Optimization of Wax Model Printing using a DLP 3D Printer for Castable Wax Resin material

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Abstract. Wax material can be used to make craft items as models that are printed using 3D printing. Custom and mass production processes for craft items can be carried out according to customer needs. This research aims to find the best process parameters in optimising the wax printing process as a printed model using 3D Printing DLP technology to have the best dimensional accuracy, geometric accuracy, and surface roughness. The method used is a design of experiment with factors in the form of exposure time and layer thickness, each of which has three levels to produce the best response: dimensional accuracy, geometry, and surface roughness. The research results show that print parameters with an exposure time value of 16 seconds and a layer thickness of 0.06 are the best experiments in producing dimensional accuracy of the print results. This is indicated by the smallest shrinkage percentage value of 0.41%. Meanwhile, to obtain smooth print results with minimal defects, printing is carried out with an exposure time parameter of 14 seconds with a layer thickness of 0.06 mm.

1 Introduction

Introducing new digital manufacturing technologies provides new options for businesses to increase productivity, customization, and sustainability [1]. Currently, the mask image projection stereolithography (MIP-SLA) process is known, where images of 2D cross-sectional components are projected onto the surface using the MIP-SLA technique by curing each layer in one exposure. So, this process reduces production time significantly because it cures the entire resin layer in one irradiation step. MIP-SLA has two variants, namely digital light processing (DLP) technology and liquid crystal display (LCD); DLP is widely used by researchers for 3D printing [2]. With its extremely high printing resolution and superior surface finish quality over all other additive techniques, DLP is a unique additive manufacturing process garnering significant attention from researchers and commercialization [3]. The photopolymerisation reaction is a reaction that occurs in DLP printers and 3D LCDs.

The photopolymerisation reaction occurs when the resin is polymerised after light exposure. The light projector on a DLP 3D Printer project the image, while the LCD 3D printer uses a liquid crystal display to generate a mask and block light from the light-emitting diode (LED) back panel [4]. 3D LCD printers from manufacturers such as Phrozen, Ackuretta, and Kudo have become popular in the last two years. LCD Printers use colour LCD panels to create a mask to block 405 nm light from the LED back panel. Because the light transmission efficiency of conventional colour LCD panels ranges from 5% to 14%, a small percentage of UV rays can penetrate the LCD and reach the resin [5].

The DLP printing method has the advantage of high surface treatment and finish, while cost and time inefficient [6]. A digital micromirror device (DMD) chip modulates ultraviolet (UV) light, and the patterned light is projected onto a photocurable material to cure each individual layer to a precise shape. DLP has grown in popularity as a sort of stereolithography [7]. Two-dimensional (2D) unit operations are repeated to generate three-dimensional (3D) structures. Each layer in DLP printing is created in a single exposure, and depending on the optical system, the distinctive configuration within a single layer can be scaled to minuscule dimensions (20–50 µm). Every part of the digital model is printed layer by layer. DLP printing has been widely employed in biomedical engineering sectors such as tissue engineering, drug delivery, and implantation because of its free-form printing features, outstanding shape accuracy, and faster printing speed [8].

The speed of the DLP system is an advantage of DLP technology. DLP projectors print all layers simultaneously, resulting in much shorter print times. The speed of a DLP projection system is decreased to print times comparable to FDM printers [9].

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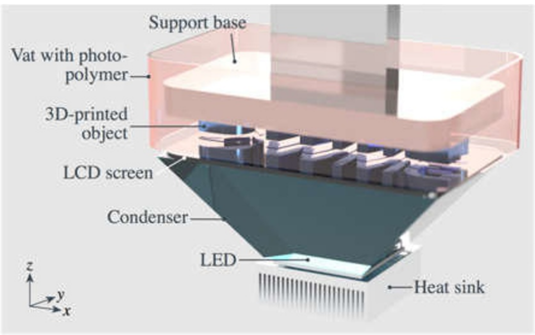

Fig. 1. Proses DLP 3D Printing [10]

In recent years, the concept of continuous DLP printing, achieved by replacing advanced layer-by-layer curing with continuous curing, has been applied to improve printing efficiency and shape accuracy. The Jacobs working curve (the relationship between the photocurable material's thickness and the energy absorbed from UV light when exposed to UV light) was used to obtain accurate printing parameters/high precision printing results using certain photocurable materials in a Digital Light Processing (DLP) study. Nevertheless, using conventional experimental methods, it takes a lot of time and material to measure the differences in cured thickness under UV light exposure for each photocurable material. The solid absorbance, liquid absorbance, and gelation time are the only three physical characteristics of the photocurable material that might affect the Jacobs working curve analysis in this model. Furthermore, a strong correlation is achieved between the experimental data and the analytical Jacobs working curve by varying the concentration of the UV absorber in the photocurable material. To predict the DLP printing parameters, the Jacobs working curve analytics of polyethylene (glycol) diacrylate (PEGDA) hydrogel and gelatin methacrylate (GelMA)/decellularized extracellular matrix (dECM) bioink were utilized. These proved accurate enough to print 3D complex structures, such as triangular cones, diamond grids covered in spherical shells, and three periodic minimum surfaces (TPMS). Printing photocurable materials with high precision is possible using this theoretical model of the Jacobs working curve DLP, which establishes the basis for appropriate DLP printing parameters [8].

Wax material can be used to make craft items as models that are printed using 3D printing. Custom and mass production processes for craft items can be carried out according to customer needs. Research is needed regarding the procedures discussed in making molds using 3D printing models and calculating their suitability for custom and mass production. This research aims to find the best process parameters in optimizing the wax printing process as a printed model using 3D Printing DLP technology to have the best dimensional accuracy, geometric accuracy, and surface roughness. The DLP printing method has the advantage of flat surface treatment and the finish being high, while it is cost- and time-inefficient. However, this printing method was suitable for jewelry/craft-making use. Better research can be conducted if an efficient printing method is chosen for future jewelry/craft designs [6].

In terms of the 3D printing method, which is suitable for ornamental use, it was found that the DLP 3D Printer is suitable for use in the jewelry/craft industry. The DLP printing method for making ornaments can be used by curling and mixing various materials. If the DLP printing method is used appropriately in the production and design of ornaments, time and costs can be reduced. In practice, various materials can be carried out through different production methods to increase high-added value [6].

2 Method

The materials used in the research consisted of selecting printing equipment as a DLP-based 3D printer and selecting materials in the form of castable wax resin. The experiment was carried out using the design of experiment method with factors, levels, and responses at this stage, shown in Fig.2.

The full factorial method was chosen based on the selection of factors, levels, and responses because it involved two factors and three levels in the experiment. The sequence of experimental runs is shown in Table 1 based on the full factorial matrix.

Table 1. The sequence of runs based on the full factorial matrix.

Run	**Exposure Time (second)**	**Layer Thickness (millimetre)**
1	12	0,04
2	12	0,06
3	12	0,08
4	14	0,04
5	14	0,06
6	14	0,08
7	16	0,04
8	16	0,06
9	16	0,08

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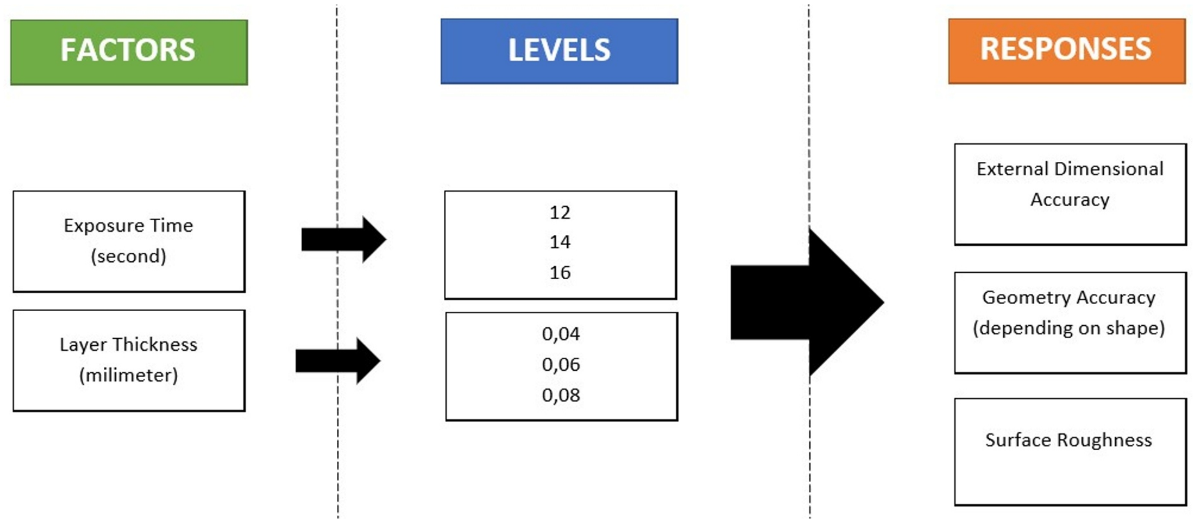


Fig. 2. Design of Experiment for wax model printing process using DLP 3D Printer Proses DLP 3D Printing [10]

The experimental stages of wax printing produce output in the form of dimensional accuracy, geometric accuracy, and surface roughness where the most optimal value is the smallest value, which means achieving a value close to zero is the best quality, so the S/N ratio calculation used is the smaller is better method with the formula 1.

$$-10 \times \log (\textstyle\sum Y^2/n) \tag{1}$$

The results of the S/N ratio calculation are then used to calculate the S/N roundness value using a combination of levels of each factor. S/N roundness is calculated by getting the average value of responses at the same level on a factor. The S/N roundness results are then entered into the S/N roundness ratio response table from the influence of factors. The delta value is the average sum of the maximum and minimum values. Meanwhile, rank is the order from highest to lowest delta value. These delta and rank values will determine the target of the smaller is better method.

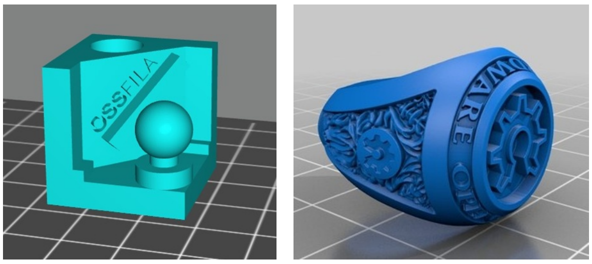
Analysis of Variance (ANOVA) for S/N is carried out to obtain the P value, which will determine the influence of each factor on the response being tested.

The shrinkage percentage is calculated to identify what percentage of shrinkage occurs in the printed product. The smaller the shrinkage value, the better the dimensional accuracy. Calculation of shrinkage percentage is carried out using formula 2.

$$\textit{Skin Percentage} = [(\textit{Dimension in design} - \textit{Print dimension}) : \textit{Dimension in design}] \times 100 \tag{2}$$

3 Result and discussion

The optimisation process for printing castable wax resin was carried out by printing the Ossfila Calibration Cube design, which was downloaded via the Ultimaker Thingiverse website and had dimensions of 25 mm (X axis), 25 mm (Y axis) and 25 mm (Z axis). This design was chosen because it has dimensional components in the X, Y and Z axes and has a spherical design whose diameter can be measured. There is text to see the clarity and detail of the print results. This experiment also carried out a design in the form of an Open-Source Hardware Ring designed by DJSplitterPro, which was downloaded via the Ultimaker Thingiverse website. The Open-Source Hardware Ring design was chosen because it has parts such as carved shapes and embossed letters that can be used to identify the details of the printed results. The Ossfila Calibration Cube and Open-Source Hardware Ring design is shown in Fig. 3.



(a) (b)

Fig. 3. Printed designs of (a) Ossfila Calibration Cube, (b) Open-Source Hardware Ring

The 3D DLP/LCD Printer machine used in the printing process is Anycubic Photon Mono 4K produced by ANYCUBIC, which is capable of printing with a layer thickness between 0.01 - 0.15 mm, which has a UV-LED light source with a wavelength of 405nm. The castable wax resin used in the printing process is Phrozen Castable Resin Wax 40, which is orange in colour. The wash and cure process for the print results is carried out using a Creality UW-01 Wash and Cure machine using 99% Isopropyl Alcohol liquid. The slicing process is carried out using the Anycubic Photon Workshop 3D Slicer software, which can be used for free. Fig. 4 shows the process from design to print results from the experiments carried out.

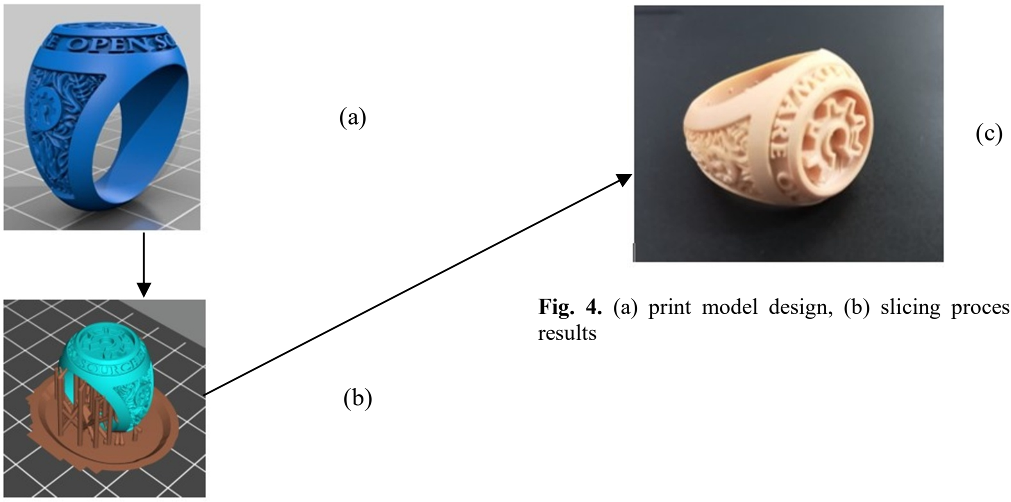
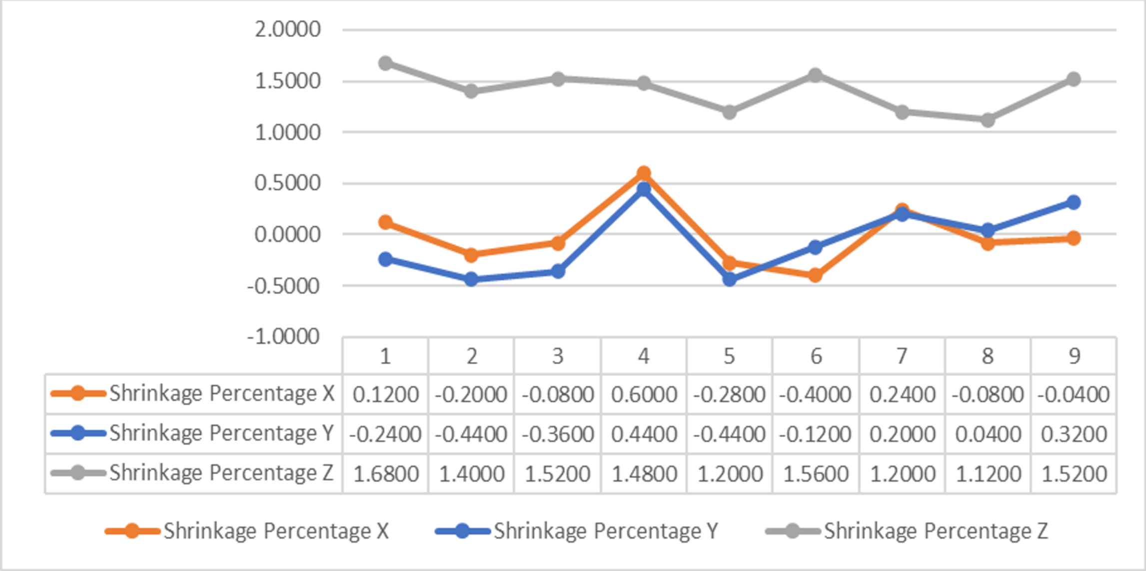


Fig. 4. (a) print model design, (b) slicing process, (c) print results



	1	2	3	4	5	6	7	8	9
Shrinkage Percentage X	0.1200	-0.2000	-0.0800	0.6000	-0.2800	-0.4000	0.2400	-0.0800	-0.0400
Shrinkage Percentage Y	-0.2400	-0.4400	-0.3600	0.4400	-0.4400	-0.1200	0.2000	0.0400	0.3200
Shrinkage Percentage Z	1.6800	1.4000	1.5200	1.4800	1.2000	1.5600	1.2000	1.1200	1.5200

Fig. 5. Graph of shrinkage percentage of printed results

Print results using a DLP/LCD 3D Printer show a change in dimensions in the print results. Dimensional differences can be measured by calculating the shrinkage value, a percentage of shrinkage that compares the design size with the resulting size. The shrinkage percentage graph of the printed results is shown in Fig. 5.

The average shrinkage percentage to calculate the best shrinkage value is shown in Table 2. The best value is obtained from the lowest percentage value for each experiment or on each axis.

Fig. 5 shows the lowest shrinkage value, namely in the 8th experiment with an average shrinkage of 0.41%, which shows that in the 8th experiment with print parameters where the exposure time value was 16 seconds, and layer thickness was 0.06, this was the best experiment in producing an accuracy of printed dimensions. Meanwhile, the shrinkage value on each axis shows that the smallest shrinkage occurs on the X axis with an average shrinkage percentage value of 0.2267%, and the largest shrinkage occurs on the Z axis with an average shrinkage percentage value of 1.4089%, so the best dimensional accuracy occurs in the printing process towards the X axis.

Printing process defects are unexpected. The experimental results show several defects in the printing process, including cracks, shrinkage, parts peeling off, and resin residue that has not been cleaned properly.

No	Shrinkage Percentage X	Shrinkage Percentage Y	Shrinkage Percentage Z	Average
1	0.1200	0.2400	1.6800	0.6800
2	0.2000	0.4400	1.4000	0.6800
3	0.0800	0.3600	1.5200	0.6533
4	0.6000	0.4400	1.4800	0.8400
5	0.2800	0.4400	1.2000	0.6400
6	0.4000	0.1200	1.5600	0.6933
7	0.2400	0.2000	1.2000	0.5467
8	0.0800	0.0400	1.1200	0.4133
9	0.0400	0.3200	1.5200	0.6267
Average	0.2267	0.2889	1.4089	

Table 2. Percentage of shrinkage of castable wax resin printing results

Fig.6 and Fig.7 shown the fineness of the print result is identified by looking at the number of defects that occur in the print result. The fewer number of defects that occur indicates that the printing process produces the best print results. Based on the analysis of the printed photos, it was concluded that the best results were shown in experiment number 5, which looked very detailed and had very clear text. This indicates that printing castable wax resin using a DLP/LCD 3D printer produces the best printing results at an exposure time parameter of 14 seconds with a layer thickness of 0.06 mm.

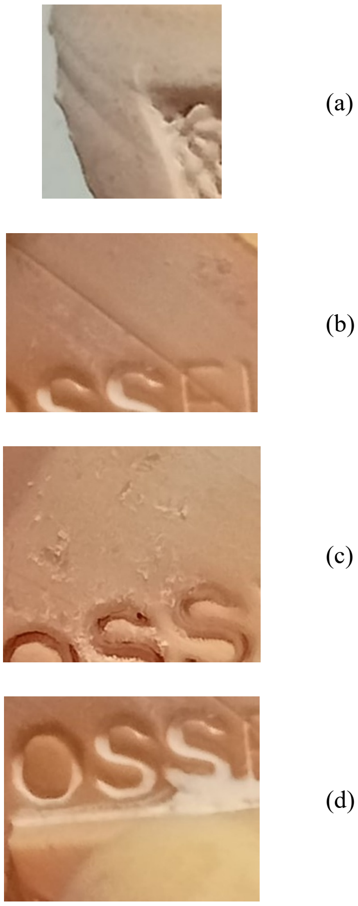


Fig. 6. Defects in the castable wax resin printing process using a DLP/LCD 3D printer, (a) shrinkage, (b) cracks, (c) peeling parts and (d) unclean resin residue.

Fig. 7. Best print results in experiment number 5

4 Conclusion

Based on the experimental results in printing castable wax resin using a DLP/LCD 3D Printer, it was concluded that to obtain a minimum shrinkage percentage, carry out the printing process with an exposure time parameter of 16 seconds and a layer thickness of 0.06 mm. Meanwhile, to obtain smooth print results with minimal defects, printing was carried out with an exposure time parameter of 14 seconds with a layer thickness of 0.06 mm. So castable wax resin is suitable for printing handicraft models using a DLP/LCD 3D Printer.

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