foam2 experiment on spacecraft "bion-m1" and future perspective

L. Santo [a], F. Quadrini [a], W. Villadei [b], G. Mascetti [c], V. Zolesi[d,]*

[a] *Industrial Engineering Dep., University of Rome "Tor Vergata", Via del Politecnico 1, 00133 Rome, Italy*
[b] *Italian Air Force, Head Quarter, Viale dell'Università ,4, 00185 Rome, Italy*
[c] *Italian Space Agency, Via del Politecnico snc, 00133 Rome, Italy*
[d] *Kayser Italia s.r.l., Via di Popogna, 501, 57124 Livorno, Italyl*

Abstract

Shape memory epoxy foams and composites were tested in April 2013, on board the BION-M1 spacecraft through the Soyuz-2 launch vehicle, with the aim to study their behaviour in microgravity for future applications. The on-orbit Ribes_Foam2 experiment consisted in the heating of three samples in various configurations having different shapes (a prototype of actuator, a sheet of composite laminate and parallelepiped) packed on ground, to evaluate the shape recovery capabilities in the space environment. As expected, micro-gravity does not affect the ability of the samples to recover their shape in these configurations but it poses limits for the heating system design because of the difference in heat transfer on earth and on orbit. In this work, the main results of the experiment are discussed. They have provided useful information for the development of actuators and deployable structure, highlighting future perspectives.

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Keywords: cellular (foam) structures, polymer foams, shape memory polymers, heat treatment

Introduction

Shape memory polymers (SMPs) are a new class of materials for aerospace applications as light actuators, structural parts with reduced size during transport, and expandable/deployable structures [1]. The shape memory

* Corresponding author.
E-mail address: sntldn00@uniroma2.it

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effect can be observed by performing a typical thermo-mechanical cycle [2]. Firstly, the polymer is processed to receive its permanent shape. Secondly, it is heated and deformed in a new configuration that can be stored by cooling. Heating up the stored sample above a transition temperature it recovers its original shape. This concept has been also applied to open cellular (foam) structures and the presence of pores can magnify shape memory effects also in polymers with low memory properties. Moreover, the material can be packed in a very small volume because of pore collapsing, without generating any foam damage [3].

A new foaming process for thermosetting resin, called solid-state foaming, was proposed by the authors in order to obtain polymer foams [4-5]. This method is simpler than conventional foaming methods and gives homogeneous closed-cell foams with excellent mechanical properties and remarkable shape memory properties. In the solid-state foaming process, uncured thermosetting tablets are fabricated by pressing commercial powders in a steel mould at room temperature and used as foam precursors. The tablets foam when heated in an oven at high temperature. No blowing agent must be added because the foaming mechanism depends on the uncured resin boiling point.

Shape memory properties can be also given to composite materials and structures by using shape memory polymers (SMPs) matrices or integrating parts made of SMPs [6-7]. Some examples are reported in [7] where shape memory composite tubes and plates were fabricated by adding a shape memory layer between two carbon fibre reinforced skins. An optimal adhesion between the different layers was achieved thanks to the compatibility of the prepreg matrix and the shape memory material. Shape memory composite structures were also produced by joining composite shells with shape memory foams. Some mechanical, dynamic mechanical and shape recovery tests were performed to show the properties of such materials and structures. Results confirmed the ability of this class of materials to easily change their shape without affecting the mechanical stiffness of the recovered structures.

Thanks to their properties, epoxy foams by solid-state foaming were selected to build prototypes of actuators for space applications [5] and subsequently, prototypes of shape memory epoxy foams were built for an experiment on the International Space Station (ISS) during the final space shuttle mission NASA STS 134 [8-9]. Micro-gravity does not affect the ability of the foams to recover their shape but it poses strong limits for the heating system design because of the difference in heat transfer on earth and in orbit [8]. A full recovery of the foam samples was not achieved due to some limitations in the maximum allowable temperature on ISS for safety reasons. A 70% recovery was measured at a temperature of 110°C and on ground laboratory experiments showed that 100% recovery is reached just by increasing the maximum temperature to 120 °C.

For the ISS experiment (I-FOAM) [8], a small equipment was designed and built to simulate the actuation of simple devices in microgravity conditions. Three different configurations were chosen according to previous studies (compression, flexure and torsion) [8]. The same equipment has been also used also in the following experiment (Ribes_Foam2) during the Russian BION-M1 mission of the Soyuz spacecraft (20th of April 2013) in which for the first time a shape memory polymer composite (SMC) sheet was also prototyped [9]. Main results from this second experiment are discussed in this paper with the aim to highlight future perspective in the field.

1. Materials and methods

1.1 Materials and samples production

A commercial epoxy resin (3M ScotchkoteTM 206 N), which is available as an uncured green powder, has been used for the samples production. The solid-state foaming process has been used for the foam preparation [4]. Tablets with a weight of 4g and a diameter of 20 mm were made by compaction at room temperature of the resin powder in a steel mold. The tablets were foamed by using a muffle at 320°C for 8 min. Both foaming and successive cooling were performed in air. The final epoxy foam density was about 0.36 g/cm^3 with a foaming ratio close to 4. Two foam blocks were extracted by machining from the initial cylindrical foams. The first block (24x8x8 mm^3) was used for the compression configuration, and the second block (nominal size 14x8x8 mm^3) for the actuator. The memory step was made by heating the samples in an aluminum mold having the cavity equal to the sample cross section (8x8 mm^2); this way buckling was avoided during compression by a piston of the same size. The compression load was kept on the piston during the mold cooling. At the end of the memory step, a 50% reduction was obtained for the height of both samples whereas the other two sizes remained unaltered.

The sample with compression configuration is then placed in an aluminum housing with three holes for optic