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Shaping tissue with shape memory materials☆

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ABSTRACT

After being severely and quasi-plastically deformed, shape memory materials are able to return to their original shape at the presence of the right stimulus. After a brief presentation about the fundamentals, including various shape memory effects, working mechanisms, and typical shape memory materials for biomedical applications, we summarize some major applications in shaping tissue with shape memory materials. The focus is on some most recent development. Outlook is also discussed at the end of this paper.

Contents

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1. Introduction

All materials are able to respond to certain stimuli by means of changing their chemical or physical properties accordingly [1–6]. Sometimes, the corresponding reaction appears in a way as shape alternation. Elastic deformation in response to stressing is a classic example, in which the reaction is spontaneous and instantaneous, although in some viscous materials, time delay is expected. Hence, such a phenomenon may be called as the shape change effect. On the other hand, in some occasions, the deformed shape (or temporary shape) may maintain virtually forever and the original shape is recovered (either fully or partially) only when the right stimulus is applied. This may be called as the shape memory effect [7,8]. From energy point of view, the difference between these two effects is due to the difference in energy barrier between the original and temporary shapes, as illustrated in Fig. 1. While the shape change effect has been widely used in many applications, including drug delivery in biomedical applications [9,10], the shape memory technology, which utilizes the fascinating and powerful shape memory effect, can provide a convenient solution for many practical problems, including shaping tissue, which mainly includes reconfiguration and shape/position maintenance etc. [7,11–17].

Correspondingly, we may name a material with the shape change effect or shape memory effect as the shape change material or shape memory material, respectively. However, it should be pointed out that one material may behave both as shape change material and as shape memory material, depending on the environmental conditions and the exact application. For instance, at low temperatures, NiTi shape memory alloy has the shape memory effect, while at high temperatures, it is superelastic, which is basically the shape change effect [18].

It should be pointed out that the term of shape memory and superelastic technologies (SMST) has been introduced two decades ago (evidenced by the series of SMST conferences since 1994 and till today). However, the original term was largely meant for the applications of NiTi in medical devices. The current expansion of the shape memory technology covers all types of materials which have the shape memory effect either intrinsically or extrinsically.

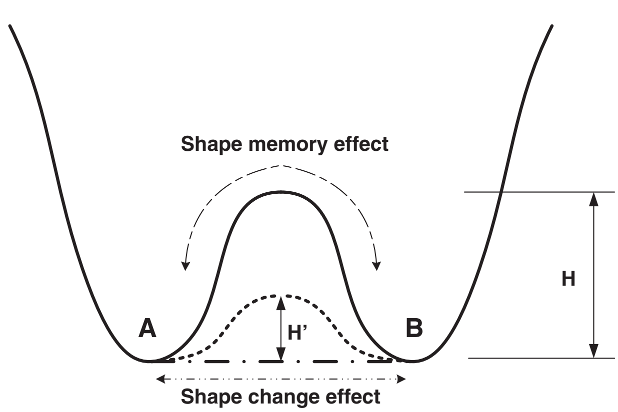

Fig. 1. Illustration of the energy difference in the shape memory effect and shape change effect.

The technical advantages of shape memory materials originate from their abilities to maintain the temporary shape, even the distortion is severe, and at the presence of the right stimulus, they are able to return to the original shape or to generate actuation force if free shape recovery is restricted. As revealed in Fig. 2(a), the shape recovery strain of a polyurethane shape memory polymer is over 100%; while polyurethane shape memory polymer foam is able to fully recover its original shape upon heating, even after being compressed to over 80% (Fig. 2(b)). The actuation stress in NiTi shape memory alloy can be up to 500 MPa [19], which is the reason why NiTi wires have been used for orthodontics since 1970s [20]. Fig. 3 reveals an ant with a polyurethane micro tag mounted on one of its legs. Since the recovery strain of this material is on the order of 100%, the actuation stress is always less than a few MPa, and the actuation temperature for shape recovery is at around 35 °C, the damage to the ant during tag mounting, if any, can be effectively minimized [21].

One of the most important achievements in modern medicine is minimally invasive surgery [23]. Laparoscopic cholecystectomy was the first minimally invasive procedure developed and widely accepted [23–25]. Since then, the techniques have gained widespread applications in various surgical specialties. Many procedures are now well established as routine practices, including Nissen fundoplication for gastro-esophageal reflux disease, appendicectomy, adrenalectomy, splenectomy and many other advanced procedures.

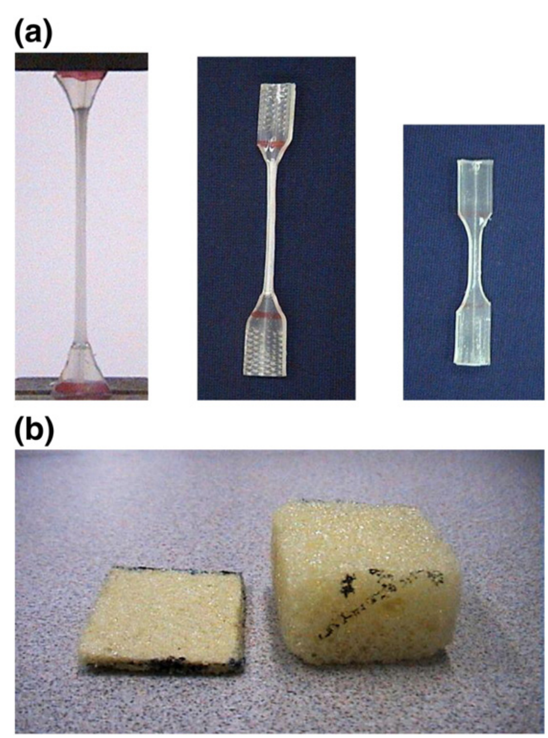

Fig. 2. (a) The shape memory effect in a polyurethane shape memory polymer. Left: in uniaxial tension; middle: after pre-stretching; right: after heating for shape recovery. Reproduced with permission from [8]. Copyright 2012 Elsevier Ltd; (b) compressed polyurethane shape memory polymer foam (left) and after shape recovery by heating (right).