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Fundamental investigation on the mechanisms of shape memory polymer reversibility

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Abstract

Shape memory materials are a new generation of materials for numerous applications in the field of life and industry have found. The use of these materials in response to external stimuli such as temperature, light, electric or magnetic fields and changes in pH, a new technology in engineering science. Changing the properties of bulk materials such as changes in shape, color and refractive index of this is the use of external stimuli. In fact, these shape memory materials in their molecular structure and can store in its primary structure.

Materials that exhibit shape memory, the ability to change shape and stay in a temporary shape and its permanent shape recovery are caused by external stimuli. Of shape memory materials in specific applications such as intelligent fibers, tubes with retractable liquidity, packaging and medical care, such as self-adjusting orthodontic wires and stents for blood vessels are open.

In this study, an overall strategy reversible shape memory in a semi-crystalline materials was found that the strategy of combining three different behavior of shape memory include conventional one-way shape memory, reversible shape memory two-way and one-way shape memory, was obtained.

Keywords: shape memory, reversible, one-way shape memory, two-way shape memory

Introduction

Smart materials are defined as materials that can sense the environment and/or their own state make a judgment and then change their functions according to a predetermined purpose. Such smart functions provided by smart materials are distinct from smart systems or facilities because they do not rely on the complicated sense-response structure of a feedback system. Instead, they can be intrinsically sensitive to changes in their ambient environment, such as temperature, optical wavelength, absorbed gas molecules and pH values.

Shape memory polymers (SMPs) represent a technologically important class of responsive materials for which the response lies in the shape change. More specifically, the conventional definition of an SMP is a polymer can be deformed and subsequently fixed into a temporary shape, which would remain stable unless it is exposed to an appropriate external stimulus that triggers the polymer to recover to its original shape. Accordingly, the associated behavior of SMP is called polymer shape memory effect (SME). Although various forms of external stimuli may be utilized as the recovery trigger, the most typical one is direct heating that leads to a temperature increase. The first recognition of polymer SME, as suggested by Mather *et al.*, can be traced back to a patent in 1940s in which “elastic memory” was mentioned [1-10].

Stimuli-responsive polymers significantly change their properties such as shape, mechanical properties, phase separation, surface, permeability, optical properties, and electrical properties upon small variation of environmental conditions such as temperature, electric field, pH, light, magnetic field, electrical field, sonic field, solvent, ions, enzymes, and glucose [1-11].

Smart materials are defined as materials that can sense the environment and/or their own state make a judgment and then change their functions according to a predetermined purpose. Such smart functions provided by smart materials are distinct from smart systems or facilities because they do not rely on the complicated sense-response structure of a feedback system. Instead, they can be intrinsically sensitive to changes in their ambient environment, such as temperature, optical wavelength, absorbed gas molecules and pH values.

As one of the most important branches of smart materials, shape-memory materials (SMMs), which include shape-memory alloys (SMAs), shape-memory ceramics and shape-memory polymers (SMPs), have been rapidly developed in the past few decades [12-16]. SMMs have the capability to memorize a permanent shape and to be programmed for one or many

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temporary shapes, while spontaneously recovering their original permanent shapes from temporary deformations upon exposure to an external stimulus.

The term “shape-memory” was first proposed by Vernon in 1941 [17]. However, the importance of SMPs was not recognized until the 1960s, when cross-linked polyethylene (PE) was used for making heat-shrinkable tubes and films [18]. More efforts to develop SMPs began in the late 1980s, accelerating in the 1990s and making significant progress only in the past 5–10 years. With the rapid development and wide investigation of SMPs, their features are more and more prominent, particularly compared with SMAs. SMPs have several advantages: (1) they can use diverse external stimuli and triggers: in addition to heating, there are many alternative ways to trigger the shape recovery (e.g., light, magnetic field, chemical and electricity) which can co-exist, leading to multi-sensitive materials; (2) they show highly flexible programming: the programming can be done with different stimuli through single and multi-step processes; (3) they have a broad range of structural designs: there is an abundance of approaches for designing net-points and switches for various types of SMPs. Additionally, different polymers and foreign materials can be used to construct different SMEs; (4) they possess tunable properties: the properties of SMPs can be engineered very easily and accurately tuned using composites, blending and synthesis methods; (5) they are well-suited for responses to human senses/tissues and biodegradability: SMPs are made from polymers, which are soft materials that provide an abundant array of choices for making highly biodegradable, biocompatible and comfortable devices to interface with our bodies, offering unique opportunities for smart medical, biological and garment-integrated devices; (6) they can be very light and can occupy a large volume (foam): these properties are extremely important for applications, such as aerospace devices, air force items and airplane components.

In this study, an overall strategy reversible shape memory in a semi-crystalline material was studied that the strategy of combining three different behavior of shape memory include conventional one-way shape memory, reversible shape memory two-way and one-way shape memory, was investigated.

Material and Method

In this study we used of some chemical material include: Poly octylene adipate, adipic acid, 1,8-octanediol, methanol, 2,2-diethoxyacetophenone, chloroform and scandium triflate catalyst. We had two processes for this investigation, a) Synthesis of Poly octylene adipate. The procedure below describes the synthesis of polymer 2 (DP = 10, Mn = 2563 g/mol), while the other polymers from Table 1 have been synthesized in a similar way. A dry flask was charged with adipic acid (3.0 g, 20.53 mmol), 1,8-octanediol (3.242 g, 22.17 mmol), and scandium triflate catalyst (0.303 g, 0.62 mmol). The flask was nitrogen purged before heating the reaction to 80 °C. After 5 h, vacuum was lowered slowly to 40 Torr, and remained at that pressure for 24 h at which time it was pulled to 3 Torr for an additional 6 h. The polymerization was terminated by dissolving the polymer in CHCl₃, filtering, and precipitating in cold methanol (−78 °C). Final yield was 4.378 g of white

solid. End group functionalization was performed according to procedures described elsewhere [11].

b) Thermoset Elastomer Fabrication. End-capped POA (1.500 g, 0.55 mmol) was mixed with 1 mL chloroform in a dry vial, and then a drop (~0.2 μL) of 2,2-diethoxyacetophenone was added into the mixture. The vial was vortexed for 1 min then sonicated for 0.5 h. The mixture was poured into the mold and exposed to 365 nm light for 5 min. The thermoset elastomer was then removed from the mold and put under vacuum at a high temperature (70 °C, 20 Torr) overnight. The gel fraction was measured by a Soxhlet extractor using CHCl₃ as the extracting solution, extraction time 24h, and solvent evaporation occurred in the vacuum oven for 24 h. Apparent cross-linking density was calculated as $\nu = E/3RT$, where E is the tensile storage modulus measured by DMA at strain $\epsilon = 0.1\%$, frequency $f = 1$ Hz, and temperature $T = 80$ °C. Table 1 summarizes chemical compositions and physical properties of the prepared elastomers [11].

Results and Discussion

The test was planned in a kind of semi-crystalline elastomer to deform at 60 °C and then cooling it to a temperature of 5 °C deformation is reversible. Followed by heating to 38 °C and then cooling it to a temperature of 5 °C resulted in a change reversible in the range of angles between 115 degrees to 155 degrees, and this is well and without applying any external force at all stages of researcher it is possible. Such fluctuations angle to a large extent repeatable: As soon as heating and cooling cycles, the samples are reversible without loss of memory, modify and retrieve them.

It should be noted that 38 °C above the melting point of the crystalline phase in the polymer is part of this phenomenon occurs. Partial melting in the initial shape memory polymer provides the opportunity to be kept and protected and continues to be recycled as the primary form of cooling and crystallization occurs. According to the crystallization degree of cross linking density of the samples and data communication crystallization conditions, resulting in partial melting point of the crystalline phase volume fractions for each sample individually relate.

Transfer form reversible in all these tests is quite spontaneous and without applying any external force is applied. However, unlike the behavior of shape memory reversible two-way, one-way process requires re-programming the original shape at a temperature equal to the protocols by which shape memory triple in the report [1-11].

It should be noted that this process is quite different in terms of shape memory process is conceptually similar, though for a matter to be discussed. Although the relative contribution to the overall deformation of partial melting and temperature-dependent cross linking density in the sample. Dependence cross linking density is causing some samples with various degrees of crystallinity. Therefore, should the effects of partial melting temperature of a sample and then a network effect for a report of the same chemical composition and differences in the density elastomer cross linked be discussed. The following figure show reversible shape memory of poly octylene adipate. That oligomers used to synthesize shape memory elastomers, cross linking density and melting temperature can be controlled by changing the degree of polymerization of oligomers and copolymerization.



Fig 1: reversible shape memory polymer of poly octylene adipate

Result

Semi-crystalline elastomer composition can be adjusted construction of cross linking chemical and physical network of crystals can be examined under articles binary network. Shape memory chemical cross links physical network while maintaining the original shape of crystals is a temporary form.

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