SHAPE-MEMORY POLYMER BASED COMPOSITE MATERIALS AND THEIR APPLICATIONS

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1 General Introduction

Shape-memory polymers (SMPs) are able to recover their original shape upon exposure to an external stimulus. The shape-memory phenomenon in SMPs arises from a dual segment system, in which one segment is highly elastic and the other is able to remarkably reduce its stiffness in the presence of a particular stimulus [1]. SMPs have a far higher recoverable strain (up to 400%), much lower density, more convenient processing and fabrication techniques, and properties that are more easily tailored to better accommodate the requirements of a particular application than the shape-memory alloys (SMAs). In addition to these advantages, low cost-not only for the materials themselves but also in processing and fabrication-enables the use of SMPs for a wide range of applications [2]. In this article, synthesis of two novel thermosetting SMP, fiber reinforced SMP composites (SMPCs) and their electrical activation, as well as the applications of SMPCs are discussed.

2 SMP composites (SMPCs)

The main limitation of thermoplastic SMPs for the application is irreversible deformation during memory programming due to the creep. The styrene-based and epoxy-based thermosetting SMPs that, unlike traditional thermoplastic SMP, are capable of high thermomechanical properties are reported. Therefore, we introduced chemical crosslinks to improve in creep, strain recovery rate and strain fixity rate, where they are important quantities for describing shape-memory effect. Additionally, experimental results reveal that these two novel thermosetting SMPs have wider transition temperature from 37 to 150^{o}C, higher shape recovery ratio ranged from 90 to 99%, higher elastic modulus of 2 to 3 GPa at room temperature, *etc*.

SMPs can be activated not only by heat/magnetism (similar to SMAs), but also by light/moisture and even a change of pH value. The utilization of electricity to induce the SMPs is desirable owing to controllable and effective. Extensive research have been done on conductive SMPCs by blending conductive fillers, including carbon black [3], conductive hybrid fibers, chained Ni powder [4] and continuous carbon fibers. We currently introduce carbon-based nanopaper to the SMP, and carbon nanofibers (CNFs) were blended to facilitate heat transfer and improve electro-active response of the SMP nanocomposite, as shown in Figure 1 [5]. Beyond this, light-induced SMPs has been realized through the incorporation of optic fiber and radiation absorporative particles that act as heat delivery system. Upon irradiation with light of a suitable wavelength, the light is sent through the heat delivery system to trigger the SMP [6]. Recently, indirect activation by means of lowering the transition temperature of SMP has been achieved. As immersed into a special chemical solvent, solvent molecules diffuse into the polymer network and act as plasticizers, resulting in shape recovery [7].

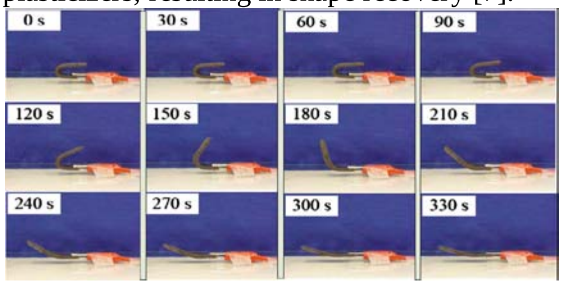

Fig. 1. Series of photographs demonstrating the macroscopic shape memory effect of the SMP composite. The permanent shape is a flat strip, and the temporary shape is a right-angle shape. Reprinted with permission from Reference 5. ©2010, American Institute of Physics.

However, the pure SMPs in general exhibit lower strength and stiffness, which limits their use for many applications. The low stiffness produces a small recovery force in the process of temperature transition. Thus incorporation of reinforcing fillers have been investigated to improve the mechanical properties and diversify the applications of SMPs. It was reported increase in elastic modulus, due to the incorporation of SiC. The increase in failure stress and decrease in recovery rate had been demonstrated, as a result of addition of glass fiber. Similar observation was reported for SMPCs by using carbon fiber reinforcement [2].

3 Applications of SMPCs

Continuous fiber reinforced SMPCs currently cover a broad range of application areas ranging from outer space to automobiles. Recently, they are being developed and qualified especially for deployable hinges, trusses, antennas and smart mandrels, as well as morphing skin. And a deployable SMPC hinge that consists of two curved shells is placed together in opposing directions [8]. Figure 2 shows the deploy process of the prototype of a solar array actuated by carbon fiber reinforced SMPC hinge. The solar arrays were suspended on a setup that simulated a zero-gravity environment. Applied by a 20 V, the hinge was bent to a storage angle of 90^o by the application of an external force at 80^oC. After fixing the deformed shape at room temperature, the hinge was heated again by applying the same voltage. The solar array was deployed in 80s.

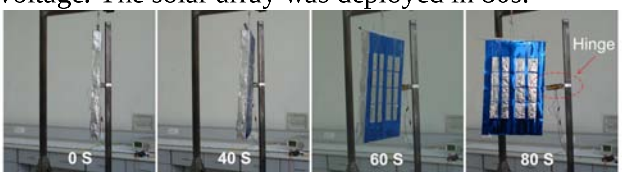

Fig. 2. Shape recovery process of a solar array prototype actuated by an SMPC hinge. Reprinted with permission from Reference 8. ©2009, Institute of Physics and IOP Publishing.

Based on the actuation of fiber reinforced SMPC in large deflection deformation, we discuss its mechanism that is required for design principle of deployable structure. The strain energy expression of the SMP/fiber system was derived. According to the minimum energy principle, the expression for all key parameters was derived, including critical buckling curvature and neutral plane position, *etc*. Based on the microbuckling of carbon fiber, SMPC realizes large geometrical deflection deformation. Moreover, we achieve the morphing skin from SMPC by designing a wear flexible training-edge wing. Furthermore, the wind vibration analyses have already been conducted.

We have recently witnessed rapid development in SMPs and SMPCs. Their advantages have attracted attention from academic researchers as well as industrial engineers. Although a number of applications have been identified, many more products are currently being developed. With the further development and the emergence of new types of SMPs and SMPCs, the range of applications is expected to expand more widely in the near future.

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