EVALUATING THE INFLUENCE OF TECHNOLOGICAL PARAMETERS ON THE SHAPE ACCURACY OF 3D PRINTED RESIN LIQUID CRYSTAL DISPLAY PRODUCTS USING RESIN-WAX MATERIALS

ĐÁNH GIÁ ẢNH HƯỞNG CỦA THÔNG SỐ CÔNG NGHỆ ĐẾN CHẤT LƯỢNG SẢN PHẨM IN 3D-LCD BẰNG VẬT LIỆU NHỰA SÁP

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ABSTRACT

Shrinkage is one of the important issues when fabricating casting patterns using 3D printing technology. This article presents the process of studying the influence of five input technological parameters, including layer thickness, exposure time, infill density, shell thickness, and final layer exposure, on the shape accuracy of models for Invesment Casting (IC) made with LCD (Liquid Crystal Display) 3D printing technology using Anycubic Dental Castable Resin material. The experimental plan was designed according to Response Surface Methodology (RSM) and data analyzed using Minitab software. The results showed that technological parameters and the interaction between them have a great influence on the set goal, and the optimal set of parameters found includes: layer thickness of 0.0662 mm, exposure time of 20s, infill density is 20%, shell thickness of 1.7121 mm, and final layer exposure of 80s. The success of the research contributes to improving the quality of 3D Resin LCD printing products in the field of prototyping for the IC process towards applications serving the needs of the manufacturing industry in developing countries, including Vietnam.

Keywords: *IC; LCD; Technological parameters.*

TÓM TẮT

Co ngót là một trong những vấn đề quan trọng khi chế tạo mẫu đúc bằng công nghệ in 3D. Bài báo này trình bày quá trình nghiên cứu ảnh hưởng của năm thông số công nghệ đầu vào, bao gồm độ dày lớp, thời gian phơi sáng, mật độ lấp đầy, độ dày vỏ và phơi sáng lớp cuối cùng, đến độ chính xác hình dạng của các mô hình Đúc mẫu (IC) được tạo ra bằng công nghệ in 3D LCD (Màn hình tinh thể lỏng) sử dụng vật liệu Nhựa đúc nha khoa Anycubic. Kế hoạch thử nghiệm được thiết kế theo Phương pháp bề mặt đáp ứng (RSM) và dữ liệu được phân tích bằng phần mềm Minitab. Kết quả cho thấy các thông số công nghệ và sự tương tác giữa chúng có ảnh hưởng lớn đến mục tiêu đặt ra và bộ thông số tối ưu được tìm thấy bao gồm: độ dày lớp là 0,0662 mm, thời gian phơi sáng là 20 giây, mật độ lấp đầy là 20%, độ dày vỏ là 1,7121 mm và phơi sáng lớp cuối cùng là 80 giây. Thành công của nghiên cứu góp phần nâng cao chất lượng sản phẩm in 3D Resin LCD trong lĩnh vực tạo mẫu cho quá trình IC hướng tới ứng dụng phục vụ nhu cầu của ngành công nghiệp sản xuất tại các nước đang phát triển, trong đó có Việt Nam.

Từ khóa: *IC; LCD; Technological parameters.*

1. INTRODUCTION

AM (Additive Manufacturing) technology in general and 3D resin printing technology in particular are experiencing strong developments and have been applied in many different fields. Some researchers [1, 3] have focused on understanding and determining the influence of spray process parameters on the dimensional stability of wax samples. Meanwhile, H. N. Huynh et. al. [4] showed that the type of filling and the number of shell layers had the most important influence on the percentage of ash remaining in the mold of an investment casting process.

Regarding research to improve the quality of 3D resin printed products, A. Katheng and colleagues [5] concluded that curing time and temperature parameters affect the dimensional accuracy and degree of curing of products using SLA technology. D. P. Romli, M. Yanis, and D. S. Amrillah [6] studied the effects of layer thickness parameters, exposure time, and final layer exposure time on the surface roughness of test specimens manufactured by DLP technology. S. L. Campanellia and colleagues [7] performed a statistical analysis of the product manufacturing process of 3D resin printing technology using the Viper Si2 device. The results showed that for each different resolution, the values of the parameters would be different. Z. Zhang et al. [8] showed that for DLP technology, the optimal layer thickness was 50 µm, and for SLA technology, the dimensional accuracy increases as the layer thickness decreases. S. L. Sherman and colleagues [9] studied the influence of product location parameters on the machine table, layer thickness, and shell thickness on the shape accuracy of the sample. The results show that the DLP device meets the requirements when the layer thickness is between 50 and 100 microns. The survey shows that, with the IC, the (dimensional and shape) accuracy of the sample is one of the important criteria to evaluate the quality of casting products. The application of AM technology, especially 3D printing, has many potentials in this field due to the advantages of time, flexibility, and low cost. For a casting pattern made from 3D printing, accuracy is always an important criterion. The devices used in the study are mostly industrial machines. In addition, experimental planning methods and optimized tools are often used to determine the impacts of input parameters on output goals and optimize product quality depending on its features.

2. METHODOLOGIES AND DATA

The purpose of this study is to understand the influence of parameters in the 3D printing process of the liquid material Resin-LCD on the accuracy of the test sample, thereby helping to minimize intermediate errors and increase the final casting product quality. The experimental and analysis processes are conducted according to the following steps:

- Select the input parameters and their value levels.
- Develop an experimental plan according to the RSM method.
- Select and manufacture test samples.
- Collect, analyze, and evaluate data.

Accordingly, input parameters, including two groups: fixed parameter groups and variable parameter groups, are selected based on survey results, statistics of published research projects, and the actual machine operation process. The variable parameters and their values are presented in

Table 1. The experimental plan was designed according to the B-type quadratic symmetric composite planning method (Face-centered Central composite design - FCCCD) with five parameter inputs. Each numerical parameter has three value levels: low (denoted -1), medium (denoted 0), and high (denoted +1). The total number of tests determined by the FCCCD method is 32.

The experimental matrix with parameters in encoded form is shown in Table 2. Regarding test samples, currently, there is no standard test sample specifically for sample products used in the molding process fabricated by using AM technology in general and AM technology using resin in particular. With the goal of investigating the influence of deformation during the manufacturing process on dimensional accuracy for small-sized models, the team proposed a test sample with a hollow cylindrical shape with an outer diameter of 30 mm, a height of 35 mm, and a wall thickness of 5 mm, as shown in Figure 1.

Table 1. Parameters and experimental values

Fixed parameters						
Parameters	**Symbol**	**Encode**	**Unit**	**Value**		
				Low level (-1)	**Medium level (0)**	**High level (1)**
Layer Thickness	A	x1	mm	0.05	0.06	0.07
Exposure Time	B	x2	s	20	22	24
Infill Density	C	x3	%	20	40	60
Shell Thickness	D	x4	mm	1.5	2	2.5
Bottom Exposure Time	E	x5	s	60	70	80

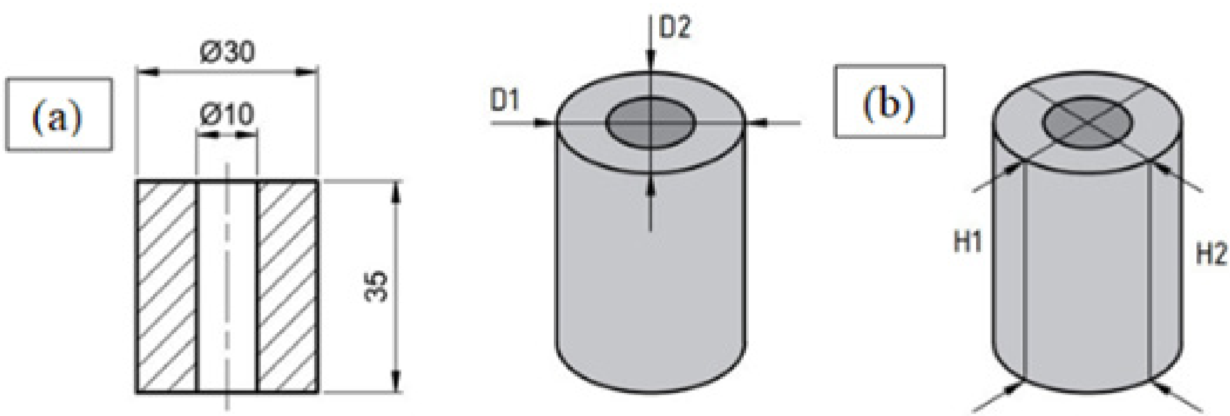

Figure 1. Test sample (a) and measurement location (b) outer diameter (D) and height (H).

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Table 2. Experimental matrix and results

No.	Coding factor					D (mm)	H (mm)	No.	Coding factor					D (mm)	H (mm)
	x1	x2	x3	x4	x5				x1	x2	x3	x4	x5		
1	-1	-1	-1	-1	1	29.95	35.48	17	-1	0	0	0	0	29.92	35.31
2	1	-1	-1	-1	-1	29.92	35.29	18	1	0	0	0	0	29.93	35.28
3	-1	1	-1	-1	-1	29.97	35.44	19	0	-1	0	0	0	29.86	35.12
4	1	1	-1	-1	1	29.88	35.39	20	0	1	0	0	0	29.79	35.25
5	-1	-1	1	-1	1	29.96	35.47	21	0	0	-1	0	0	29.89	35.33
6	1	-1	1	-1	-1	29.92	35.44	22	0	0	1	0	0	29.85	35.24
7	-1	1	1	-1	-1	29.95	35.5	23	0	0	0	-1	0	29.82	35.18
8	1	1	1	-1	1	29.95	35.42	24	0	0	0	1	0	29.79	35.2
9	-1	-1	-1	1	1	29.98	35.22	25	0	0	0	0	-1	29.77	35.26
10	1	-1	-1	1	-1	29.83	35.29	26	0	0	0	0	1	29.79	35.25
11	-1	1	-1	1	-1	29.96	35.19	27	0	0	0	0	0	29.82	35.29
12	1	1	-1	1	1	29.91	35.25	28	0	0	0	0	0	29.79	35.3
13	-1	-1	1	1	1	29.97	35.49	29	0	0	0	0	0	29.76	35.31
14	1	-1	1	1	-1	29.80	35.27	30	0	0	0	0	0	29.77	35.26
15	-1	1	1	1	-1	29.98	35.24	31	0	0	0	0	0	29.80	35.1
16	1	1	1	1	1	29.81	35.15	32	0	0	0	0	0	29.81	35.19

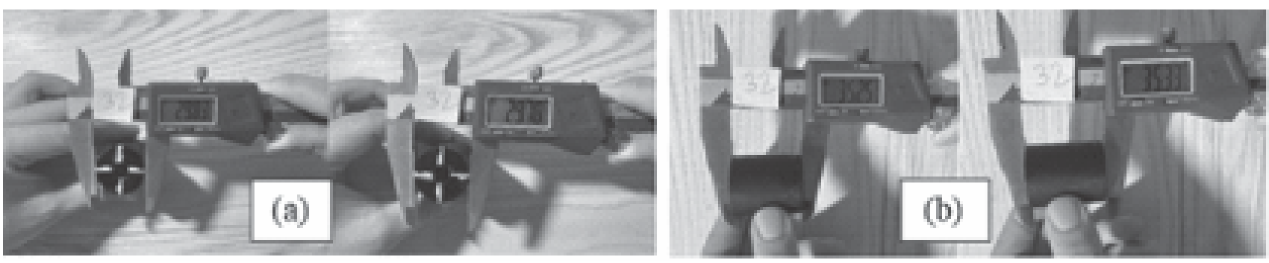

Figure 2. Measure outside diameter D1, D2 (a) and height H1, H2 (b) with sample No. 32

After designing on Solidworks software, setting the parameters, the model is sliced and converted to G-codes for manufacturing on the PhotonS series resin 3D printing device using liquid resin material type Anycubic Dental Castable Resin. This is a material used to make models for the casting process in dentistry. After the fabrication process, the sample is postprocessed and stored at room temperature for 24 to 48 hours. Then, the sample was measured using an electronic caliper from Insize with an accuracy of ± 0.03 mm to collect straight size data in height (H) and diameter (D). The measurement positions are shown in Figure 2. Each dimension is measured at two perpendicular positions, and the average value is taken. Measurement results are presented in Table 2.

3. RESULTS AND DISCUSSION

Experimental data analysis is performed on Minitab 19 software with a second-order polynomial regression equation with the following general form:

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{\substack{i=1 \\ i,j=1}}^{k} b_{ij} x_i x_j \quad (1)$$

In which:

y is the output response.

x_i, x_j are factors, respectively i, j.

k is the total number of input factors.

According to the results of variance analysis, the diameter size (D) has a Lack-of-fit value (P-value) less than 0.05. This showed that the regression equation for diameter with the RSM method is not appropriate. Meanwhile, the analysis of variance for the height dimension (H) has a Lack-of-fit value (P-value) greater than 0.05. This shows that the regression equation for the height dimension with the RSM method was appropriate, meaning that the proposed model matches the data well. The distribution chart shows that most of the data obtained follow a normal distribution with 95% confidence. From there, the encrypted regression equation representing the relationship between height dimension (Y) and input parameters (x_i) is determined as follows:

$$Y = 35.2564 + 0.0994\,x1 + 0.0367\,x4 + 0.0591\,x4*x4 \quad (2)$$

Through the Pareto chart, it can be seen that the layer thickness parameter (A, coded as x1) has the greatest impact, followed by the shell thickness parameter (D, coded as x4). From there, the research team made some comments as follows:

The layer thickness parameter has a great influence on the dimension in height (z direction), this shows the characteristics of AM technology in general and Resin 3D printing technology in particular, meaning the thickness error of each layer will affect the overall error of the product. The shell thickness parameter also plays an important role because the smaller the thickness, the larger the deformation, affecting dimensional errors. In addition, the values of the layer thickness parameter have a small difference (0.01 mm) plus a large exposure time (greater than 20 s). From there, the exposure time parameter has no effect on the target. The final layer exposure time parameter is a factor that helps details adhere tightly to the print bed surface and ensures the quality of the first printing layers. Experiments show that this parameter has very little impact on the set goal. In terms of directions, for the xy direction, the layer thickness will affect the shrinkage of Resin when curing. Analysis of the measurement results shows that the level ☞

of variation between the measured results and the nominal diameter of the sample is very low (max = 29.98 mm; min = 29.75 mm; avg = 29.86 mm). This is also the reason why the regression equation does not match because there is too little change. With the above viewing angle, the LCD will create details with good XY geometric accuracy. For the z direction, both layer thickness and shell thickness affect the size in this direction. The experimental results are larger than the nominal size as a result of the expansion process during curing. Especially in the final layers, the curing process takes place freely, leading to a rough surface causing geometric errors. The difference between the experimental value and the predicted results is shown in Figure 3. To compare and evaluate the accuracy of the predicted results according to RSM, the authors used the average absolute error value (Mean Absolute Error – MAE) between data sets. MAE value is calculated according to formula (3).

$$MAE = \frac{1}{N}\sum_{i=1}^{n}|y_i - \hat{y}_i| \quad (3)$$

In which: y is the actual observed value; y_i is the predicted value; N is the total number of experiments.

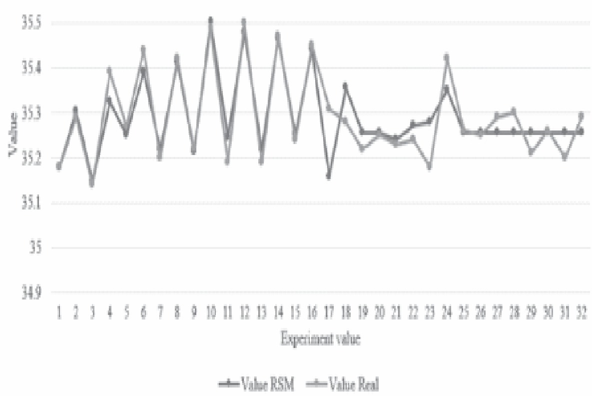

Figure 3. The difference between the experimental value and the predicted value.

Performing optimization using the Response Optimizer tool on Minitab 19, the result is the optimal set of parameters for the height dimension with the following values: Layer thickness (A) of 0.0662mm, exposure time (B) of 20 s, infill density (C) of 20%, shell thickness (D) of 1.7212mm, and bottom exposure time (E) of 80 s. The results show that the MAE index is very small (MAE = 0.032475). This shows that the RSM method predicts results with high accuracy. However, in RSM, there are still R-Large Residual values that create a disproportionate impact on the regression model.

4. CONCLUSIONS

The study presents the experimental process to understand the influence of five input parameters, including layer thickness, exposure time, infill density, shell thickness, and bottom exposure time, on the shape accuracy of the sample used for the process. The IC process is fabricated by using DLP technology and resin-wax material. Data analysis results show that the layer thickness parameter has the greatest influence, followed by the shell thickness parameter. At the same time, the authors also determined the optimal set of parameters for dimensional accuracy in the Z direction. With a MAE value of 0.032475, it shows that RSM has very good prediction ability for the set goal. However, in order to be able to use LCD technology to create samples for the IC process, it is necessary to continue to research the effects of other technological parameters, select more appropriate value levels for the parameters, and continue. Continue to build prediction models for other important quality criteria, such as surface quality and the amount of ash remaining after burning the sample. ❖

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