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Mission STS-134: Results of Shape Memory Foam Experiment[☆]

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ABSTRACT

Shape memory epoxy foams were used for an experiment aboard the International Space Station (ISS) to evaluate the feasibility of their use for building light actuators and expandable/deployable structures. The experiment named I-FOAM was performed by an autonomous device contained in the BIOKON container (by Kayser Italia) which was in turn composed of control and heating system, battery pack and data acquisition system. To simulate the actuation of simple devices in micro-gravity conditions, three different configurations (compression, bending and torsion) were chosen during the memory step of the foams so as to produce their recovery on ISS. Micro-gravity does not affect the ability of the foams to recover their shape but it poses limits for the heating system design because of the difference in heat transfer on Earth and in orbit. A recovery about 70% was measured at a temperature of 110 °C for the bending and torsion configuration whereas poor recovery was observed for the compression case. Thanks to these results, a new experiment has been developed for a future mission by the same device: for the first time a shape memory composite will be recovered, and the actuation load during time will be measured during the recovery of an epoxy foam sample.

1. Introduction

In recent years, new materials with high performances or novel functionalities have been developed for aerospace applications. Shape memory materials have attained the interest of researchers to build self-deployable structures or actuators but shape memory alloys (SMA) have been preferred for a long time. In 2002, an innovative hold down/release and deployment device actuated by shape memory wires (Nitinol) was designed [1]. In 2004, a nano-muscle SMA actuator was designed as well [2]. In 2006, a SMA actuator was used in the gas release mechanism for the Rosetta Lander's Ptolemy instrument [3]. In 2008, an actuator with SMA working with the sun's heat was designed and a prototype was tested [4]. In 2008, SMAs were used for a new concept of space power generation that exploited cycles of dilatation and contraction of a spinning tethered system exposed to solar radiation [5]. Despite of their high force, long stroke, small size, light weight, silent operation, SMA actuators pose serious problems because of their poor stability and controllability [6]. More recently, SMAs have been evaluated also for building adaptive beams [7] or cantilever wings [8] but problems about a careful control of the material recovery are still

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open. A possible solution can be provided by using a different class of shape memory materials, i.e. shape memory polymers (SMPs). SMPs can change their shape on exposure to an external stimulus, that is mainly heat, but light, electric and magnetic fields may also be used.

A typical thermo-mechanical cycle permits to observe the shape memory effect on SMPs. It consists of three main stages. In the first, the material is processed to receive its permanent shape; in the second, it is heated and deformed in a new configuration that is stored by cooling. In the third stage, heating up above a characteristic temperature (which is generally the glass transition temperature for thermoset polymers) it recovers its original shape. The subsequent cooling of the polymer below the transition temperature leads to the material stiffening and no further recovery of the temporary shape can be observed (one-way shape memory effect). The described thermo-mechanical cycle can be repeated more than once [9,10]. In literature, studies about fiber reinforced [11], nanocomposite [12], polyurethane-based [13] and epoxy based materials [14,15] are reported. In the case of polymer foams, an interesting concept, so-called cold hibernated elastic memory (CHEM) has been discussed [10,16]. A structure of any shape is compacted to a very small volume in a flexible state above the transition temperature and later cooled below this temperature to a glassy state. The external compacting forces are removed when the stowed structure is frozen and the part can be stored in a cold hibernate state for nearly unlimited time below transition temperature. A compacted part can be heated above the transition temperature to a flexible state and the original shape will be restored by simultaneous foam elastic recovery and SMP effect. This procedure is very interesting for a fully deployed structure that can also be re-compacted. CHEM solutions were designed for space applications and some data by NASA are available on the web. PU shape memory polymer foams were generally used because they exhibit combination of the hard-soft transition with the collapsible structure of the foam. As a result, they have shown interesting thermo-mechanical properties in terms of strain recovery and shape fixity. Main disadvantages in their use are the impossibility for the long-term and high-load working application. In fact, due to the relatively low glass transition temperature (maximum 70 °C), PU-SMPs tend to recover the initial shape also in cold hibernation, and show low stiffness, which results in small actuation load. Better results have been achieved by using epoxy resins [15]. Also in this case, epoxy foams behave better than bulk samples, showing a recovery about 90% of the compressive strain. Common methods for producing epoxy foams are generally complex and expensive, and chemical and processing details of the materials are generally proprietary. A new foaming process for thermosetting resin, so-called solid-state foaming, has been used by the authors [17]. This process is able to produce high performance foams starting from a thermosetting powder without any addition of blowing agents; it is low cost and time effective. The obtained foams exhibit high shape memory properties and are very interesting for space application [18]. In order to evaluate the behavior of this new class of materials, an experiment has been designed [19] and performed in microgravity onboard the ISS [20]. It was found that microgravity does not affect the shape recovering because recovery loads are so high to

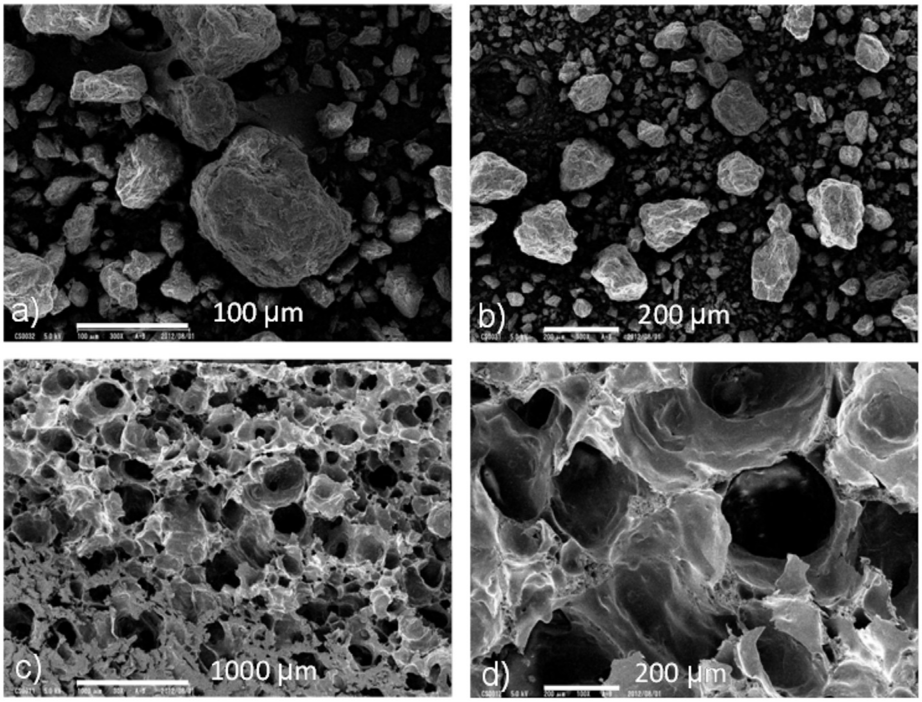

Fig. 1. SEM images with different magnifications of the thermosetting powder (a–b) and the epoxy foam cross-section (c–d), courtesy of Prof. Makio Naito, "Joining and Welding Research Institute" (JWRI) at the Osaka University.