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STUDY OF 4D PRIMITIVES' SELF-TRANSFORMATION

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INTRODUCTION

The simplest options for 4D printing applications is the use of shape memory polymers, that are capable of thermal transformations. [1]

Shape transformation researches are often performed on 3D printed primitives with the active part on which the transformation occurs. For active parts, a combination of active and passive material is used. Active material shrinks when heated above its Tg and below its Tm. Passive material does not change its shape but serves as support for transformation into a specific direction [2, 3].

In order to control the transformation, it is important to properly prepare the material for printing. Polymers are hygroscopic [3, 4, 5, 6], so the filaments must be dried before printing.

The transformation depends on the residual stress created during the 3D printing. During the extrusion materials transition to a highly elastic state. The polymer chains are forcibly oriented in the longitudinal direction of the material flow through the extrusion nozzle. As soon as material leaves the nozzle, it begins to cool and solidify, forcing the chains to maintain their rearranged state.

When the 3D object is reheated above the Tg of the active material, the polymer chains begin to reorient back into their chaotic, or low energy mode, causing shrinkage along the printed direction and changing the shape of the 3D printed object [2, 3, 7, 8].

To control the described transformation, it is first necessary to optimize the printing conditions – printing speed [3, 7, 9] and speed of cooling [9].

Our research presents the most important parameters that we must optimize before and during the printing process. In this way we create good conditions for the study of the self-transformation of primitives, based on which we intend to establish a mathematical model to predict the level of the primitives' transformation.

METHODS

The schematic diagram of our research is presented on Figure 1. Presentation of 4D primitives' self-transformation and shape recovery cycle of printed primitive were presented on Figures 2 and 3.

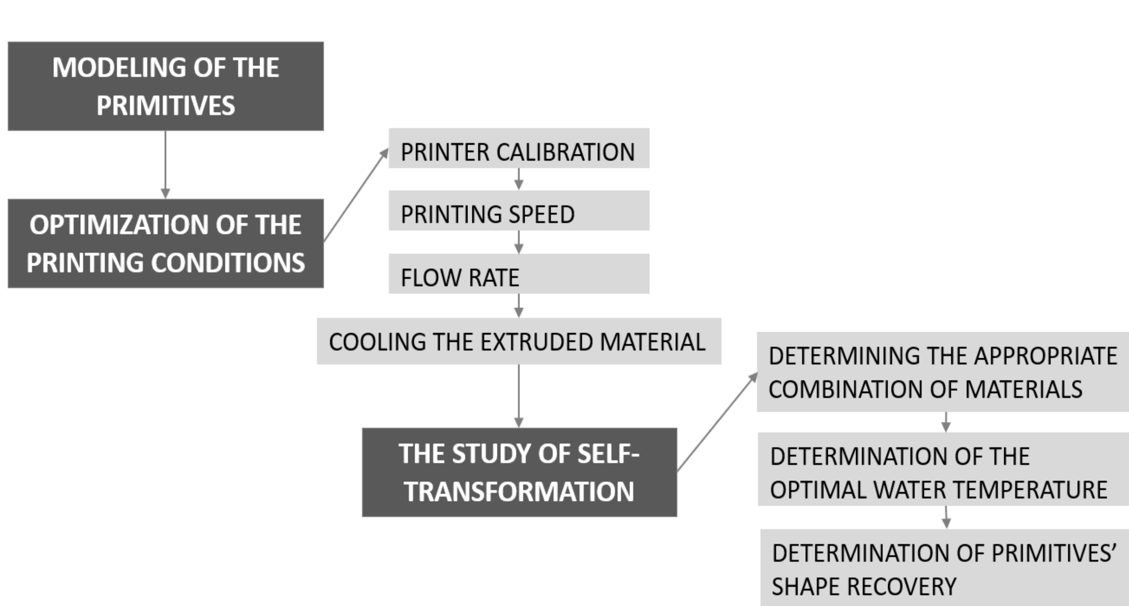

Figure 1: Shematic diagram of research workflow.

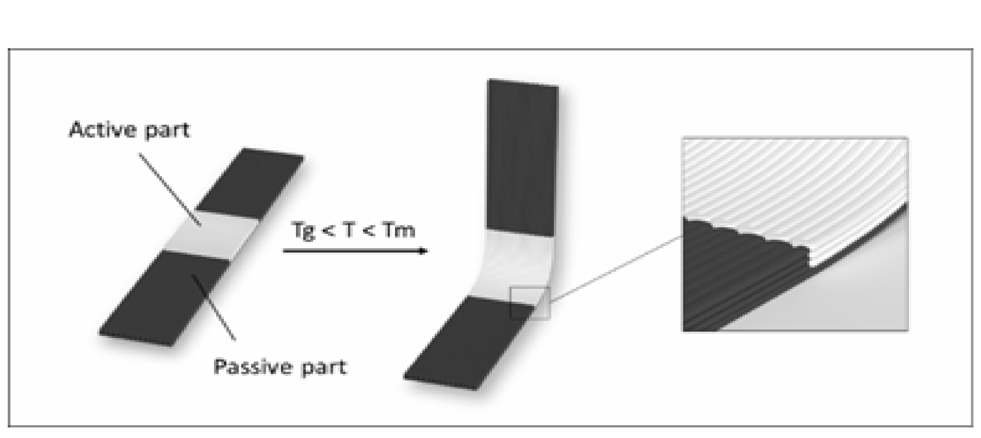

Figure 2: Printed primitive and its self-transformation.

Figure 3: Shape recovery cycle of printed primitive; Phase 1 (left) – printed flat structure, Phase 2 (center) - self-transformation in hot water, Phase 3 (right) - transformation with force and hot water back into flat structure.

RESULTS

Determining the appropriate combination of materials

Primitives with an active part length of 10 and 15 mm were printed at a printing speed of 15 mm/s. The self-transformation was tested in hot water first at 70°C and 80°C. At each temperature three primitives were tested. The results are given in Figures 4 and 5.

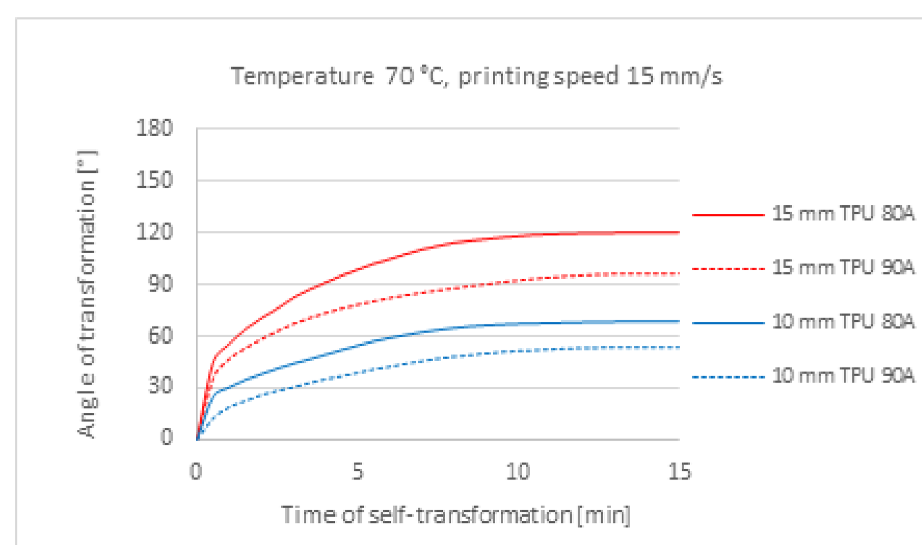

Figure 4: Angle of transformation of the primitives' (PLA/TPU80 and PLA/TPU90) depending on time in hot water at 70 °C. The lengths of active part were 10 and 15 mm. Primitives were printed at 15 mm/s.

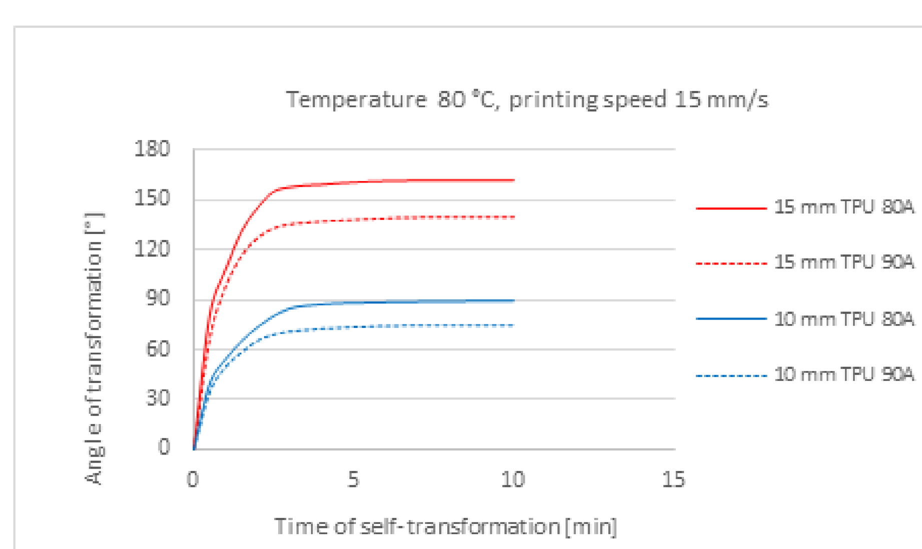

Figure 5: Angle of transformation of the primitives' (PLA/TPU80 and PLA/TPU90) depending on time in hot water at 80 °C. The lengths of active part were 10 and 15 mm. Primitives were printed at 15 mm/s

Determining the optimal water temperature

The primitives with combination of PLA and TPU90 thermoplastic materials were printed at printing speed of 22 mm/s. The length of active part was 15 mm. To determine the optimal temperature water heated to 60, 70, 80 and 90 °C was used. Results are presented in Figure 6.

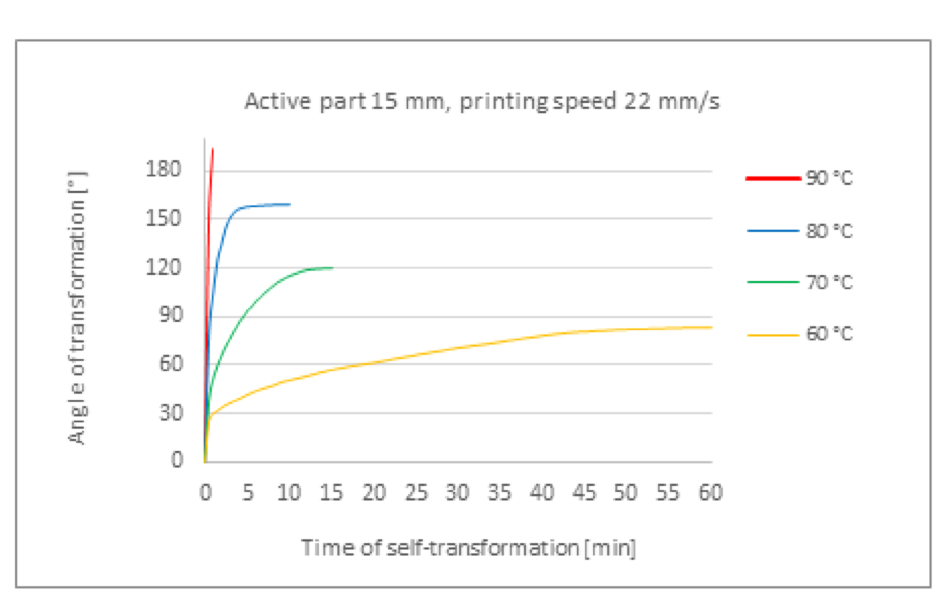

Figure 6: Angle of transformation of the primitives' (PLA/TPU90) depending on time in heated water at 60, 70, 80 and 90 °C. The length of active part was 15 mm. Primitives were printed at 22 mm/s.

Determination of primitives' shape recovery

Testing of primitives' shape recovery response was performed on primitives immersed in hot water at 70°C. The length of primitives' active part was 15 mm. Firstly, the structures were subjected to four additional self-transformation cycles, i.e. they were heated and placed in a flat position, cooled and then immersed in hot water again to allow self- transformation. This process was repeated four times to increase the total number of transformation cycles to five. The results are visible in Figure 7.

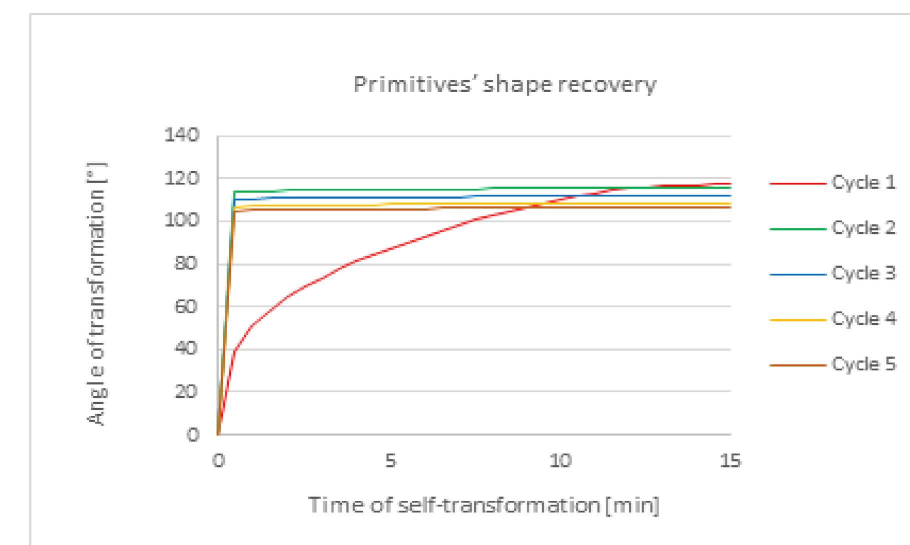

Figure 7: Results of primitives' (TPU90/PLA) shape recovery. Primitives were subjected to five self-transformation cycles in hot water at 70 °C.

CONCLUSION

For a successful study of 4D primitives' self-transformation we must ensure optimal printing conditions, select the appropriate combination of materials and the optimal temperature of the water as external stimuli. We found that in addition to printer calibration it is necessary to determine the appropriate printing speed, flow and cooling rate of the material. Since the active part of the primitive consists of two different materials it is important that the sandwich structure of materials is properly deposited and has achieved a good adhesion between the layers. The size of the transformation is also influenced by the passive material used on the active part of the primitive since it provides support during the transformation. We found out that the size of the transformation is influenced by the length of the active part of the primitive, the printing speed and the temperature of the hot water. A higher angle of transformation is achieved when the active part is longer and when the printing speed and the temperature of the water are higher.

In our case, we can conclude that for quality and controlled transformation it is recommended to make primitives with a length of the active part of 15 mm, to use max. print speed 22 mm/s and hot water as external stimuli at 70 °C. This is the basis on which we can make a mathematical model for predicting the primitives' self-transformation and a model for predicting the primitives' shape recovery.

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