

Tensile Properties Regression Analysis of FDM 3D Printed Composites with ONYX Matrix and Different Fibres

Pejo Konjatić, Josip Kačmarčik*, Marko Katinić, Lamija Mešeljević

Abstract: The influence of infill density, number of layers, and fibre type on the tensile mechanical properties of composite parts produced by FDM 3D printing with continuous fibre reinforcement (CFR) was investigated. Specimens made of ONYX composite material reinforced with carbon, glass, and aramid fibres were tested using a static tensile test according to ISO 527. A linear regression model was developed to correlate mechanical properties with 3D printing parameters. However, the influence of infill density could not be reliably determined due to the automatic generation of solid infill around fibre layers and at boundary layers in the utilized 3D printing software. These reinforcements provided varying degrees of enhancement, with carbon and glass fibres showing the highest increase in strength, glass fibres offering the best enhancement in fracture strain, and carbon fibres in stiffness. The obtained models for tensile strength, strain at maximum stress, and modulus of elasticity can be useful in the design of 3D printed parts, offering a simple solution for the prediction of mechanical properties.

Keywords: 3D printing; composite materials; aramid fibres; carbon fibres; fibreglass; tensile properties

1 INTRODUCTION

Additive manufacturing, commonly known as 3D printing (3DP), revolutionized the process of design and creation in various industries [1-3]. The most accessible, economical, and widely applicable 3D printing technology in recent years is FDM (Fused Deposition Modelling), where the process is based on the extrusion and melting of thermoplastic material (filament) through a heated nozzle and layering it onto a platform along a predefined path, where the filament cools and solidifies to form a 3D object. The main advantage of selecting the FDM process is the production of components without the need for pre-prepared tools, such as injection moulds, making it very useful for rapid prototyping. Since FDM 3D printing is a relatively new technology, the mechanical properties of the materials produced and their testing still present many unknowns and have been the subject of numerous recent studies [4-8].

FDM printing typically uses thermoplastic polymers like polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), and polyethylene terephthalate glycol (PETG), and nylon, each offering different levels of strength, quality, and cost. Recent advancements include materials reinforced with chopped microfibres, such as carbon or glass, which significantly enhance mechanical properties and thermal stability. This range of materials allows for greater flexibility in selecting the appropriate material for specific applications. However, despite recent advancements, conventional FDM processes still face challenges such as lower strength and stiffness, poor dimensional accuracy and surface finish, and limited thermal stability compared to traditional manufacturing methods and composites. Development of technology for 3DP of continuous fibre reinforced addressed these shortcomings and make a milestone in applicability and reliability of 3D printed parts [9, 10]. Unlike the chopped microfibres, the continuous fibres are printed directly into the parts, serving as the structural foundation and enhancing overall performance offering better strength, uniformity, and

enhanced structural integrity. The technology available in the market with this feature is also known as continuous filament fabrication (CFF). However, 3DP is a challenging process where different process parameters influence the result. This has prompted numerous studies in recent years on the impact of various composite 3DP process parameters on different characteristics of the final part. The improvement of mechanical properties is one of the most important benefits of 3DP composites, so a significant number of research studies address it. Tensile testing is a fundamental and widely used test for examining the mechanical properties of various materials, providing essential information about the material's mechanical behaviour necessary for designers and engineers, so it is also widely implemented in 3DP research.

Analysing the influence of matrix and fibre material for FDM printing filament, process parameters and developing analytical/numerical models for predicting the mechanical properties of 3DP is one of the important research directions. The ability of known micromechanical models to predict modulus of elasticity and tensile strength for 3D printed composites with different glass fibre volume fraction is investigated in [11]. In the [12] the effect of various FDM printing parameters on the impact resistance of 3D-printed composites with glass fibre is investigated. Similarly, in [13], the dependence of the modulus and the strength on concentric carbon fibre reinforcement and density of 3D printed materials is examined, and models for optimization of 3DP configuration are proposed. Regression analysis of tensile strength, modulus and energy absorption as function of 3DP parameters is conducted in [14]. The effect of the material storage and aging is also investigated [15]. Interested readers can find numerous other studies of similar content that further underscore the significance and appeal of this topic.

The influence of fill density and number of layers with fibre reinforcement on tensile mechanical properties of 3D printed composites with ONYX material is experimentally and statistically investigated in this study. Additionally, three different types of fibre reinforcement, carbon, fibreglass and

aramid (Kevlar®) are considered. The ISO 527 standard [16-17], which defines the tensile testing of plastics, was applied for the investigation. Three characteristics were determined in the testing: tensile strength (maximum stress), elongation at tensile strength, and modulus of elasticity under tension (Young's modulus). Markforged Mark Two 3D printer [18] and materials for additive manufacturing from the Markforged [19] are used in experimental investigations. The aim of the research is to develop regression models that correlate various tensile mechanical properties with the parameters of the 3D printing process and usage of different fibres. Such models for different fibres may not be readily available in the open access literature. While modest in novelty, this work contributes to a deeper understanding of the relationships between process parameters and final mechanical properties in 3D printed composites. These models may be useful in optimizing the design and production of 3D prints, providing valuable guidance to the industry.

2 MATERIALS AND METHODS

2.1 Specimens Geometry

The ISO 527 standard regulates the test parameters for materials tested at room temperature. It defines the procedure for tensile testing of plastics, providing guidance on measuring mechanical properties such as tensile strength and elongation at break. The standard offers both normal (type 1) and small (type 5) specimens. For the convenience of faster 3D printing and compatibility with the test equipment regarding maximum force, small type 5A specimens were selected for investigation. The dimensions of the specimen are provided in Tab. 1 and Fig. 1.

Table 1 Dimensions of test specimen type 5A (ISO 527)

Feature	Dimensions / mm
l_2	≥ 75
b_2	$12,5 \pm 1$
l_1	25 ± 1
b_1	$4 \pm 0,1$
r_1	$8 \pm 0,5$
r_2	$12,5 \pm 1$
L	50 ± 2
L_0	$20 \pm 0,5$
h	≥ 2

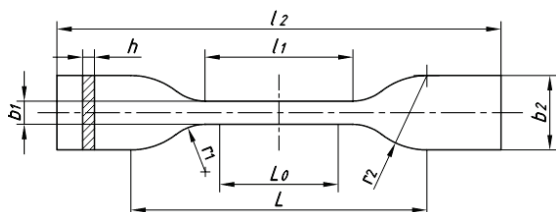


Figure 1 Tensile test specimen type 5A (ISO 527)

2.2 3D Printing

The Markforged Mark Two printer, as shown in Fig. 2, was used for 3D printing. It features a single print head equipped with two distinct nozzles. One nozzle is specifically

designated for printing polymer material, while the other is dedicated to laying continuous fibre lines within the polymer. These fibres serve to reinforce the 3D printed parts, significantly enhancing their stiffness and strength. The FDM process proceeds continuously to produce a basic block of the 3D printed part, with the print head operating one nozzle at a time to avoid interaction between the two types of filament. This additive manufacturing process, known as Continuous Fibre Reinforcement (CFR), enhances the printed part with continuous fibres within the polymer matrix.

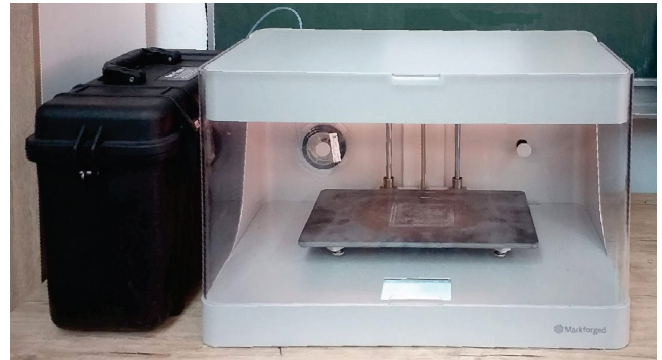


Figure 2 Markforged Mark Two 3D printer

The investigated specimens were 3D printed using ONYX as a composite base, reinforced with continuous fibres from carbon, fibreglass, or aramid (Kevlar®), printed into the samples parallel to the ONYX printing process. ONYX is a relatively new material, a filled plastic composed of engineering nylon fused with chopped carbon micro fibres. It offers high strength, toughness, and chemical resistance, both as a standalone material and when reinforced with continuous fibres to produce aluminium-strength parts. Each type of utilized fibre possesses unique characteristics: carbon fibres excel in strength and rigidity, glass fibres provide a balance of strength and flexibility, and Kevlar fibres offer high strength combined with flexibility. The selection of fibres for composite 3D printing depends on specific application requirements and manufacturing preferences. Tab. 2 provides the mechanical properties of the materials utilized for 3D printing, as provided by the manufacturer (Markforged).

Table 2 Mechanical and physical properties of used materials [20]

Properties	Onyx	Carbon Fibre	Fibreglass	Kevlar
Density / g/cm ³	1,2	1,4	1,5	1,2
Tensile Stress at Yield / MPa	40	/	/	/
Tensile Strength / MPa	/	800	590	610
Tensile Modulus / GPa	2,4	60	21	27
Flexural Strength/ MPa	71	540	200	240
Tensile Strain at Break / %	25	1,5	3,8	2,7
Flexural Modulus / GPa	3	51	22	26

The Eiger software [21] is utilized for setting 3DP parameters and serves as the official 3DP software for all Markforged printers, providing users with control over the 3D printing process. Fig. 3 illustrates the setup of the 3D model of the specimen in Eiger software showing the position of the specimen in the printer bed for 3DP. The specimen 3D model is previously prepared in CAD software.

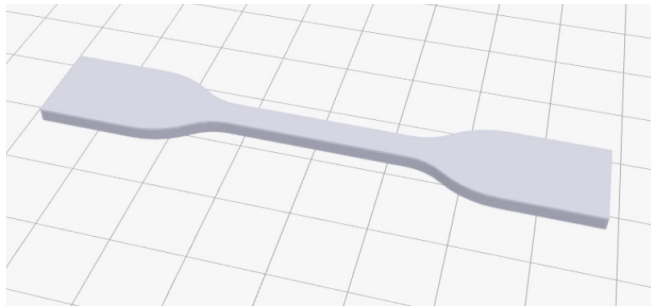


Figure 3 The setup for 3DP: a test specimen on the bed

In this study, the triangular fill pattern, which is widely used in 3D printing, is selected for the 3D printed composite matrix. For this pattern, adjustments of filling density ranging from 28% to 54% are provided in the Eiger software. Besides this minimum and maximum fill density values, the median value of 41% is investigated. A single line of material is designated as the wall thickness for parts. Default setup in the software, consisting of 4 solid plastic layers at the top and bottom, was retained for 3D printing the specimens. The concentric fibre fill type, selected from the options for reinforcing fibre layers in parts, was utilized. Additionally, the option of a single line of fibre placed adjacent to walls was selected. This resulted in two longitudinally oriented fibres, next to specimens' walls, in a reinforced layer in the narrow part of specimen relevant for tensile testing. An example of a reinforced layer of a test specimen, printed with 41% infill, is shown in Fig. 4. The number of reinforcement layers is varied, with choices ranging from 4, 6, to 8 layers. The layer height for 3DP process was 0,125 mm for specimens with carbon fibre, and 0,1 mm for fibreglass and Kevlar fibres reinforcement, corresponding to fibre thickness.

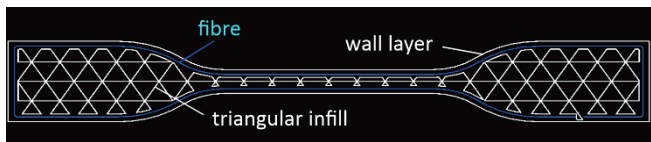


Figure 4 An example of reinforced layer in a test specimen (41% fill density)

2.3 Design of Experiment

Two numeric factors (fill density, number of reinforced layers) and one categorical factor (the different fibre type) were investigated in the research. A full factorial design with three levels of numeric factors is employed in the design of the experiment, with two additional central points, resulting in a total of 11 experimental points. This design is replicated for each of the three fibre types, yielding a grand total of 33 experimental points. The central points were used to check the linearity of the experimental system and to assess the impact of the factor means on the studied responses. Tab. 3 provides the plan of experiment, detailing the order and values of the experimental points. Additionally, Fig. 5 illustrates the implemented design of experiment with displayed coded and true values.

Table 3 Plan of experiment

Specimen	A: Fill Density in %	B: No. of reinforced layers	C: Fibre type
1	28	4	Carbon Fibre
2	54	4	Carbon Fibre
3	28	8	Carbon Fibre
4	54	8	Carbon Fibre
5	28	6	Carbon Fibre
6	54	6	Carbon Fibre
7	41	4	Carbon Fibre
8	41	8	Carbon Fibre
9	41	6	Carbon Fibre
10	41	6	Carbon Fibre
11	41	6	Carbon Fibre
12	28	4	Kevlar
13	54	4	Kevlar
14	28	8	Kevlar
15	54	8	Kevlar
16	28	6	Kevlar
17	54	6	Kevlar
18	41	4	Kevlar
19	41	8	Kevlar
20	41	6	Kevlar
21	41	6	Kevlar
22	41	6	Kevlar
23	28	4	Fibreglass
24	54	4	Fibreglass
25	28	8	Fibreglass
26	54	8	Fibreglass
27	28	6	Fibreglass
28	54	6	Fibreglass
29	41	4	Fibreglass
30	41	8	Fibreglass
31	41	6	Fibreglass
32	41	6	Fibreglass
33	41	6	Fibreglass

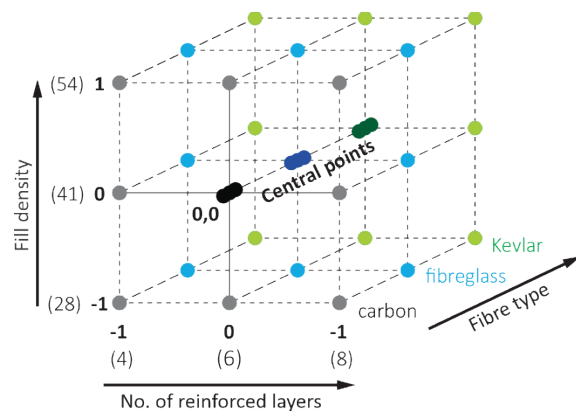


Figure 5 Three level full factorial design with two numeric and one categorical factor

In this study, explicit blocking was not incorporated into the experimental design. The experiment followed a full factorial design with replication and randomization, which allowed us to investigate the effects of the primary factors—fill density, number of reinforced layers, and fibre type— independently. Potential sources of variability, such as material batch differences or 3D printer calibration inconsistencies, were controlled by using the same material batch for all specimens and maintaining consistent calibration and environmental conditions throughout the study. These measures ensured homogeneity across the experimental units and reduced the need for blocking.

In order to increase the reliability of the results, randomization was integrated into the test procedure. The order of the samples was randomized to randomly distribute any uncontrolled variability across the test series.

3 RESULTS

3.1 Tensile Test Results

The test samples were tested at room temperature at a speed of 2 mm/min on a Shimadzu AGS-X 10 kN tensile testing machine (Fig. 6). Each test specimen was marked before testing to avoid potential errors due to accidental sample mix-up. An example of tested specimens for each fibre type is shown in Fig. 7.



Figure 6 Shimadzu AGS-X 10 kN tensile testing machine

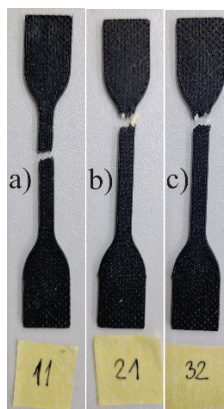


Figure 7 Examples of tested specimens with different fibre types: a) carbon, b) aramid, c) fibreglass

Using the data obtained from the static tensile test machine, the values for maximum stress, modulus of elasticity and deformation were calculated according to the ISO 527, and the obtained results are shown in the Tab. 4. Graphical representation of results is shown in charts on Fig. 8a, 8b and 8c, for maximum tensile stress (tensile strength), strain at maximum stress and tensile elastic modulus (Young's modulus), respectively.

Table 4 Tensile test results

Specimen	Maximum stress R_m / MPa	Strain at maximum stress ϵ_m	Young's modulus E / MPa
1	97,29	0,0610	2172,8
2	93,99	0,0719	2944,6
3	127,61	0,0632	3086,3
4	131,29	0,0527	2693,8
5	103,31	0,0664	2637,4
6	110,51	0,0578	2129,9
7	90,55	0,0682	2815,5
8	121,56	0,0673	2399,9
9	108,84	0,0578	2539,7
10	102,21	0,0593	2539,6
11	105,04	0,0934	1065,2
12	76,46	0,0851	1266,4
13	73,09	0,1014	1596,5
14	106,60	0,1018	1559,3
15	107,94	0,0907	1443,2
16	92,02	0,0975	1222,8
17	87,29	0,1031	1206,7
18	76,51	0,1120	1510,0
19	112,65	0,1001	1233,4
20	90,64	0,0981	1280,9
21	87,72	0,0974	1274,8
22	86,15	0,1360	1158,7
23	85,16	0,1273	1077,6
24	81,42	0,1360	1559,8
25	127,73	0,1732	1509,9
26	131,41	0,1554	1377,0
27	112,44	0,1498	1276,8
28	100,21	0,1360	1135,4
29	88,42	0,1188	1605,1
30	121,87	0,1423	1387,8
31	117,14	0,1349	1378,3
32	108,41	0,1343	1416,4
33	108,97	0,0610	2172,8

3.2 Regression Analysis

Regression analysis is done using Stat-Ease 360 [22], the commercial software with capabilities for data analysis, including tools for design and analysis of deterministic computer experiments. Stat-Ease automatically fits polynomial models up to sixth-order polynomials to model experimental results and afterwards based on statistical data such as p -values, lack of fit, and R -squared values compares the models, and recommends the statistically most appropriate model. The statistical data of regression analysis for suggested models of three responses in investigated experiment is given in Tab. 5 and Tab. 6.

The adjusted R -squared value considers the number of predictors in the model, while the predicted R -squared value estimates the model's performance on new data. Higher R -squared values indicate a better fit of the regression model to the data, implying that the model can effectively explain the

variability observed in the response variable. For example, the R -squared values for the response variable E (Young's modulus) indicate that approximately 97,16% of the variance is explained by the linear regression model, making it the most effective predictor among the three responses. Therefore, E is considered to provide the best results in this analysis.

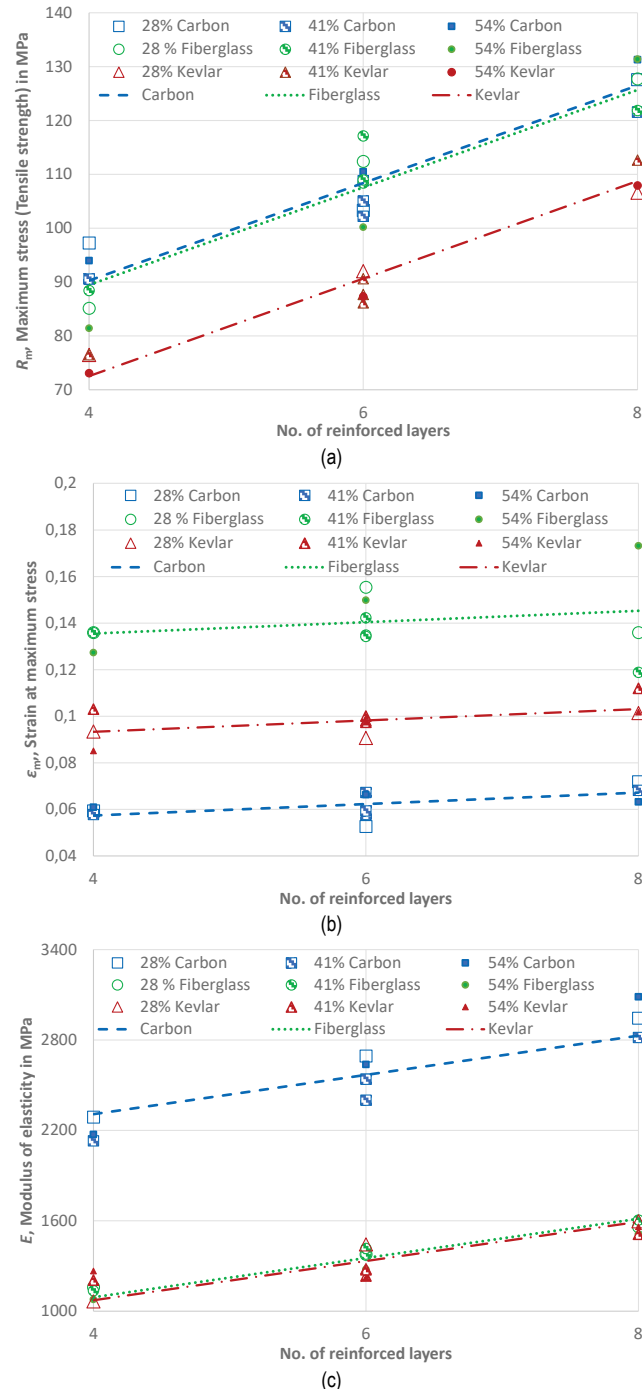


Figure 8 Tensile test results and linear regression models for (a) maximum stress (tensile strength), (b) strain at maximum stress, (c) Young's modulus

Table 5 Summary of statistical fit data

Response	Model	Model p -value	Lack of fit p -value	Lack of fit F -value	Adjusted R^2	Predicted R^2
R_m	Linear	$< 10^{-4}$	0,2593	1,72	0,923	0,9055
ϵ_m	Linear	$< 10^{-4}$	0,012	6,86	0,9218	0,901
E	Linear	$< 10^{-4}$	0,0227	5,34	0,9716	0,964

Table 6 ANOVA analysis for linear models' factors.

Response	Data	A: Fill Density	B: Reinforced layers	C: Fibre type
R_m	F -value	0,3493	281,73	52,7
	p -value	0,5593	$< 10^{-4}$	$< 10^{-4}$
ϵ_m	F -value	0,4995	4,74	188,11
	p -value	0,4856	0,038	$< 10^{-4}$
E	F -value	0,5016	109,63	494,61
	p -value	0,4846	$< 10^{-4}$	$< 10^{-4}$

The p -values less than 0,0500 indicate model terms are significant. In this case, the ANOVA analysis confirmed observation from the test results that A: Fill density factor is not significant. Drawing from that the modified linear models are generated in software, without the term for A: Fill density.

The inclusion of central points in the experimental design confirmed the linearity of the response surface, as no significant deviations were observed. This validated the use of linear regression models for the analysis, as demonstrated by the R^2 values presented in Tab. 5. The linear models for maximum stress, strain at maximum stress and modulus of elasticity obtained at the end of analysis, for three investigated fibre types, are shown in Fig. 8, alongside the corresponding experimental results for comparison. The coded equations for the models are:

$$R_m = 102,20 + 18,10 \cdot B + 6,19 \cdot C[1] + 5,37 \cdot C[2] \quad (1)$$

$$\epsilon_m = 0,1003 + 0,0049 \cdot B - 0,038 \cdot C[1] + 0,0401 \cdot C[2] \quad (2)$$

$$E = 1751,19 + 260,35 \cdot B + 816,74 \cdot C[1] - 398,21 \cdot C[2] \quad (3)$$

The coded values of the factors in Eqs. (1)–(3) are given in Tab. 7. Coded values were used to enable the development of a single model encompassing all fibre types, as categorical variables can only be incorporated into the regression analysis using such coded values. For consistency, all other variables were also presented using coded values.

Table 7 Coded values for model factors

Fill Density in %	Numeric factors			Categoric factors		
	A	Reinforced Layers	B	Fibre Type	C[1]	C[2]
28	-1	4	-1	Carbon	1	0
41	0	6	0	Fiberglass	0	1
54	1	8	1	Kevlar	-1	-1

ANOVA values for the modified models, excluding the fill density term, are given in Tab. 8. This exclusion resulted in models that better fit the experimental data, as evidenced by the increased F -values for the remaining factors, which indicates their stronger influence on the observed responses.

Table 8 ANOVA analysis for modified linear models' factors

Response	Data	B:	C:
		Reinforced layers	Fibre type
R_m	F-value	288,2	53,91
	p-value	$< 10^{-4}$	$< 10^{-4}$
ϵ_m	F-value	4,83	191,41
	p-value	0,0362	$< 10^{-4}$
E	F-value	111,55	503,26
	p-value	$< 10^{-4}$	$< 10^{-4}$

4 DISCUSSION

4.1 Explanation of the Lack of Influence of Fill Density

From the results, it is evident that the fill density has no significant impact on the test outcomes. This unrealistic finding can be explained by delving into the print preparation process within the Eiger software, specifically by examining each individual material layer. Given that the samples were 2 mm thick, considering the specimens with carbon fibres with 0,125 mm layer height, each sample comprised 16 layers. The first and last 4 layers of each sample were identical, as they were printed with solid fill (Fig. 9) to ensure structural stability (a default setting in the software). Additionally, the software automatically incorporated 2 solid fill layers both before and after the fibre reinforced layer. Consequently, despite adjusting the fill density within the range of 28% to 54%, the majority of layers were printed with solid fill. It can be concluded that the adjustments in fill density were applied solely to the fibre reinforced layers, while the first and last 4 layers of each sample, as well as the layers before and after the fibre reinforced layer, were printed with solid fill for structural stability. Similar reasoning could be made also for specimens with glass and Kevlar fibres with 0,1 mm layer height. This limitation implies that the influence of fill density cannot be accurately assessed on samples of these dimensions with additional reinforced layers.

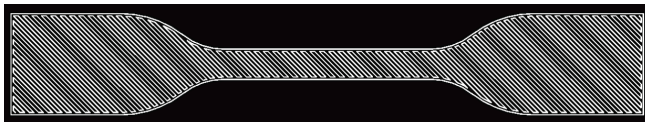


Figure 9 A solid fill layer example in a test specimen (four top and bottom layers, and two layers under and above a reinforced layer)

4.2 Influence of Different Fibres on Mechanical Properties

The results and obtained models clearly show that reinforcing the part with fibres leads to a significant improvement in the mechanical properties of the material. It can also be observed that different types of fibres offer varying degrees of mechanical enhancement, which can be somewhat related to their mechanical properties as presented in Tab. 2.

The results for the elastic modulus (Fig. 8c), where the highest values were obtained for carbon fibres, and similar values for glass and Kevlar fibres, can be directly associated with the tensile modulus values of the fibres (60 GPa for carbon, and 21 GPa and 27 GPa for glass and Kevlar, respectively). Additionally, observations for maximum strain (Fig. 8b), with the highest values for fibreglass, followed by

Kevlar and carbon, clearly relate to the fibre values (3,8% for fibreglass, 2,7% for Kevlar, and 1,5% for carbon).

From the results for maximum stress (Fig. 8a), it can be observed that carbon and fibreglass provide the best and similar reinforcement, significantly higher than Kevlar. This finding is not entirely supported by the tensile strength values for the fibres, where carbon shows a value of 800 MPa, higher than the similar values of 610 MPa and 590 MPa for Kevlar and fibreglass, respectively. This indicates that the mechanical behaviour of fibre-reinforced composites is a result of complex interactions between the matrix and fibres. Consequently, it is not always possible to directly correlate the composite's mechanical properties to the individual properties of the fibre and matrix. Therefore, testing the final composite is the best practice to fully understand its performance. This is especially true when considering fracture behaviour, which is well known in composite micromechanics.

5 CONCLUSIONS

The study confirmed that ONYX 3D printing filament offers excellent mechanical properties compared to conventional materials used in additive manufacturing. Further reinforcement with fibres leads to additional enhancements in tensile strength, fracture deformation, and stiffness. Graphite and glass fibres provide the highest increase in strength, fibreglass offers the best enhancement in fracture deformation, and graphite in stiffness.

As the result of the research, a common linear model for three different fibre types (carbon, fibreglass and Kevlar) was established, correlating the degree of fibre reinforcement, characterized by the number of reinforced layers, with the tensile mechanical properties. While a unified model for different fibres type was advantageous in simplicity and practicality, individual models for each fibre type could have offered greater model agreement with experimental data. It was also intended to address the influence of the fill density in the investigation, however, due to how the internal structure of the part is created in the used 3DP software, the most of the layers were printed with solid infill. Consequently, it was not possible to achieve the effects of fill density for the experimental set-up implemented. Addressing this issue would require larger specimens and different 3D structures in a part. Future studies could benefit from accounting for uncontrolled sources of variability through explicit blocking, which would strengthen the statistical validity of the results.

The proposed models for tensile strength, strain at maximum stress and modulus of elasticity could be very useful in design of 3D printed parts, offering simple solution for prediction of mechanical properties of a part. However, the models are limited to the parts with similar dimension and loading conditions to the conducted tensile tests. Also, model's accuracy is somewhat limited because of small number of tested specimens. Nevertheless, the study presented here could be used as a starting point and guide for further and more profound research.

6 REFERENCES

- [1] Bhuvanesh Kumar, M., & Sathiya, P. (2021). Methods and Materials for Additive Manufacturing: A Critical Review on Advancements and Challenges. *Thin-Walled Structures*, 159, 107228. <https://doi.org/10.1016/J.TWS.2020.107228>
- [2] Tofail, S. A. M., Koumoulos, E. P., Bandyopadhyay, A., Bose, S., O'Donoghue, L., & Charitidis, C. (2018). Additive Manufacturing: Scientific and Technological Challenges, Market Uptake and Opportunities. *Materials Today*, 21(1), 22–37. <https://doi.org/10.1016/J.MATTOD.2017.07.001>
- [3] Park, S., Shou, W., Makatura, L., Matusik, W., & Fu, K. (Kelvin). (2022). 3D Printing of Polymer Composites: Materials, Processes, and Applications. *Matter*, 5(1), 43-76. <https://doi.org/10.1016/J.MATT.2021.10.018>
- [4] Kristiawan, R. B., Imaduddin, F., Ariawan, D. U., & Arifin, Z. (2021). A Review on the Fused Deposition Modeling (FDM) 3D Printing: Filament Processing, Materials, and Printing Parameters. *Open Engineering*, 11(1), 639-649. <https://doi.org/10.1515/eng-2021-0063>
- [5] Hsueh, M.-H., Lai, C.-J., Wang, S.-H., Zeng, Y.-S., Hsieh, C.-H., Pan, C.-Y., & Huang, W.-C. (2021). Effect of Printing Parameters on the Thermal and Mechanical Properties of 3D-Printed PLA and PETG, Using Fused Deposition Modeling. *Polymers*, 13, 1758. <https://doi.org/10.3390/polym13111758>
- [6] Amza, C. G., Zapciu, A., Constantin, G., Baciu, F., & Vasile, M. I. (2021). Enhancing Mechanical Properties of Polymer 3D Printed Parts. *Polymers*, 13, 562. <https://doi.org/10.3390/polym13040562>
- [7] Afonso, J. A., Alves, J. L., Caldas, G., Gouveia, B. P., Santana, L., & Belinha, J. (2021). Influence of 3D Printing Process Parameters on the Mechanical Properties and Mass of PLA Parts and Predictive Models. *Rapid Prototyping Journal*, 27(3), 487-495. <https://doi.org/10.1108/RPJ-03-2020-0043>
- [8] Kačmarčik, J., Čosić, A., Muminović, B., & Hadžalić, M. (2021). Ispitivanje zateznih svojstava uzoraka napravljenih 3D Printanjem FDM postupkom od PLA materijala. In *Proceedings of 12th Research/expert Conference with international participation (QUALITY 2021)*, Neum, Bosnia and Herzegovina, 16-19 June 2021, 131-136. (in Bosnian)
- [9] Sanei, S. H. R., & Popescu, D. (2020). 3D-Printed Carbon Fibre Reinforced Polymer Composites: A Systematic Review. *J. Compos. Sci.*, 4(3), 98. <https://doi.org/10.3390/jcs4030098>
- [10] Li, J., Durandet, Y., Huang, X., Sun, G., & Ruan, D. (2022). Additively Manufactured Fibre-Reinforced Composites: A Review of Mechanical Behavior and Opportunities. *Journal of Materials Science & Technology*, 119, 219-244. <https://doi.org/10.1016/j.jmst.2021.11.063>
- [11] Hetrick, D. R., Sanei, S. H. R., Bakis, C. E., & Ashour, O. (2021). Evaluating the Effect of Variable Fibre Content on Mechanical Properties of Additively Manufactured Continuous Carbon Fibre Composites. *Journal of Reinforced Plastics and Composites*, 40, 365-377. <https://doi.org/10.1177/0731684420963217>
- [12] Sethu Ramalingam, P., Mayandi, K., Balasubramanian, V., Chandrasekar, K., Stalany, V. M., & Abdul Munaf, A. (2021). Effect of 3D Printing Process Parameters on the Impact Strength of Onyx – Glass Fibre Reinforced Composites. *Materials Today: Proceedings*, 45, 6154-6159. <https://doi.org/10.1016/j.matpr.2020.10.467>
- [13] Petcharat, N., Wiangkham, A., Pichitkul, A., Tantrairatn, S., Aengchuan, P., Bureerat, S., Banpap, S., Khunthongplatprasert, P., & Ariyarat, A. (2023). The Multi-Objective Optimization of Material Properties of 3D Print Onyx/Carbon Fibre Composites via Surrogate Model. *Materials Today Communications*, 37, 107362. <https://doi.org/10.1016/j.mtcomm.2023.107362>
- [14] PIRAMANAYAGAM, S. R., KALIMUTHU, M., NAGARAJAN, R., ABDUL KARIM SAIT, A. M., KRISHNAMOORTHY, R. K., ISMAIL, S. O., SIENGCHIN, S., MOHAMMAD, F., & AL-LOHEDAN, H. A. (2021). Experimental Investigation and Statistical Analysis of Additively Manufactured Onyx-carbon Fibre Reinforced Composites. *J of Applied Polymer Sci*, 138, 50338, <https://doi.org/10.1002/app.50338>
- [15] Radojičić, S., Konjatić, P., Katinić, M., & Kačmarčik, J. (2023). The Influence of Material Storage on Mechanical Properties and Deterioration of Composite Materials. *Tehnički vjesnik*, 30(5), 1645-1651. <https://doi.org/10.17559/TV-20230308000422>
- [16] Standard ISO 527-1:2019: Plastics, Determination of Tensile Properties, Part 1: General Principles. International Organization for Standardization.
- [17] Standard ISO 527-2:2012: Plastics, Determination of Tensile Properties, Part 2: Test conditions for moulding and extrusion plastics. International Organization for Standardization.
- [18] Markforged, Mark Two. Available online: <https://markforged.com/3d-printers/mark-two> (accessed on 19.07.2024)
- [19] Markforged, 3D Printing Materials. Available online: <https://markforged.com/materials> (accessed on 19.07.2024)
- [20] Markforged, Material datasheet, Composites. Available online: <https://www-objects.markforged.com/craft/materials/CompositesV5.2.pdf> (accessed on 19.07.2024)
- [21] Markforged, Eiger. Available online: <https://markforged.com/software> (accessed on 17.04.2024)
- [22] Stat-Ease 360. Available online: <https://www.statease.com/software/se360/> (accessed on 19.07.2024)

Authors' contacts:

Pejo Konjatić, PhD, Full Professor
Mechanical Engineering Faculty in Slavonki Brod, University of Slavonki Brod,
Trg Ivane Brlić Mažuranić 2, 35000 Slavonki Brod, Croatia
pkonjatic@unisb.hr

Josip Kačmarčik, PhD, Associate Professor
(Corresponding author)
Faculty of Mechanical Engineering in Zenica, University of Zenica,
Fakultetska 1, 72000 Zenica, Bosnia and Herzegovina
josip.kacmarcik@unze.ba

Marko Katinić, PhD, Associate Professor
Mechanical Engineering Faculty in Slavonki Brod, University of Slavonki Brod,
Trg Ivane Brlić Mažuranić 2, 35000 Slavonki Brod, Croatia
mkatinic@unisb.hr

Lamija Mešeljević, Assistant
Faculty of Mechanical Engineering in Zenica, University of Zenica,
Fakultetska 1, 72000 Zenica, Bosnia and Herzegovina
lamija.meseljovic@unze.ba