Investigation of full arrangement of models on the mechanical properties of samples made from photopolymer material FullCure 720

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Abstract. The results of experimental studies to determine the relationship between arrangement of synthesized model on build platform of 3D printer ObjetEden 350 and mechanical properties of the model fabricated from FullCure 720 photopolymer material were described. During the study, measurements of hard-fabricated samples were made, and the strength and plastic properties of FullCure 720 photopolymer material while tensile test were analyzed.

1. Introduction
To study the effect of arrangement synthesized models on the build platform of 3D printing system ObjetEden 350 using PolyJet technology on the mechanical properties of photopolymer material FullCure 720 [1, 2], samples were designed and fabricated (figure 1). Mechanical properties determine the structural strength of materials.

Figure 1. Samples size used in experiment.

The algorithm for samples arrangement on the build platform and define the appropriate technological parameters for fabrication, particularly was presented in [1, 3, 4]. It should be noted that in order to minimize the influence of random parameters of the process under study on the response function (the final result of the experiment), it is necessary to proceed a series of experiments under the same conditions - to randomize experiments over time [5-7]. Thus, the number of test samples was 72 pieces (figure 2).
2. Description of research models

2.1. Hardness test
The main mechanical properties of the material include: strength, stiffness, elasticity, ductility, hardness, impact strength.

Hardness tests are one of the most common types of mechanical tests due to their simplicity, high performance, as well as the possibility of non-destructive testing of both laboratory samples and finished products [8]. The methods for determining hardness depending on the speed of load application are divided into static and dynamic, and according to the method of load application, they are divided into pressing and scratching methods.

In all existing hardness testing methods, a properly prepared surface layer of the sample is important. It should, as far as possible, fully characterize the material whose hardness must be determined. All surface defects (scale, potholes, dents, gross risks, etc.) must be removed. The quality requirements of the test surface depend on the test method and usually involve its grinding, and even polishing. The measurement was carried out using a portable hardness test machine HardnessTesterTH160. When measuring, three repetitions (three points) were carried out on each sample. The results of samples measurements from photopolymer material FullCure 720 are presented in table 1 [9, 10].

| Sample № | Lieb hardness (HL) | Sample № | Lieb hardness (HL) | Sample № | Lieb hardness (HL) | Sample № | Lieb hardness (HL) |
|----------|--------------------|----------|--------------------|----------|--------------------|----------|--------------------|
| 1-1      | 777                | 1-19     | 674                | 2-1      | 795                | 2-19     | 706                |
| 1-2      | 784                | 1-20     | 645                | 2-2      | 788                | 2-20     | 719                |
| 1-3      | 788                | 1-21     | 599                | 2-3      | 778                | 2-21     | 706                |
| 1-4      | 855                | 1-22     | 720                | 2-4      | 854                | 2-22     | 811                |
| 1-5      | 852                | 1-23     | 781                | 2-5      | 849                | 2-23     | 797                |
| 1-6      | 838                | 1-24     | 969                | 2-6      | 853                | 2-24     | 786                |
| 1-7      | 848                | 1-25     | 764                | 2-7      | 837                | 2-25     | 780                |
| 1-8      | 825                | 1-26     | 759                | 2-8      | 838                | 2-26     | 768                |
| 1-9      | 824                | 1-27     | 751                | 2-9      | 844                | 2-27     | 848                |
| 1-10     | 820                | 1-28     | 849                | 2-10     | 841                | 2-28     | 846                |
| 1-11     | 842                | 1-29     | 836                | 2-11     | 844                | 2-29     | 836                |
| 1-12     | 839                | 1-30     | 837                | 2-12     | 836                | 2-30     | 674                |
| 1-13     | 793                | 1-31     | 621                | 2-13     | 840                | 2-31     | 671                |
| 1-14     | 840                | 1-32     | 668                | 2-14     | 837                | 2-32     | 709                |
| 1-15     | 838                | 1-33     | 662                | 2-15     | 832                | 2-33     | 813                |
| 1-16     | 837                | 1-34     | 774                | 2-16     | 850                | 2-34     | 741                |
| 1-17     | 849                | 1-35     | 767                | 2-17     | 848                | 2-35     | 777                |
| 1-18     | 845                | 1-36     | 750                | 2-18     | 849                | 2-36     | 760                |

Table 1. Lieb hardness test results.
2.2. Mechanical test

Mechanical properties are determined by the mechanical test results of standard sample. Each of these tests differs in the sample loading scheme, the prevailing direction of stresses arising in the sample, and the type of sample failure \[11\].

By the nature of changes in the current load in time, mechanical tests are distinguished: static, dynamic and fatigue.

Static tests are those where an investigation sample of the test material is subjected to a constant or gradually increasing load. The most important types of static tests are: tensile test, compression test, bending test, shear test, torsion test.

As a result of statistical test, the strength, elastic and plasticity properties of materials are determined.

The tensile test was carried out on a TestometricFS 150 AX tensile testing machine. All samples were stretched, in the amount of 72 pieces. During the test, the machine recorder automatically builds a relationship graph between the tensile load $F$ (N) acting on the sample and the absolute elongation of the sample caused by this load $\Delta l$ (mm). An example of such dependence is presented in figure 3.

![Figure 3. Practical dependence between tensile load and absolute elongation of sample № 1-2.](image)

The numerical values of $F$ and $\Delta l$ by themselves do not characterize the properties of the material, since they depend on the size of the test sample. The largest cross-sectional area of sample $S_0$, the greater force $F$ necessary for its deformation. The larger initial length $l_0$, the greater absolute elongation $\Delta l$ (sample will stretch more).

![Figure 4. View of destructed samples.](image)
Flat samples with a cross-sectional area S₀ of standard size from the studied FullCure 720 photopolymer material were fixed in the grips of testing machine and stretched under an ever-increasing load until break.

The nature of the plastic deformation was uneven and gradually localized in a certain part of the sample. After the local stresses in this region exceeded the ultimate strength, the sample was destroyed (figure 4).

Table 2 presents the main results of tensile tests of the samples.  
To compare the sample test results made from the same FullCure 720 material, it is necessary to build a relationship between the stresses $\sigma$ (MPa) arising in the cross sections of the sample and the relative elongation of the sample $\varepsilon$ (%).

| Sample № | Force, N | Elongation, mm | Sample № | Force, N | Elongation, mm | Sample № | Force, N | Elongation, mm | Sample № | Force, N | Elongation, mm |
|----------|----------|----------------|----------|----------|----------------|----------|----------|----------------|----------|----------|----------------|
| 1-1      | 960      | 2,5            | 1-19     | 1020     | 2,7            | 2-1      | 1080     | 3,5            | 2-19     | 900      | 2,6            |
| 1-2      | 1160     | 4,0            | 1-20     | 1000     | 2,6            | 2-2      | 1040     | 3,3            | 2-20     | 950      | 2,8            |
| 1-3      | 1140     | 3,8            | 1-21     | 1060     | 3,6            | 2-3      | 1100     | 3,1            | 2-21     | 1000     | 2,9            |
| 1-4      | 1250     | 2,9            | 1-22     | 800      | 1,5            | 2-4      | 1200     | 3,1            | 2-22     | 1200     | 3,5            |
| 1-5      | 1040     | 3,2            | 1-23     | 480      | 0,7            | 2-5      | 1200     | 2,7            | 2-23     | 840      | 2,0            |
| 1-6      | 1240     | 3,8            | 1-24     | 1100     | 2,2            | 2-6      | 1200     | 3,5            | 2-24     | 880      | 1,7            |
| 1-7      | 1260     | 3,0            | 1-25     | 480      | 0,7            | 2-7      | 1250     | 3,0            | 2-25     | 730      | 1,1            |
| 1-8      | 1080     | 3,4            | 1-26     | 480      | 0,7            | 2-8      | 1200     | 3,0            | 2-26     | 520      | 1,1            |
| 1-9      | 1200     | 3,0            | 1-27     | 560      | 1,2            | 2-9      | 1200     | 3,4            | 2-27     | 480      | 1,1            |
| 1-10     | 900      | 1,5            | 1-28     | 600      | 0,9            | 2-10     | 1050     | 2,6            | 2-28     | 580      | 1,0            |
| 1-11     | 620      | 3,7            | 1-29     | 700      | 1,2            | 2-11     | 900      | 2,9            | 2-29     | 580      | 1,3            |
| 1-12     | 665      | 1,6            | 1-30     | 700      | 1,1            | 2-12     | 1200     | 3,2            | 2-30     | 460      | 0,9            |
| 1-13     | 1000     | 2,0            | 1-31     | 440      | 0,7            | 2-13     | 1000     | 2,3            | 2-31     | 460      | 0,9            |
| 1-14     | 1000     | 2,4            | 1-32     | 620      | 1,2            | 2-14     | 1000     | 2,7            | 2-32     | 620      | 1,7            |
| 1-15     | 630      | 1,7            | 1-33     | 720      | 1,2            | 2-15     | 880      | 1,9            | 2-33     | 500      | 1,2            |
| 1-16     | 1000     | 1,9            | 1-34     | 1080     | 2,2            | 2-16     | 1200     | 2,6            | 2-34     | 600      | 1,4            |
| 1-17     | 1000     | 1,7            | 1-35     | 700      | 3,3            | 2-17     | 900      | 1,9            | 2-35     | 1080     | 1,9            |
| 1-18     | 700      | 1,3            | 1-36     | 600      | 1,9            | 2-18     | 900      | 2,5            | 2-36     | 1000     | 1,9            |

The resulting relationship (see figure 3) is called the material tensile diagram. The numerical values of $\sigma$ and $\varepsilon$ completely characterize the strength and plastic properties of the photopolymer material of the samples under static tension.

3. Results

Analysis of the measuring hardness results showed that the samples 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 28, 29 have the highest hardness obtained during the studies. These samples correspond to the orientation of the synthesized model on the build platform of ObjetEden 350 machine with a maximum overall dimension along the X or Y axes. The sample coating surface and support material does not have a special effect on hardness [12, 13].

Analysis of the obtained results while tensile test of samples from photopolymer material showed that the highest strength and plastic properties of the Full Cure 720 material are observed for samples 3, 4, 5, 6, 7, 8, 9. These samples are characterized by maximum overall dimension along the X axis on the
build platform of ObjetEden 350 machine. Figure 5 shows a schematic representation of the synthesized model on the build platform and forces direction acting on the sample during tension. A value of 0.016 mm characterizes the thickness of each layer during fabrication. As the study results showed, the surface coating of samples and the support material do not significantly affect the strength properties.

Figure 5. Arrangement of fabricated samples to achieve maximum strength and plastic properties of FullCure 720 photopolymer material.

4. Conclusions
Based on the studies, it was experimentally defined that in the process of fabrication photopolymer models from FullCure 720 material using PolyJet technology on the ObjetEden 350 3D printing system to obtain master models with high mechanical properties (the highest hardness and high strength and plastic properties), it is necessary to orient the model maximum overall dimension along the X axis (direction of the printing unit track), and along the X or Y axes, if not possible. It was found that the sample coating surface and support material has no significant effect on the mechanical properties of the samples [14-16].

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