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COMPARISON OF THE TENSILE STRENGTH OF FDM PRINTED SPECIMENS WITH DIFFERENT INFILL DENSITIES MADE OF PA12 AND PA12+CF15

Łukasz Miazio

ORCID: 0000-0002-4693-4779
Faculty of Technical Sciences
University of Warmia and Mazury in Olsztyn

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Abstract

The research presented in this article represents a further stage in studies on the strength of components printed using 3D printing technology, specifically FDM (Fused Deposition Modelling). The article presents the results of tensile strength tests on samples printed from PA12 and PA12+CF15 materials, while previous studies by the author focused on PLA material.

Basic material data provided by manufacturers and distributors of materials used in the FDM method, such as tensile strength and Young's modulus, refer to the most favourable model orientation during printing. However, in additive technologies, particularly FDM, the constructed object shows significant layering differences (in the *Z* direction). The direction of material deposition (in the *XY* plane) is also crucial. Additionally, the strength is influenced by the degree and type of infill within the model and the temperature during printing. For these reasons, it is essential to understand the relationship between technological parameters and the resulting strength for specific materials. This study aimed to determine the tensile strength of samples printed with varying infill percentages.

In the context of the new material, PA12+CF15, it is essential to understand how the addition of carbon fibers affects the mechanical properties of prints compared to traditional materials, such as PA12 and PLA. Carbon fibers can significantly increase the strength and stiffness of the composite, potentially leading to applications in producing parts with high strength requirements. Therefore, studying the strength of materials concerning various printing parameters is crucial for developing the potential of FDM technology and its industrial applications.

Correspondence: Łukasz Miazio, Katedra Mechaniki i Podstaw Konstrukcji Maszyn, Wydział Nauk Technicznych, Uniwersytet Warmińsko-Mazurski, ul. M. Oczapowskiego 11, 10-957 Olsztyn, e-mail: lukasz.miazio@uwm.edu.pl

PA12+CF15 is composed of polyamide 12 (PA12), a thermoplastic material with good chemical resistance, abrasion resistance, and flexibility. The addition of 15% carbon fibers (CF15) reinforces the composite structure, leading to increased stiffness, mechanical strength, and deformation resistance. The study shows that this addition enhances PA12's strength by approximately 13%, also facilitating printing by reducing shrinkage.

Introduction

The research presented in this article represents a further stage in analysing the strength of components printed using FDM (Fused Deposition Modelling) technology (Choi et al. 2011). Previous studies by the author on PLA material (Miazio 2015, 2017) covered tensile analysis of samples with various infill densities. The conclusions drawn from these studies provide the foundation for this stage, which focuses on the new PA12+CF15 composite and its potential in advanced industrial applications. Specimens printed from PA12 and PA12+CF15 have also been reported in previous studies, such as those by Saharudin et al. (2021), Major et al. (2022), and Kam et al. (2023).

Currently, 3D printing is becoming increasingly popular and is widely used in rapid prototyping (RP) methods (Upcraft, Fletcher 2003). Due to its affordability and accessibility, FDM printers are also gaining popularity among individual users. Basic material data provided by manufacturers and distributors, such as tensile strength and Young's modulus, refer to the optimal orientation of the model during printing. However, objects constructed using additive FDM technology exhibit significant layer heterogeneity (in the Z-axis), and the direction of material deposition (in the XY plane) has a crucial impact on the final strength properties. Additionally, mechanical strength is influenced by infill density and type, as well as the printing temperature. In this study, however, the author limit the analysis exclusively to the influence of infill density. This decision is based on the findings from prior research on PLA (Miazio 2015, 2017), which demonstrated that the grid infill pattern provides sufficient mechanical predictability and repeatability across varying density levels. By maintaining the same grid infill methodology for PA12+CF15, the study ensures direct comparability with historical PLA data while isolating the effect of density as the primary variable.

The objective of this study is therefore to specifically determine the effect of these technological parameters on the strength of samples made from PA12 and PA12+CF15. In the context of the new PA12+CF15 material, it is essential to understand how the addition of carbon fibers affects the mechanical properties compared to traditional materials such as PLA. The addition of carbon fibers enhances the mechanical strength and stiffness of the composite, which can be especially useful in producing parts with increased strength requirements. The impact of carbon fiber on the strength of specimens was also examined by Bochnia et al. (2021).

PA12+CF15 is a polyamide composite reinforced with carbon fibers, combining high mechanical strength with low weight, making it an attractive material for applications in the aerospace, automotive, defence industries, and precision engineering. PA12, which forms the base of this composite, is a thermoplastic material with high chemical resistance, abrasion resistance, and flexibility. The addition of 15% carbon fibers (CF15) strengthens the composite structure, resulting in increased stiffness, mechanical strength, and resistance to deformation.

Understanding these relationships can serve to further optimize the printing process and expand the potential applications of FDM technology across various industrial sectors where high-quality, reliable materials are essential.

Technology FDM

The FDM (Fused Deposition Modeling) technology (CHOI et al. 2011) involves gradually building a model by layering molten thermoplastic material, which is extruded through a nozzle. The central component is a thermal print head with a filament feeder (extruder) that precisely places the material onto the work surface. The nozzle moves in the horizontal plane (X and Y axes), while the work platform, known as the print bed, shifts vertically (Z-axis), enabling the object to be constructed layer by layer. Each newly deposited layer cools quickly and bonds with the previous layer, creating a cohesive and robust structure.

The FDM method utilizes various materials, such as ABS, polycarbonate, PLA, nylon, and others. The most commonly used materials are ABS and PLA due to their mechanical properties, availability, and ease of printing.

A pivotal moment in the development of FDM technology was the release of some patents held by Stratasys, which initiated the growth of the RepRap project – the most popular open-source FDM system (RepRap 2024). Due to Stratasys' trademark protection of the term "Fused Deposition Modelling" (FDM), the RepRap project uses the term Fused Filament Fabrication (FFF) to avoid potential legal conflicts.

Tensile testing of plastics

After designing the test specimens in accordance with the PN-EN ISO 527:1998 standard, their geometry was saved in the STL format, which is necessary for generating machine code. The dimensions of the specimen are shown in the Figure 1 and in Table 1. The STL format represents the surface of the model using a mesh of triangles, with each triangle having its vertex coordinates (x, y, z) and a normal vector to the surface. However, this representation can introduce some inaccuracies, as the triangles do not always perfectly match the actual shape of the model. In the case of the tested specimens, a mesh consisting of 108 triangles was used. To improve accuracy, the number of triangles can be increased, but this results in larger file sizes.

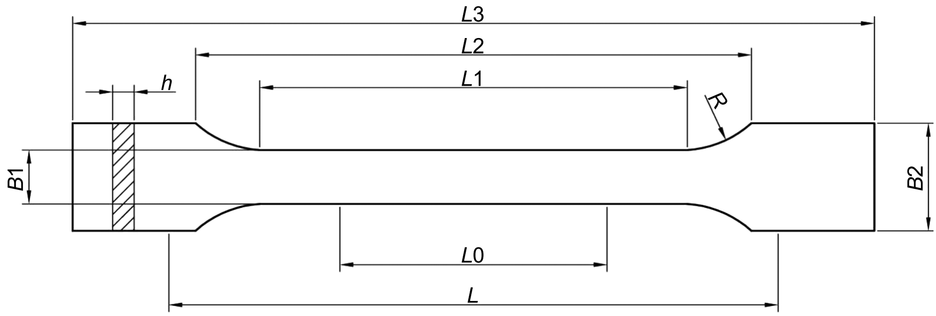

Fig. 1. Universal test specimen
Source: based on PN-EN ISO 527:1998.

Table 1
Dimensions of the test specimen

Dimensions of the test specimen	Type *B*1 [mm]
*L*3 – total length	150
*L*1 – length of the part limited by lines	40
R – radius	60
*L*2 – distance between the wide, parallel parts	106
*B*2 – width at the ends	20
*B*1 – width of the narrow part	10
H – recommended thickness	4
*L*0 – measuring length	50
L – initial distance between the grips	115

Source: based on PN-EN ISO 527:1998.

The machine code, known as G-code, was generated based on the STL file using Cura software (Ultimaker Cura 2024). The specimens were then printed using PA12 and PA12+CF15 materials from Fiberlogy. A 0.4 mm diameter nozzle made of hardened steel was used, ensuring high wear resistance, which is particularly important when printing with materials containing carbon fibers, glass fibers, or metals. All specimens were printed flat, along the *Y*-axis of the printer, to maintain process consistency. Each specimen was printed with fixed parameters:
– first layer print speed: 20 mm/s,
– print speed: 60 mm/s,
– nozzle temperature: 275°C,
– layer height: 0.2 mm,
– thickness of the top and bottom layers: 0.6 mm,
– thickness of the side walls: 0.8 mm.

Additionally, a heated bed was used, with a temperature set to 100 ±5°C.

For the PA12+CF15 material, successful printing was carried out on BuildTak film (BuildTak 2024) at 100 ±5°C. In contrast, the PA12 material was printed on masking paper tape. The printing of pure PA12 encountered several issues, as the material exhibited significant shrinkage, causing the specimens to detach from the bed surface. This issue was resolved by using masking paper tape.

During the printing of the specimens, a 45° grid infill pattern (Fig. 2) relative to the *Y*-axis was used – consistent with the methodology applied in the author's earlier studies on PLA (Miazio 2015, 2017). This choice allowed for a direct verification of whether the relationship between strength and infill density observed for PA12+CF15 follows a similar trend to that previously identified for PLA. The infill density was varied from 10% to 100%, in 10% increments. For each infill density, three specimens were printed, ensuring an adequate number of samples for strength analysis.

Fig. 2. Cross-section of the specimen with a 45° cross-hatch fill density: *a* – 10%, *b* – 20%

Results

The obtained results from the tensile tests, depending on the infill density, are summarized in Table 2. The results from the three tests were repeatable, indicating that the test was correctly performed. Additionally, a graph of the average tensile force as a function of the specimen's infill density was plotted (Fig. 3).

Table 2

Summary of the tensile forces for specimens printed from PA12+CF15

Infill density [%]	Test 1: tensile force [kN]	Test 2: tensile force [kN]	Test 3: tensile force [kN]	Average tensile force [kN]
1	2	3	4	5
10	0.87	0.84	0.87	0.86
20	0.88	0.89	0.92	0.90
30	0.99	1	0.99	0.99

cont. Table 2

1	2	3	4	5
40	1.03	1.03	1.03	1.03
50	1.1	1.12	1.13	1.12
60	1.15	1.18	1.17	1.17
70	1.28	1.26	1.27	1.27
80	1.38	1.38	1.39	1.38
90	1.58	1.54	1.56	1.56
100	1.74	1.73	1.76	1.74

Table 3

Summary of the tensile forces for specimens printed from PA12

Infill density [%]	Test 1: tensile force [kN]	Test 2: tensile force [kN]	Test 3: tensile force [kN]	Average tensile force [kN]
10	0.55	0.55	0.55	0.55
20	0.60	0.63	0.60	0.61
30	0.68	0.68	0.68	0.68
40	0.78	0.75	0.75	0.76
50	0.76	0.76	0.75	0.76
60	0.80	0.83	0.85	0.83
70	0.93	0.95	0.93	0.93
80	1.00	1.00	1.00	1.00
90	1.18	1.15	1.20	1.18
100	1.28	1.26	1.29	1.28

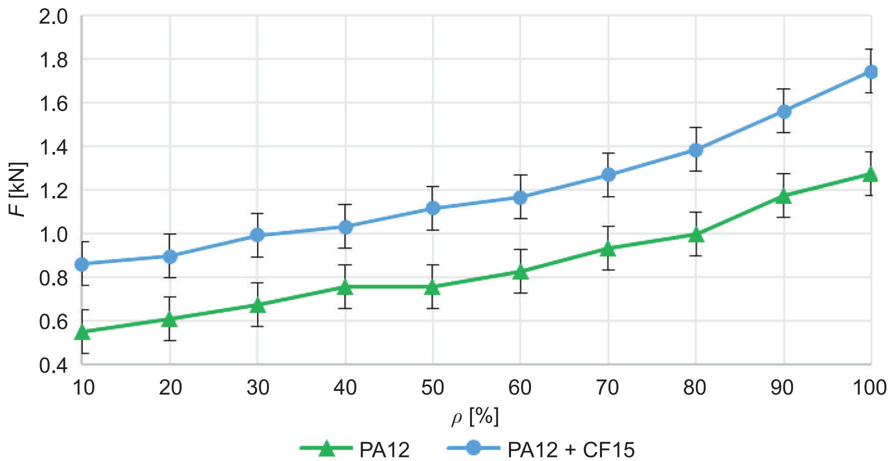

Fig. 3. Graph of the average tensile force as a function of the specimen's infill density

Tensile force vs. elongation graphs were also created. Figure 4 shows sample force curves for tensile tests of specimens with 100% infill and 30% infill.

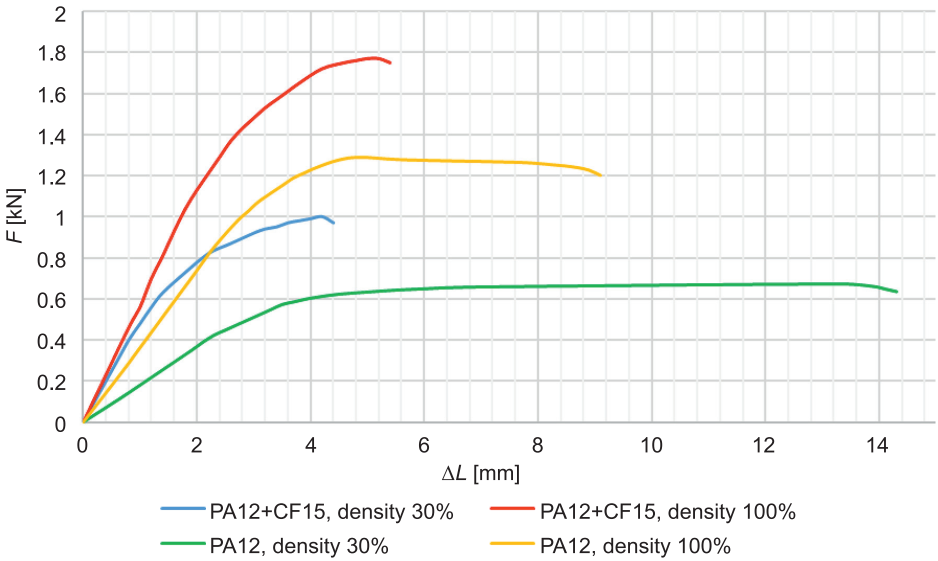

Fig. 4. Tensile curve of the specimen

Conclusions

The composite PA12+CF15, consisting of polyamide 12 (PA12) and 15% carbon fibers (CF15), shows significant improvements in mechanical properties compared to pure PA12. Polyamide 12 is a thermoplastic material with excellent chemical resistance, high wear resistance, and flexibility, making it a popular choice for applications requiring durable components. The addition of carbon fibers significantly strengthens the composite structure, leading to increased stiffness, mechanical strength, and resistance to deformation. The results of the conducted studies indicate that the addition of carbon fibers increases the tensile strength of PA12 by approximately ~36% (Table 2 vs. Table 3).

Additionally, the presence of carbon fibers reduces filament shrinkage during the 3D printing process. This phenomenon is of great practical importance because it reduces the risk of printed parts detaching from the print bed and improves the dimensional accuracy of the models, allowing them to maintain their original geometry more effectively. The presence of carbon fibers reduces shrinkage, as evidenced by the improved bed adhesion of PA12+CF15 compared to pure PA12. Due to these properties, PA12+CF15 becomes a more predictable and easier-to-process material compared to pure PA12, particularly for applications requiring high-quality prints.

These findings suggest that PA12+CF15 is a promising material for use in 3D printing technology, especially in the production of parts that need to exhibit high mechanical strength, wear resistance, and durability, while also offering improved dimensional accuracy and easier processing during the printing process. Potential applications include the automotive, aerospace, and manufacturing industries, particularly for components that require high durability and resistance to mechanical loads. As the next step, the authors plan to investigate the influence of different infill patterns (e.g., gyroid, honeycomb, concentric) on the strength of PA12+CF15 prints. This study will assess how geometric variations in infill design – including density gradients, orientation angles, and topological complexity – affect load distribution. The results will provide guidelines for tailoring infill strategies to specific mechanical requirements, enabling the creation of lightweight yet durable structures for industrial applications.

References

Bochnia J., Błasiak M., Kozior T. 2021. *A comparative study of the mechanical properties of FDM 3D prints made of PLA and carbon fiber-reinforced PLA for thin-walled applications*. Materials, 14(22): 7062. https://doi.org/10.3390/ma14227062

BuildTak. 2024. https://www.buildtak.com (2.10.2024).

Choi J., Medina F., Kim Ch., Espalin D., Rodriguez D., Stucker B., Wicker R. 2011. *Development of a mobile fused deposition modeling system with enhanced manufacturing flexibility*. Journal of Materials Processing Technology, 211(3): 424-432. http://dx.doi.org/10.1016/j.jmatprotec.2010.10.019

Kam M., İpekçi A., Şengül Ö. 2023. *Investigation of the effect of FDM process parameters on mechanical properties of 3D printed PA12 samples using Taguchi method*. Journal of Thermoplastic Composite Materials, 36(1): 307-325. https://doi.org/10.1177/08927057211006459

Major M., Kalinowski J., Kosiń M. 2022. *Tensile strength of elements printed from ABS, PA6+CF15, PA12+CF15 materials*. Materiały Budowlane, 10: 82-85. https://doi.org/10.15199/33.2022.10.21

Miazio Ł. 2015. *Tensile strength test of samples printed in FDM technology with different filling density*. Mechanik, 7: 533-538. https://doi.org/10.17814/mechanik.2015.7.269

Miazio Ł. 2017. *Research on tensile strength of specimens printed in FDM technology with different density of filling – hexagonal and concentric filling*. Przegląd Mechaniczny, 6: 51-53. http://dx.doi.org/10.15199/148.2017.6.11

PN-EN ISO 527:1998. Plastics – Determination of tensile properties.

RepRap. 2024. https://reprap.org (access: 2.10.2024).

Saharudin M. S., Hajnys J., Kozior T., Gogolewski D., Zmarzły P. 2021. *Quality of surface texture and mechanical properties of PLA and PA-based material reinforced with carbon fibers manufactured by FDM and CFF 3D printing technologies*. Polymers, 13(11): 1671. https://doi.org/10.3390/polym13111671

Ultimaker Cura. 2024. https://ultimaker.com/en/products/ultimaker-cura-software (2.10.2024).

Upcraft S., Fletcher R. 2003. *The rapid prototyping technologies*. Assembly Automation, 23(4): 318-330. http://dx.doi.org/10.1108/01445150310698634