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Shape memory polymers for composites

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ABSTRACT

Shape memory polymers (SMPs) are a class of active, deformable materials that can switch between a temporary shape, which can be freely designed, and their original shape. With their large deformation, low density, various stimulation methods, good biocompatibility and other advantages, SMPs have become widely accepted as smart materials. However, SMPs have many limitations and weaknesses that are exposed in engineering applications. For this reason, the significance of SMP composites (SMPCs) has been analyzed in terms of four aspects: reinforcement, innovation and improvement of driving methods, the creation of specific deformations and the creation of multifunctional materials. We then introduce the constitutive theory of SMPs and the post-buckling analysis of SMPCs. Afterward, we introduce the extensive applications of SMPCs in the fields of aerospace, biomedical equipment, self-finishing, deformable mandrels and the 4D printing of active origami structures, demonstrating their ability to undergo active driving and deformation, their adaptiveness, their ease of transport and their rapid production capacity, which fully demonstrate the unique advantages of SMPs in solving application problems. Finally, the advantages and disadvantages of SMPCs in applications are summarized, and the prospects for new SMPCs and new SMPC structures are described.

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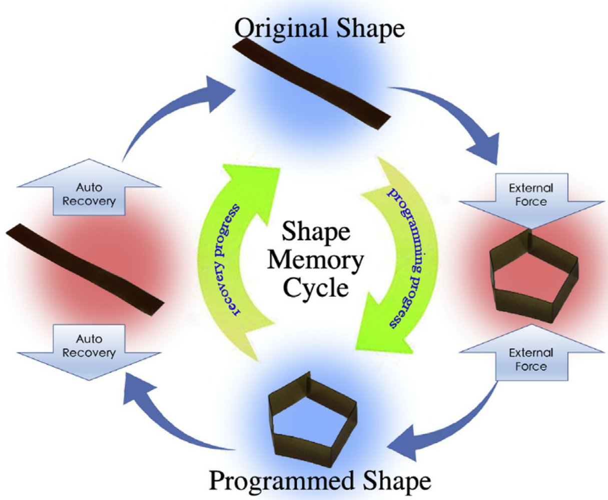
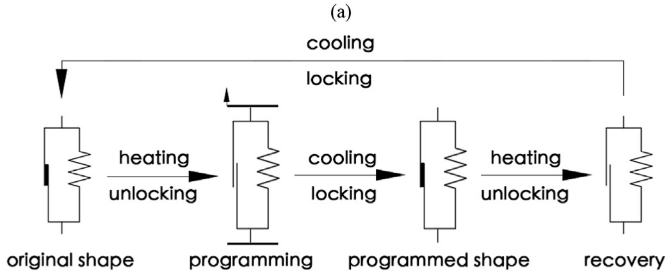
1. Introduction

The shape memory effect (SME) is a special mechanical phenomenon usually described by the shape memory cycle (SMC). Fig. 1.1 shows a highly common shape memory cycle. SMC represents the mechanical process that embodies the shape memory effect of that kind of material, and a more exact definition will be explained later. The shape memory effect is common in polymers, but most examples are inferior. One class of polymers can provide excellent shape memory effects and they are predominantly used in shape memory applications. They are called shape memory polymers (SMPs). Shape memory polymers are active deformable materials that undergo large deformations, first mentioned by Vernon et al. in a dental patent in 1941 [1]. In the sixties, heat-shrinkable tubes entered the market [2,3]. Their applications have drawn substantial research attraction. As the seventies began, a number of commercial companies developed their own shape memory polymers [4]. Since the end of the last century, researchers have begun to systematically study shape memory polymers. The principle of shape memory has been increasingly elucidated, and diverse shape memory effects have been observed [5].



(a)



(b)

Fig. 1.1. Once flowers have opened for the day, can the material revert to its original form again? This return can be achieved by shape memory effects. (a) This shape memory cycle consists of two hot stages (red background) and two cold stages (blue background), and the shape changes occur during the hot phase. First, the original shape (straight) is heated and can be adjusted by an external force into a special shape (pentagonal). This shape can be fixed after cooling. This stage is called the programming process, and the temporary shape is called the programming shape. When heated again, the material will return to its original shape and output a certain recovery force. This stage is called the recovery process. (b) Shape memory effect is easy to understand by an analogy. A spring and a telescopic rod with a lock are connected in parallel. When locked, the spring can be stretched without external force. Conversely, when unlocking, the spring restores the original length. We are about to find that the spring (entropy-based elastic network) and the shape lock have corresponding features in the polymer. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Taking the initiative to change shape is vitally necessary for animals and even other organisms. Compared to inorganic ceramics and metal materials, polymer materials show natural advantages such as lower density, better biological and organic compatibility, and easier modification and processing. Accordingly, shape memory polymers are blossoming in radiant splendor in the field of active polymers. Actively moving materials can be effectively deformed in shape by external stimulation [6–9]. Examples such as shape memory polymers, electroactive polymers [10,11], photo-induced polymers [12], and hydrogels [13,14] have been the subject of substantial research. Actively moving materials are often categorized by response behavior, and the differences in properties between different actively moving materials are significant.

Shape memory polymers are materials driven by external stimuli that actively switch between multiple shapes. Compared with other materials, shape memory polymers have the advantages of high stress tolerance [15], the ability to undergo large deformations [2], a rich selection of driving methods (including heat 3456, light [7,8], electricity [9–11], magnetism [12,13] wetting [14], and pH [16]), excellent radiation resistance and good biocompatibility [17], which make them a research hotspot in the field of actively moving materials.

At present, shape memory polymers have many applications in aerospace [18], medicine [19–21], self-finishing smart textiles [22,23] and electronic devices [24], and self-assembling structure [25–27]. Specific applications, including low-impact release mechanisms in the aerospace field, large spatial deployable structures, shape memory polymer sutures, minimally invasive surgical instruments with good biocompatibility, the active deformation or self-finishing of textiles, electronic devices, and variable mandrels, which effectively solve the thorny problems of the corresponding fields, show the great power of shape memory polymers. The above applications involving composites will be described in detail in Section 5.