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FEATURES OF PHOTOPOLYMER 3D PRINTING TECHNOLOGY

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ABSTRACT

3D printing technologies have become widely popular and are now utilized across a broad range of fields, from science to manufacturing. Certain areas, such as the production of dental prosthetics and casting of gold jewelry, have become heavily reliant on 3D printing, particularly photolithography technology. This high-precision method employs photopolymer resin as its primary material.

The development of the technology and the significant interest in it have led to the emergence of new materials with diverse physico-chemical properties, such as flexible photopolymers resistant to wear, or casting photopolymers, among others.

Currently, the main focus of improvement lies in automating production processes to eliminate the need for constant oversight, enabling 3D printing to be integrated into large-scale manufacturing. This aligns with the transition to Industry 4.0, incorporating the Internet of Things (IoT).

The authors analyzed the defects of photopolymer 3D printing using test samples and identified the technological parameters that influence their occurrence.

Keywords: Additive technologies, photopolymer 3D printing, technological parameters, print quality, defects.

1. INTRODUCTION

3D printing is widely used today in various fields, ranging from everyday life to industrial applications. It is employed to create research prototypes in manufacturing, dental prosthetics, and a broad range of plastic-based consumer goods. Businesses leverage 3D printing to produce diverse items, thanks to the availability of numerous technologies and materials. These technologies enable the creation of models with a wide array of physical properties, including flexibility, high strength, and custom compositions. Some materials can even burn out without residue, a crucial feature for producing master models and casting jewelry.

The two most widespread technologies are Fused Deposition Modeling (FDM) and Stereolithography (SLA):

FDM Technology involves layer-by-layer deposition of heated plastic along a defined trajectory. It stands out for its affordability, both in terms of equipment and materials.

Stereolithography uses liquid photopolymer resin that polymerizes into solid plastic under UV light.

Sub-Technologies of StereolithographyThere are three main sub-technologies of SLA, distinguished by the light source and the method of forming horizontal cross-sections.

SLA Technology.This sub-technology employs a laser and scanning systems to direct the laser beam across the working platform. The laser acts as the light source, while scanners ensure the layer is formed by tracing the horizontal cross-section. The accuracy of this technology depends entirely on the laser's resolution, defined by the size of the laser spot, which can range from 50 µm to 300 µm, determining the resolution along the X and Y axes.

The next sub-technology is DLP, which uses a projector with a DLP matrix. In this technology, the horizontal cross-section is generated simultaneously across the entire working surface as a black-and-white image. Exposure occurs only in the white areas, as UV radiation is produced by the projector lamp and passes through the matrix, where white pixels are transparent and allow a high degree of UV light penetration, unlike black pixels, which block the light.

The latest technology today is LCD, which is rapidly developing and is now used more widely than SLA and DLP due to the low cost of machines and high printing speed. LCD technology employs a modified LCD screen that retains only the matrix, without backlighting or polarizing films. This design allows the screen to pass UV light through open pixels while blocking it in closed pixel areas, thus forming the horizontal cross-section of a layer.

A monochrome LCD screen has been developed, where the traditional RGB colors have been replaced with only two states: open (white) and closed (black). This reduces UV light losses and increases printing speed. With the use of a monochrome screen, layer exposure times have decreased from 12–15 seconds (depending on the light system) to 2.5–3 seconds, effectively quadrupling the speed.

The light system uses a UV LED matrix emitting light in the 395–405 nm range, which is ideal for curing photopolymer resin. As a result, LCD technology is currently the most popular photopolymer technology due to its affordability and high printing speed.

To automate the technology, it is necessary to identify all the technological factors that influence the creation of deviations in quality indicators and defects.

2. ANALYSIS OF TECHNOLOGICAL PARAMETERS AND THEIR IMPACT ON THE QUALITY INDICATORS OF PHOTOPOLYMER PRINTING

The determination of technological parameters is the primary task in managing the technological process of photopolymer printing. Once resolved, the quality indicators will depend solely on the quality of model preparation for printing. The technological parameters of photopolymer printer operation depend on two interconnected groups of factors:

– the construction of the photopolymer printer;

– the physicochemical properties of photopolymers.

The first key parameter influenced by both the printer's construction and the properties of the photopolymer is the exposure time. It is divided into two subparameters: the exposure time for base layers and the exposure time for main layers.

The base layer parameter is responsible for the model's adhesion to the printer platform.

Adhesion is the process of bonding dissimilar or similar materials together. During adhesion, liquid plastic forms hydrogen bonds between the surface and the plastic, macromolecules diffuse from the plastic into the surface, and the plastic penetrates microcracks or micropores on the surface. The bond strength depends on the material's properties, contact shape, surface texture and roughness, as well as parameters such as pressure, temperature, etc.

The main layers of the model exhibit better adhesion among themselves, as the bonding occurs between layers of the same material. Therefore, significantly less time is typically required for their formation compared to the base layers. Generally, the adhesion of photopolymer layers to each other is much stronger than the adhesion between the photopolymer and the metallic platform plate.

These parameters are affected by the illumination systems, their power, the density of the photopolymer, and its coloration, which may complicate the passage of UV radiation due to the addition of dyes to the photopolymer.

To adjust these parameters, it is necessary to experimentally print several test models and then determine deviations from the established quality indicators and identify any defects.

Defects characteristic of the base layer exposure time parameter include:

– The so-called "elephant foot," where deviations from the specified dimensions occur only in the base layers (Figure 1), caused by excessive exposure time of the photopolymer.

Figure 1 – Deviation of base layers relative to regular layers

– Delamination between base and main layers occurs when the adhesion between the photopolymer cured on the base layers and the regular layers is insufficient, causing the model to detach from the base layers. This defect arises due to a significantly longer exposure time for the base layers compared to the main layers (Figure 2).

Figure 2 – Delamination between base layers and regular layers

– Delamination from the platform occurs when the adhesion between the base layers and the platform is insufficient. As a result, the model remains in the resin vat. This defect arises due to insufficient exposure time for the base layers (Figure 3).

Figure 3 – Detachment from the platform during printing

– Excessive adhesion of the model to the platform after printing is also considered a defect. It can lead to surface damage when removing the model from the platform. The part of the model in contact with the platform forms stronger interfacial bonds due to excessive exposure time for the base layers, causing the model to adhere too firmly to the platform.

Defects influenced by the exposure time of the main layers include:

– Model delamination, which occurs due to the model's heavy weight, the force required to separate it from the film, and insufficient exposure time for the main layers (Figure 4).

Figure 4 – Delamination of the part

– Detachment of supports from the model and surface damage occurs when there are excessively thin elements and the exposure time parameter for the main layers is insufficient (Fig. 5).

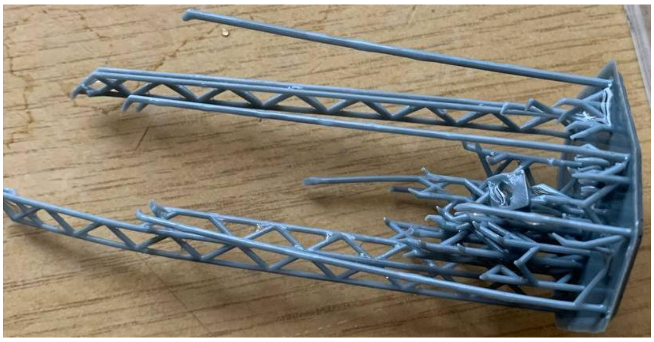
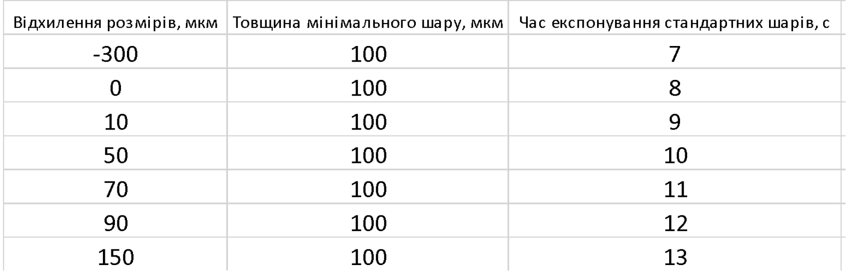


Figure 5 – Separation of parts from supports

– The occurrence of defects, expressed as physical changes in dimensions, arises both from insufficient and excessive exposure time of the main layers.

Experimental studies have identified the dependency of dimensional deviations on exposure time, which is summarized in Tables 1 and 2.

Table 1 – Dependency of dimensional deviations on exposure time



Відхилення розмірів, мкм	Товщина мінімального шару, мкм	Час експонування стандартних шарів, с
-300	100	7
0	100	8
10	100	9
50	100	10
70	100	11
90	100	12
150	100	13

To validate the results, a repeated study was conducted using a thinner print layer of 50 μm, and the findings are summarized in Table 2.2

Table 2 – Dependency of dimensional deviations on exposure time

Відхилення розмірів, мкм	Товщина мінімального шару, мкм	Час експонування стандартних шарів, с
-100	50	7
0	50	8
30	50	9
50	50	10
60	50	11
80	50	12
100	50	13

The next technological parameter is the number of base layers. This parameter, along with the exposure time of the base layers, is used to improve adhesion to the build platform. Without base layers, and given that photopolymer has low adhesion to the metal platform, during printing, the model may remain at the bottom of the resin vat due to stronger adhesion to the vat's bottom, resulting from its physical properties. A large number of base layers, due to higher polymerization altering the photopolymer's physico-chemical structure, can reduce adhesion between the base layers and regular layers.

Since LCD-based photopolymer printers use a film as the bottom of the resin vat, which can stretch and lacks a photopolymer mixer, the platform lifts slightly after curing each layer and then lowers to the next position. This serves to mix the photopolymer, fill the vat space after curing the previous layer, and separate the printed part from the film. Adhesion occurs not only between polymerized photopolymer layers and the platform but also between the vat bottom and the model.

One of the main limitations of using a large vat in LCD technology, combined with the difficulty of manufacturing large LCD screens with high resolution, is the transparent vat bottom, which must exhibit very low adhesion to the photopolymer. Using materials that do not meet these requirements can damage the vat bottom, making model printing impossible. Using large films increases the load on the screen, potentially causing its damage or excessive stretching of the film, leading to its possible rupture.

Thus, movement is executed by motors controlled by software that regulates the lift height and speed, depending on the film tension and cross-sectional area of the layer. If the lift height is less than the film's stretch height, the printed part may stop adhering and remain on the platform during printing.

Figure 6 – Residuals of the model on the film

The mixing speed is determined by the photopolymer's viscosity. Excessive speed may cause thin elements to detach from the model and mix into the liquid photopolymer, leading to surface defects or even damaging the screen and film.

Layer thickness is a technological parameter that affects the surface roughness of the model and its vertical resolution. The thinner the model layer, the smoother the surface and the better the reproduction of features on vertical surfaces.

This parameter directly influences the printing time, accounting for 70% of the printing process, while the remaining 30% is spent on platform movement, mixing, and technical pauses to cool the LED matrix and screen. Reducing the layer thickness increases the number of work cycles, including mixing and pauses, meaning a model printed with a 50 μm layer will take twice as long as one printed with a 100 μm layer. Simultaneously, thinner layers require shorter exposure times to prevent over-curing and dimensional deviations.

The layer thickness parameter is divided into two technological parameters: the thickness of the base layers and the thickness of the main layers.

The thickness of the base layers ensures better adhesion to the platform. A primary defect caused by excessive exposure time is the alteration of base layer dimensions relative to the main layers, known as the "elephant foot" effect.

Thus, the main defects that may occur during printing include:

– Increased dimensions of the base layers compared to the main ones;
– Unprinted thin elements;
– Changes in the geometry of the part;
– Printed models remaining at the bottom of the vat;
– Defects on the external surface.

3. CONCLUSION

As a result of the analysis, technological parameters and their impact on part defects were identified. The main technological parameters are exposure time, layer thickness, and lift height during mixing.

Insufficient exposure time leads to delamination of the part, detachment from supports, and changes in physical dimensions. Excessive exposure time results in the "elephant foot" effect, delamination between base layers and regular layers, and an increase in physical dimensions. Layer thickness affects surface roughness and exposure time. Insufficient lift distance during mixing causes the model to stick to the film.

Thus, the main defects arise from mismatches between the technological parameters, the properties of the photopolymer, and the characteristics of the equipment.

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