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Direct 4D printing using Shape Memory Polymers: an experimental and simulation-based investigation

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Abstract

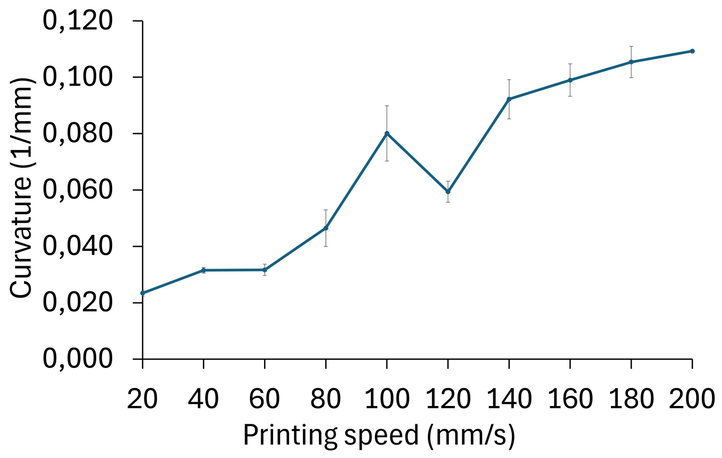
The present study focuses on structures composed of Shape Memory Polymers that exhibit bending behavior when exposed to higher temperatures due to strain mismatches inside the structure. The strain is induced in the material during the printing process using the Fused Deposition Modeling (FDM) method. During experiments it is observed, that the printing speed, with which the samples are printed, has a significant influence on the bending behavior. With the measured curvature and strain it is possible to simulate this behavior via an analytical and a numerical solution.

4D printing

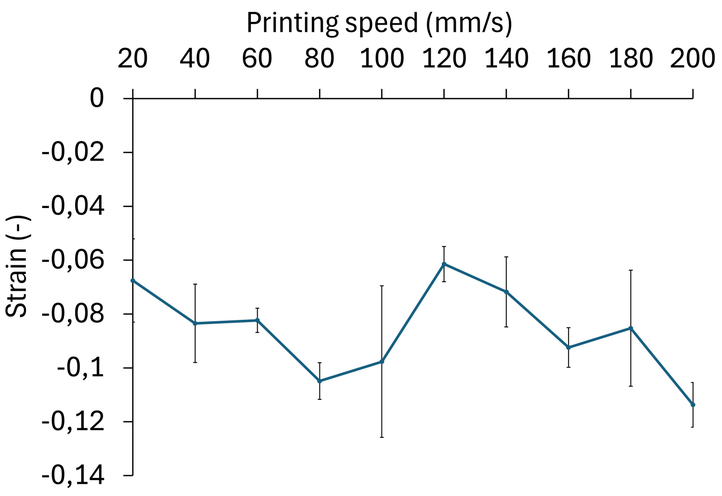
In 2013 the concept of 4D printing was introduced by Tibbits' research group at the TED (Technology, Entertainment, Design) scientific gathering [6]. The term 4D printing describes the process of 3D printed objects that change their shape, property or functionality over time through non-mechanical stimuli. These external stimuli can be biological, chemical or physical. The changes are predetermined and can be either chemical (e.g., color) or physical (e.g., bending or twisting). Accordingly, the used materials must be stimulus-responsive active materials [3].

Experiments

Samples with the dimensions 60 mm x 10 mm x 1.2 mm made of Polylactic Acid are printed using a FDM printer at the University of Pavia [4]. The original length l_0 is calculated with a caliper. Afterwards, the samples are heated in an oven at 80 °C for 10 min [5]. The curvature κ and the length after heating l are calculated using FIJI. Regarding the curvature, a clear relationship is visible between curvature κ and printing speed.

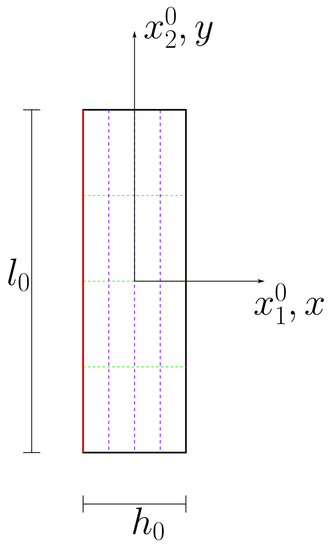


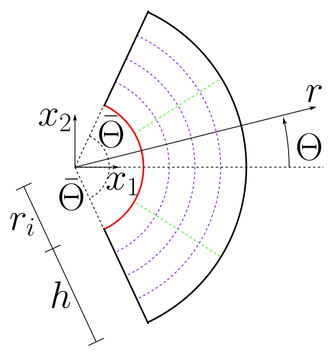
For the strain $\varepsilon = \frac{l-l_0}{l_0}$ no dependency can be derived.



Simulations

Analytical solution [1]:





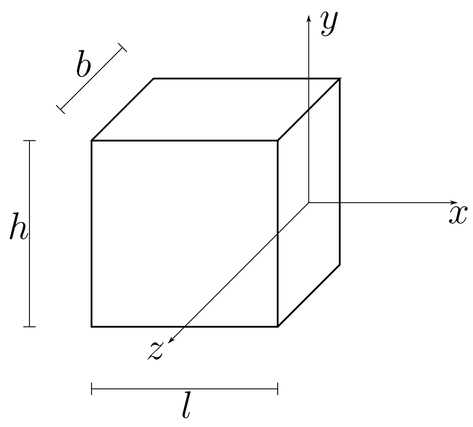
semi-angle

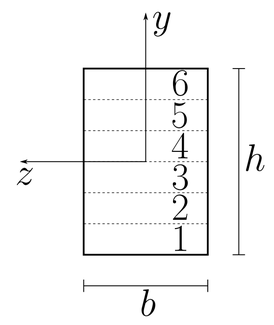
$$\bar{\Theta} = \frac{\kappa_{\text{mod}} \cdot \bar{l}}{2}$$

$$\kappa_{\text{mod}} = \frac{1}{\frac{1}{\kappa} - 1}$$

$$\bar{l} = l_0(1 + \varepsilon)$$

Numerical solution [2]:





coefficient of thermal expansion for layer i

$$\alpha_i^{\text{T}} = m(1 + (6 - i)n)$$

$$m = \frac{\varepsilon}{80 - 25}$$

$$n = \frac{6h}{35\varepsilon} \cdot \kappa$$

References

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[6] TIBBITS, S. The emergence of '4D printing'. In: *TED Talks*, 2013.