RECENT PROGRESS IN MULTI-FUNCTIONAL SOFT SMART MATERIALS AND THEIR APPLICATIONS

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Summary Soft smart polymers can change their shapes with respect to configuration or dimension upon exposure to a particular stimulus such as heat, electricity, light, magnetic, solvent and pH value. These unique characteristics enable stimulus-active polymers to be used in a myriad of fields, including clothing manufacturing, automobile engineering, medical treatment, and aerospace engineering. Soft smart polymers can be applied in smart textiles and apparels, intelligent medical instruments and auxiliaries, artificial muscles, biomimetic devices, heat shrinkable materials for electronics packaging, micro-electro-mechanical systems, self-deployable sun sails in spacecrafts, miniature manipulator, actuators and sensors, and many more. This paper presents some recent progress of soft smart materials and their applications. Special emphasis is focused upon shape memory polymer (SMP), electro-active polymer (EAP) for aerospace engineering such as space deployable structures and morphing aircraft, which has highlighted the need for development of these materials. A detailed overview of development in these smart soft materials, of which the undergoing and future applications are used in adaptive structures and active control, is presented. The paper concludes with a short discussion for multi-functional soft smart materials and their composites that are expected to extend the range of development and applications available to the related researches and engineers.

SHAPE-MEMORY POLYMER AND ITS APPLICATION

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 [1-2]. 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 [1-3]. SMPs can be activated not only by heat/magnetism (similar to SMAs), but also by light/moisture and even a change of pH value [1]. 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, conductive hybrid fibers, chained Ni powder 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 [4]. 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.

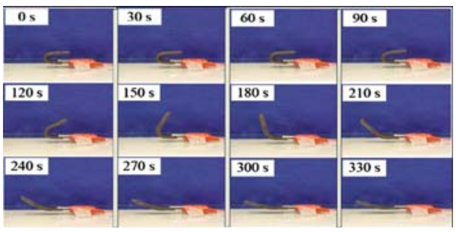

Figure 1 Series of photographs demonstrating the macroscopic shape memory effect of the SMP composite. The permanent shape is a flat strip, and the temporary shape is a right-angle shape [4].

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. 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 [5]. Figure 2 shows the deploy process of the prototype of a solar array actuated by carbon fiber reinforced SMPC hinge [5]. The solar arrays were suspended on a

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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 from 90^o to 0^o in 80s.

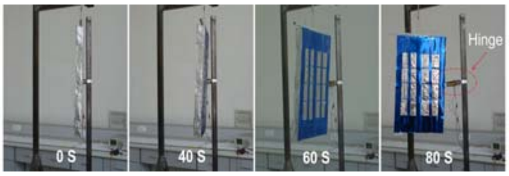

Figure 2 Shape recovery process of a solar array prototype actuated by an SMPC hinge [5].

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. 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.

ELECROACTIVE POLYMER AND ITS APPLICATIONS

Dielectric elastomers (DEs) is a type of electroactive polymer (EAP) with special mechanical and electrical performance, which could be used to develop lightweight, low-cost, compliant transducers. This is due to its remarkable properties, for example, super large deformation, high energy density, high efficiency and high responsive speed. Their potential applications include smart space robotics, energy harvesters, Braille display medical devices, and area of aeronautics and astronautics. Subject to a voltage through its thickness, a membrane of a dielectric elastomer reduces thickness and enlarges area. In order to offer guidance in the design and fabrication of excellent actuators featuring dielectric elastomers, we investigate nonlinear mechanical performance, nonlinear dielectric performance, large deformation, electromechanical stability and failure of application devices of electroactive polymer and its composites [6]. The $BaTiO_3$ based dielectric elastomer composite is fabricated and tested. The stress–strain relationship, dielectric constant and the electro-induced deformation of carbon nanotube based dielectric elastomer composite are also demonstrated. We have fabricated the rolled, folded, inflated and stacked actuators of dielectric elastomer and their mechanical and electrical properties are also investigated. Based on the stacked dielectric elastomer actuator, the energy harvest device and Braille display are designed and fabricated, and their performance demonstration is subsequently conducted [7].

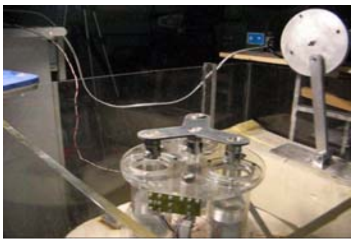
Figure 3 Photo of the ocean wave generator by using EAP energy harvesting devices [7].

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