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'Two way' shape memory composites based on electroactive polymer and thermoplastic membrane

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ABSTRACT

A practical and facile strategy was proposed to fabricate composites that not only use the properties of individual components (commercial electroactive polymer and thermoplastic resin) to their advantage, but also produce synergy effect of 'two way' shape memory properties. In this design, electroactive polymer is treated as soft segment which provides actuation force via converting electrical energy to dynamic energy. Thermoplastic material serves as 'hard segment' to help with fixation of temporary shape thanks to its re-structuring and stiffness/modulus changing abilities through the reversible transitional temperature. Compared with traditional one way and two way shape memory materials, this composite material has the capability of changing shape without pre-programming. High shape recover property (99 ± 0.3%.) has been obtained due to the rubber elasticity of electroactive polymer matrix. Many features could be brought up based on this design, such as accurate control over deformation by changing strength of applied electric field as well as tailorable stimulus temperature and mechanical properties.

1. Introduction

On the course of recreating nature's design and mimic intelligence, shape memory polymers(SMPs) as a type of intelligent materials have emerged and attracted great attention [1–3]. SMPs are known for their ability of memorizing and recovering to their original shape upon stimulation such as thermal stimulus [4,5], electric current [6–10], light [11–13], and alternating magnetic field [14–16] exposure, change of moisture [17] and PH value [18]. The broad stimulus source endow SMPs with a vast variety of applications in aerospace engineering [19,20], biomedical engineering [21,22], For thermally induced SMPs, they can be divided into two categories based on their net-point, chemical and physical. There is a new emerging simple polymer composite system made from two or more kinds of polymers with different mechanical properties that possesses material intelligence such as two way shape changing [23–26] or shape memory properties [27,28] and shape memory effect [29].

There are different forms of abovementioned composite polymer. The mostly investigated structures are laminates and fiber submerged in matrix. Tamagawa et al. took advantage of different thermal expansion ratio between epoxy and carbon fiber-reinforced epoxy plates to fabricate laminate with two way shape changing effect [25]. This type of shape changeable material can also perform under load because there is no obvious softening during heating. Later they reported similar design using a poly (vinylchloride) (PVC) plate and a carbon fiber reinforced plastic plate (CFRP) [26]. The same group later improved this kind of thermal responsive two way shape change polymeric laminate by introducing electrical activation [23] and larger and more precise control over deformation during heating [30]. Hu's group proposed to utilize SMPU and PU to achieve SMP laminate composite where releasing of elastic strain in SMP and the bending force of elastic layer initiated deformation during heating and cooling respectively [31,32]. To improve mass distribution, a novel and simple way to optimize the contact between one phase and another by introducing electrospun nanofiber into elastic matrix was reported [33,34].

In this study, we present non-traditional two way shape memory system of electroactive (EAP)/poly(ε-caprolactone) (PCL) composites. This design exempts this material from training before usage in traditional two way SMPs [28] and from external mechanical force in one way SMPs. This kind of composites was achieved based on the combination of EAP and thermoplastic feature of PCL filler. The material design not only optimized the property of each ingredient, but also introduced new properties of shape memory effect. EAP are employed for their large deformation under electrical field. Their similarity with natural muscles such as light

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weight, energy saving and biocompatibility lead to their application in artificial muscles [35–38]. These characteristics of EAP and drastic change of mechanical properties of PCL near its transitional temperature led to the idea of synergize them to achieve shape memory properties.

In this shape memory composite system, thermoplastic PCL serves as a "hard segment" and elastic matrix (EAP) mainly acts as a "soft segment". As shown in Fig. 1(a), when stimulus temperature is higher than transitional temperature which is melting temperature of PCL, PCL will melt. At the same time, voltage is applied on EAP, leading to deformation of the composite. After the composite reaches a desired shape, voltage is still applying to keep the deformed shape with removal of heating source. When the temperature is dropped below transitional temperature of PCL, temporary shape is fixed and voltage can be removed. Upon heating, the frozen strain is released leading to recover the composite to its original shape.

This design provides accurate control over deformation by changing strength of applied electric field as well as tailorable stimulus temperature and mechanical property of composite. The fixation rate can be improved by employing thermoplastic filler with higher modulus. Compared with previous reported literatures [39,40], this novel structure investigated in this article requires no training process and possesses larger deformation. EAP/PCL shape memory composite in this study opens up more doors towards soft actuators.

2. Material and methods

2.1. Materials

Poly(ε-caprolactone) (PCL, CaPa 6500, M_n = 40,000–50,000; density: 1.146 g/mL) pellets were obtained from Perstorp Chemical Trading Co., Ltd. EAP raw materials, poly-dimethyl-siloxane (PDMS) based formulation, with three components were purchased from BJB Enterprises Inc., U.S.A. (manufacturer type TC-5005 A/B-C). All chemicals involved were used as received.

2.2. Fabrication of EAP/PCL composite

EAP/PCL composites were fabricated as follows. Firstly, PCL nonwoven membranes were produced via electrospinning technique. Spinning sols were prepared as 14 wt% PCL in CH_2Cl_2 solvent. The processing parameters were optimized at the flow rate

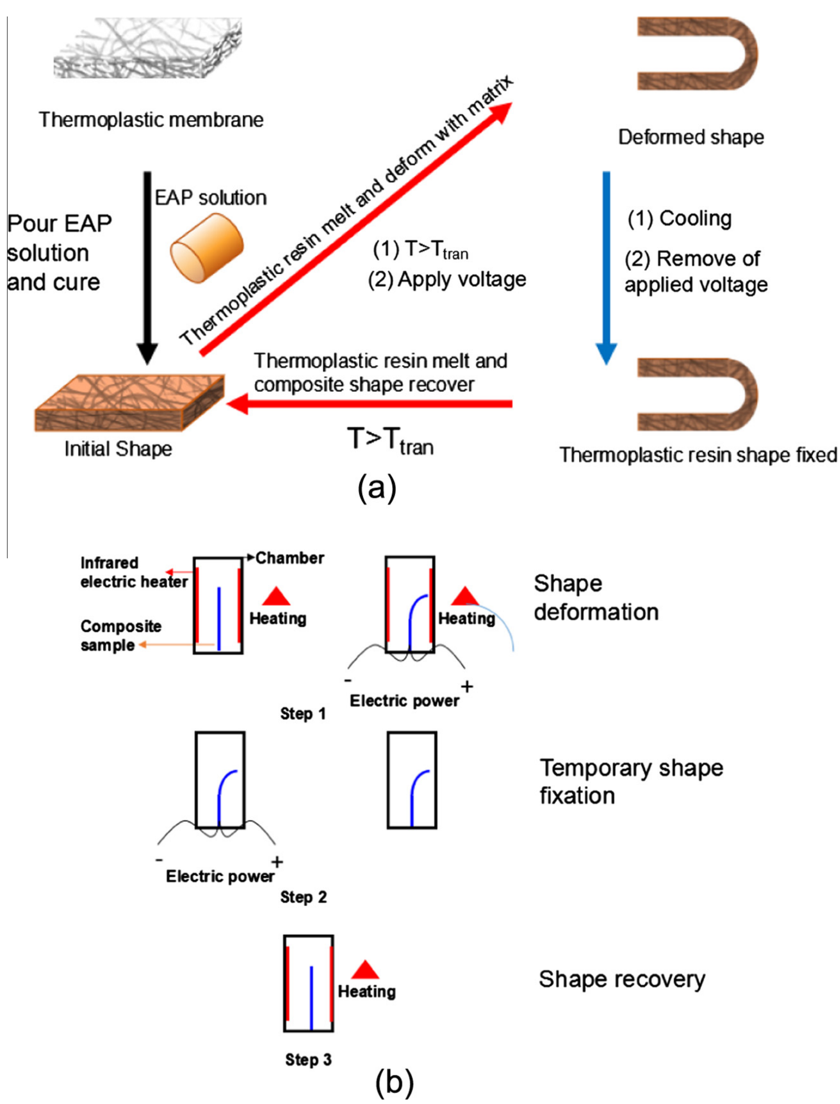

Fig. 1. (a) Schematic illustration of EAP/PCL shape memory composite fabrication and shape memory cycles, thermal transition temperature (T_{ran}); (b) experimental setup for two way shape memory investigation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)