THE APPLICATION OF VAT POLYMERIZATION TECHNIQUE FOR WORKPIECE FABRICATION

KARIN KANDANANOND

Faculty of Industrial Technology, Valaya Alongkorn Rajabhat University, Thailand

ABSTRACT

Vat polymerization is one of the additive manufacturing techniques. The focus of this study is the performance assessment of a vat polymerization system that has the digital light processing (DLP) system as its ultraviolet (UV) source. In this study, ADLP vat polymerization system was utilized to fabricate a work piece, and the objective is the measurement of the average surface roughness indicating the surface quality of a work piece. After a work piece was fabricated at a certain condition focused on different input factors (exposure time, bottom exposure time, bottom layer count, layer thickness, lifting speed, lifting distance, and retract speed), the average surface roughness was measured using a surface roughness tester. The measurements were done on the top side of a work piece. Three measurements were performed on three different spots to investigate the surface quality. The results indicate that the values of average surface roughness measured from the different spots fluctuate in a small range.

KEYWORDS: Average Surface Roughness, Digital Light Processing, Vat Polymerization

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INTRODUCTION

One of the traditional manufacturing processes is subtractive manufacturing (SM). This process involves the removal process using different fabrication methods, e.g., cutting, drilling, grinding, milling, turning. Work pieces are machined manually, or they are fabricated by computer numerical control (CNC) machines. For a CNC system, a solid model is designed by computer aided design (CAD) software and it is served as an input for a fabrication tool. Afterwards, another computer software (computer aided manufacturing: CAM) plays an important role by controlling machine tools to fabricate work pieces. On the other hand, additive manufacturing (AM) is another manufacturing method that an object is graphically designed by the utilization of CAD software and it is converted into standard tessellation language or standard triangle language (.stl) file. Later, the object is sliced into thin layers by slicer software and G-code is generated and exported to the system. Finally, a three-dimensional (3D) object is built by following G-code instructions. Generally, this method is simply called 3D printing.

According to the contemporary technology, two AM methods are widely utilized. One is the fused filament fabrication (FFF) or fused deposition modelling (FDM) that each layer of polymer is joined together with the previous layer of material. The polymer filament is melted by a nozzle or print head and deposited on the print bed. An FFF system is shown in Figure 1. Another technique is the application of liquid photopolymer resin that is hardened or cured by a UV source. Nowadays, the AM technology is affordable and comes in different range for both amateur and professional practitioners. Therefore, the objective of this study is to assess the performance of an AM method, DLP vat polymerization, to fabricate a work piece. The experiment was based on the setting of the following input factors: exposure time, bottom exposure time, layer thickness, lifting speed, lifting distance, and

retract speed. The response of this experiment is average surface roughness measured at the top side of a work piece.

Figure 1: FFF System.

LITERATURE REVIEW

Hofstetter et al (2017) investigated the fabrication of fiber-reinforced polymers by material extrusion and vat polymerization techniques. Tensile strength and Young's Modulus were two characteristics of fabricated polymers to be studied. Valentincic et al (2017) studied the capability of a low-cost DLP vat polymerization system. The factors leading to the inaccuracy were identified and these were uneven illumination, direction of illumination and printing parameters (exposure time, layer thickness, and time between two consecutive exposures). The design of experiment was Taguchi's design. Davoudinejad et al (2018) assessed the performance of a vat photo polymerization machine when miniaturized polymer components were fabricated. The assessment was based on the different dimensions and geometries. Stirrer et al (2018) developed the technique of hot lithography that the photosensitive resin was heated and cured at the higher temperature than the room temperature. The result showed that the high temperature led to the low viscosity, low printing time, and better mechanical characteristics. Ghouli et al (2020) studied the effect of total printing time, layer thickness, and layer exposure time on the quality of specimens. The 365 nm wavelength photopolymer resin was used while the projector had 2500 ANSI lumens. Revilla-Leon et al (2020) determined the optimal setting of printing angulations to minimize the surface roughness of intaglio of the clear silicone. The fabrication system was a vat polymerization system and different print orientations were utilized in the study. Due to Gonzalez (2020), biocompatibility polymer parts were printed in the

controlled conditions by using a commercial DLP system. The analysis was conducted on the resin composition and post-printing process.

METHOD

The selected AM method is the vat polymerization. For vat polymerization, liquid photopolymer resin in a vat or tank is hardened or cured by UV light. Resin is fabricated according to the imported model. There are different subcategories of vat polymerization methods and these are, e.g., stereo lithography (SLA), liquid crystal display (LCD), and digital light processing or direct light processing (DLP). In this research, the performance of a DLP-sourced-vat polymerization system was assessed by considering the surface quality of a work piece. The process of DLP vat polymerization is graphically illustrated in Figure 2.

DLP vat polymerization system

Figure 2: DLP vat Polymerization Process

According to Figure 2, a CAD model of the work piece was imported into a computer and it was converted into a still file. The still file was later sliced into layers by utilizing slicer software. It was subsequently imported into the vat polymerization system that each layer of work piece was built by flashing light from a DLP projector on the photopolymer resin. The digital micro mirror device (DMD) in a projector controlled the reflection of flashing light on the resin. After the resin was successfully cured, the platform was moved upward. In this study, the quality of work piece was measured in the form of average surface roughness (Ra) which is the average of deviation (Z_i) from the mean line of surface sampled along the evaluation length (L) as shown in the example of Ra calculation (Figure 3). The calculation of Ra is elaborated in (1).

$$Ra = \frac{\sum_{i=1}^n Z_i}{n} \quad (1)$$

Figure 3: Graphical Representation of Example of Ra Calculation (Kandananond, 2020)

EXPERIMENT

The system used in this study was based on DLP-sourced vat polymerization and it was shown in Figure 4. Due to Figure4, some photopolymer resin was filled in the vat while the platform was at the upward position.

Figure 4: DLP vat Polymerization System

The specification of this system was listed in Table 1. According to Table 1, the wavelength of UV integrated beam is 405 nm. The minimum layer thickness of work piece to be fabricated is 0.03 mm while the maximum is 0.05 mm. On the other hand, the photopolymer resin has a wavelength range of 395-405 nm.

Table 1: Specification of DLP vat Polymerization System

Parameter	Value
UV integrated beam	405 nm
Layer thickness	0.03-0.05 mm

For this study, a 3D model was created by CAD software and it had the flat surface on both sides (top and bottom). Afterwards, it was imported as the still file into slicer software and the settings of input factors for the fabrication system are shown in Figure 5. The DLP vat polymerization system was operated by focusing on the following in puts: exposure time, bottom exposure time, bottom layer count, layer thickness, lifting speed, lifting distance, and retract speed. The exposure time was set at 6 seconds while the bottom exposure time was 50 seconds. The bottom layer count was set at 8. The layer thickness was 0.05 mm, and the lifting speed was 65mm/min. Other factors were lifting distance and retract speeds which were set at 5 mm and 150 mm/min, respectively. The measurement equipment used in this study was a surface roughness tester which has the measuring range of Ra starting from 0.05 μm .

Figure 5: Input Factors and Settings

RESULTS

After the photopolymer resin was successfully cured, the zoom area of a finished work piece was shown in Figure 6. The surface roughness tester was utilized to measure the top side. On the top side, the Ra of three different spots (Ra1, Ra2, and Ra3) were measured and listed in Table 2. Ra1, Ra2, and Ra3 were 1.32, 1.5, and 1.41 μm , respectively.

Figure 6: Zoom area of a Finished Work Piece and Measurement Spots (Top Side)

Table 2: Ra Measurement on Work Piece

Side	Ra (μm)		
	Ra1	Ra2	Ra3
Top	1.32	1.5	1.41

CONCLUSIONS AND DISCUSSIONS

A 3D model was created and passed to the slicer software. Afterwards, the model was sliced into layers and imported into the DLP-sourced-vat polymerization system to fabricate a work piece. The material used was a photopolymer resin with a wavelength of 405 nm. The focused factors were exposure time, bottom exposure time, bottom layer count, layer thickness, lifting speed, lifting distance, and retract speed. The Ra measurement was performed on the top side of a finished work piece. Ra on three different positions was measured, and the results show that the values of Ra deviate in a small range. The further study might be conducted on the cases that work pieces have different orientations or settings of input factors

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