Effect of Printing Orientation on Thermomechanical Behavior of SLA 4D-printed Shape Memory Epoxy

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1. Introduction

Traditional manufacturing of complex polymeric parts is time-consuming, often less accurate, and requires significant post-processing. Additive manufacturing (AM), or 3D printing, addresses these issues by building objects layer-by-layer from a digital model. This layering process, where each layer is deposited and solidified in sequence, enables the creation of complex shapes and structures not feasible with conventional methods. A significant advancement in this field is the emergence of 4D printing, which extends the capabilities of 3D printing by introducing the time as the fourth dimension. This innovative approach merges smart shape memory materials with 3D printing, leading to manufacturing smart devices that can change their shape or function in response to an external stimulus, such as heat.

Despite the numerous advantages of 3D printing techniques, AM faces the challenge of anisotropy in manufactured devices due to layer-by-layer building of devices. Anisotropy refers to the directional dependence of a material's properties, meaning that a material can exhibit different strengths, stiffness, or thermal properties in different directions. [1][2]

This study employs a shape memory epoxy resin (SMEp) in the stereolithography (SLA) 3D printing method, focusing on how the orientation of 3D printing influences the thermo-mechanical behaviors of the 4D printed shape memory polymer.

2. Additive Manufacturing of Epoxy Resin

The terms "printing orientation" or “build orientation” are typically used in the context of 3D printing to describe the direction in which an object is built layer by layer. It suggests the positioning of the printed object relative to the build platform and is directly related to how the object is printed.

Epoxy resin SOMOS WaterShed R XC11122 was used as a photopolymerizable prototyping material, suitable for additive manufacturing of highly detailed parts with high clarity, toughness and water-resistance.

As illustrated in Fig. 1a and Fig. 1b, dogbone shape specimens, which is the standard geometry for tensile testing, are additively manufactured from shape memory epoxy using SLA technology, SLA-3500 laser stereolithography 3D-printer. The specimens were printed layer-by-layer from lateral (SMEp 1) and top-down surface (SMEp 2), respectively.

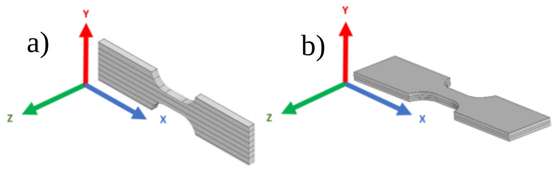

Fig. 1. Two dogbone-shaped specimens with identical geometry, 3D printed from (a) the lateral surface and (b) the top-down surface.

In fact, 3D printing this sample from the lateral surface produces a higher number of layers, each with a smaller surface area. Conversely, building from the top-down surface results in fewer layers, but each layer has a larger surface area.

3. Mechanical Investigation

Figure 2a and 2b illustrate the mechanical properties of SMEp1 and SMEp2 at room temperature (25°C) and elevated temperature (75°C), respectively. At room temperature, SMEp2 exhibits increased ductility and flexibility, whereas SMEp1 demonstrates a higher yield strength with less elongation at break. Upon heating to 75°C, SMEp2 displays a more pronounced thermal expansion than SMEp1. This could be attributed to the larger surface area of the layers within 3D printed SMEp2, which may result in greater expansion and less dimensional stability under thermal stress. The differences in elongation at break between SMEp1 and SMEp2 at 75°C seem to be due to the difference in their initial thermal expansion characteristics.

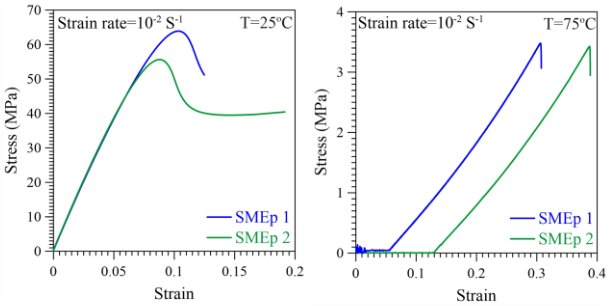

Fig. 2. Stress-strain behavior comparison of SMEp1 and SMEp2 at (a) room temperature and (b) 75°C.

4. Thermomechanical Investigation

The thermomechanical properties of the 3D printed SMEp1 and SMEp2 dog-bone shape specimens with glass transition temperature (T_g) of 53˚C were investigated, using a tensile testing machine and an environmental thermal chamber, through the following steps: 1) Heating to T_g+20=75˚C, 2) Tensile loading to a pre-determined strain value at a constant strain rate of 10^{-2} s^{-1}, 3) Cooling the specimen to room temperature while keeping the maximum strain, 4) Unloading the specimen at a constant strain rate of 10^{-2} s^{-1}, 5) Heating the specimen to T_g+20=75˚C under zero-force to restore the original shape. Shape fixity and shape recovery of the SMEp1 and SMEp2 were calculated from the experimental results (stress-strain curve in Fig. 3) using equations 1 and 2, respectively [3]:

$$S_f = \frac{\varepsilon_{un}}{\varepsilon_m} \cdot 100\% \tag{1}$$

$$S_r = \frac{\varepsilon_m - \varepsilon_{ir}}{\varepsilon_m} \cdot 100\% \tag{2}$$

while ε_m, ε_{un} and ε_{ir} are the maximum strain loading, the strain obtained after unloading at room temperature, and the irrecoverable strain after heating, respectively.

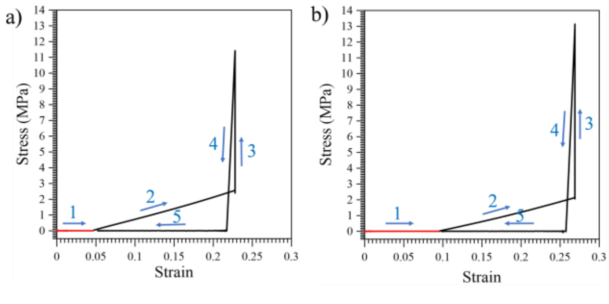

Fig. 3. Stress-strain behavior comparison of (a) SMEp1 and (b) SMEp2 during a thermomechanical cycle.

Table 1. Shape memory parameter comparison for SMEp1 and SMEp2.

	SMEp1	SMEp 2
Thermal Expansion (%)	4.5	9.1
Shape fixity (%)	95.05	95
Shape recovery (%)	75	66.45

The thermomechanical analysis reveals that SMEp2, despite having the same geometry as SMEp1, exhibits a greater thermal expansion and reduced shape recovery when printed top-down. This is attributed to the larger surface area of the 3D printed layers within SMEp2. The results clearly demonstrate the nnegative impact of thermal expansion on the shape recovery capabilities of a shape memory polymer.

5. Conclusion

This research examined the influence of printing orientation relative to the 3D printer platform in stereolithography (SLA) technology on the thermomechanical properties and shape memory behavior of shape memory epoxy. The findings indicated that specimens printed in a top-down orientation exhibit greater thermal expansion, which adversely affects their shape recovery capabilities. Selecting the optimal printing orientation is crucial for configuring 3D printing processes to achieve the desired material properties.

6. References

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