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Experimental Determination of the Mechanical Properties of Onyx Material

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Abstract. The main objective of the study is to determine the mechanical properties of the composite material produced by 3D printing. Experimental verification of the influence of the orientation and thickness of the layers was carried out. The test specimens for the experiment are fabricated by 3D printing from Onyx material using the Fused filament fabrication (FFF) method. The investigation of the mechanical properties is carried out using static tensile testing on the Inova FU-O-160-1260-V1 machine. The shape and dimensions of the test specimens are defined by the ASTM D638-14 standard. The study aims to determine the mechanical properties of Onyx material and specify the influence of the orientation of the layers and the thickness of the specimens on these mechanical properties.

Introduction

The issue of research and development of advanced transport vehicles that use unconventional lightweight construction materials, alternative drives, modular construction, and intelligent assistance systems is essential for the further development of intelligent transport in the future. The development of vehicles that do not produce any emissions due to their operation is the current trend in the automotive industry. This is visible in the development of special vehicles for rescue services, agriculture, and forestry. The driving parameter for the new design solutions being developed is to increase the proportion of energy-saving materials that are preferably recycled or recyclable while maintaining the same or better properties. The use of fiber-reinforced polymer composites in the design of a special vehicle is essential for zero emissions achievement. This trend of new solutions leads to the development of lightweight material structures in order to reduce the environmental impact [1]. The main benefits of composite materials are their stiffness, strength, lightweight, resistance to corrosion, stability, and reliability [2]. The reinforcing function performs reinforcement in the form of fibers, flakes, or dispersed particles [3,4]. With the expansion of plastics into the market, fiber-reinforced polymer composites have begun to be applied in practice [5]. Depending on the fiber length, the polymers can be reinforced with long or short fibers [4,6], however, composites reinforced with long fibers achieve better mechanical properties [7]. Fiber-reinforced polymer composites are produced by combining resin and fibers. Commonly, fibers are made from materials such as glass, carbon, aramid or basalt, and others [1, 8, 9]. More frequent use of glass fiber-reinforced polymer composites is due to their excellent ratio between price and mechanical properties. The carbon composite showed higher tensile and compressive modulus. In-plane shear properties of both the composites were comparable and interlaminar shear properties of glass composites were observed to be better than the carbon composite, because of the better nesting between the glass fabric layers [10, 11].

Although 3D printing has been undergoing a significant increase in interest only recently, the current state is the result of long-term development that began in the 1980s. The technology of 3D printing has advanced significantly in recent years and is now crucial in the technical field. It enables the design of complex components, reduces the cost of manufacturing them, and saves prototyping and development time. Various polymers with different mechanical and thermal properties are currently used as filament materials for the FFF printing method. Low strength and excessive thermal expansion are polymers' drawbacks, which restrict their wider application. Reinforcing fibers or particles are included in the polymer matrix to alleviate such a disadvantage. As a result, the mechanical and thermal properties of the newly formed composite material are improved [12].

This study aims to experimentally measure and evaluate the selected mechanical properties of test specimens fabricated using the FFF method (Fig. 1) from Onyx material. The specimens will be subjected to static tensile testing. Subsequently, the influence of the thickness and orientation of the layers concerning the loading direction will be evaluated.

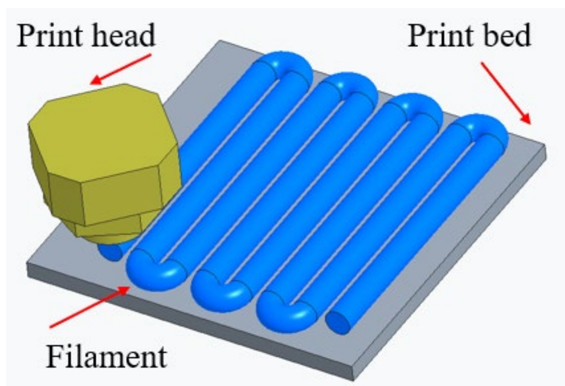

Fig. 1. *Fundamental scheme of FFF method.*

Materials and Methods

The test sample is made by 3D printing technology according to ASTM D638-14 standard from Onyx material. The dimensions of the test specimen are designed according to the Type I specimen in this standard (Fig. 2). The experiment was conducted with specimen thicknesses of 0.5 mm or 1 mm.

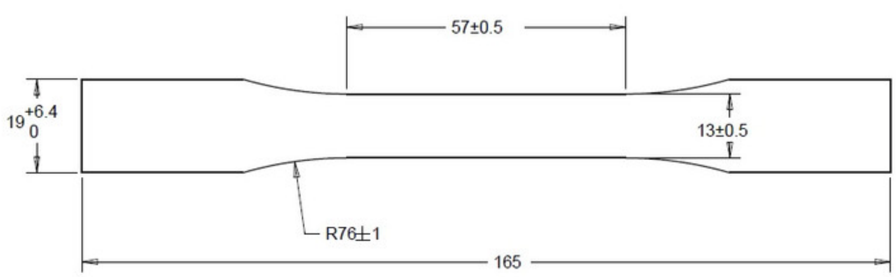

Fig.2. *Test specimen according to ASTM D638-14 standard.*

The Onyx material is a blend of nylon and chopped short randomly oriented carbon fibers. The material components have a very high surface quality and the fiber reinforcements add rigidity. These fibers form a micro-carbon reinforcement and make the components strong, rigid, and achieve very precise dimensions with digital design. The combination of nylon and carbon fiber has achieved both strength and high heat resistance. The material can withstand temperatures up to 145° C. The material can be utilized either on its own, as previously noted, or it can be further reinforced with high-strength fibers for even superior mechanical qualities [13].

The bi-axial experimental testing device INOVA FU-O-160-1260-V1 located in the laboratory of the Department of Applied Mechanics, SJF Žilina (Fig. 3) was used for the experimental measurements. To achieve accurate results from the static tensile test, the equipment was calibrated prior to the actual test. The device loads the test specimen by pulling away the jaws of the machine until it breaks. The specimen is placed in the jaws of the machine so that the long axis of the specimen is coincident with the imaginary axis of the jaws of the machine in the load direction. The jaws grip the specimen evenly and firmly so that the specimen does not slip during the test, but care must be taken to ensure that the specimen is not damaged by too strong of a grip.

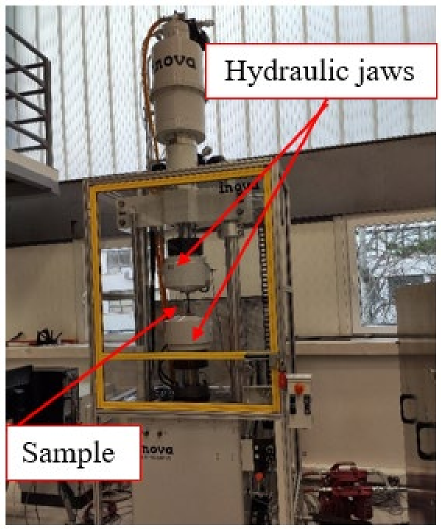

Fig. 3. *Testing device INOVA FU-O-160-1260-V1.*

A total of 4 sets of test specimens were produced, each set containing a different layer arrangement as well as different layer thicknesses. In terms of their identification, the sample sets are labeled A, B, C, and D. Each set consists of five test specimens numbered 1 to 5. All samples are printed with the face lying on the x-axis. Figures 4 and 5 illustrate the arrangement and direction of the layer stacking of printed samples, as well as the direction of loading.

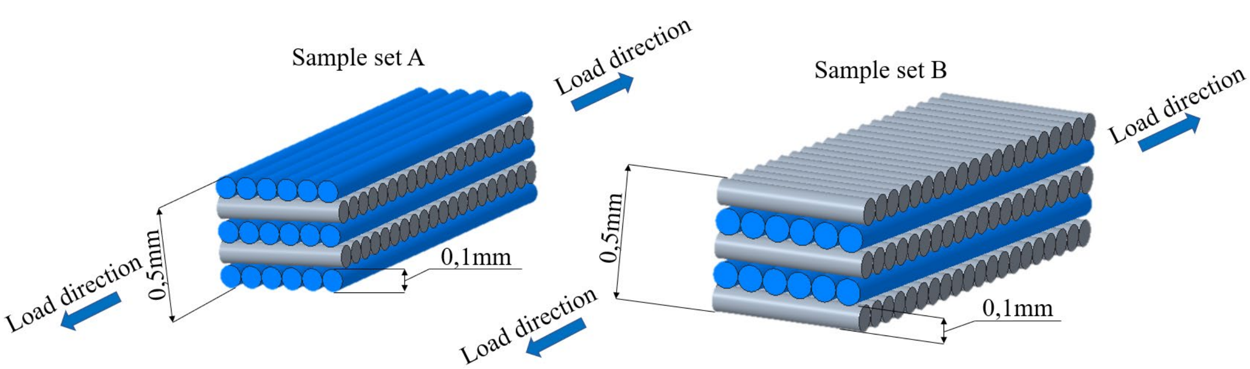

Fig. 4. *Arrangement of layers of sample sets A and B.*

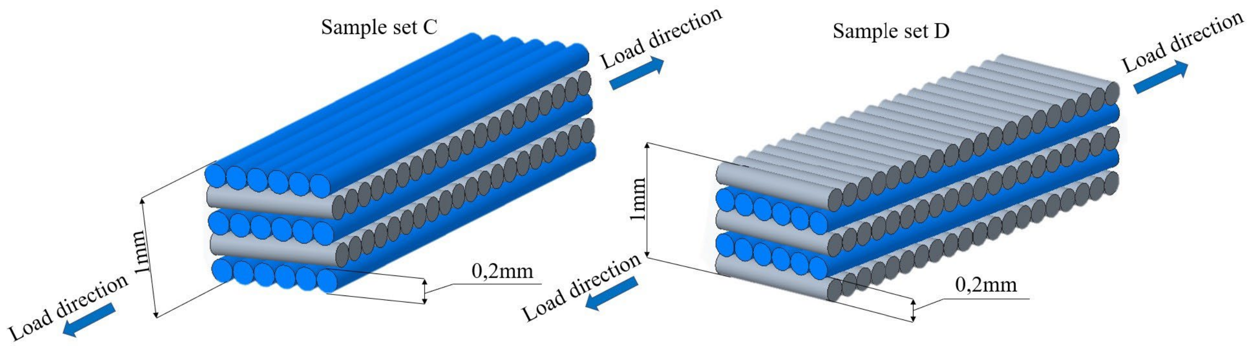

Fig. 5. *Arrangement of layers of sample sets C and D.*

Results and Discussion

Based on the tensile test performed, information about the test progress was obtained from the software of the experimental device. The test specimens after the static tensile test are shown in Figures 6 and 7 together with the tensile diagrams that were created.

To summarize and evaluate the experimentally verified mechanical properties of the Onyx composite material under static loading, a summary Table 1 was created. The average values from the experimental measurements for the tested sets A to D are recorded in the table. Figures 8 and 9 show the average values of ultimate strength and ductility.

Cross-sections of the ruptured specimen from sample set A were examined using a scanning electron microscope (SEM) to determine the behavior of the material during loading. The presence of voids between each filament within the single lamina is shown in the illustration (Fig. 10).

Fig. 6. *Test specimen No 2 of the sample set A after the static tensile test.*

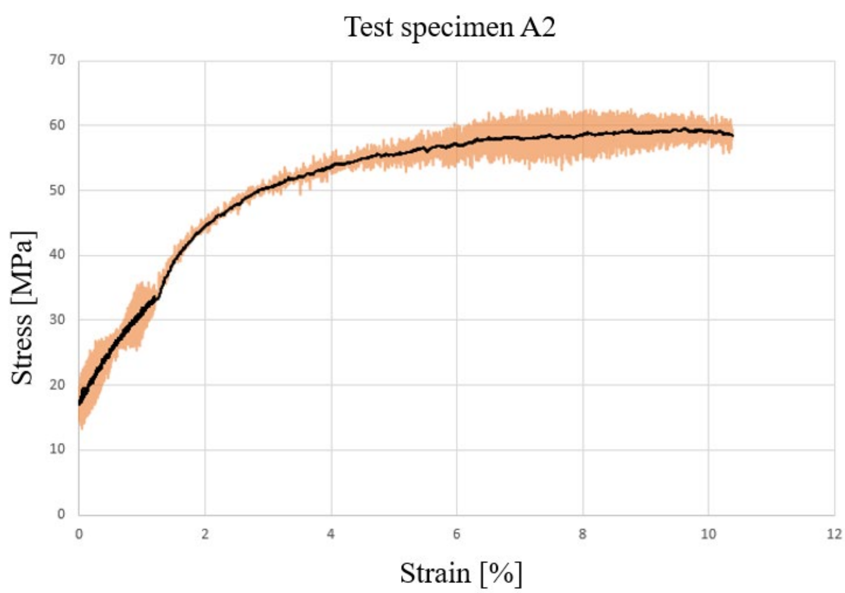

Fig. 7. *Tensile test diagram of test specimen A2.*

Table 1. Summary results of mechanical properties of Onyx composite material

Sample set	R_m [MPa]	$R_{p0.2}$ [MPa]	F_m [N]	A_t [%]
A	56.14	17.30	364.89	9.46
B	43.93	12.32	284.28	14.84
C	39.78	14.40	517.19	15.56
D	38.22	14.56	496.92	16.01

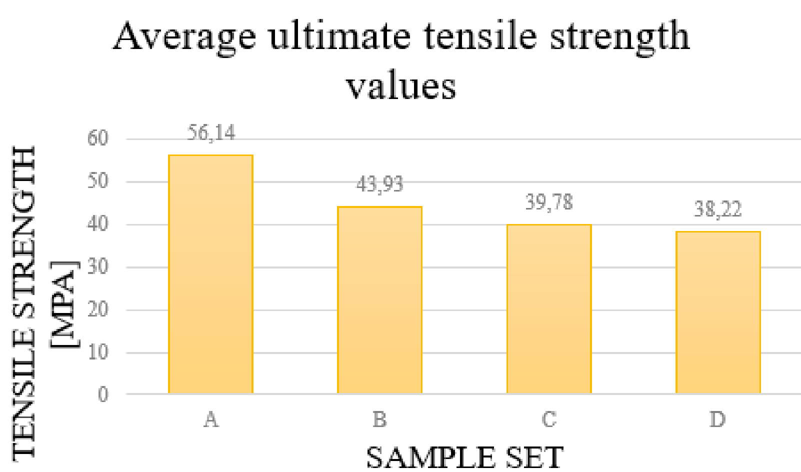

Fig. 8. *Average ultimate tensile strength values.*

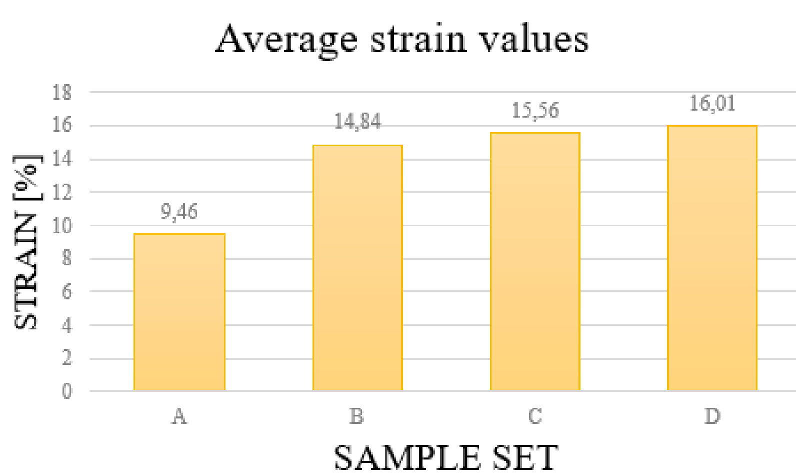

Fig. 9. *Average strain values.*

The presence of voids contributes to a limited connection between the filaments and laminas. The impact of tensile loading on the various composite phases is shown in images with a higher magnification - nylon filaments that are overstretched and broken carbon fibers (Fig. 11). The illustrations also demonstrate a laminate failure process. The broken carbon fibers may be observed in the laminas that are oriented in the load direction. The rupture propagated between the filaments in the case of laminas aligned perpendicular to the load direction, showing a lower strength between them. Only laminas aligned with the load direction effectively transfer tensile loading [4].

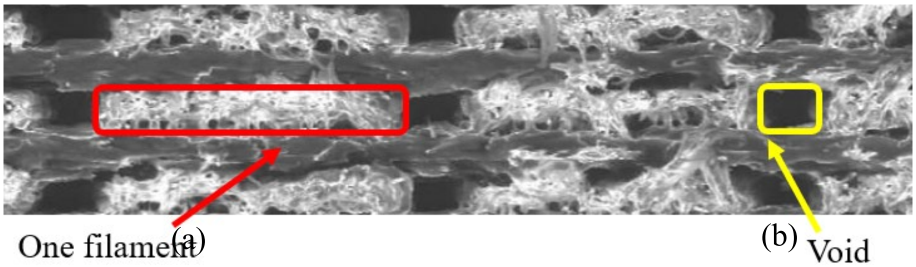

Fig. 10. *Cross section of ruptured specimen (100x magnification, detector LVSD) [4].*

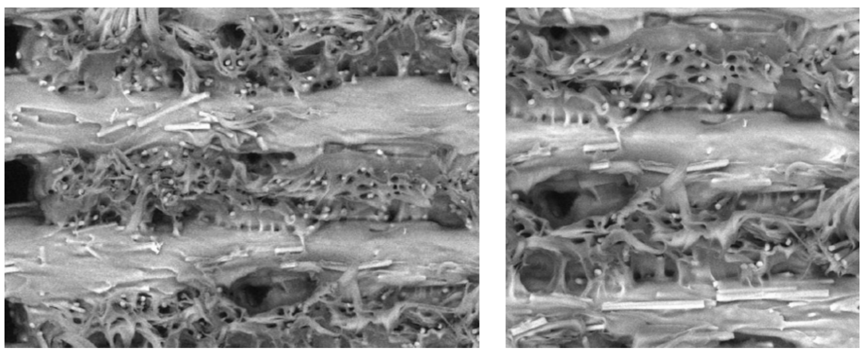

Fig. 11. *Cross section of ruptured specimen (a) 300x magnification, detector BSE; (b) 500x magnification, detector BSE [4].*

Conclusions

From the evaluation of the experimental results, it can be concluded that the strength and stiffness of the composite material depend critically on the strength and stiffness of the fibers themselves. The orientation of the fibers itself is also very important as it significantly influences the other mechanical properties of the composites. At the same time, it is evident that the very different mechanical properties of the fibers and the matrix give rise to a complex state of stress in the composite structure. This is mainly a matter of the bonding between the fibers and the matrix itself and, at the same time, the behavior of the particular arrangement of these fibers in the volume. For a given composite material, i. e. with randomly oriented fibers, changes in the mechanical properties can most likely only be altered by changing the content or volume of these fibers in the individual layers. In this particular case, the reinforcement content of the material tested did not change. The only parameters that changed were the orientation and stacking of the layers of the composite. And it was this factor that proved to be the reason for the changes in the experimental measurement results. The explanation for the decrease or increase in the individual mechanical properties of the composite used could be explained by the quality of the bond between the fiber and the matrix - the material thickness (number of layers) vs. ultimate strength. An explanation can be sought among the infinite number of interfaces, which usually exhibit less strength than each component individually. These interfacial areas and their volume fraction in the composite are where failure is expected to occur and propagate. Thus, with their enormous number, a large amount of energy is converted in a small area into the work required to create the failures or cracks. The more of these layers were 3D printed on top of each other, the lower the strength values were - confirming the assumption.

In this work, the mechanical properties of composite test specimens made of Onyx material were experimentally verified. The mechanical properties of the test sets of specimens differed from each other based on the thickness of the specimens and the orientation of the layers during 3D printing. This work opened up possibilities for further investigation of the properties of composite materials fabricated by 3D printing. There are many ways to investigate composites and thus achieve a significantly more comprehensive view of their properties. Further research could also focus on other types of stresses whether static, dynamic or hardness testing.

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References

[1] M. F. Ashby. Materials Selection in Mechanical Design, Elsevier Butterworth Heinemann. Burlington, 2005.

[2] R.M. Jones. Mechanics of Composite Materials, 2nd Ed., Taylor and Francis, New York, 1999.

[3] M.Y. Khalid et al. Natural fiber reinforced composites: Sustainable materials for emerging applications. Results Eng. 11 (2021) art.100263. https://doi.org/10.1016/j.rineng.2021.100263

[4] J. Majko et al. Tensile Properties of Additively Manufactured Thermoplastic Composites Reinforced with Chopped Carbon Fibre, Materials 15 (2022) art.4224. https://doi.org/10.3390/ma15124224

[5] F. Van der Klif et al. 3D Printing of Continuous Carbon Fibre Reinforced Thermo-Plastic (CFRTP) Tensile Test Specimens. Open J. Compos. Mater (2016), 6, 18–27. http://dx.doi.org/10.4236/ojcm.2016.61003

[6] G.W. Melenka et al. Evaluation and prediction of the tensile properties of continuous fiber-reinforced 3D printed structures. Compos. Struct 153 (2016) 866-875. https://doi.org/10.1016/j.compstruct.2016.07.018

[7] F. Ning et al. Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling. Compos. Part B Eng. 80 (2015) 369-378. https://doi.org/10.1016/j.compositesb.2015.06.013

[8] Fiber Reinforced Polymer (FRP) Composites Market Analysis By Fiber Type (Glass, Carbon, Basalt, Aramid), By Application (Automotive, Construction, Electronic, Defense), By Region, And Segment Forecasts, 2018-2025, Grand View Research (2017). Report ID: GVR-2-68038-006-4. [online]. 2017. [viewed: 2023-01-31] Available from: https://www.grandviewresearch.com/industry-analysis/fiber-reinforced-polymer-frp-composites-market

[9] T. Liptáková, P. Alexy, E. Gondár, V. Khunová, Polymérne konštrukčné materiály, EDIS, Žilina, 2012. ISBN 978-80-554-0505-6

[10] G.D. Goh et al. Recent progress in additive manufacturing of fiber reinforced polymer composite, Adv. Mater. Technol. 4 (2019) art.1800271. https://doi.org/10.1002/admt.201800271

[11] G.D. Goh et al. Characterization of mechanical properties and fracture mode of additively manufactured carbon fiber and glass fiber reinforced thermoplastics, Mater. Des. 137 (2018) 79-89. https://doi.org/10.1016/j.matdes.2017.10.021

[12] K. Kandananond. Surface Roughness Reduction in A Fused Filament Fabrication (FFF) Process using Central Composite Design Method, Prod. Eng. Arch. 28 (2022) 157-163. https://doi.org/10.30657/pea.2022.28.18

[13] Introducing Our New Markforged Material: Onyx. [online]. 2023. [viewed: 2023-01-31]. Available from: http://markforged.com/resources/blog/introducing-our-new-markforged-material-onyx