

# Study of the Mechanical Properties of 3D-printed Onyx Parts

Vladimir Blanuša

The Higher Education Technical  
School of Professional Studies in  
Novi Sad, Mechanical engineering  
Novi Sad, Srbija  
blanusa@vtsns.edu.rs

Vesna Petrović

The Higher Education Technical  
School of Professional Studies in  
Novi Sad, Protection engineering  
Novi Sad, Srbija  
petrovic.v@vtsns.edu.rs

Jovan Mijić

Grundfos Serbia d.o.o.  
Production,  
Mechanical engineering  
Indija, Serbia  
j.mijic91@gmail.com

Aleksandar Čabrilo

The Higher Education Technical  
School of Professional Studies in  
Novi Sad, Mechanical engineering  
Novi Sad, Srbija  
cabrilo@vtsns.edu.rs

**Abstract**— This paper presents the results of testing the mechanical parameters (Yang's modulus of elasticity, yield stress and tensile strength) of test specimens printed from Onyx polymer in a selected 100% filling press with a print layer thickness of 0.1 mm and an angle of  $\pm 45^\circ$ . The test specimens were printed using the Markforged FDM printer. The obtained results indicate good elastic properties of the tested material, and certain values of the mechanical parameters are in agreement with the literature values.

**Keywords**—3D printing; FDM printing technology; Onyx; Yang's modulus of elasticity, tensile strength

## I. INTRODUCTION

Printing 3D models belongs to the group of newer technologies that change the environment in which we live every day. Improvement of existing and development of new types of printers is very active even today. The very parts obtained by these technologies find increasing practical application.

3D printing enables firms and companies to produce prototypes much faster and more economically than before, often in a few days or sometimes in just a few hours of product design. Designers create models using softwares or computer aided design (CAD) systems, and then with the help of slicing software and 3D printers, prototypes are made [1]. Today, 3D printing technologies are used very effectively for the production of functional parts, while this was once the case only in the production of prototypes. Printing technology is still in constant development, so even today we are working on an even greater increase in the fineness of the details that can be made, increasing accuracy, improving the mechanical properties of the manufactured parts, increasing the printing workspace, i.e. the dimensions of the parts that can be obtained by 3D printing, developing printers for printing different types of materials, etc.

Printing different types of materials with the 3D printers themselves gives even greater opportunities for the practical application of the parts obtained with this technology. There are printers that print parts from metal, polymer, nylon, sugar and other types of materials [2,3,4,5].

Probably the most common 3D printing technique is the FDM printing method - "Fused Deposition Modeling". Based on the name of this technology, one can already conclude the principle of printing by applying molten material. The material in the form of a wire is brought to the extrusion head by means of a transport system (rollers, conducting pipes, switches, etc.). In it, the wire melts and while it is in a liquid state, it is pushed out through the nozzles. The molten material is stacked in layers on a platform which, after each layer, is lowered by the thickness of the new layer. The path of the of the machine is generated by the computer based on the "CAD" model, and then it is forwarded to the control system in the form of a control program. The extruded layer, while in liquid form, is combined with the previously extruded layer. Layer formation is achieved by moving the extrusion head in the "XY" plane or by moving the platform while also lowering it [6,7].

Recently, there has been the development of special types of 3D printers that have the ability to print parts with several types of materials, where the first material is called the base material, while the other materials are called reinforcement materials. In this way, it is possible to print functionally applicable parts that have several times better mechanical properties than parts obtained from polymers (ABS or with PLA), which greatly increases their practical application and gives a new dimension in the printing of functionally applicable parts [8].

## II. 3D PRINTER MARKFORGED MARK TWO

The 3D printer "Markforged Mark Two" belongs to the group of FDM printers and consists of all the basic parts like all printers from this group (stand, housing, work table, head, extruder, gears, etc.). The printer head moves in the horizontal plane in the X and Y axes, while the work table moves in the Z axis, i.e. in the vertical axis. The thickness of the layers that can be printed on the printer itself are: 0.1 mm, 0.125 mm and 0.2 mm.

Onyx is used as a printing material. Before the actual printing, it is necessary to coat the surface of the work table

with a special glue to prevent bad adhesion between build plate and first layer. Onyx is a material that is specially made for Markforged printers and consists of tough nylon with micro-carbon reinforcement, shown in Fig. 1. The printer model itself has two generations, with the first generation model intended for printing only Onyx material, while the second generation printer can also be used for printing other types of filaments (various types of ABS and PLA). The temperature of the print head reaches about 275°C which represents the melting temperature of Onyx.

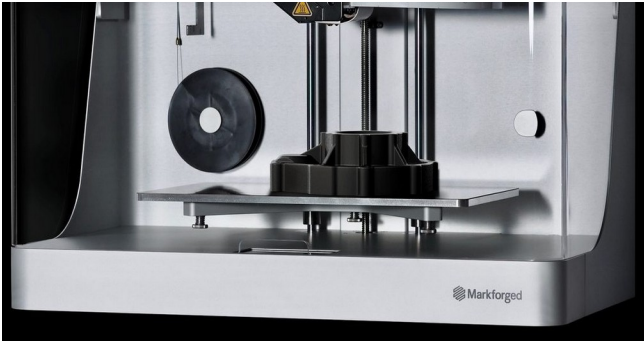


Fig. 1. Appearance of the “Markforged Mark Two” 3D printer

The appearance of the 3D printer "Markforged Mark Two"

Basic features of the printer:

- Manufacturer: Markforged,
- 3D printing technology: FDM,
- Printer dimensions: 584x330x355 mm,
- Work surface: 320x132x154 mm,
- Closed chamber: YES,
- Layer thickness: 0.1, 0.125, 0.2 mm

### III. PREPARATION FOR PRINTING

Preparation for printing is done with the help of the specialized program package "Markforged". The program package has the ability to read files with the ".stl" extension that were previously created and saved in one of the software systems for 3D modeling (for example, Autodesk Inventor, SolidWorks, AutoCAD, etc.).

It is done in the software package itself:

- creating folders for each user separately if necessary,
- review of printer use by each user,
- choosing the basic or reinforcing materials,
- overview of the dimensions of the work, the time required for printing, the required amount of material, defining the name of the work,
- setting the thickness of the print layer,

- part scaling,
- print density setting (in percent %),
- and other [9].

After loading the model into the program, its scale is adjusted and the model is positioned on the working platform of the printer. Defining the position of the object depends a lot on the geometry and dimensions of the model. The appearance of the graphic environment of the program package for the preparation of 3d printing is shown in Fig. 2.

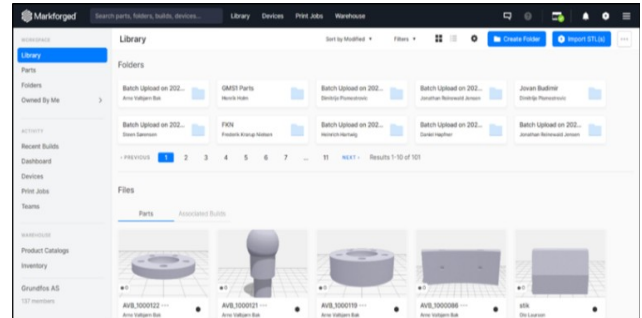


Fig. 2. Layout of the graphic environment of the program package for 3D printing "Markforged"

Very important parameters in preparation for printing are certainly the thickness of the print layer, which directly affects the accuracy of dimensions, the roughness of the surface of the part and production, the position of the 3D model on the printer's desktop, the filling density (up to a maximum of 100% according to theory), the placement of glue on the printer's desktop.

Fig.3 shows a set 3D model of a press tube used for testing tensile strength with technological parameters displayed.

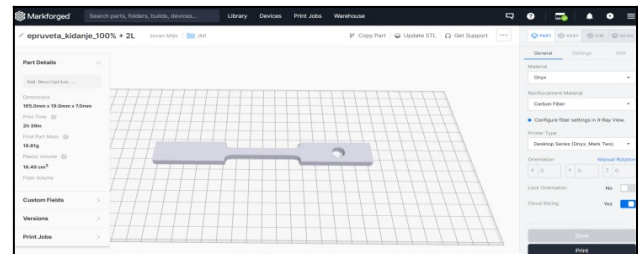


Fig. 3. The appearance of the test specimens placed on the working plate of the printer

There are several options when setting the gain such as:

- Presentation of the reinforcement on the basic material,
- Selection of the layer in which reinforcement is performed,
- Selection of the thickness of the reinforcement layer,
- Selection of the number of reinforcement layers (2,3,4 separate layers),
- Method of placing the reinforcement (reinforcement in strips or full filling of the entire layer),
- And another.

The appearance of the graphic environment in which the technological parameters of reinforcement are adjusted is shown in Fig. 4.

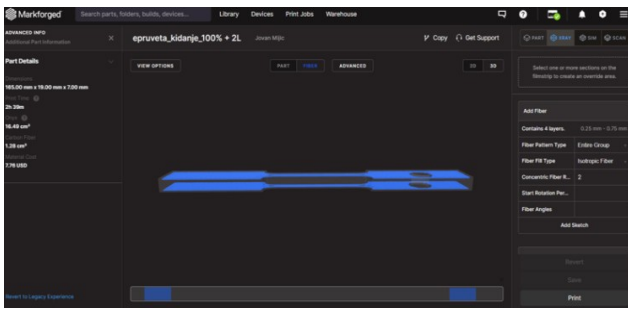


Fig. 4. Appearance of technological parameter settings in model reinforcement

#### IV. PRINTING OF TEST SPECIMENS

In this research, the tensile strength of test specimens printed on the aforementioned Markforged Mark Two 3D printer will be tested. Three pieces of test specimens were printed from each test specimens. And onyx was used as the base material.

Three test specimens were printed, and the selected printing strategy was 100% filling, and the coating thickness was 0.1 mm. The printer deposits successive layers in a fixed orientation at  $\pm 45^\circ$ . The appearance of the test specimens is shown in Fig. 5.



Fig. 5 Appearance of printed test specimens with base material only and fill density of 100%

#### V. TENSILE STRENGTH TEST

Tear testers are instruments for testing the tensile, compressive and bending strength of materials by measuring force and deformation to obtain the  $F-\Delta L$  stress diagram, and are used to determine the basic mechanical properties of metals, plastics, composites, textiles and other materials according to standards such as ISO 6892-1 and EN ISO 13934-1. During this tearing, the test specimens will be tested for the maximum force and tensile strength of the material itself and the material with reinforcement. The physical properties of the test specimens used for testing are given in Table I.

TABLE I. PHYSICAL CHARACTERISTICS OF TEST TESTS OF THE TESTED MATERIAL

	Onyx 100% sample 1	Onyx 100% sample 2	Onyx 100% sample 3	average value
Mass [g]	18.3872	18.0518	17.813	18.084
Volume [cm <sup>3</sup> ]	19.0553	19.0553	19.0553	19.0553
Density [g cm <sup>3</sup> ]	0.9649	0.9473	0.9348	0.949

The appearance of the test specimens after tearing is shown in Fig. 6.



Fig. 6 Appearance of the test specimens after tearing

The results of the mechanical properties of the samples will be presented through force-elongation and stress-deformation diagrams. On Fig. 6 shows the Force-Elongation diagrams for all three samples, while Fig. 7 shows the stress-strain diagrams of the same samples.

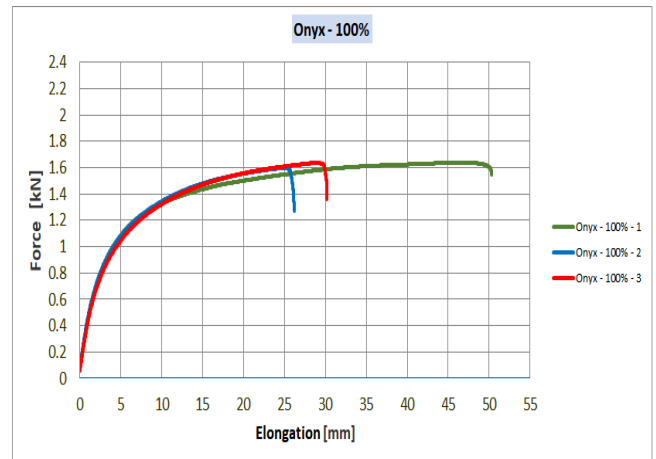


Fig. 7 Layout of the "Force-Elongation" diagram

Based on the results shown in the diagram, Fig. 7, a high elasticity of the material can be observed, where the elongation changes significantly, so that the elongation at break in sample 1 reaches as much as 50 mm, while in the remaining two it is 26 mm and 30 mm. During printing, the test specimens with the greatest elongation (Onyx 100%-1) was the first on the work table. During the printing of the stand, part of it came off in the area where the test specimens was located, which caused reinforcements in the test specimens itself during printing. The very structure of the specific test specimens for this reason gave almost double the elongation of the other two test specimens.

The values of the maximum forces  $F_{max}$  of the samples are approximately equal and amount to about 1.6 kN. The obtained values showed great agreement with the results of other authors [8,9] under the given printing conditions.

Based on the results shown in the diagram, Fig. 8, it is observed that the tensile strength for all three samples is about 33 MPa.

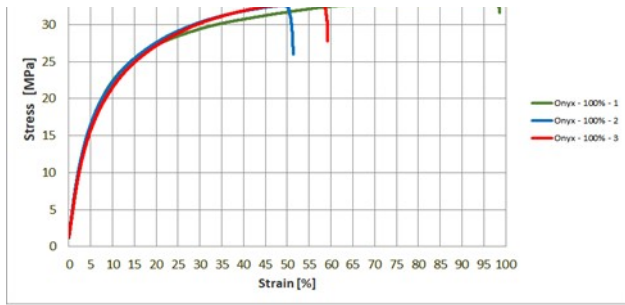


Fig. 8 Layout of the "Stress-Strain" diagram

Data were processed according to the recommendations of the standard used. The Young's modulus ( $E$ ) was calculated by considering the linear part of the stress-strain curve using linear regression in Excel, with the validity criterion being a regression coefficient  $R^2 > 0.99$ . The adopted elastic limit is  $Re_{0.2}$ , corresponding to the elastic limit at 0.2% elastic deformation and mechanical resistance, which is the maximum mechanical stress of the stress-strain curve. The values for samples 2 and 3 are approximate, while for sample 1 a significantly lower value was registered. This deviation is probably due to the possible separation of part of the material during the printing process, which has already been pointed out. The obtained  $Re_{0.2}$  values for samples 2 and 3 are expected [8]. The maximum tensile strength values of all samples are around 33 MPa. The obtained values are completely in agreement with the results [8], while they are less than the results [9].

Systematized test results of all samples are given in Table II.

TABLE II. MECHANICAL PARAMETERS OF THE TESTED MATERIAL

	$F_{max}$ [kN]	$Re_{0.2}$ [MPa]
Measurement 1	1.63	19.7
Measurement 2	1.59	28,2
Measurement 3	1.63	32.3
Mean value	1.62	26.73
	$E$ [MPa]	$Rm_{mean}$ [MPa]
Measurement 1	3.860	33.4
Measurement 2	7.415	32.6
Measurement 3	8.290	33.4
Mean value	6.52	33.1

## VI. CONCLUSION

The development and exploitation of new materials is a very important driver of new innovations and improvement of existing ones. The improvement of mechanical properties as well as other performance of materials enables the direct advancement of technology in mechanical engineering, electrical engineering, medicine and other branches of

industry, while contributing to greater economic profitability, reducing waste, making products more durable, more efficient, more environmentally friendly, which is necessary for the competitiveness of the industry. It is for this reason that the examination of different properties of materials as well as their analysis is very important from the aspect of finding specific markets where it is possible to incorporate parts with these properties and to obtain certain advantages, whether it is about the economic aspect or the quality of the obtained parts.

Applicatively significant mechanical parameters of the Onyx samples showed high elasticity (elongation at break reaches up to 50 mm) and a maximum stress value of 33 MPa. The obtained values indicate better mechanical properties of Onyx than ABS material [8], while it should be borne in mind that the price of Onyx filament is about 5 times more expensive compared to filaments made of ABS and PLA.

## ACKNOWLEDGMENT

This paper presents part of the research that represents the continuation of the research on the project "Influence of the technological parameters of the FDM method of 3D printing on the most important mechanical properties of functionally applicable parts", Project number: 142-451/2300/2023-02/1. The project was financed by the Provincial Secretariat for Higher Education and Scientific Research of the Autonomous Province of Vojvodina..

## LITERATURE

1. M. Plančak, "Brza izrada prototipova, modela i alata", Fakultet tehničkih nauka-Novi Sad, 2009.
2. P. Lakkala, S. Ram Munnangi, S. Bandari, M. Repka, „Additive manufacturing technologies with emphasis on stereolithography 3D printing in pharmaceutical and medical applications: A review “International Journal of Pharmaceutics, Vol. 5, 2023, pp. 1-16.
3. E. MacDonald, R. Salasi, D. Espalin, M. Perezi, E. Aguilera, D. Muse, and B. R. Wicker, "3D printing for the Rapid Prototyping of Structural Electronics," IEEE Access, Num. 2, 2014, pp. 234-242.
4. D. Espalin, W. Muse, E. MacDonald and R. B. Wiker, "Printing multifunctionality: structures with electronics," Int. J. Manuf. Technol., Num. 72, 2014, pp. 963-978.
5. Z.X. Khaoo, E. J. Teoh, Y. Liu, K. C. Chua, S. Yang, J. and Y. W. Yeong, "3D printing of smart materials: A review on recent progresses in 4D printing," Virtual and Physical Prototyping, Num. 10 (3), 2015, pp.103-122.
6. V. Petrović, A. Čabrilo, V. Blanuša, P. Balaban., B. Savić, G.V. Mner, "Influence of Density of 3D Printing Using the FDM Method on Productivity and Mechanical Properties of ABS," Materials Science Forum, Vol. 1128, 2024, pp 59-65.
7. V. Blanuša, A. Đurković, "Mogućnosti 3D štampe primenom štampača ZORTRAX M200 PLUS," 6 Međunarodna konferencija Upravljanje znanjem i informatika, 2020, pp. 93-100.
8. D. Nikiema, P. Balland, A. Sergent, "Study of the Mechanical Properties of 3D-printed Onyx Parts: Investigation on Printing Parameters and Effect of Humidity", Chinese Journal of Mechanical Engineering: Additive Manufacturing Frontiers 2 (2023) 100075..
9. F. Bárnika, M. Vaško, M. Handrika, F. Dorčiaka, J. Majko, "Comparing mechanical properties of composites structures on Onyx base with different density and shape of fill", Transportation Research Procedia 40, 2019, pp.616–622
10. X. Chen, C. I. Barnes, T. H. C. Childs, B. Henson, F. Shao, "Materials tactile testing and characterisation for consumer products affective packaging design," Materials & Design, Vol. 30, Issue 10, 2009, pp. 4299-4310.