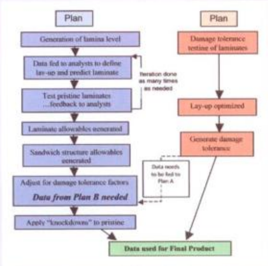

SMPs

Applications for shape-memory polymer composites in aerospace

The applications for shape-memory polymers and composites in aerospace have been widely studied since the 1980s. As shown in this paper, these promising smart materials are being particularly developed and qualified for space deployable structures, morphing structures, smart mandrels, optical reflectors, smart textiles and fabrics.

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Shape-memory polymers (SMPs) are able to respond to a specific external stimulus by means of certain significant macroscopic properties such as shape. The basic molecular architecture of SMPs is a polymer network underlying the active movement. An SMP must consist of dual-segments, one that is highly elastic and another that is able to reduce its stiffness upon a particular stimulus. The latter can be either molecular switches or stimulus-sensitive domains. Upon exposure to a specific stimulus, the switching/transition is triggered and strain energy stored in the temporary shape is released, which consequently results in shape recovery.

SMPs undergo significant macroscopic deformation upon the applicatio of an external stimulus (e.g., heat, electricity, light, magnetism, moisture and even a change in pH value) [1-2]. Thermo-responsive SMPs are the most common. At a macroscopic level, as illustrated in Figure 1, the typical thermomechanical cycle of a thermo-responsive SMP consists of

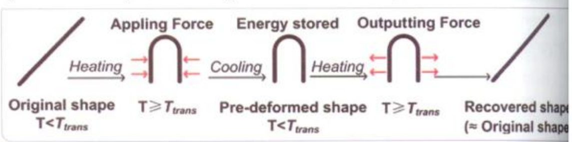

Fig.1: Schematic of shape-memory effect during a typical thermomechanical cycle [2]

the following steps: fabrication of the SMP into its original shape; heating the SMP above the thermal transition temperature (Ttrans) (either glass transition temperature, Tg, or melting temperature, Tm), and deformation of the SMP by applying an external force, cooling well below Ttrans, removal of the constraint to obtain a temporary predeformed shape; when needed, heating of the predeformed SMP above Ttrans, and then recovery of the SMP towards its original shape (recovered shape).

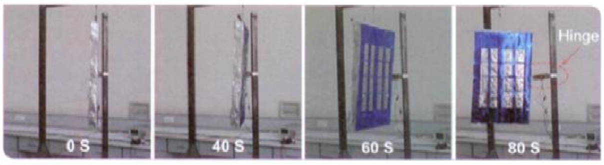

Fig. 4: Shape recovery process of a solar array prototype actuated by an SMPC hinge [5]

In addition to thermo-responsive SMPs, electro-activated SMPs have been developed and their significance will increase in the years to come [3]. As shown in Figure 2, carbon nanotubes (CNTs) were electrically induced into aligned chains in an SMP/carbon black (CB) composite and the fabricated conductive SMP composites could be actuated by a low electrical power [4]. The figure at right shows the sample dimension and experimental setup for Sample C.

Space deployable structures

For traditional aerospace deployable devices, the change of structural configuration in orbit is accomplished through the use of a mechanical hinge, stored energy devices or motor-driven tools. There are some inherent drawbacks to traditional devices, such as complex assembling processes, large volumes and undesired effects during deployment. In contrast, the deployment devices fabricated using SMPs and their composites may overcome certain disadvantages.

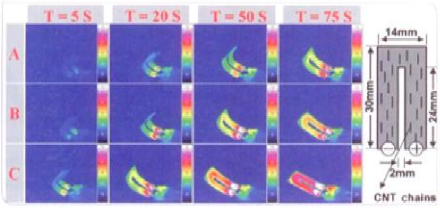

Fig. 2: Snapshots of shape recovery and temperature distribution [4]
Sample A: SMP/CB, Sample B: SMP/CB/CNT (random), Sample C: SMP/CB/CNT (chained).

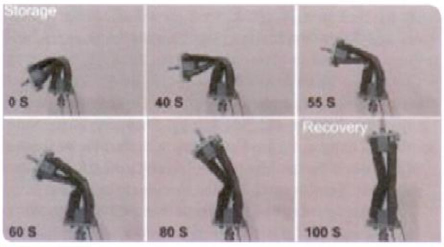

Fig. 3: Shape recovery process of an SMPC hinge [2]

A hinge [1-2] was designed using shape-memory polymer composites (SMPC). The SMPC hinge was then used to actuate a solar array prototype. The hinge consists of two curved circular SMPC shells. The weight of each piece of SMPC laminate is much lower than that of traditional devices. Figure 3 shows the deployment process of the SMPC hinge [2].

Figure 4 shows the deployment process of a solar array prototype which is actuated by an SMPC hinge [5]. Heated by a voltage, the SMPC hinge was bent to its original storage angle (folded state) upon applying an external force at a relatively soft state above the SPMC's T_g. After fixing the storage shape at room temperature, the SMPC hinge was heated again by applying the same voltage. The solar array prototype, actuated by the SMPC hinge, deployed from the folded state to the unfolded one, which, in practice, could let the solar array get more energy.

Morphing structures

Aircrafts are designed to be multi-functional in order to be able to perform more missions during one flight, combining features such as more efficient cruising and higher manoeuvrability. When an aircraft enters a different portion of its flight envelope, its performance may deteriorate rapidly. To solve this problem, researchers have proposed an in-flight shape change system for aircrafts. Accordingly, both the efficiency and flight envelope can be improved by adjusting the various shapes depending on the different targeted characteristics, such as speed, energy saving and manoeuvrability. Finding a proper skin under certain criteria is crucial. SMPs show more advantages for this application because their elastic moduli can be controllably changed by external stimuli.

A morphing concept of a variable camber wing [2] was developed, as shown in Figure 5. It comprises a flexible SMP

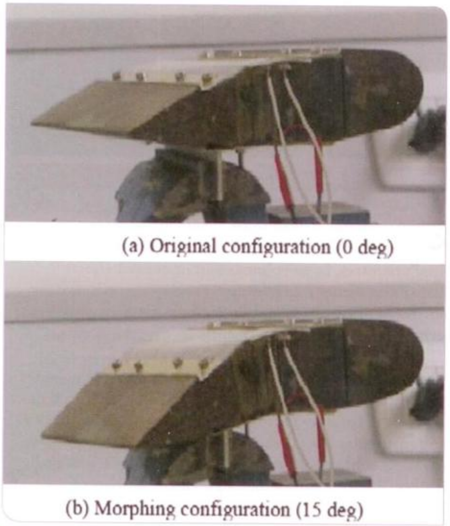

Fig. 5: Photograph of the original and morphing configurations of the variable camber wing [2]

skin, a metal sheet and a honeycomb structure. The metal sheet replaces the traditional hinges and keeps the surface smooth during the camber change. Honeycomb, which is high-strain capable in one direction without dimensional change in the perpendicular in-plane axis, provides distributed support to the flexible skin. The flexible SMP skin covers the wing to create a smooth aerodynamic surface.

Smart mandrels

Mandrels with sophisticated structures are used to fabricate moulded or filament-wound composite parts. Conventional mandrel processes use multi-piece metal or water-soluble mandrels. This solution is usually costly and requires substantial time and energy to remove the mandrels. For some multi-shaped aircraft parts such as air ducts, and bottle-shaped parts, it is quite difficult to lift out the mandrels. Due to their large reversible deformation properties, SMPs can be used to design smart mandrels with complicated shapes and further facilitate their extraction. These mandrels can maintain their dimensional accuracy like a traditional mandrel while being rapidly removable and reusable at low cost.

This way, SMP hollow mandrels were heated above Ttrans, the temperature at which the SMP becomes flexible and can expand in the limit of a metal mould with a cavity in the desired mandrel shape. The SMP was then cooled until it became hard again, resulting in an exact copy of the cavity. Filament was twined onto the SMP mandrel to form a composite part. After curing the composite, the SMP mandrel was reheated above Ttrans. This allowed the mandrel to return to its original shape for easy extraction. Figure 6 shows the carbon fibre reinforced composite parts which were formed from the shape-memory mandrels next to them.

Fig. 6: Carbon fibre reinforced composites parts and the corresponding mandrels
a) Multi-shaped parts
b) Bottle-shaped parts

Other applications

As a novel kind of smart material, SMPs currently cover a broad range of application areas ranging from outer space to automobiles. In addition to the above-mentioned applications, SMPs are also used in the following sectors: booms, antennas, grippers, mirrors, optical reflectors, intravascular delivery systems, hood/seat assemblies, adjustable automotive brackets, biomedicine products, self-healing composite systems, smart textiles and fabrics, shape-memory toys, and automobile actuators. ■

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