**Вісник Тернопільського національного технічного університету**
**https://doi.org/10.33108/visnyk_tntu**
Scientific Journal of the Ternopil National Technical University
*2020, № 2 (98) https://doi.org/10.33108/visnyk_tntu2020.02*
*ISSN 2522-4433. Web:* ***visnyk.tntu.edu.ua***

**UDC: 62-408.8: 621.9.015: 621.9.019**

# COMPARATIVE ANALYSIS OF THE QUALITY OF PLASTIC PRODUCTS FORMED BY DLP AND FDM 3D PRINTING TECHNOLOGIES

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***Summary.*** *3D printing is the innovative technology widely used in all developed countries of the world and opens up significant potential for its application in various areas of human activity. The features of 3D objects creation using two the most commonly used additive manufacturing technologies – fused deposition modeling (FDM) and stereolithography version (SLA) - Digital Light Processing (DLP) are considered in this paper. By these technologies application the samples at various 3D printing modes using polylactide biopolymer (PLA) as consumable material are created and investigations of their geometry, structure, and mechanical properties (interlayer strength and elongation up to material rupture) are carried out. On the basis of the obtained results the influence of the specified print parameters, such as the extreme admissible values of 3D products layers thickness for FDM and DLP technologies, on the formed samples quality is investigated.*

***Key words:*** *3D printing, additive manufacturing, FDM technology, DLP technology, thermoplastic polymers, photopolymers, bioplastic.*

*https://doi.org/10.33108/visnyk_tntu2020.02.040* *Reseived 20.02.2020*

**Statement of the problem.** Nowadays, 3D printing market is rapidly growing and is being enlarged with new models of unique production equipment, the possibilities of which are almost unlimited while forming the products made of different materials, including polymer ones. Printed aircraft parts and units, printed car body, printed apartment house, printed clothing, printed medical implants - this is much more than the list of modern additive technologies achievements. However, the most interesting thing is that printing can be performed by practically any materials: polymers, engineering plastics, composite powders, various types of metals, ceramics, sand, concrete, wood, and recently even by food and biological substances [1–6]. Due to the availability and usability, 3D printing by various types of plastic is the most widely used at present. There is a number of 3D plastic printing methods differing in both consumable materials use and their application principle, but the most popular ones used for domestic service (office) and industry due to their availability are: fused deposition modeling (FDM) and stereolithography version (SLA) – Digital LED Projection (DLP). Both technologies are used in the paper to determine the features of product forming process and created products quality.

**Analysis of the available investigations.** The modern pace of industrial development requires the selection of production technologies that can be implemented in the shortest time involving minimal investments resulting in high-quality products manufacturing. At present the additive technologies (in English literature – Additive Manufacturing, Additive Fabrication or AM-, AF-technologies), which are increasingly used in all spheres of human activity and are one of the most interesting and promising areas of industrial production, meet these requirements [7–9]. The additive technologies are also called layer synthesis technologies, 3D printing, 3D technologies, rapid prototyping, layer modeling, digital production, etc.

It is accepted to understand the general term «additive» as a group of technologies enabling to create 3D fused deposition modeling objects based on CAD (Computer-Aided Design) model by gradual adding the output material to the future product, which is different from the traditional methods of the part creation where the excess material is removed from the workpiece monolith by machining. CAD model is the created digital layout, which must be formed using additive technologies on 3D printer. 3D CAD model can be developed by own design using computer-aided design method, and created due to the data collected by 3D scanner.

The essence of Additive Manufacturing (AM) can be represented as follows:


The key factor is that 3D printing significantly shortens the process chain duration from the idea or drawing to the product, and at the same time reduces the labor, material and energy consumption for its manufacturing. Thus, additive manufacturing makes it possible to create the final functional products directly from the designer or engineer by computer and printer, without additional technological operations application.

**The objective of the paper** is to investigate the influence of polymer technologies and FDM parameters and DLP 3D polymer printing on the manufactured products quality.

**Statement of the problem.** The selection of 3D printing modes parameters by fused deposition modeling (FDM) and digital LED projection (DLP) technologies, making it possible to obtain samples with the most acceptable low and high quality for each technology and materials is carried out in this paper.

**Materials and methods.** Thermoplastic biopolymer PLA (polylactide) in the form of solid-state filament with 1.75 mm diameter for FDM 3D printing, manufactured by «Monofilament» Company (Kyiv), and photopolymer resin Wanhao 405nm UV resin based on polylactide and UV- hardeners for DLP 3D printing, manufactured by «Wanhao» Company are used in this investigation (Table 1).

**Table 1**

Materials, technologies and 3D printing parameters of the samples

| **Sample №** | **Consumable material** | **Layer thickness, μm** | **Printing time, min.** |
|---|---|---|---|
| Fused deposition modeling (**FDM**) | | | |
| **1** | Thermoplastic biopolymer PLA **(polylactide)** in the form of filament | 300 | 8 |
| **2** | Thermoplastic biopolymer PLA **(polylactide)** in the form of filament | 80 | 29 |
| Digital LED projection (**DLP**) | | | |
| **3** | Photopolymer resin based on polylactide PLA **(polylactide)** | 50 | 126 |
| **4** | Photopolymer resin based on polylactide PLA **(polylactide)** | 35 | 179 |

FDM 3D is performed on Flashforge Creator Pro 3D printer, produced by Zhejiang Flashforge 3D Technology Co., Ltd. – «FlashForge». Parametrs of samples 3D printing by FDM technology are given in Table 2.

**Table 2**

Parameters of FDM 3D printing of the samples

| Output parameters | Sample № 1 | Sample № 2 |
|---|---|---|
| Extrusion temperature, ºC | 200 | 200 |
| Platform temperature (table), ºC | 50 | 50 |
| Layers thickness, mm | 0.30 | 0.08 |
| Thickness of the first layer, mm | 0.30 | 0.20 |
| Printing speed, mm/sec. | 80 | 80 |
| Movement speed, mm/sec. | 110 | 110 |
| Sample filling, % | 100 | 100 |
| Filling type | line | line |

DLP 3D printing is performed by Wanhao Duplicator 8 3D printer, manufactured by «Wanhao» Company. The 3D printing parameters of DLP samples are shown in Table 3.

**Table 3**

Parameters of DLP 3D printing of the samples

| Output parameters | Sample № 3 | Sample № 4 |
|---|---|---|
| Lens mode | DLP normal | DLP normal |
| Photopolymer density, g/ml | 1.1 | 1.1 |
| Layers thickness, mm | 0.05 | 0.035 |
| Number of lower layers, pcs. | 3 | 3 |
| Polymerization time, sec. | 10 | 10 |
| Polymerization time of lower layers, sec. | 50 | 50 |
| Sample filling, % | 100 | 100 |

The surface quality of the samples formed using both FDM and DLP technologies is tested by means of Versamet-2 combined transmission/reflection optical polarization microscope in × 200 and × 400 optical magnification range.

**Results of the investigation.** FDM 3D-printing.Fused deposition modeling FDM is the most widely used 3D-printing technology in the world, millions of 3D printers are operating on its basis, from the cheapest to the industrial 3D printing systems. In order to create products by FDM 3D printing, the filament made of various thermoplastic materials supplied as coils, is used. The filament can be of two standard diameters: 1.75 and 3 millimeters, depending on the printer specification [10].

Like in all 3D printing technologies, the first step for physical object production is to create its digital 3D model. 3D model in STL format is transmitted to 3D printer software. The program automatically (or manually) places the model in the virtual space of the working chamber. Then the program calculates the elements of auxiliary structures – supporting structures under the overhanging elements of the object and calculates the required amount of consumable materials, as well as the time of prototype «growing». Before the printing process start, the model is automatically divided into horizontal layers and calculations of the movement paths (print head) are carried out. The extruder is the device equipped with mechanical driver for filament feed, heating element for filament melting and nozzle through which the direct extrusion – the supply of the melt polymer material to the formed product working surface is performed (Figure 1). The obtained settings are stored, the model is converted to the control code for 3D printer. Then the filament from the coil is unwound for inserting into the extruder and 3D printing process is started directly: the extruder melts the filament and with high accuracy feeds the melt polymer material by thin layers to 3D printer working surface in accordance with the printing algorithm and CAD 3D model. After the layer application, polymer material is cooled and solidified, and the platform on which the object is formed is lowered to the magnitude equal to the applied layer thickness. Movement of the head and platform in 3 planes (Figure 1) is given by the algorithm developed in advance by means of special software.

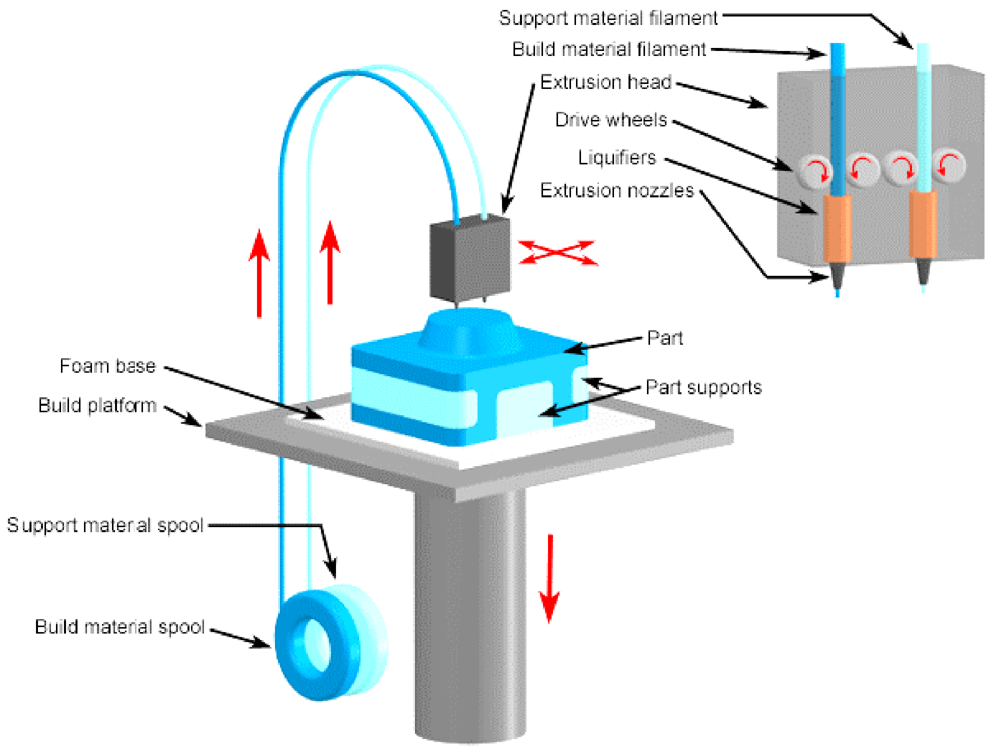


**Figure 1.** Schematic diagram of FDM 3D printer extruder and the process of 3D model creation [11]

After creation process completion, the auxiliary structures are removed (manually or dissolved in special solution). The finished product can be used in the printed form or subjected to any further processing.

The photographs of configuration and microstructure of samples № 1 and № 2 formed by fused deposition modeling (FDM) technology according to the printing parameters from Table 2 are shown in Figure 2. The parameters selection is based on the extreme acceptable values for the given technology and material thickness of 3D product layers (Table 1), which directly affect the samples quality. Photos 1a and 2a (Figure 2) show the samples structure increased by 200 times, photos 1b and 2b increased by 400 times. The results description and analysis are presented below.

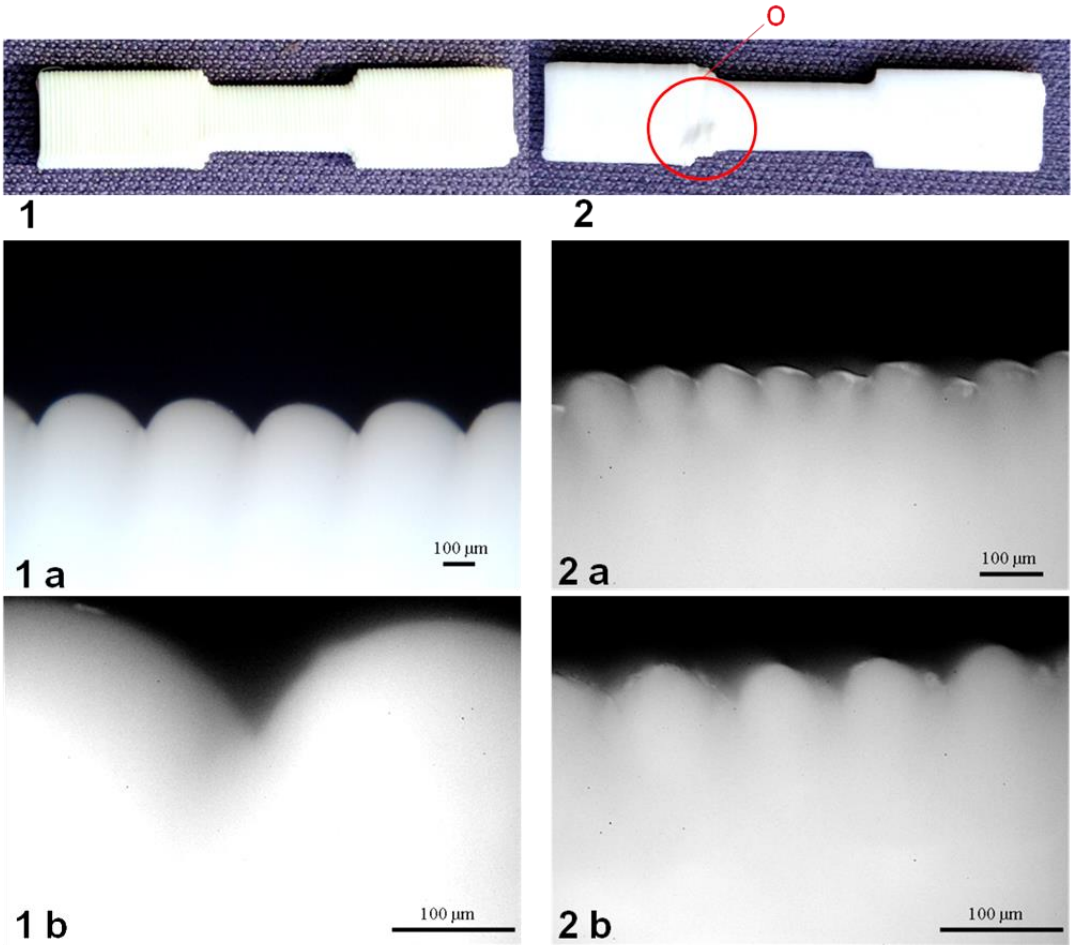


**Figure 2.** The configuration of samples 1 and 2, their microstructure (a, b)

***DLP 3D-printing.*** Stereolithography (SLA) is one of the first and most precision additive technologies in the world [12–14]. Its essence is that under the influence of laser radiation on those layers of liquid photopolymer resin (consumable material) corresponding to the walls of the given object their layer-by-layer hardening and finished product formation take place. DLP technology works on the basis of this 3D printing method and according to the same principle, but instead of using expensive laser emitters, as in SLA installations, this technology uses LED projectors, which at times reduce the cost of 3D printers. The difference between these methods is that the laser in SLA installations polymerizes gradually (each point of the object is quickly passed by laser beam) liquid photopolymer, and in DLP 3D printers the digital LED projector illuminates the entire layer at the same time [15, 16]. It is believed that due to this fact DLP printing makes it possible to reproduce the objects faster. At the same time, 3D printers operating on DLP technology show high results that are comparable in accuracy and quality to the original laser stereolithography (SLA) technology.

3D object creation by DLP technology, like any other 3D technology, starts with the fact that the software bundled with the printer, breaks the digital 3D model into horizontal layers with the given thickness and converts it into the control code for 3D printer. Then, the print material is poured into the printer bath, where working table is immersed on the transparent bottom with the indentation from the bottom to one (first) layer of the future object (Figure 3).

The projector located under the bath projects the first layer image on the bottom and, due to UV radiation, photopolymerization of the plastic which is reached by the image from the projector takes place. After that, the working table is risen to the height of the next layer, which is lit and attached to the previous one. So, layer by layer, printed 3D object grows.

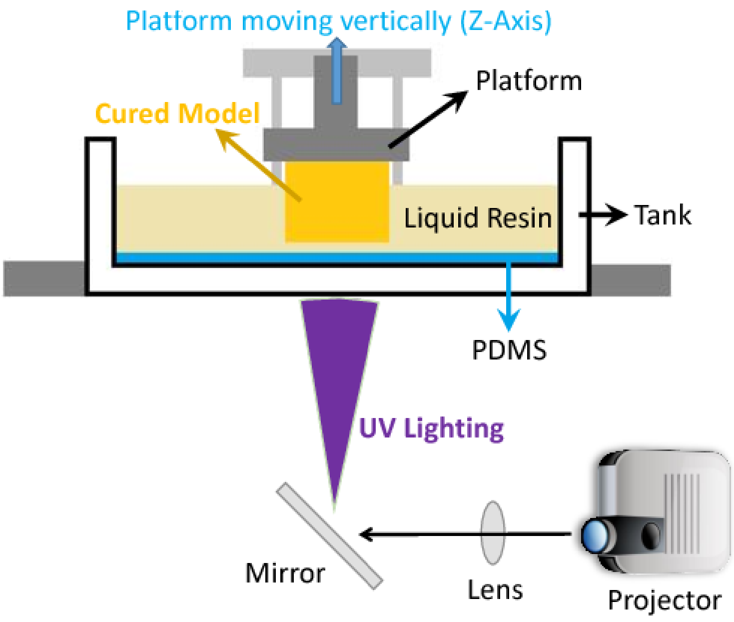


**Figure 3.** Schematic diagram of DLP 3D printing [17]

As in SLA 3D printing, there are two options for DLP 3D printing devices: one creates the object from the bottom up the top (the working platform is lowered), and the other creates the object from the top down to the bottom (the working platform is risen).

DLP 3D printing, as well as FDM printing, alongside with the object creation, requires the application of supporting structures or supports used for the product parts attachment to the platform base and prevent product deformation when overhanging elements are available.

In addition, it is necessary to wash the products in special solutions after the completion of 3D printing in DLP technology, as well as to irradiate them with ultraviolet light. The first one is needed for final purification of the products from the photopolymer residues, and the second – for the complete products hardening.

The photographs of configuration and microstructure of samples № 3 and № 4 formed by digital LED projection (DLP) technology according to the printing parameters from Table 3 are shown in Figure 4. The parameters selection is based on the extreme acceptable values for the given technology and material thickness of 3D product layers (Table 1), which directly affect the samples quality. Photos 3a and 4a (Figure 4) show the samples structure increased by 200 times, photos 3b and 4b – increased by 400 times.

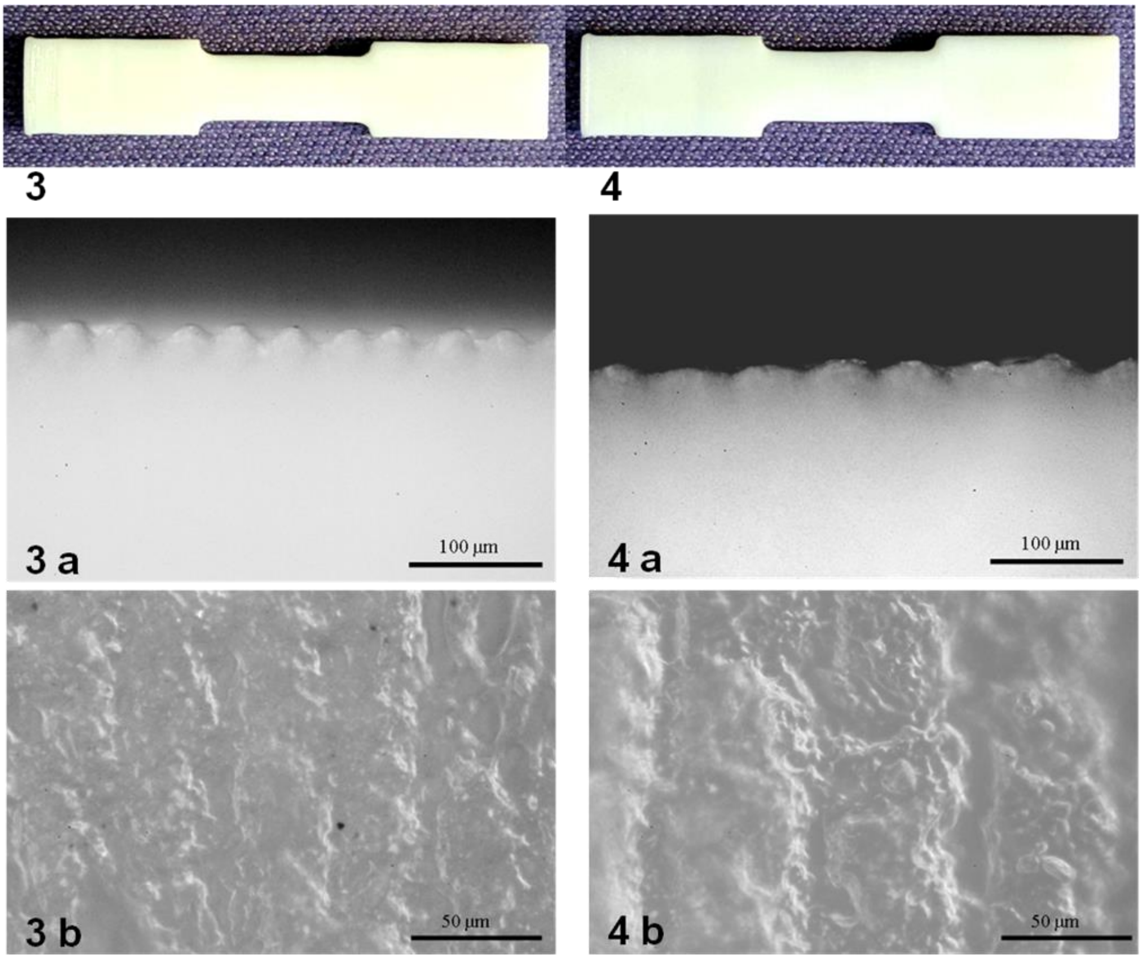


**Figure 4.** The configuration of samples 3 and 4, their microstructure (a, b)

**Analysis of the investigation results.** As it is evident from Figure 2 and Figure 4, the samples obtained by FDM technology have lower resolution in comparison with those by DLP. Sample 2, made by FDM technology with the layer thickness approximated to DLP technology – 80 μm, has significantly smaller visible layer lines than sample 1, but there are inaccuracies (Figure 2) around complex elements eliminated by the supporting structures creation (including soluble ones). In addition, chemical and mechanical polishing can be used in order to improve the surface quality of FDM samples.

Samples 3 and 4 (Figure 4) obtained by DLP technology have sharp edges, clear part outlines, smooth surface and minimal visible layer lines. The sample of the highest admissible quality (3) does not differ significantly from the sample of the lowest admissible quality (4), since the possibility of determining the layer thickness, which depends on the photopolymer type, varies within narrow range 35–50 μm.

Mechanical investigations concerning uniaxial tensile strength by means of FP-10 tensile-testing machine proved that the average elongation till the samples fracture ranges from 8% to 9% for FDM technology and from 8% to 10% for DLP technology, here the strength of PLA base material is 56.9 MPa. It is determined that the interlayer strength of the formed products does not significantly depend on the selected 3D modeling technology.

**Conclusions.** From presented 3D printing technologies, DLP is an excellent option for creating complex geometric parts requiring precision tolerances and having high demands for surface quality, roughness, and accuracy. DLP printing speed is affected only by the number of layers (it makes no difference one X part is printed individually or n-number of X parts) and the layer light time, so single products creation is not effective and it is reasonable to use the

FDM method. As a comparison, the printing time of one part by FDM and DLP technologies is shown in Table 1. FDM 3D printing is ideal for basic models as well as quick and inexpensive simple parts prototyping.

In future, we are going to carry out the investigation of filled polymeric materials, including those filled by nanoparticles.

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## УДК: 62-408.8: 621.9.015: 621.9.019

# ПОРІВНЯЛЬНИЙ АНАЛІЗ ЯКОСТІ ВИРОБІВ З ПЛАСТМАС, СФОРМОВАНИХ ЗА ТЕХНОЛОГІЯМИ DLP ТА FDM 3D ДРУКУ

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***Резюме.*** *3D друк є інноваційною технологією, яка отримала широке розповсюдження в усіх розвинених країнах світу і відкриває значні можливості для її застосування у різних сферах життєдіяльності людини. 3D друк – це процес створення виробів на основі даних тривимірної комп'ютерної моделі шляхом послідовного додавання шар за шаром вихідного матеріалу на майбутній виріб. Технологію 3D друку також називають адитивним виробництвом (англ. Additive Manufacturing, що походить від англійського дієслова «to add» – «додавати»). Упродовж останнього часу ринок тривимірного друку стрімко зростає і поповнюється новими моделями унікального виробничого обладнання, яке дозволяє створювати об'ємні моделі при використанні практично будь-яких вихідних матеріалів. Друкувати можна полімерами, інженерними пластиками, композитними порошками, різними типами металів, керамікою, піском, бетоном, деревом, а в останній час навіть їжею і біологічними речовинами. Однак найрозповсюдженішим на сьогодні є 3D-друк різними типами пластику за рахунок доступності та практичності. В даній роботі розглянуто особливості створення 3D об'єктів з полімерних матеріалів при використанні двох найпоширеніших технологій адитивного виробництва – формування виробів методом пошарового наплавлення (FDM) і варіант стереолітографії (SLA) – цифрова світлодіодна проекція (DLP). При застосуванні даних технологій сформовано зразки на різних режимах 3D друку із використанням як витратного матеріалу біополімеру полілактиду (PLA) та проведені дослідження їх геометрії, структури та механічних властивостей (міжшарової міцності та відносного видовження до розриву матеріалів). Виходячи з отриманих результатів, досліджено вплив заданих параметрів друку, а саме, крайніх допустимих значень товщини шарів 3D виробів для FDM та DLP технології на якість сформованих зразків.*

***Ключові слова:*** *3D друк, адитивне виробництво, FDM технологія, DLP технологія, термопластичні полімери, фотополімери, біопластик.*

*https://doi.org/10.33108/visnyk_tntu2020.02.040* *Отримано 20.02.2020*