

INFLUENCE OF POST-CURING DURATION ON THE MECHANICAL AND THERMOMECHANICAL PROPERTIES OF 3D-PRINTED PARTS VIA MSLA

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1. Introduction

Additive Manufacturing (AM) has driven a billion-dollar market in recent years [1], gaining attention for enabling the production of complex yet cost-effective geometries. This layer-by-layer process offers speed, cost efficiency and flexibility in various sectors, such engineering, medicine, etc. [2-4]. Among AM techniques, stereolithography (SLA) is the oldest and widely used one [2,5]. It constructs solid objects from liquid polymer resins through UV or visible light exposure [6]. Advances led to masked stereolithography (MSLA), which uses a mask between the light source and resin tank to cure 2D patterns. SLA parts often exhibit insufficient mechanical strength due to incomplete polymerization, necessitating post-curing for enhanced properties [1-3]. Bonada et al. [7] found that post-curing with visible light achieves a 77% monomer-to-polymer conversion, while UV light reaches 89%. Ahmad et al. [3] demonstrated that UV curing at high temperatures improves mechanical properties by increasing the mobility of free radicals. Zhao et al. [1] found that conventional ovens enhance tensile strength more than microwave ovens. For photocurable acrylate resins, post-curing improves tensile strength while reducing elongation, shifting the glass transition temperature (T_g) higher due to polymer crosslinking [2]. Given these findings, this study will evaluate the post-curing process for Anycubic's Flexible Tough UV resin, which offers enhanced ductility over conventional resins for final applications.

2. Experiment

A commercial Anycubic's Flexible Tough UV photocurable resin based on PMMA was used. It was selected due to its higher impact resistance and flexibility, making it suitable for product development due to its ductile-elastic behavior. Specimens were printed in an Anycubic Photon Mono SE 3D printer with a 405 nm UV LED matrix. The manufacturer's slicing parameters were used. Specimens were printed horizontally, without supports. The exposure time was 30s for the first six layers and 1.5s for the remaining ones, with a layer height of 50 μm . After printing, specimens were washed using the Anycubic Wash&Cure 2.0 with 95% isopropyl alcohol for 5 minutes. Curing times of: 15, 30, and 45 min were tested.

Dynamic-mechanical analysis (DMA) was performed using a Netzsch DMA 242 in dual cantilever mode, with an amplitude of 60 μm , temperature range of 10°C to 120°C, and frequencies of 1, 5 and 10 Hz. Specimens (60 \times 10 \times 3 mm) were fabricated in duplicate. Tensile tests followed ASTM D638, using an Emic DL1000 machine at 5 mm/min. Five type IV specimens were produced for each post-curing condition (15, 30, and 45 min).

3. Results and Discussions

Post-curing time influenced the T_g temperature, as shown in Fig. 1. The T_g was determined from the $\tan \delta$ peak and increased with frequency. The highest T_g was observed at 45 min and 10 Hz (75.4°C). At 1 Hz, the T_g was 65.4°C for 45 min.

The storage modulus was analyzed at 25°C and 40°C. At 25°C, E' increased with frequency, with the highest value recorded for 30 min of post-curing. Comparing 15 and 45 min, a 1.3% decrease was observed. At 40°C, the highest E' was found for 45 min, showing a gradual 1.7% increase with exposure time. A 73.7% drop in E' was noted when comparing 25°C and 40°C, highlighting the temperature effect (Fig. 2).

Tensile test results (Fig. 3) revealed a progressive increase in fracture strength and Young's modulus with longer post-curing times. The fracture strength increased by 35%, while Young's modulus increased by 73% between 15 and 45 min. The highest experimentally obtained values were 20.86 \pm 0.14 MPa (fracture strength) and 1.24 \pm 0.2 GPa (Young's modulus) for 45 min of post-curing. These values were significantly lower than the manufacturer's

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data (35-45 MPa and 0.8-1.2 GPa), likely due to resin degradation caused by isopropyl alcohol, as also reported by Riccio et al. [6].

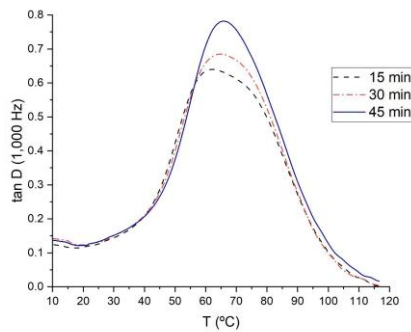


Fig. 1. Glass transition temperature (T_g).

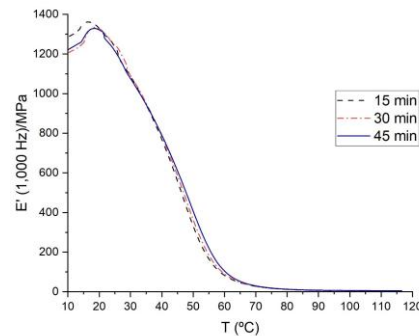


Fig. 2. Storage modulus variation according to the post-curing time.

In tensile tests, Young's modulus increased by 59% between 15 and 45 min. In DMA, E' at 25°C was highest at 30 min, while at 40°C, it was highest at 45 min. Fracture strength also increased with longer post-curing, showing a 32% increase between 15 and 45 min due to internal solidification and better arrangement of polymer chains. The T_g temperature increased by 2.5% on average across all frequencies.

Despite the observed improvements, fracture strength remained 67.8% lower than the lowest value in the manufacturer's data for all post-curing conditions. However, E' values were comparable to the manufacturer's range, particularly at 45 min of exposure. The discrepancy in fracture strength may be attributed to isopropanol degradation of the acrylic polymer matrix.

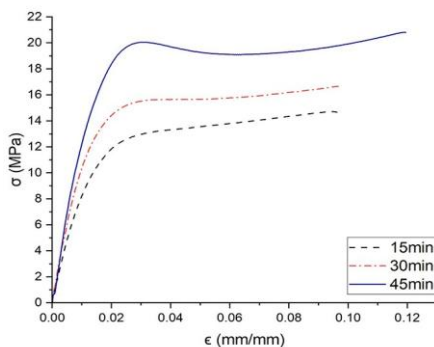


Fig. 3. Stress-strain curves of printed specimens exposed to 15, 30 and 45 minutes of post-curing.

4. References

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