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FACTOR ANALYSIS OF PHOTOPOLYMER RESINS FOR 3D PRINTING

Igor NEVLIUDOV, Dmytro NIKITIN, Igor BADANYUK, Roman STRELETS, Yegor KOROTUN

Department of Computer-Integrated Technologies, Automation and Mechatronics;
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

ABSTRACT

3D printing is one of the key elements of Industry 4.0, which is the fourth industrial revolution. This technology allows you to create objects with three-dimensional shapes from various materials, including metals, plastics, ceramics and others. It is used in many industries, including medicine, aviation, automotive and engineering. The main advantage of 3D printing is the ability to create objects without a large amount of production and tooling costs. Instead, 3D printing allows you to create objects directly from digital models, which reduces production time and costs. Photopolymer 3D printing has a number of advantages, such as affordability, high precision of manufacturing parts, simplicity of technology and a large number of free software. Due to these advantages and features of the technology, this manufacturing method can be used in many areas, such as radio electronics (development of cases), jewellery production (creation of master models for casting), dentists (creation of dental prostheses), creation of decorative models for interior design.

The authors studied the influence of different brands of photopolymer resins on the accuracy of the geometric dimensions of the model and the presence of defects in 3D printing using LCD technology. To verify this, the authors conducted a factor analysis of the photopolymer resins most commonly used for photopolymer printing using IBM SPSS26. They also produced test samples at different settings of the print profile in the Chitubox software with different model exposure parameters.

Keywords: additive technologies, photopolymer 3D printing, resins, factor analysis, production, technical quality control.

1. INTRODUCTION

3D printing is one of the key elements of Industry 4.0, which is the fourth industrial revolution. This technology allows you to create objects with three-dimensional shapes from various materials, including metals, plastics, ceramics and others. It is used in many industries, including medicine, aviation, automotive and engineering. The main advantage of 3D printing is the ability to create objects without a large amount of production and tooling costs. Instead, 3D printing allows you to create objects directly from digital models, which reduces production time and costs [1-2].

In Industry 4.0, 3D printing is used to create customised products, reduce prototype development and production time, and produce parts for complex systems and machines where precision and quality are of great importance. Applications of 3D printing in Industry 4.0 can include processes such as prototyping, manufacturing, repair and maintenance of equipment, as well as the setup and optimisation of production processes [3].

One of the most important benefits of 3D printing is the ability to reduce the time required to develop and manufacture new products. The technology can also reduce production costs and increase productivity by optimising manufacturing processes and reducing prototyping time.

The development of additive manufacturing technologies is becoming increasingly common in industry and everyday life. 3D printing is one of the most versatile and affordable means of producing three-dimensional parts of complex shapes. Currently, 3D printers can produce parts made of plastic (FDM printing), metal (SLS/SLM printing) and photopolymer (SLA, DLP and LCD printing). Photopolymer 3D printing has a number of advantages, such as affordability, high precision of manufacturing parts, simplicity of technology and a large number of free software. Due to these advantages and features of the technology, this manufacturing method can be used in many areas, such as jewellery production (creation of master models for casting), dentists (creation of dentures), creation of decorative models for interior design.

Photopolymer plates allow for the reproduction of complex images with text, dashed and raster elements. Compared to metal forms, they have a higher ink transfer capacity, which ensures prints with increased optical density. The principle of producing printing elements is identical for all types of printing, except screen printing. When exposed through a negative under the influence of ultraviolet rays, the photopolymer layer undergoes photopolymerisation and insoluble areas are formed. These areas are the printing elements on which ink is later applied. In screen printing plates, the insoluble areas are intermediate elements, and the areas where the photopolymers are soluble are the printing elements. Photopolymer plates have a number of advantages:

- the process of manufacturing photopolymer printing plates is fast, affordable and cheap;
- their use improves working conditions and does not pollute the environment;
- the printing plates have a better ink acceptance and output compared to other forms;

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- the use of photopolymers significantly reduces the consumption of non-ferrous metals;
- the forms are resistant to binding inks and detergents;
- can reproduce small images on the print;
- have high durability of parts.

Due to these advantages, there are many areas of application for photopolymer 3D printing. This is an extremely large field that covers an incredible number of tasks. These include:

- jewellery (manufacturing of master models);
- medicine (dentistry, dental prostheses, fillings, etc.)
- aerospace industry (manufacturing of paddles for drills);
- Mechanical engineering (creation of housings and component parts);
- prototyping (development of test models);
- modelling (creation of models for architectural layouts);
- design;
- souvenir products.

2. FACTOR ANALYSIS OF PHOTOPOLYMER RESINS

Today, printing technologies with photopolymer resins and powder materials are among the most popular for precision prototyping compared to other additive manufacturing technologies, as they allow for the production of parts for various purposes with high precision and detail.

There are several technologies for polymer illumination in photopolymer printers [5]. Three main ones can be distinguished [4]:

- SLA - Selective Laser Sintering;
- DLP - Digital Light Processing;
- LCD - Liquid Crystal Display.

LCD technology is the most affordable photopolymer technology for consumers. A printer with photopolymer illumination by an LED UV matrix using an LCD display as a mask, Figure 1.

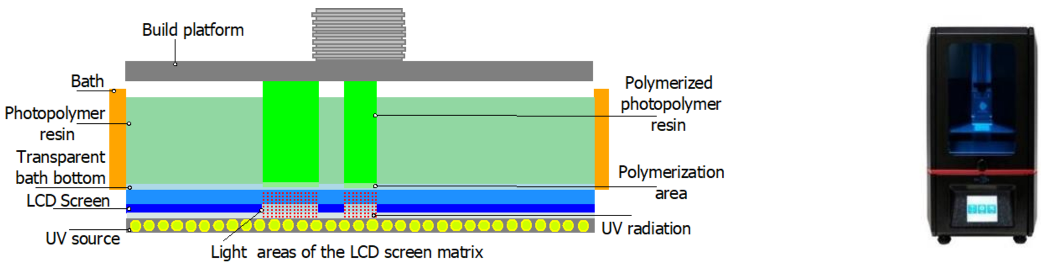

Figure 1. – Diagram of the LCD printer operation

The photopolymer is illuminated by an LED matrix, and the image is formed by an LCD display that displays a cross-section of the moulded part frame by frame. While the differences between classic SLA technology and DLP and LCD are obvious, DLP and LCD illumination technologies are often confused, which is incorrect, as each of these technologies has its own characteristics that affect the printer's capabilities and print quality [5].

Regardless of the photopolymer printing technology, the main material used for the dotting is photopolymer resin. Photopolymers are high-molecular-weight organic substances whose molecules "polymerise" with each other under the influence of light in the presence of initiators and lose their ability to dissolve. This process is called photopolymerisation, Figure 2.

At the moment, there are many manufacturers and brands of photopolymer resins. Their prices are determined by printing accuracy and the minimum allowable layer height, as well as additional characteristics. They can also be divided into the following types:

- standard resins for sinking;
- resins for melt-blown models;
- biocompatible resins;
- temperature-resistant resins;
- chemically resistant resins;
- mechanically resistant resins.

It is possible to highlight the following: the preservation of the geometric dimensions of the model when printing on the front depends not only on the chosen printing technology, but also on the printing material (photopolymer). The main characteristics of a photopolymer that affect the accuracy of 3D printing are

- layer exposure time (time of UV radiation exposure to the photopolymer), s

- layer thickness, μm;
- polymerisation wavelength, nm;
- radiation intensity, Lm;
- shrinkage coefficient of the photopolymer, %.

For each photopolymer, these values are different, so the study of the influence of these parameters on the model is an urgent task.

The aim of the study is to determine the effect of photopolymer resins on the preservation of the geometric dimensions of a 3D model at different values of exposure parameters.

To achieve this goal, it is necessary to solve the following tasks:

- conduct a factor analysis and select which resins will be used for the study;
- create an experimental plan;
- develop an automated visual control of deviations in the geometric dimensions of the model;
- based on the data obtained, conduct a sample check;
- to build a regression-correlation model of the influence of resin properties and printing parameters on the deviation of the geometric dimensions of the 3D model.

The main objective of this work is to determine the effect of different brands of photopolymer resins on the preservation of the geometric dimensions of the model. Therefore, at the first stage, it is necessary to choose which photopolymer resins we will use in further research.

At the moment, there is a wide range of photopolymers on the market, so 9 photopolymers were selected that are most often used by an ordinary user. And the main characteristics that can affect the deviation of the geometric dimensions of the model were selected, Table 1.

Table 1. – Brands and characteristics of photopolymer resins for the study

№	Resin name	Min. polymerisation wavelengths, nm	Max. polymerisation wavelength, nm	Min. Shrinkage coefficient, %.	Max. Max. shrinkage coefficient, %.	Time of layer illumination, s	Time of illumination of base layers, s	Layer thickness, μm	Radiation intensity, Lm
1	Anycubic 405nm UV [6]	405	405	2,76	3,54	5	15	35	1600
2	Plexiwire Resin Basic [7]	405	450	3,04	3,82	7	20	35	1800
3	MonoFilament Basic [8]	405	450	2,37	4,22	7	25	35	1600
4	FunToDo [9]	225	415	1,27	2,43	6	17	20	2600
5	Wanhao Castable [10]	395	420	1,16	1,16	8	15	35	2600
6	BlueCast CR3A [11]	400	410	3,74	4,82	4	9	10	1800
7	Elegoo 3D [12]	385	450	5,37	5,74	3	10	35	1600
8	Weistek [13]	385	410	2,38	3,02	7	15	50	1800
9	Tevo [14]	380	420	3,53	4,22	8	12	50	2400

To build a multiple regression model of the effect of resins on the dimensions of a 3D model, we plan to select two brands of photopolymers with the best initial performance. To decide which resin brands to choose, we will use factor analysis.

Factor analysis allows you to reduce the sample size. If an object is described by many features or characteristics that can be interrelated (when one characteristic changes, another changes), factor analysis allows all these characteristics and features to be reduced to a smaller number without disturbing the data for further analysis.

To conduct the analysis, we enter the initial data into IBM SPSS Statistics 26 [15-16]. Thus, we get 8 parameters that describe a specific brand of photopolymer resin. For the results of the calculation. In terms of adequacy and Bartlett's test of sphericity, we look at the value of 0.685. This value is greater than 0.5 and proves that the factor analysis was successful, Figure 2a.

Another table that is needed is the table of inverted component matrices (Component Matrix), Figure 2b.

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KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,685
Bartlett's Test of Sphericity	Approx. Chi-Square	82,341
	df	28
	Sig.	,000

a)

Component Matrix[a]

	Component		
	1	2	3
Max. Коефіцієнт усадки, %	,951		
Min. Коефіцієнт усадки, %	,943		
Інтенсивність випромінювання, Лм	-,775		
Час засвітлено шару, с	-,755	,540	
Час засвітлено базових шарів, с		,693	-,564
Товщина шару, мкм		,662	,602
Max. Діапазон довжини хвилі полімеризації, нм		,609	
Min. Діапазон довжини хвилі полімеризації, нм	,501	,535	

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

b)

a) the degree of adequacy and Bartlett's criterion; b) matrix of inverted components

Figure 2. – Research results

We obtained 8 initial characteristics and 3 components (three macro factors). The values obtained are correlations, for example: the maximum shrinkage coefficient correlates with the first factor by 0.951 (significant correlation);

The layer illumination time simultaneously correlates with the first factor by -0.755 (significant correlation) and with the second factor by 0.54 (weak correlation).

For the convenience of further evaluation of photopolymer resins, we will rename the newly obtained variables: FAC1_1 - "Shrinkage Indicators"; FAC2_1 - "Exposure Time and Layer Height"; FAC3_1 - "Adhesion Indicators of the First Layers".

To make it convenient to work further, it is necessary to bring these values to a normal state. To do this, all the values of the factors must be divided into three equal intervals (to make a ranking of the series). This will allow you to describe the values using points (1 - low, 2 - medium; 3 - high level). In the Data View, we get new variables NFAC1_1, NFAC2_1, and NFAC3_1, which can be used to make an assessment. If we substitute these values for a specific resin brand, we get an assessment of three indicators, Table 2.

Table 2. – Results of the evaluation of photopolymer resins

№	Resin type	Evaluation indicators		
		Shrinkage characteristics	Exposure time and layer height	Adhesion performance of the first layers
1	Anycubic 405nm UV	3	1	2
2	Plexiwire Resin Basic	2	3	2
3	MonoFilament Basic	2	3	2
4	FunToDo	1	3	1
5	Wanhao Castable	1	2	3
6	BlueCast CR3A	3	1	1
7	Elegoo 3D	3	2	1
8	Weistek	1	2	3
9	Tevo	2	1	3

A test 3D model with a large number of basic geometric shapes was selected for the study, Figure 3.

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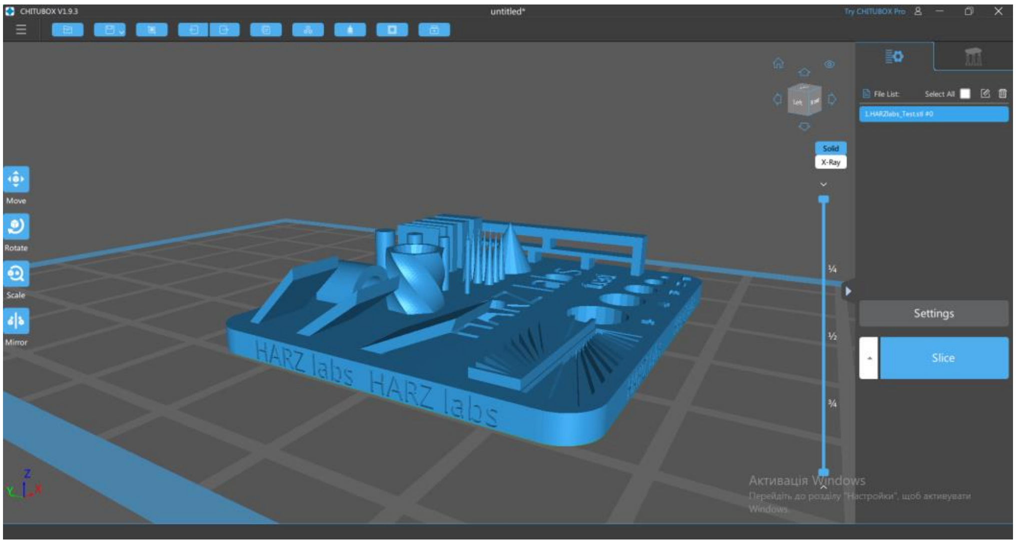


Figure 3. – The working window of ChituBox V1.9.3

The elements will allow controlling deviations in geometric dimensions with different resins and at different values of processing parameters. The overall dimensions of the model are 37×30.29×7 mm.

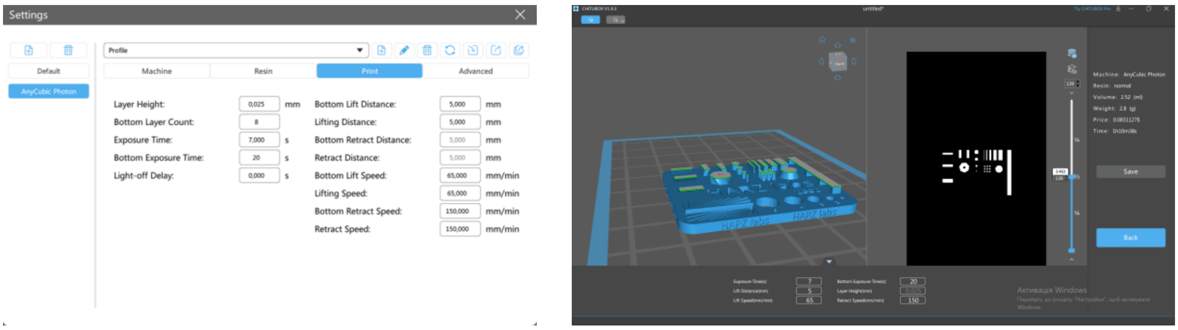
ChituBox V1.9.3 software is used to prepare the model for printing and set the processing parameters, which generates a G-code based on the specified parameter values.

The study will be conducted on the basis of two brands of photopolymer resins, Plexiwire Resin Basic and MonoFilament. The parameters that will be changed during the experiments are as follows:

- exposure time of the basic layers (Time), from 7 seconds to 12 seconds;
- exposure time of the base layers (Base time), 20 and 25 seconds;
- layer thickness (Thickness), 25 and 35 μm;
- Intensity of UV radiation, 1600 and 1800 Lm.

This range of values was chosen according to the characteristics of these resins. The radiation wavelength is 405 nm, the number of base layers is 3. In total, 96 test samples were made to build a regression model and identify correlations, 48 samples for each resin brand. The deviations of the geometric dimensions of the model are measured along three axes (XYZ).

To do this, separate settings for exposure time and layer height were created for each sample in ChituBox V1.9.3, Figure 4. The radiation intensity values are adjusted using the settings in the layout itself.

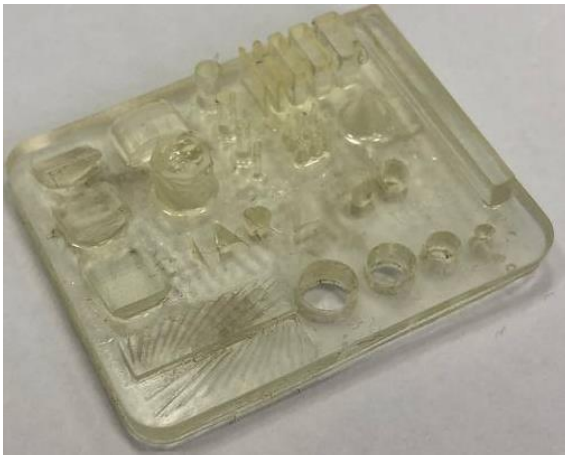


a) b)

a) setting up a print profile in ChituBox V1.9.3; b) results of model preparation

Figure 4. – Preparing a model in ChituBox V1.9.3

За результатами виготовлення зразків було отримано 96 тестових моделей, рисунок 5.



a) b)

a) test samples Plexiwire Resin Basic; b) test samples MonoFilament.

Figure 5. – Test samples

3. CONCLUSION

Based on the results of the analysis, it is possible to highlight the following: the preservation of the geometric dimensions of the model when printing on the front depends not only on the chosen printing technology, but also on the printing material (photopolymer). The main characteristics of a photopolymer that affect the accuracy of manufacturing a part in 3D printing are: layer exposure time (time of UV radiation exposure to the photopolymer), s; layer thickness, µm; polymerisation wavelength, nm; radiation intensity, Lm; photopolymer shrinkage factor, %. Experimental studies of the influence of exposure parameters in 3D printing on the preservation of the geometric dimensions of the model were carried out. The influence of these parameters when using different brands of photopolymer resins was also considered. A factor analysis of photopolymer resins was carried out to select the best two brands in terms of their properties. According to the results, these resin brands are Plexiwire Resin Basic and MonoFilament Basic. Based on the results of the research and the resulting regression model, it can be said that the largest parameter that affects the deviation of the geometric dimensions of the model is the exposure time for each axis:

- 0.8983 for Plexiwire Resin Basic;
- 0.8967 for MonoFilament Basic resin;
- 0.8975 for the resin average coefficient.

This indicates that the shorter the exposure time of the layer, the less parasitic illumination and the smaller the deviation of the model dimensions. The next variables that strongly influence the deviation are: radiation intensity, layer height. The least influential factor was the exposure time of the base layers.

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