Sequential Motion Ability of 4D-printed Structures Based on Photopolymers with Broad Glass Transition

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ABSTRACT

With the term "4D-printing" [1], modern literature refers to the application of additive manufacturing technologies (3D-printing) on materials able to change their shape in response to an external stimulus, such as shape memory polymers. The interest towards 4D-printed structures (the 4th dimension representing their shape evolution along time) relies on an easy realization of smart devices with complex or customized shapes, on an enhanced control of the transformation kinetics through a properly structured geometry [2], and on the achievement of complex transformation, among which highly controlled sequential shape transformations [3]. Sequential motion, i.e. the ability for a structure to change in different locations and at different times under a same stimulus, plays a relevant role in designing shape-shifting structures with highly effective contractions and deployment, and in self-opening and self-locking mechanisms. Such a response, early pursued by technological approaches (multiple material printing; functionally graded structures), is recently approached on material based strategies, such as the employ of multiple shape memory polymers or polymers capable of the so-called temperature memory effect. This latter response, shown by polymers presenting a broad glass transition [4] or melting temperature region [5], consists in the possibility to conveniently control the transformation temperature by the deformation temperature, and may be at the basis of a multiple shape memory effect and od sequential transformations.

In this work the shape memory capabilities of 3D-printed structures, obtained by a commercial photopolymer presenting a broad glass transition, were studied, with particular interest towards the description of the temperature memory effect and its exploitation in multiple shape memory response and in sequential deployments. The structures, ranging from simple shapes (cubes, plates, bars) to more complex ones (auxetic structures; self-locking mechanisms), were printed through stereolithography. The shape memory response of specimens, deformed at various temperatures, was studied with the aim to describe the shape evolution as a function of temperature and time. The former set of experiments revealed that the temperature triggering the shape memory effect strongly depends on deformation temperature, and that a multi-step deformation history carried out at various temperatures determines a multiple shape memory behaviour; the latter set of experiments revealed that the deformation temperature governs also the recovery time-scale at a given temperature, and that by deforming various regions of a same specimen at different temperatures, it is possible to control the recovery response in a sequential deployment fashion. This was testified both in simple unfolding tests carried out on double-folded bars and in the more articulated motion of a self-locking structure. Ongoing researches are focusing on analytical models for the temperature-memory response.

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