Evaluation of Hardness, Surface Roughness, and Impact Strength of Additive Manufactured Ultraviolet Resin-Based Polymer

R. Venkatesh, R. Prabhakaran, J. Jerold John Britto, K. Amudhan, and G. Karan Kumar

Abstract Using additive manufacturing technology, objects can be created layer wise by a single machine rather than utilizing molds and dies. A digital-projection light source is used to cure the surface of a liquid photopolymer in digital light processing (DLP) technique. This method is best for items with complicated structures and small cross-sectional areas that demand a high level of surface finish and strength. Objects are created for variety of angles using a variety of input parameters. 3D printing technologies based on DLP printing are commonly utilized to fabricate complex items without the use of tools or machining. Numerous variables influence the design of 3D printed parts, and they differ for each design and process. The layer thickness, pattern diameter, pattern spacing, and hollow thickness are the initial factors to be considered for DLP printed test coupons. In the present paper, DLP 3D coupons are printed using ultraviolet sensitive resin ($\lambda = 405$ nm). The primary objective of the work is to study the influence of support orientation on the surface finish and toughness of the DLP 3D printed test coupons as per ASTM standards.

Keywords Additive manufacturing · DLP · Hardness · Surface roughness · Impact strength ultraviolet-sensitive resin

1 Introduction

Additive manufacturing of complicated items follows either top-down or bottom-up DLP technique. The bottom-up strategy, which involves periodic separation of the part from the vat's surface, enables the insertion of a new fresh layer of slurry. The primary issue with the top-down approach [1] is that the thickness of the

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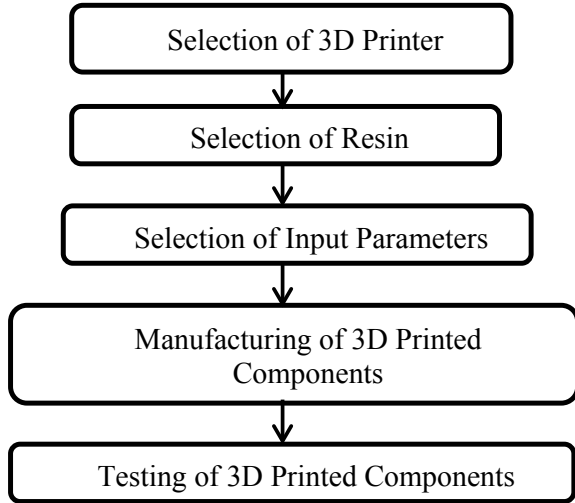e-mail: venkateshr@ritrjpm.ac.in

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printed slices is not exact and consistent. The rising ubiquity and complexity of microfluidic systems necessitate a highly adjustable fabrication approach for speedy and convenient microfluidic system production. The printing resolution, accuracy, repeatability, surface roughness, wetting ability, and biocompatibility of the printed microfluidic chips [2, 3] were determined. Micro-manufacturing techniques include stereolithography (SLA), DLP, the liquid crystal display—DLP-coupled technology, two-photon polymerization (TPP), and inkjet [4]. Silicon nitride ceramic components with simple cuboid, complicated honeycomb, and lattice architectures were manufactured using additive manufacturing and pyrolysis techniques. Compressive properties of a complex-shaped ceramic [5, 6] structure were determined. Combining material jetting with material extrusion in a hybrid system processes for additive manufacturing will be introduced. Not only is this technology capable of printing non-Newtonian viscous silicon [7]. SLA is a 3D printing process that is gaining popularity. Mechanical properties of 3D printed materials are difficult to get from technical datasheets, and even when they are available, these data are frequently required to do in-house mechanical evaluation. Calculations are made for the ultimate tensile strength, Young's modulus, strain at maximum stress, and strain [8–10] at break. The microwave properties for a wide range of materials, formed by two types of additive technology of SLA, were extracted in the X-band (8–12 GHz). The flexibility [11] of this technique and availability of low-cost commercial material suggest many potential applications in the microwave range. A new framework composed of a soft, biocompatible, and bio-stable resin has been produced. It is capable of characterizing the material's rheological and thermal properties in a systematic manner in order to guide the 3D printing process and has established a variety of processing parameters. Parametric studies are used to establish the optimal printing parameters, such as layer height, temperature, and printing speed, with the goal of decreasing porosity while maximizing the geometric correctness of the 3D printed samples as assessed by micro-CT [12]. A typical SLA 3D-printed material, in which the SLA 3D-printed composite material has a short life due to its high crosslinking density and brittleness. A few studies have examined the use of self-healing materials into 3D printing in order to extend the life of the materials. The capacity of these microcapsules to survive the SLA 3D printing process intact is established, as is the distribution of microcapsules throughout printed specimens by X-ray nano-computed tomography [13] imaging. SLA 3D printing is utilized to generate bespoke tablet geometries by encapsulating ascorbic acid (AA) in ethylene glycol [14]. The strength of 3D printed material has been determined using ASTM and ISO mechanical tests. Included are the mechanical properties of 3D printed items. The principal qualities include tensile, bending, compressive, fatigue, and impact strength [15].

2 Materials and Methods

A photopolymer is a polymer that alters its properties when exposed to light, usually in the ultraviolet or visible range. The material hardens as a result of cross-linking

Fig. 1 Methodology followed

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when exposed to light. A photopolymer [16, 17] is a mixture of monomers, oligomers, and photo-initiators that cure into a rigid polymeric substance. Ultraviolet (UV) resin is the commonly used curing material in DLP.

Method UV curing is a newer method that uses light energy instead of heat [18] to cure. UV-resistant resins are compounds that can be cured in a short time with energy released from ultraviolet irradiation devices. Hardness was measured with the use of Rockwell hardness testing machine, and the roughness was measured with the use of Mitutoyo surface roughness tester. Izod and Charpy impact strength were measured with the use of impact testing machine. Figure 1 depicts the methodology followed in the present work.

2.1 Digital Light Processing

DLP is a liquid to solid 3D printing process where a light projector is used to cure the photopolymer resin. DLP is very similar to SLA, but the only change is that instead of a UV laser to cure the photopolymer resin, a conventional light source is used. DLP-based 3D printing technology comes from the image projection technology.

This approach converts working light sources to photosensitive materials using optical micro-electromechanical chipsets and a set of micron-sized, programmable mirrors. The mirrors spin to direct the light path onto the photosensitive resin. The projection plane controlled by digital micro-mirror device and lens determines the 3D printing resolution. Thus, DLP printing has a high resolution, usually in the micron range [19]. Unlike laser-assisted 3D printing, when light is projected onto resin using DLP technology, the full layer is created immediately. It provides for quick printing

Fig. 2 DLP 3D printer used

[19, 20]. The DLP machine (Fig. 2) used has layer resolution: 25–100 µm and XY dots per inch (DPI) 47 µm with print volume of 115 mm × 65 mm × 155 mm.

2.2 Setting of Process Parameters

The basic parameters for 3D printed parts are layer thickness, pattern diameter, pattern spacing, hollow thickness, and support orientation. In this work, the speed, layer, and hollow thickness are kept constant, while the support orientation is varied. The details of the process parameters are listed in Table 1.

Table 1 Process parameters

Parameter	Specifications
Speed	3 mm/s
Layer thickness	0.05 mm
Hollow thickness	2 mm
Support orientation	0°, 45°, 60°, and 90°

Fig. 3 Charpy test specimen
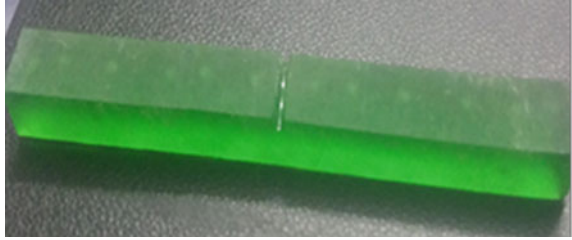
Fig. 4 Izod test specimen

2.3 Fabrication and Testing

The object's 3D model is created using NX-CAD software package, and the object's part model file is converted to an STL file. The STL file is transferred to the printer in the required file format after slicing; the liquid polymer resin is safely exposed to light from the DLP projector. The DLP machine uses a projected light source to cure the entire layer at once. The part is formed layer by layer. The exposed liquid polymer solidifies, lowering the building plate, and exposing the liquid polymer to get cured again.

The process is repeated layer after layer until the 3D model is complete. The Charpy and Izod impact tests are used to determine the object's hardness, surface roughness, and impact strength. The Charpy test specimen ASTM A370 (Fig. 3) and the Izod test specimen ASTM D256 (Fig. 4) were used.

3 Results and Discussions

3.1 Rockwell Hardness Test

The Rockwell hardness test is the most commonly used hardness test method for determining the hardness of the object. The Rockwell test is used to measure the depth of penetration by using ball indenter under a large load (major load) compared to the

penetration made by a preload (minor load). Hardness was measured by Rockwell hardness testing machine. Here, the applied load was 100 kg, and a ball-type indenter was used.

3.2 Surface Roughness Test

Surface roughness was measured by using Mitutoyo surface roughness tester at a probe velocity of 0.1 m/s. The surface roughness was measured by Mitutoyo surface roughness tester with sampling length of 2.5 mm and measuring speed of 0.5 mm/s. The stylus tip radius is 3 μm.

3.3 Toughness Test

The Charpy and Izod impact tests are used for determining the impact resistance of materials. Based on the energy absorbed by material up to the fracture, the toughness can be calculated. A pivoting arm is raised toward a specific height, and then, it will be released. The arm strikes down hitting a V-notched specimen and then breaks the specimen.

4 Conclusion

DLP is more precise than SLA and fused deposition modeling. DLP printing is capable of producing intricately detailed items with excellent dimensional precision. It has a lower operating cost than SLA, consumes less resin, and produces less waste material. DLP is a speedier procedure than other technologies such as FDM and SLA. Finally, the hardness, surface roughness, and impact strength of the object in various patterns with varying support orientations were determined. From Table 2, it is observed that for speed of 3 mm/s and layer thickness 0.05 mm, 0° orientation has better impact strength, hardness, and surface roughness.

Table 2 Hardness, impact strength, and surface roughness for different orientation angles

S. No.	Orientation (°)	Hardness (HB)	Surface roughness (μm)	Impact strength (J)	
				Charpy	Izod
1	0	27.28	73.64	3.2	3.6
2	45	26.33	123.71	2.4	3.2
3	60	25.41	146.48	2.2	3.4
4	90	27.12	120.02	2.6	3.0

References

1. Santoliquido O, Colombo P, Ortona A (2019) Additive manufacturing of ceramic components by digital light processing: a comparison between the ' bottom-up ' and the ' top-down ' approaches. J Eur Ceram Soc 39(6):2140–2148. https://doi.org/10.1016/j.jeurceramsoc.2019.01.044

2. Lee JM, Zhang M, Yeong WY (2016) Characterization and evaluation of 3D printed microfluidic chip for cell processing. Microfluid Nanofluidics 20(1):1–15. https://doi.org/10.1007/s10404-015-1688-8

3. Doronin FA, Rudyak YV, Rytikov GO, Evdokimov AG, Nazarov VG (2021) 3D-printed planar microfluidic device on oxyfluorinated PET-substrate. Polym Test 99:107209. https://doi.org/10.1016/j.polymertesting.2021

4. Fiedor P (2020) A new approach to micromachining: high-precision and innovative additive manufacturing solutions based on photopolymerization technology

5. Wang M (2019) Polymer—derived silicon nitride ceramics by digital light processing based additive manufacturing. (January):5117–5126. https://doi.org/10.1111/jace.16389

6. Rasaki SA, Xiong D, Xiong S et al (2021) Photopolymerization-based additive manufacturing of ceramics: a systematic review. J Adv Ceram 10:442–471. https://doi.org/10.1007/s40145-021-0468-z

7. Liravi F, Toyserkani E (2018) A hybrid additive manufacturing method for the fabrication of silicone bio-structures: 3D printing optimization and surface characterization. Mater Des 138:46–61. https://doi.org/10.1016/j.matdes.2017.10.051

8. Cosmi F, Dal Maso A (2019) A mechanical characterization of SLA 3D-printed specimens for low-budget applications. Mater. Today Proc. 32:194–201. https://doi.org/10.1016/j.matpr.2020.04.602

9. Pooput K, Channasanon S, Tesavibul P et al (2020) Photocurable elastomers with tunable mechanical properties for 3D digital light processing printing. J Polym Res 27:322. https://doi.org/10.1007/s10965-020-02289-w

10. Konstantinou G, Kakkava E, Hagelüken L, Warriam Sasikumar PV, Wang J, Makowska MG, Moser C (2020) Additive micro-manufacturing of crack-free PDCs by two-photon polymerization of a single, low-shrinkage preceramic resin. Addit Manuf 101343. https://doi.org/10.1016/j.addma.2020.101343

11. Arbaoui Y, Laur V, Maalouf A, Queffelec P (2015) 3D printing for microwave: Materials characterization and application in the field of absorbers. In: 2015 IEEE MTT-S international microwave symposium IMS 2015, pp 1–3. https://doi.org/10.1109/MWSYM.2015.7166769

12. Bachtiar EO et al (2020) 3D printing and characterization of a soft and biostable elastomer with high flexibility and strength for biomedical applications. J Mech Behav Biomed Mater 104(December):103649. https://doi.org/10.1016/j.jmbbm.2020.103649

13. Shinde VV, Celestine AD, Beckingham LE, Beckingham BS (2020) Stereolithography 3D printing of microcapsule catalyst-based self-healing composites. ACS Appl Polym Mater 2(11):5048–5057. https://doi.org/10.1021/acsapm.0c00872

14. Karakurt I, Aydoğdu A, Çıkrıkcı S, Orozco J, Lin L (2020) Stereolithography (SLA) 3D printing of ascorbic acid loaded hydrogels: a controlled release study. Int J Pharm 584(February):1–9. https://doi.org/10.1016/j.ijpharm.2020.119428

15. Dizon JRC, Espera AH, Chen Q, Advincula RC (2018) Mechanical characterization of 3D-printed polymers. Addit Manuf 20. https://doi.org/10.1016/j.addma.2017.12.002

16. Crivello JV, Reichmanis E (2014) Photopolymer materials and processes for advanced technologies. Chem Mater 26(1):533–548. https://doi.org/10.1021/cm402262g

17. Phillips R (1984) Photopolymerization. J Photochem 25(1):79–82. https://doi.org/10.1016/0047-2670(84)85016-9

18. Shukla V, Bajpai M, Singh DK, Singh M, Shukla R (2004) Review of basic chemistry of UV-curing technology. Pigm Resin Technol 33(5):272–279. https://doi.org/10.1108/03699420410560461

19. Ngo TD, Kashani A, Imbalzano G et al (2018). Additive manufacturing (3D printing): a review of materials, methods, applications and challenges. Compos Part B 143:172–196
20. Lu Y, Mapili G, Suhali G et al (2006) A digital micro-mirror device-based system for the microfabrication of complex, spatially patterned tissue engineering scaffolds. J Biomed Mater Res A 77(2):396–405. https://doi.org/10.1002/jbm.a.30601