4D Printed Structures with Tunable Surface Roughness based on Hygro-responsive Polymer and Vat Photopolymerization

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Abstract

Due to the advantages of additive manufacturing—including speed, cost efficiency, and sustainability—it expands the idea to 4D printing (4DP), which reflects the surroundings and changes the structure's shapes or properties accordingly. Following the trend of the additive manufacturing field, this research focuses on the design and fabrication of structures using shape-changing polymers that adjust their surface roughness in response to environmental stimuli.

Research Objective

The objective of the research is to explore advanced 4DP and facilitate the development of 4DP using VPP with a commonly used polymer that has hygro-responsive properties to demonstrate 4D-printed property of surface roughness.

Method

3D Printing via Vat Photopolymerization

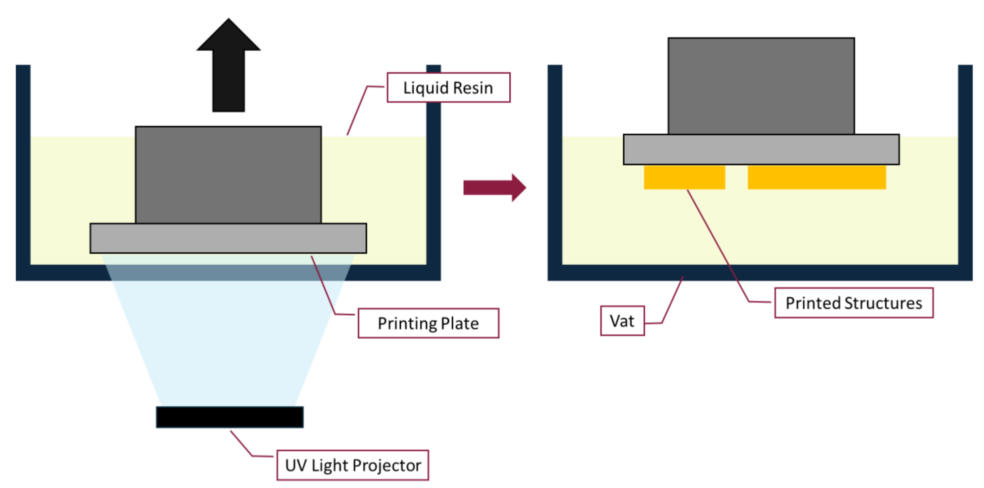

Figure 1. 3D Printing Method of Using Vat Photopolymerization

Mesh Structure Designs

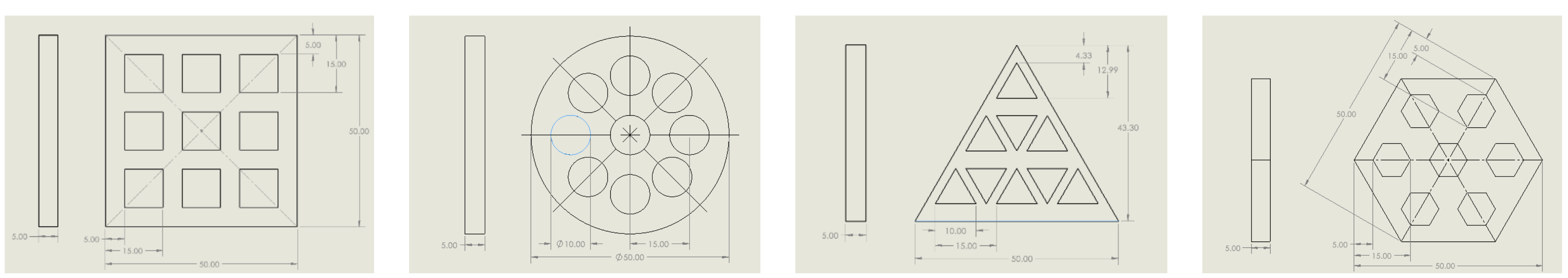

Figure 2. Drawings of Mesh Structures Printed via VPP with Liquid Resin

Printing Parameters

Table 1. Printing Parameters for Mesh Structures

Parameters	
Exposure Time	6 s
Bottom Exposure Time	35 s
Lift Distance	6 mm
Lift Speed	60 mm/min
Layer Height	0.005 mm

Photopolymerization using Surface Tension

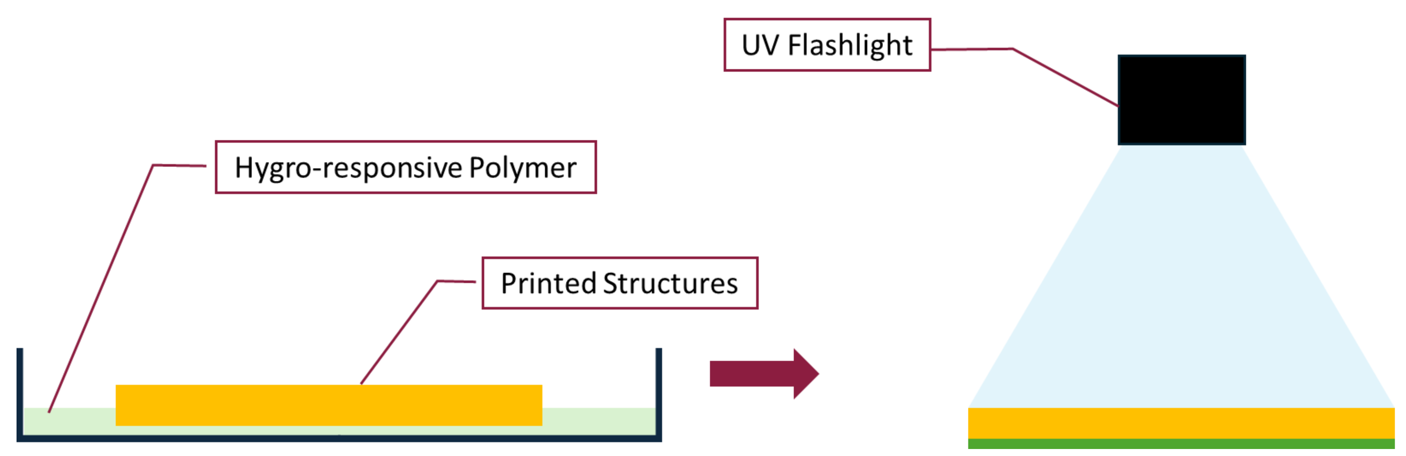

Figure 3. Curing Method of Hygro-responsive Polymer using Surface Tension

Hygro-responsive Materials: Phase-separated

Table 2. Chemical Ratio of Phase-separated Hygro-responsive Material

Materials	Ratio (Mass)		
Polyethylene Glycol (PEG)	7 (1.4 g)	3 (0.6 g)	0
Poly(propylene glycol) (PPG)	5 (1 g)	4 (0.8 g)	1 (0.2 g)
2-Hydroxyethyl methacrylate (HEMA)	10 (2 g)	10 (2 g)	10 (2 g)
2-hydroxy-2-methylpropiophenone	50 (10 g)	50 (10 g)	50 (10 g)

Hygro-responsive Materials: Thermal-responsive

Table 3. Chemical Ratio of Temperature responsive Hygro-responsive Material

Materials	Ratio (Mass)		
N-isopropylacrylamide (NIPAAm)	10 (1 g)	5 (0.5 g)	3 (0.3 g)
N,N'-Methylene-bis(acrylamide) (MBAm or MBAA)	7 (0.7 g)	5 (0.5 g)	7 (0.7 g)
Phenylbis(2,4,6-tri-methylbenzoyl)phosphine oxide	1 (0.1 g)	1 (0.1 g)	1 (0.1 g)

Future Work

1. Print mesh structures and develop hygro-responsive polymers using surface tension photopolymerization method
2. Examine how the printed hygro-responsive polymers react to changes in surroundings
3. Analyze the thermal and mechanical properties of the printed structure
4. Identify potential applications for the structure, especially leveraging its patterned surface roughness

Acknowledgements

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Reference: [1] Han, D., Lu, Z., Chester, S. A., & Lee, H. (2018). Micro 3D printing of a temperature-responsive hydrogel using projection micro-stereolithography. *Scientific Reports*, *8*(1). doi:10.1038/s41598-018-20385-2 [2] Ragelle, H., Tibbitt, M. W., Wu, S.-Y., Castillo, M. A., Cheng, G. Z., Gangadharan, S. P., … Langer, R. (2018). Surface tension-assisted additive manufacturing. *Nature Communications*, *9*(1). doi:10.1038/s41467-018-03391-w [3] Wang, Z., Heck, M., Yang, W., Wilhelm, M., & Levkin, P. A. (2023). Tough peggels by in situ phase separation for 4D printing. *Advanced Functional Materials*, *34*(20). doi:10.1002/adfm.202300947

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