TOWARDS 4D PRINTED PLA ACTUATORS

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Introduction

4D printing enables the use of "smart materials" that can be transformed in a pre-programmed way under an external stimulus. This is known as '4D printing', with the fourth dimension referring to time [1]. Shape Memory Polymers (SMP), specifically thermally activated SMP, have been largely developed in the past decade due to their lightweight, ease of forming, low costs for manufacturing, high deformations and high shape recovery ratios [2]. In particular, self-bending structures made of bilayer composites have been proposed [3]. In this work, preliminary results for the development of a thermo-responsive structure made of a polymer-paper bilayer are presented.

Materials and methods

In this study, polylactic acid (PLA) filaments from *RS PRO* with a diameter of 2.85 mm and a density of 1.24 g/cm^3 were used. All the samples were manufactured with an *Ultimaker 2 Extended* + printer. The extruder diameter was 0.6 mm, the nozzle temperature was set at 210 °C and the platform temperature at 60 °C. DSC (Differential Scanning Calorimetry) tests were performed on printed polymer, using a Q20 from *TA Instruments*. Tensile tests were performed using an *INSTRON* 5982 machine with a cross-head speed of 0.5 mm/min. Longitudinal strain was measured by a 25 mm gauge length extensometer. Tensile specimens were dog-bone shaped, following the standard NF_T_54-034, with a 60 mm gauge length and a 4 mm thickness, made of 37 PLA layers. Three different orientations of the printed filaments were used: longitudinal (0°), transverse (90°) and crossed (±45°). Bi-layer structures were made of only one layer of PLA deposited on a copy paper of 80 g/m^2. A heating plate at 100 °C was used as an external stimulus.

Results

The DSC thermogram made on 3D printed PLA shows that its glass transition temperature (T_g) is equal to 59 °C (Figure 1a). It gives its activation temperature as a SMP. A small endothermic peak appears at a temperature situated just above T_g, due to the physical ageing of the material. Moreover, an exothermic peak centered near 104 °C can be seen on the thermogram, corresponding to the cold crystallization and finally the melting peak is located around 154 °C. The area values of these two last peaks are similar (20.50 J/g and 17.71 J/g). Using a melting enthalpy of 100% crystalline PLA equal to 93.6J/g [4], it gives a degree of crystallinity of 3%. This result shows that the printed PLA is almost amorphous.
Tensile curves obtained for the three different directions are presented in Figure 1b. Results show the strong influence of the filament orientation on the PLA tensile properties. Ultimate strength and Young modulus of 0° samples are higher than ±45° and 90° ones. The Young modulus measured for the 0° samples is very close to the reference value provided by the supplier (3990±44 MPa versus 3860 MPa).
Images of the thermo-activated bilayer structures are shown in Figure 2. The self-deployment movement can be observed for the two tested geometries. These structures recover their planar configuration

relatively quickly: after about 35s for the rolled structure, and after about 20s for the origami-type structure.

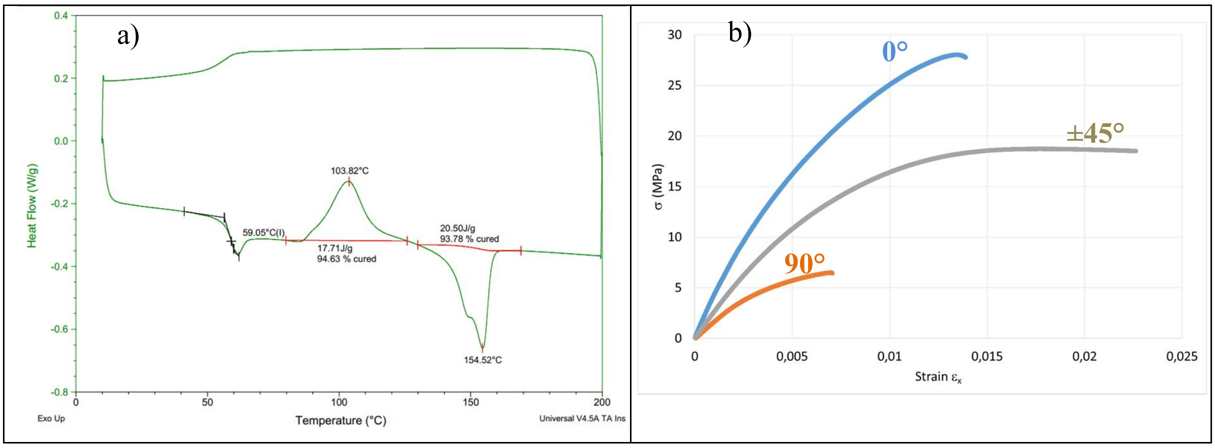

Fig. 1 – a) DSC thermogram on 3D printed PLA material. b) Tensile curves of PLA specimens with different orientations of the filament.

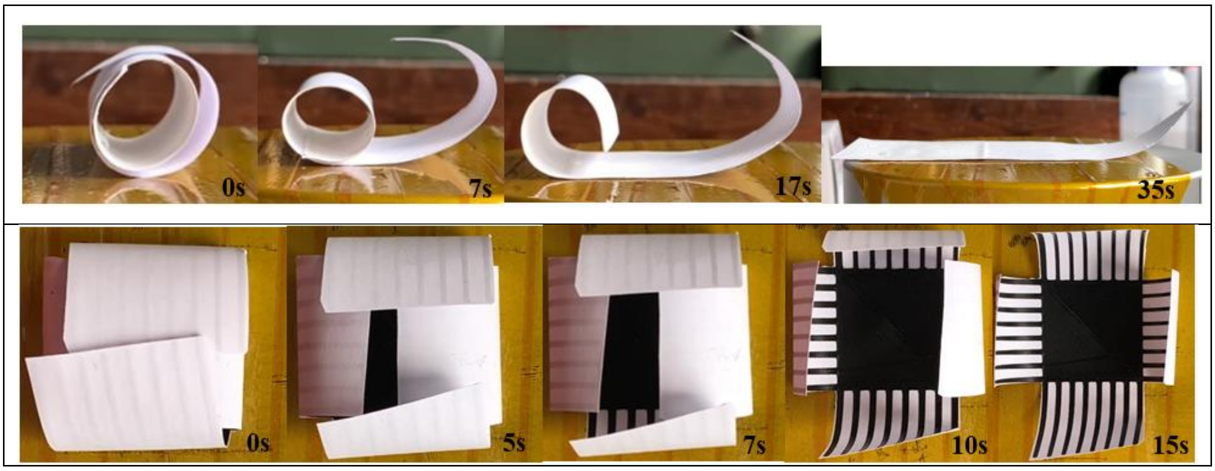

Fig. 2 – Examples of thermo-activated bilayer structures: a) Unrolling movement. b) Origami-type structure.

Conclusions

The PLA filament is a good candidate for the development of shape shifting structures: its temperature of glass transition is low (59 °C), its Young modulus is quite high (3990 MPa) and its thermo-activation speed is elevated. After testing self-bending polymer-paper bilayer, future work will involve designing morphing assemblies which integrate different components towards a wide range of applications.

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