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Thermo-Moisture Responsive Polyurethane Shape Memory Polymer for Biomedical Devices

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Abstract: Shape memory polymers (SMPs) have a number of advantages as compared with their metal counterpart, i.e., shape memory alloys, in particular for biomedical applications. The recent finding of the influence of moisture on the glass transition temperature of a polyurethane SMP, which is traditionally well-known for its thermo-responsive feature, enables us to achieve not only the so called moisture-driven for shape recovery, but also the recovery following a pre-determined sequence, i.e., programmed recovery. Utilizing these new features, we demonstrate a few novel applications of this SMP for biomedical devices, in particular, for minimally invasive surgery and cell surgery in future.

Keywords: Shape memory polymer, medical device, programmable, polyurethane, moisture responsive.

1. INTRODUCTION

Shape memory polymers (SMPs) have a number of advantages over shape memory alloys (SMAs), in particular for biomedical applications. Larger recoverable strain (well over 100%), lower density and lower cost are the most important ones among others [1]. Although photo-responsive and chemo-responsive (namely, change in pH value) SMPs are available, at present the most popular SMPs are those activated by heat, i.e., thermo-responsive SMPs. Unlike SMAs, which can be directly actuated by Joule heating, i.e., by passing an electrical current directly for heating [2], it is rather complicate to heat polymers, since they are intrinsically non-conductive in their natural form. Although electrically conductive SMPs can be realized by blending with various kinds of conductive fillers [3-9], for instance, carbon black as the simplest and cheapest filler, the actuation still cannot be triggered in a wireless manner. One of the recent developments in terms of the technologies for activating thermo-responsive SMPs is to heat SMP composites, which are mixed with magnetic particles, by applying an alternating magnetic field for induction heating [10-12]. Despite that direct wire connection is avoided, the generation of a strong enough alternating magnetic field requires an additional bulky system. Laser heating is another recent development, which is only applicable to certain transparent SMPs largely in thin wire form and requires an optic fiber for laser beam to pass through [13].

On the other hand, some SMPs have been developed to be able to recover two shapes one after another upon heating (i.e., from shape *A* to shape *B* and finally to shape *C*) [14, 15]. However, it is not easy to fabricate a SMP which can recover its original shape following a pre-determined multi-step sequence (more than two intermediate shapes), i.e., in a programmable manner.

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Recently, a new approach to trigger the recovery of a thermo-responsive polyurethane SMP has been identified [16]. This polyurethane SMP can recover its original shape upon immersing it into room temperature water, i.e., moisture-responsive, in addition to its well-known thermo-responsive feature. The moisture-driven shape recovery is due to the strong influence of moisture absorbed upon immersing into water, which can significantly lower down the glass transition temperature (T_g) of the SMP by up to over 25^{o}C [17]. Consequently, instead of heating the material to over its original T_g to trigger the actuation, the shape recovery can be initiated upon immersing into ambient temperature water due to the drop of T_g of the polymer. This finding can also be utilized as a simple and convenient approach to work out a SMP with different T_g at different locations, i.e., a SMP with a functionally gradient T_g. Consequently, the recovery can be programmed in a step-by-step manner as shown in Fig. (**1**).

With the thermo-moisture responsive feature, and the intrinsic good bio-compatibility of polyurethane, this SMP can have a wide range of bio-related applications, in particular for minimally invasive surgery and even for cell surgery. The purpose of this paper is to demonstrate some novel concepts utilizing this material for, for instance, self-tightening/self-unraveling suture, retractable stent and possibly delivering tiny devices/machines into a living cell.

2. MATERIAL BACKGROUND

The particular thermo-moisture responsive SMP is an ester-based thermoplastic polyurethane SMP obtained from the Misubishi Heavy Industries (MHI), Japan. It is prepared from diphenylmethane-4, 4'-diisocyanate, adipic acid, ethylene glycol, ethylene oxide, polypropylene oxide, 1, 4-butanediol and bisphenol A. As indicated by MHI, the T_g of this material can be tailored in order to meet the requirement of a particular application. Here, we used MM3520 and MM3550 (in pellet form), which have nominal T_g of 35^{o}C and 55^{o}C, respectively as provided by MHI, and MS-5510 (SMP solution, 30 wt% of polyurethane resin and 70 wt% of

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Fig. (15). Reversible vertical chain.

Fig. (16). Wrinkling (strips) atop 5% pre-strained SMP after shape recovery (**a**), and a zoom-in view of area A (**b**). The image is obtained by 3-D Wyko surface scanning.

(a) (b)

Fig. (17). Wrinkles (labyrinths) atop SMP without pre-straining. (**a**) Optical image; (**b**) 3-D Wyko surface scanning.

4. CONCLUSIONS

Since the polyurethane SMP is biocompatible, it is intrinsically suitable for biomedical applications. Given the unique thermo-moisture responsive feature and together with the apparent convenience in processing and fabricating into a variety of sizes and different shapes, as presented in Section 2 of this paper, it is expected that this material should have a great potential for novel biomedical devices, with easily tailored properties to meet the requirements of a particular application. A few novel devices are demonstrated to prove the feasibility of some concepts, in particular, for minimally invasive surgery and cell surgery.

ACKNOWLEDGEMENTS

We would like to thank M.S, Yahya and N. Liu for their help to conduct some of the experiments, also R.Y.G.E. Lee and W.L. Shi for their work as part of a TERP project, S.J. Goh, Y.S. Chan, Y.W. Loh, A.P. Lim, J.R. Cen and K.C. Khusbir for their efforts as part of their final year projects. The attapulgite and SEM image of it were kindly provided by Prof. G.H. Pan of Southeast University, China. This project was also partially supported by a BPE Cluster SEED Grant (SFP 011-2005) of NTU.

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Received: April 20, 2009 Revised: April 25, 2009 Accepted: April 25, 2009