Study on the Effect of Exposure Time and Layer Thickness on Properties Of 3D Printing Parts Using DLP Method

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Abstract

In recent years, 3D printing technology has been used in many industrial and home products. This paper investigates the effects of process parameters on the mechanical properties of 3D printing parts using photopolymer material. A DLP 3D printing machine was constructed for experimental researches and education. Two input control parameters: exposure time T(s) and layer thickness L(mm) were selected to investigate (i) the effects they have on various output data of tensile strength, bending strength and Shore A hardness and (ii) the effects of layer thickness to the shrinkage along Z axis. *The results can be used in the process of choosing the suitable process parameters when printing 3D using the DLP method.*

Keywords: Additive Manufacturing, 3D printing, DLP, Process parameters, Shore A hardness.

1. Introduction

Additive Manufacturing (AM) or 3D printing is a technology in which parts are fabricated layer by layer directly from 3D CAD data without removal of material with cutting tools. AM has significant advantages in Rapid Prototyping Technology because it can fabricate prototypes without moulds [2]. Furthermore, since the manufacturing process is layer based, AM can create complex structures that might not be possible with traditional manufacturing methods. In recent years, AM witnesses a trend from prototyping to manufacturing [3]. Hence, 3D printed parts need to be at better quality, more resilient to loads.

Nowadays, the standard file format for 3D printing is STL or Stereolithography created by 3D Systems and native to Stereolithography CAD software [4]. The imported STL file has to be sliced into layers and sent to 3D printing machine to begin the manufacturing process.

There are many 3D printing technologies in the world today, for example: Fused Deposition Modeling (FDM), Stereolithography (SLA), Solid-Base Curing (SBC)… [9] or Digital Light Processing (DLP). However, in Vietnam, most researches focus on the FDM technique.

The DLP 3D printing technology uses photopolymer like the SLA technology but the main difference is that DLP uses digital light projector screen instead of laser like in SLA. Because of this, DLP 3D printers can print a layer at a time and the printing speed increases noticeably. Moreover, the structure of the machines is also considerably simplified. It has the advantages and overcomes the disadvantages of SLA and SCB techniques. This paper investigates the effect of process parameters on the properties of DLP 3D printing parts. The study was conducted on a DLP 3D printer fabricated for research and educational purpose.

2. Experimental procedure

2.1 Digital light processing technology

Introduced by Texas Instrument and Digital Projection Ltd in the end of the 20th century, Digital Light Processing technology based on optical micro-electro-mechanical technology that uses a matrix of Digital Micro mirror Devices with pixel pitch of less than 5.4 μm [5]. Each device projects one or more pixels of the image. The movement of the mirrors creates the colours and shape of the image.

DLP technology can be used with a various of light sources. However, Xenon arc lamp unit is the most popular light source.

2.2 Photopolymer

Photopolymer is a polymer that changes its properties when exposed to light, often in the

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ultraviolet or visible region of the electromagnetic spectrum as shown in figure 1 [6]. To be hardened, photopolymer goes through a process known as curing where UV light induces polymerization [7].

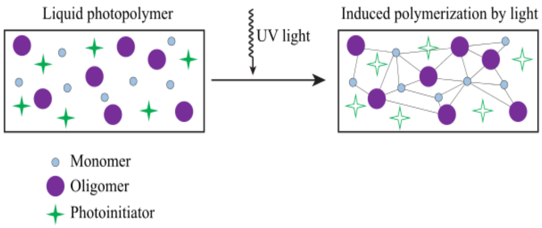


Fig. 1. Polymerization process.

2.3 DLP 3D printer

Principle of a DLP 3D printer, is shown in figure 2:

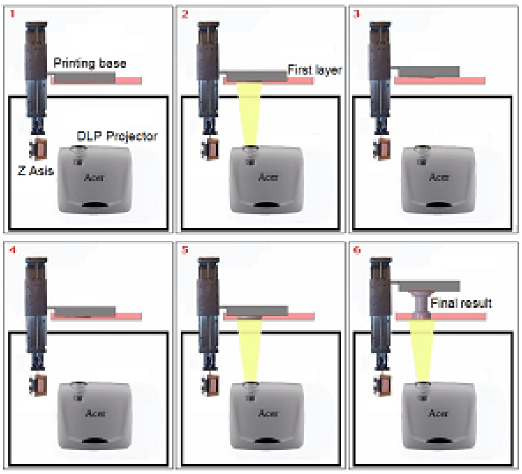


Fig. 2. DLP 3D printing process

The printing base moves closely to the bottom of the polymer sink with the distance of a printing layer.

The DLP Projector projects the shape of that layer for a period of time. The length of one exposure period depends largely on the light source and has effects on properties of printed parts.

The printing base moves up from 3 mm to 7 mm to let photopolymer fill in the printed area. In this research, to ensure a new polymer layer covering the surface, the speed of 25mm/min. was chosen to lift the base to 7 mm.

The printing base moves down. To increase productivity and guarantee convection, and ensure that the liquid photopolymer filling the new layers, the downward feed rate was set to 150 mm/min.

The DLP Projector continues projecting the next layer.

The process from 3 to 5 above repeats until final layer is printed.

There are two methods of DLP 3D printing:

- The model will be printed by being pulled layer by layer out of the polymer sink. This method has many advantages, but machine operators need to ensure that the first layer sticks firmly to the printing base and does not stick to the bottom of the polymer sink.

- The model will be printed by being pushed in the polymer sink. The new layer will be created on the surface of the liquid polymer.

A DLP 3D printer was fabricated based on the principle above, as shown in figure 3. The machine has prismatic motion on the *Z* axis. A Nema 17 Stepper motor is controlled by board Arduino 2560 embedded with Marlin source code. A power screw with the pitch of 8 mm and the diameter of 8 mm are used to convert rotary motion into prismatic motion.

The light source is the DLP office projector Acer X-113PH

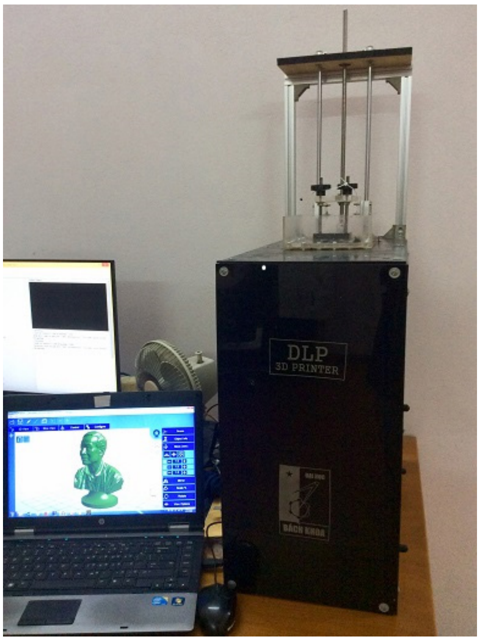


Fig. 3. DLP 3D Printer.

2.4 Experiments to calibrate printing ratio:

The testing prototype was designed as a rectangular cuboid with the dimension of 30 x 20 x 1 mm.

Chosen process parameters: $T = 40$s; $L = 0.1$ mm;

The printed prototype had the average dimension of 58.8 x 39.3 x 0.9 mm.

Since the printed parts were thin, if the shrinkage ration is ignored, the printing ratio along the *X* axis and *Y* axis is 1.96. With this result, the ratio in the Creation

Workshop software to 51% along the *X* axis and *Y* axis was calibrated to get the dimension of the printed part equal to the designed part.

2.5 Experimental model

The quality of fabricated parts can be influenced by process parameters [8]. In the DLP 3D printer, 2 control parameters are layers thickness and exposure time. Both can be controlled by slicing software and embedded control program.

The luminous intensity of the projector was set to 50% because with the too intense light source, the polymer outside projected zone would also be cured.

In addition to the effects of layer thickness to the strength of parts, another process parameter which might directly affect the strength of the printed parts is the exposure time. This is vital to the bond between layers. Too long exposure time can make the build losing its definition while too short exposure time can make the build not sticking together [3].

Table 1. Process parameters

Exposure Time *T*(s)	Layer thickness *L*(mm)
30	0.10
40	0.20
50	0.30
60	-

Photosensitive resin material used in the experiments is CTC- Xitong photosensitive resin.

Material properties: High toughness material

Cured wavelength: 405nm

The standardized testing specimens were fabricated with the process parameters as described in Table 1.

Testing specimen dimensions were used according to standard TCVN 9853:2013, as shown in figure 4.

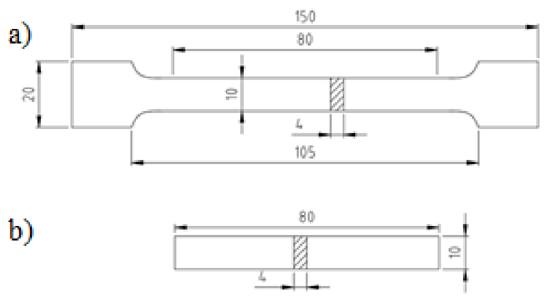
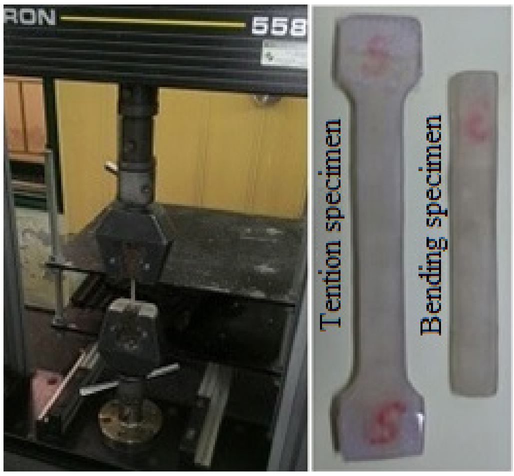


Fig. 4. a) Tension Testing specimen
b) Bending Testing specimen

The specimens and testing machines at the Laboratory of Polymer and Composite, Hanoi University of Science and Technology are shown in figure 5.



a- Tension testing. b- Specimens.

c- Flexural testing

d- Shore A testing

Fig. 5. Testing machines and specimens

3. Results and discussion:

Testing results are shown in tables 2, 3 and 4.

Table 2. Tension strength

Exposure Time T(s)	Layer thickness (mm)		
	0.1	0.2	0.3
	Tension strength (MPa)		
30	8.42	7.06	6.60
40	9.88	9.08	7.06
50	11.37	11.12	7.75
60	12.38	11.86	8.46

Table 3. Bending strength

Exposure Time T(s)	Layer thickness (mm)		
	0.1	0.2	0.3
	Bending strength (MPa)		
30	13.6	9.8	6.2
40	19.7	12.8	7.6
50	16.6	11.2	6.8
60	16.0	9.8	6.3

Table 4. Shore A hardness

Exposure Time T(s)	30	40	50	60
Average Shore A	77.33	83.33	89.33	92.00

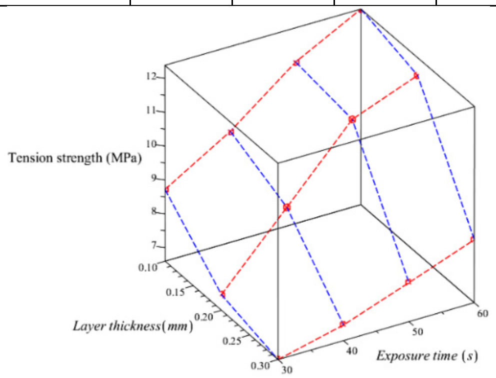


Fig. 6. Tension strength results

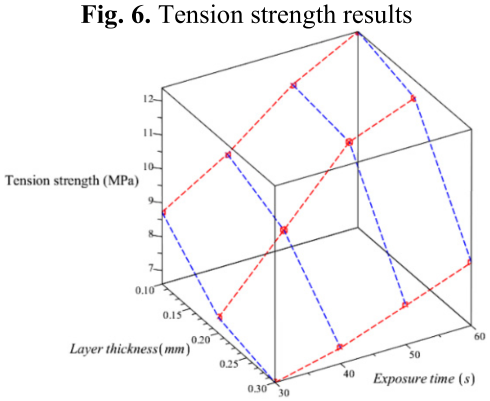


Fig.7. Flexural strength results

Based on the above results, the authors made the following observations.

3.1 Effects of layer thickness:

Increasing the layer thickness will decrease the tensile strength and the bending strength of the parts. However, when the exposure time is long enough, the effects reduce due to the fact that the thick layers have enough curing time. When the thickness reaches 0.3mm, the strength decreases significantly.

Apart from the effects of layer thickness to strength and hardness of the specimens, the layer thickness also effects the shrinkage of specimen especially along *Z* axis. The part thickness is measured by digital calliper and the results show that the shrinkage along *Z* axis is from 3.5%, 3.8% and 4.2% with the layer thickness of *L*=0.1mm, *L*=0.2mm and *L*=0.3mm respectively.

3.2 Effects of exposure time:

The tensile and bending strength of parts also increase when increasing the exposure time. However, when the layers are thin and the exposure time increases from 50s to 60s, the strength of the parts does not increase noticeably. This can be explained by the fact that the layer is thin so the exposure time of 50s is enough to cure the polymer to the highest strength possible.

Figure 8 shows that when increasing the exposure time, the Shore A hardness of parts increases almost linearly, but when the exposure time is over 50s the hardness nearly reaches the possible hardness of the polymer, thus the increase rate reduces.

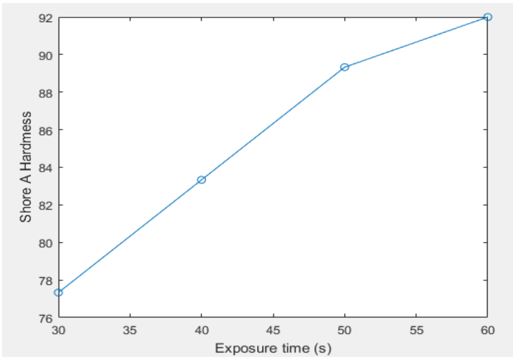


Fig.8. Shore A hardness results

4. Conclusion

After the experiments, the paper has a few suggestions for machine operators: when printing with the thick layers, long exposure time should be applied. However, the exposure time should not be too long because apart from reducing the productivity, long exposure time will make the photopolymer around the parts cured due to light scattering and increase the dimensional errors along X and Y axis. The exposure time can be adjusted based on the demanded properties of parts. Shrinkage of printing parts along Z axis increases when layer thickness increases.

Acknowledgments

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