DOI: 10.2507/34th.daaam.proceedings.xxx

# INVESTIGATING THE INFLUENCE OF PRINTING ORIENTATION AND FILAMENT DRYING ON TENSILE AND FLEXURAL STRENGTH OF FDM-PRINTED CARBON FIBER-REINFORCED POLYAMIDE COMPOSITES

Adi Pandžić, Edin Kadric & Svetozar Kolesar

**This Publication has to be referred as:** Pandzic, A[di], Kadric, E[din] & Svetozar, R[are] (2023). Investigating the Influence of Printing Orientation and Filament Drying on Tensile and Flexural Strength of FDM-Printed Carbon Fiber-Reinforced Polyamide Composites, Proceedings of the 34th DAAAM International Symposium, pp.xxxx-xxxx, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-xx-x, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/34th.daaam.proceedings.xxx

## Abstract

The rapid advancement of additive manufacturing (AM), including Fused Deposition Modeling (FDM) technology, hinges significantly upon the continuous evolution of AM materials. To enhance the mechanical characteristics of these materials, filling of carbon or glass fibers has added to them. Consequently, this research delved into the analysis of a carbon fiber-filled polyamide composite. The primary objective was to investigate the impact of printing orientation and pre-printing material drying on the tensile and flexural mechanical properties. Tensile properties were analysed in accordance with ISO 527 standards, while ISO 178 standards were employed for the evaluation of flexural properties. The findings from this study showing the influence of printing orientation and pre-printing drying on both tensile and flexural properties, thereby contributing valuable insights to the field of AM materials development.

**Keywords:** PA-CF; Composite; 3D Print; FDM; Printed Material.

## 1. Introduction

Additive manufacturing (AM), also known as 3D printing or spatial printing, is today one of the fastest growing technologies for the production of prototypes as well as fully functional products. In today's competitive industrial landscape, the adoption of additive manufacturing technologies has gained significant traction, offering a pathway to enhance competitiveness and expedite market penetration for novel products. These cutting-edge technologies find applications across diverse functional domains in various industrial sectors. Over recent years, additive manufacturing has emerged as a dynamic force driving innovation in industrial serial production processes. Notably, this transformative trend has been most pronounced within sectors such as mechanical engineering, aviation and space industry, architecture, bioengineering, automobile industry, medical and prosthetic parts, fashion and more [1], [2].

Today's market exhibits significant interest in AM technologies, with AM materials development being their key driver. Among the various AM technologies available, Fused Deposition Modeling (FDM), also known as FDM technology, Fused Filament Fabrication (FFF), or material extrusion, is a prominent and widely used method. This popular, but also complex AM technology offers advantages over traditional methods, enabling the production of simple and complex geometry products. [3], [4].

FDM 3D printing uses a thermoplastic filament from spool fed through a feeder to an extrusion head, where it's melted in the heating chamber and deposited through printing nozzle in lines on the print bed to create the final product geometry layer by layer (Figure 1). Filament materials vary from thermoplastics to composites, ceramics, and metals. Commonly used FDM materials include PLA (Polylactic Acid), PC (Polycarbonate), PET (Polyethylene Terephthalate), PP (Polypropylene), ABS (Acrylonitrile Butadiene Styrene), TPU (Thermoplastic Polyurethane), and Polyamide (Nylon) [5], [6].

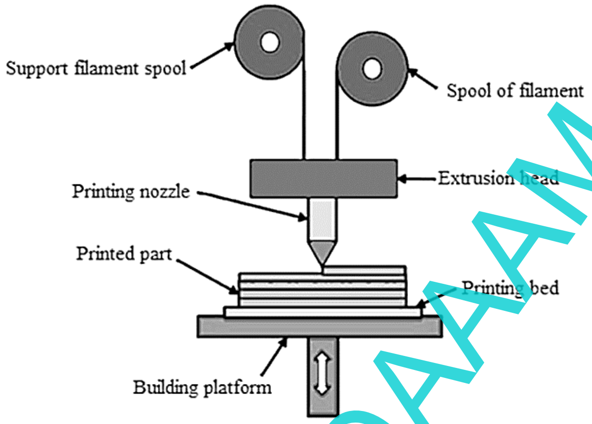


Fig. 1. FDM process and machine setup [5]

FDM excels in material versatility, offering diverse options with distinct mechanical properties. It enables cost-effective concurrent use of various materials in different forms. While polymer production dominates FDM, it can also handle metal printing. The mechanical properties of FDM-produced polymer parts are strongly influenced by printing parameters and the choice of base polymer [7], [8]. In paper [2] mentioned that extensive research in 3D printing materials has resulted to the development of polymers with desired mechanical properties and biocompatibility, where mechanical properties can be „tuned“ by adjusting the FDM printing parameters. When FDM printing parameters are mentioned, they are most often: layer height, printing orientation, printing temperature, printing bed temperature, wall thickness, printing speed, raster angle, infill density and pattern [9], [10]. In addition to the printing parameters, the mechanical properties of FDM printed materials are also affected by other factors such as the filament quality (as a base material), color of the material, drying of the material before printing (this is very important for Polyamide - Nylon), heat treatment after 3D printing, and others [11], [12].

This study investigated the effect of printing orientation and pre drying on tensile and flexural strength of FDM printed carbon fiber-filled polyamide composite (with chopped carbon fibers). In general, FDM polyamide offers good combination of strength and toughness compared to other FDM printed materials, and with good impact strength. In research paper [13] stated that polyamide (nylon) is also characterized by properties such as high impact strength, good stress cracking resistance, resistance to oils, fuels, hydraulic fluids and high tensile and flexural strength. In efforts to enhance FDM printed material properties, common reinforcement materials in polymer matrices include carbon, glass, aramid, and natural fibers. Fiber-filled polymer filaments represent an exciting composite material, offering advantages such as better dimensional stability, enhanced mechanical strength, and cost-effectiveness, thereby expanding the potential applications in FDM printing [14].

Previous research has reported a strong correlation between printing orientation and mechanical properties of FDM-printed materials [15], [16]. According to Anubhav et al. [17], part orientation significantly impacts strength and behaviour under various loads in 3D printing. They found that the orientation directly influences the cohesive bonding of deposited materials due to material deposition and layering. Notably, horizontally printed parts exhibit better tensile and flexural properties compared to the vertically printed counterparts. In a study [2] analysing the impact of five printing parameters – printing temperature, infill type and density, layer height, and printing orientation – it was found that printing orientation has the most significant influence on the tensile strength of PET-G and PLA FDM printed materials. In study [13] meintoined that different researchers have established a correlation between build orientation and the mechanical properties of FDM printed materials. Variations in the melt quality between adjacent filaments can lead to a reduction in mechanical properties, such as tensile strength, compressive strength, flexural strength, hardness, and elastic modulus. This effect is particularly pronounced in parts tested perpendicular to the direction of layer construction.

Literature review has also shown that moisture affects the properties of FDM printed PA6 material, unreinforced and reinforced with carbon fibers. In the study by Brown [18], the presence of residual water post-drying could be a factor contributing to the absence of strain softening. In the case of a 50% glass fiber-reinforced PA6, it exhibits behaviour similar to unreinforced PA6. Notably, tensile properties showed improvement after drying, while impact properties experienced a slight reduction. Also, Gong et al. [19] concluded that moisture affects 3D printing with nylon filament, and this applies to other materials as well. Excessive moisture in the filament leads to material degradation, resulting in an uneven surface finish and reduced tensile strength, especially in terms of ductility. Long-term storage without monitoring requires proper drying before reusing the filament.

## 2. Materials and methods

This research is centered on a systematic experimental exploration aimed to profound impact of two key variables, namely, printing orientation and pre-printing material drying, on the mechanical properties of Carbon Fiber-Filled Polyamide Composite. Experimental methodology is presented on flow diagram below (Figure 2).

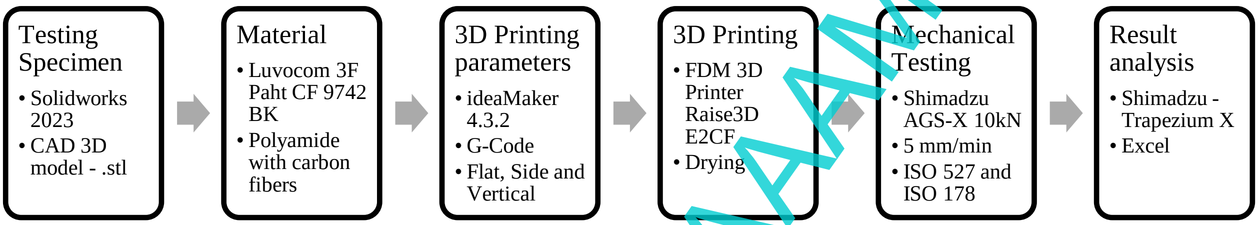


Fig. 2. Experimental methodology

Tensile and flexural testing specimens CAD 3D models were designed using Solidworks 2023. The design for the tensile testing specimen was according to ISO 527-2 standard, while the flexural testing specimen design followed ISO 178 guidelines (see Figure 3). Subsequently, these CAD 3D models were converted into .stl format, facilitating their utilization within the slicer software for the configuration of 3D printing parameters.

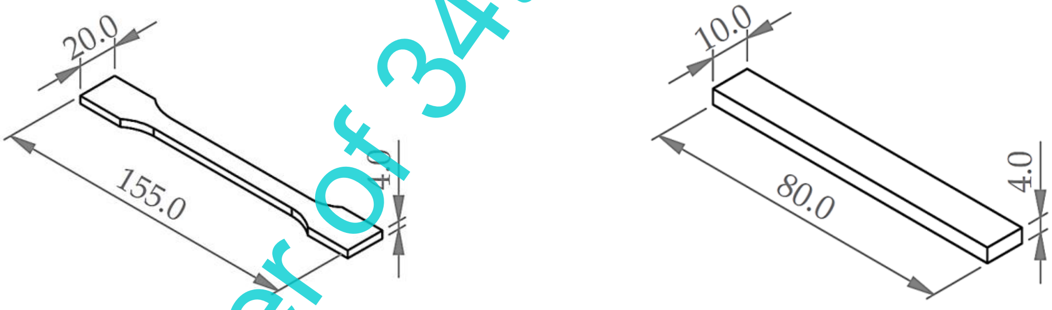


Fig. 3. Testing specimen for tensile and flexural testing

In this research "Luvocom 3F Paht CF 9742 BK" material (CF-PA6) was analysed. This material is distinguished as a high-temperature polyamide-based composite, offering the robustness of PA6 while maintaining exceptional printability characteristics. Notably, it demonstrates good resistance to water absorption, with only half the water uptake and a fourfold slower absorption rate when compared to standard PA6. Also, this material does not necessitate a heated chamber during the printing process, and it exhibits minimal warping tendencies. Furthermore, it boasts compatibility with both HIPS and PVOH support materials. With its composition consisting of 15% chopped carbon fiber reinforcement in PA6, "Luvocom 3F PAHT CF 9742 BK" is engineered for industrial applications. This material is tailored for the production of exceptionally robust and rigid components, characterized by a low coefficient of thermal expansion. Consequently, it finds prominent use in diverse sectors such as the automotive industry, textile manufacturing, office machinery, as well as apparatus and precision engineering [20]. Detailed technical specifications are presented in Table 1.

| Properties | Test Method | Units | Typical Value |
|---|---|---|---|
| Tensile Strength | ISO 527 | MPa | 170 |
| Tensile Modulus | ISO 527 | GPa | 15 |
| Tensile Elongation | ISO 527 | % | 2 |
| Flexural Strength | ISO 178 | MPa | - |
| Flexural Modulus | ISO 178 | GPa | - |
| Flexural Elongation | ISO 178 | % | - |
| Charpy Impact Strength | ISO 179 1eU | kJ/m$^2$ | 47 |

Table 1. Technical specification of CF-PA6 material by manufacturer - Luvocom 3F Paht CF 9742 BK [20]

Specimens were prepared for 3D printing using the "ideaMaker 4.3.2" slicer software, which generated the necessary G-Code. The specific printing parameters utilized are detailed in Table 2. Specimens were positioned in three different printing orientations: flat, side and vertical.

| Printing parameter | Units | Typical Value |
|---|---|---|
| Layer Height | mm | 0.15 |
| Shells | - | 4 |
| Extrusion Width | mm | 0.4 |
| Infill Density | % | 100 |
| Infill Pattern | - | Grid |
| Heated Bed Temperature | ˚C | 80 |
| Extruder Temperature | ˚C | 290 |
| Default Printing Speed | mm/s | 60 |

Table 2. Printing parameters

All testing specimens were 3D printed with Raise3D E2CF FDM 3D printer. It is FDM 3D printer with independent dual extruders (IDEX), optimized for 3D printing carbon fiber reinforced materials. This desktop 3D printer is ready for manufacturing, prototyping, and more. Specimens were printed in 3 replicas for every printing orientation: flat, side and vertical, as presented in Figure 4. Also, specimens in flat and side orientations, as ones with better strength compared to vertical orientation, were printed with pre drying filament 80 ˚C for 12h before 3D printing.

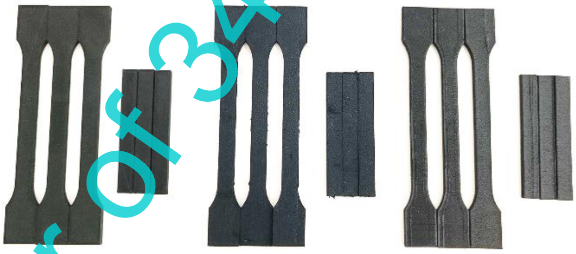


Fig. 4. FDM printed testing specimens (tensile and flexural) in flat, side and vertical orientation

Tensile and flexural mechanical testing were conducted using the Shimadzu AGS-X universal testing machine equipped with a 10 kN load cell. These tests were carried out in accordance with ISO 527 for tensile properties and ISO 178 for flexural properties, maintaining a testing speed of 5 mm/min, as illustrated in Figure 5.

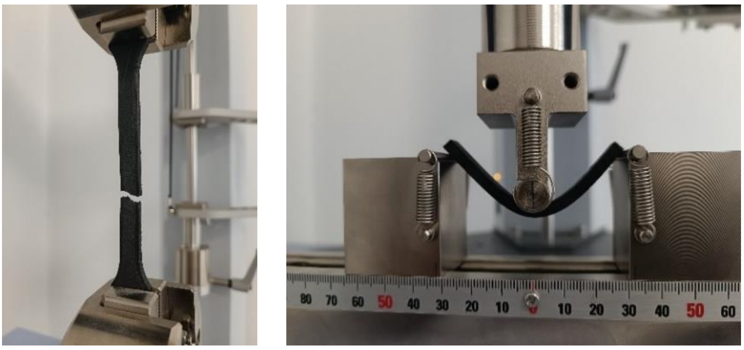


Fig. 5. Tensile (left) and flexural (right) material mechanical properties testing

All data were acquired utilizing Trapezium-X software developed by Shimadzu, subsequently subjected to statistical analysis in Microsoft Excel, stress-strain diagrams were plotted and presented in further text.

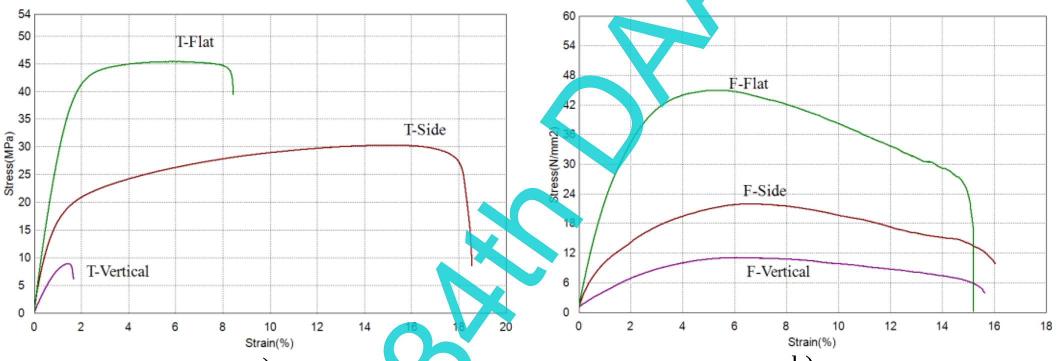
## 3. Results and discussion

After completing the mechanical properties tests, all the results were compiled and presented in Table 3. Tensile testing was performed in accordance with ISO 527 standards, while flexural testing followed ISO 178 standards, with a total of 30 specimens undergoing evaluation. Tensile and flexural strength properties were expressed through maximum stress before break (Rm) and elastic modulus (E), presented in Table 3.

| Specimen | Tensile Strength [MPa] | Tensile Modulus [GPa] | Flexural Strength [MPa] | Tensile Modulus [GPa] |
|---|---|---|---|---|
| Flat | 45.2 | 3.5 | 43.5 | 2.6 |
| Side | 30.3 | 2.8 | 21.9 | 1.1 |
| Vertical | 9.0 | 0.9 | 11.1 | 0.3 |
| Flat with drying | 50.5 | 3.5 | 54.5 | 2.8 |
| Side with drying | 30.3 | 2.8 | 32.6 | 1.1 |

Table 3. Results of examined tensile and flexural strength properties

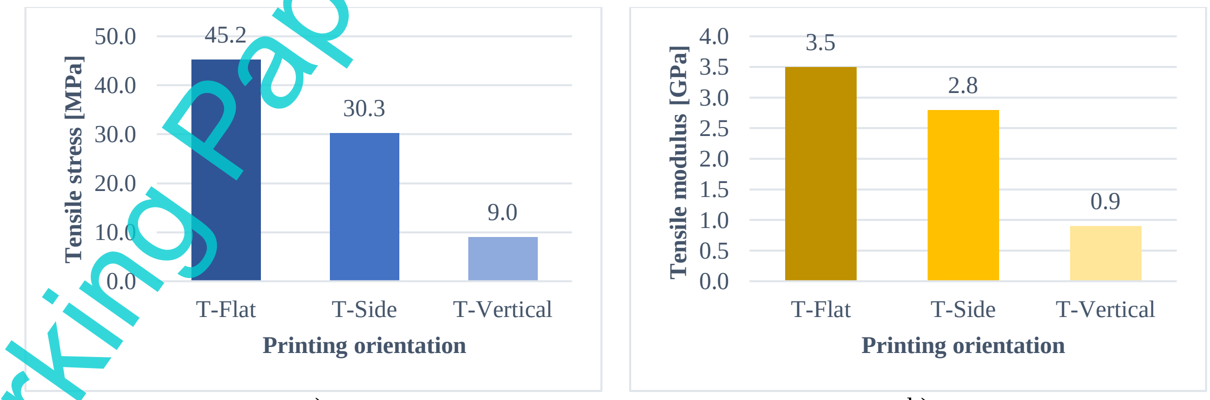
As demonstrated by the stress-strain curves (Figure 6), noticeable differences exist in the strength of FDM-printed materials depending on different printing orientations. Specimens printed in flat and side orientations showing highest tensile and flexural strength, which is expected.



a) b)

Fig. 6. Stress-Strain curves for tensile (a) and flexural (b) testing of FDM-printed CF-PA6 material: Effects of printing orientations (flat, side, and vertical)

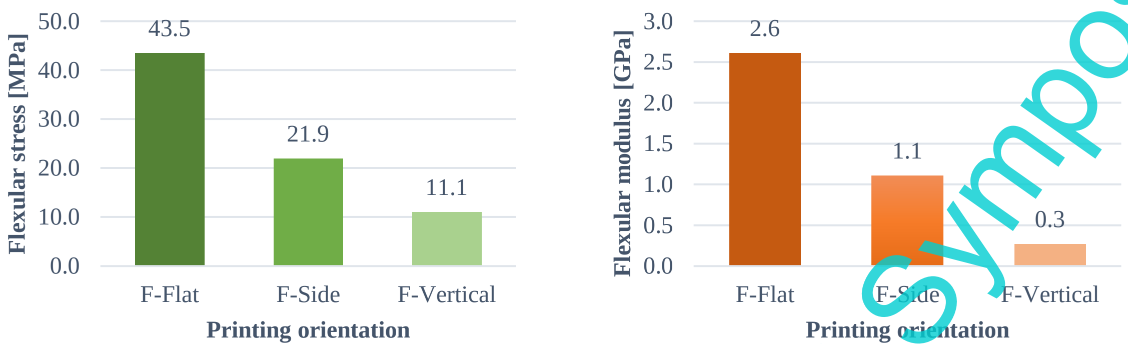
Tensile strength and modulus of elasticity differences based on printing orientation are evident in the histograms (Figure 7). Tensile strength is highest in the flat printing orientation (45 MPa), followed by the side (30.3 MPa), and lowest in the vertical (9 MPa) orientation. Similarly, the modulus of elasticity is highest in the flat printing orientation (3.5 GPa), followed by the side (2.8 GPa), and lowest in the vertical (0.9 GPa) orientation.



a) b)

Fig. 7. Comparation of tensile strength (a) and modulus (b) for specimens printed in different printing orientation

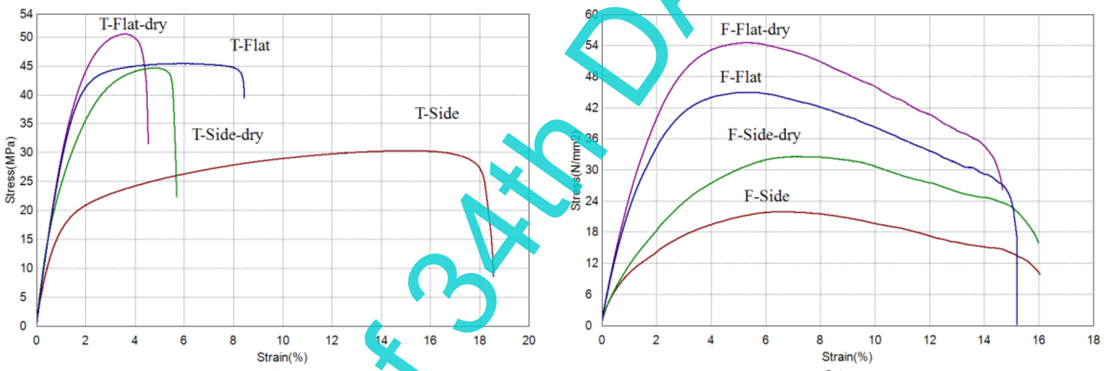
When analysing the effect of printing orientation on flexural properties, a similar trend to that observed in tensile tests emerges. Flexural strength is highest in the flat orientation (43.5 MPa), followed by the side (21.9 MPa), and lowest in the vertical orientation (11.1 MPa). The flexural modulus exhibits the same pattern, with the highest value in the flat orientation (2.6 GPa), followed by the side (1.1 GPa), and the lowest values in the vertical printing orientation (0.3 GPa).



a) b)

Fig. 8. Comparation of flexural strength (a) and modulus (b) for specimens printed in different printing orientations

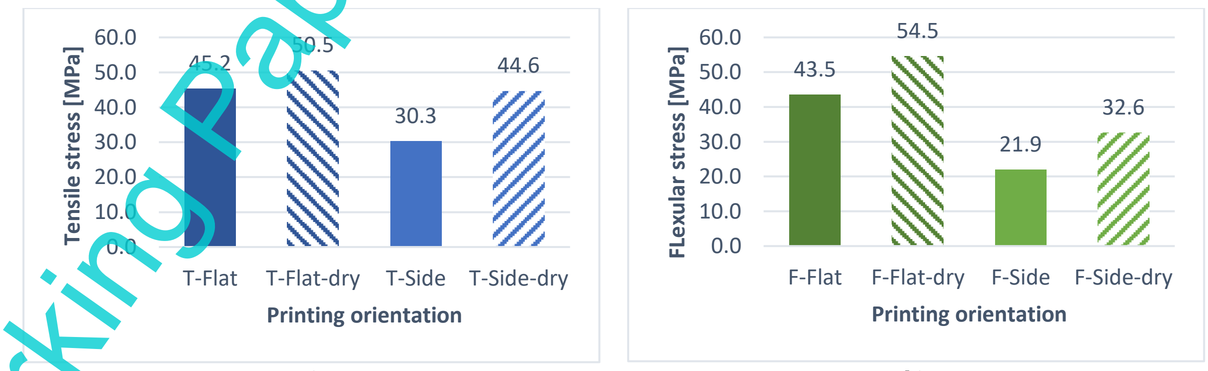
Previous research and literature recommend pre-drying polyamide (nylon) material before printing. Samples printed in flat and side orientations, which exhibited the highest tensile strength values, were compared with samples printed after filament drying. Stress-Strain diagrams illustrate how pre-drying the FDM printed CF-PA6 material significantly enhanced both tensile and flexural strength (Figure 9).



a) b)

Fig. 9. Stress-Strain curves for tensile (a) and flexural (b) testing of FDM-printed CF-PA6 material: Effects of filament drying before printing (orientations flat & side)

Comparing these results using histograms (Figure 10) reveals a noteworthy boost in both tensile and flexural strength when the CF-PA6 filament is dried prior to printing.



a) b)

Fig. 10. Comparation of tensile and flexural strength for specimens printed with and without drying material before FDM 3D printing

Drying the CF-PA6 filament at 80°C for 12 hours before 3D printing resulted in a 12% increase in tensile strength for flat-oriented specimens and a 47% increase for side-oriented specimens. Similarly, flexural strength saw a 25% increase for flat-oriented specimens and a 49% increase for side-oriented specimens.

## 4. Conclusion

Aim of this research was to analyse the influence of printing orientation and filament drying before printing on the tensile and flexural mechanical properties of FDM-printed polyamide composite material with chopped carbon fibers. After completing the tests and analysing the results, the following conclusions are:

- The technical specification of the material "Luvocom 3F PAHT CF 9742 BK" from the manufacturer includes only the values of the material's tensile mechanical properties. A comparison of the tested tensile strength and modulus of elasticity with the manufacturer's specifications revealed that the obtained results were significantly lower. The tested tensile strength varied by up to 108%, while the elastic modulus varied by up to 124%.
- Printing orientation had a substantial impact on the mechanical properties of the FDM-printed CF-PA6 material. The highest tensile and bending strength were achieved when the test sample was printed in a flat orientation, while the lowest strength was observed in the case of printing in a vertical orientation.
- Pre-drying the CF-PA6 filament before printing had a positive influence on the increase in tensile and flexural strength. Tensile strength increased by 12% for flat orientation and by 47% for curved orientation. The flexural strength of the samples printed in the flat orientation increased by up to 25%, and in the side orientation, it increased by up to 49%.
- Additionally, it was noteworthy that the samples did not break during the bending test, even in cases where they were printed in a vertical orientation, where breakage was expected.

In future research, it is recommended to focus on the optimization of drying parameters. This optimization is crucial for achieving the highest quality in printed products from this material, characterized by the desired mechanical, physical, and other properties. Additionally, future research should center on the analysis of how printing parameters influence the mechanical and other properties of CF-PA6 materials. This analysis should encompass the examination of additional mechanical properties, such as hardness, impact toughness, compressive strength, and more.

## 5. References

[1] Hodzic, D. & Pandzic, A. (2019). Influence of Carbon Fibers on Mechanical Properties of Materials in FDM Technology, Proceedings of the 30th DAAAM International Symposium, pp.0334-0342, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-22-8, ISSN 1726-9679, Vienna, Austria, DOI:10.2507/30th.daaam.proceedings.044

[2] Bembenek, M.; Kowalski, L. & Koson-Schab, A. (2022). Research on the Influence of Processing Parameters on the Specific Tensile Strength of FDM Additive Manufactured PET-G and PLA Materials, Polymers, 14, 2446, DOI:10.3390/polym14122446.

[3] Pandzic, A. & Hodzic, D. (2022). Tensile Mechanical Properties Comparation of PETG, ASA and PLA-Strongman FDM Printed Materials With and Without Infill Structure, Proceedings of the 33rd DAAAM International Symposium, pp.0221-0230, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-36-5, ISSN 1726-9679, Vienna, Austria, DOI:10.2507/33rd.daaam.proceedings.031

[4] Hodzic, D. & Pandzic, A. (2019). Influence of Carbon Fibers on Mechanical Properties of Materials in FDM Technology, Proceedings of the 30th DAAAM

[5] Mogan, J.; Harun, W.S.W.; Kadirgama, K.; Ramasamy, D.; Foudzi, F.M.; Sulong, A.B.; Tarlochan, F. & Ahmad, F. (2023) Fused Deposition Modelling of Polymer Composite: A Progress, Polymers 2023, 15, 28. DOI:10.3390/polym15010028

[6] Pandzic, A.; Hodzic, D. & Kadric, E. (2021). Experimental Investigation on Influence of Infill Density on Tensile Mechanical Properties of Different FDM 3D Printed Materials, TEM Journal, Vol. 10, No. 3, pp. 1195-1201., ISSN 2217-8390, DOI: 10.18421/TEM103-25

[7] Alarifi, I. M. (2022). A Performance Evaluation Study of 3D Printed Nylon/Glass Fiber and Nylon/Carbon Fiber Composite Materials, Journal of Materials Research and Technology, Vol. 21, pp. 884-892, DOI:10.1016/j.jmrt.2022.09.085 2

[8] Tutar, M (2023). A Comparative Evaluation of the Effects of Manufacturing Parameters on Mechanical Properties of Additively Manufactured PA and CF-Reinforced PA Materials, Polymers, 15, 38, DOI:doi.org/10.3390/polym15010038

[9] Wang, P.; Zou, B.; Ding, S.; Li, L. & Huang, C. (2020). Effects of FDM-3D Printing Parameters on Mechanical Properties and Microstructure of CF/PEEK and GF/PEEK, Chinese Journal of Aeronautics, Vol. 34, No. 9, pp. 236-246, DOI:10.1016/j.cja.2020.05.040

[10] Farashi, S. & Vafaee, F. (2022). Effect of Printing Parameters on the Tensile Srength of FDM 3D Samples: A Meta-Analysis Focusing on Layer Thickness and Sample Orientation. Progress in Additive Manufacturing, 7, pp. 565-582, DOI:10.1007/s40964-021-00247-6

[11] Jayanth, N.; Jaswanthraj, K.; Sandeep, S.; Mallaya, N.H. & Siddharth, S.R. (2021). Effect of Heat Treatment on Mechanical Properties of 3D Printed PLA, Journal of the Mechanical Behavior of Biomedical Materials, Vol. 123, DOI: 10.1016/j.jmbbm.2021.104764

[12] Hadi, A.; Kadauw, A.; & Zeidler, H. (2023). The Effect of Printing Temperature and Moisture on Tensile Properties of 3D Printed Glass Fiber Reinforced Nylon 6, Materials Today: Proceedings, DOI: 10.1016/j.matpr.2023.04.641

[13] Calignano, F.; Lorusso, M.; Roppolo, I. & Minetola, P. (2020). Investigation of the Mechanical Properties of a Carbon Fibre-Reinforced Nylon Filament for 3D Printing, Machines, 8, 52, DOI:10.3390/machines8030052

[14] Balaji, N. S.; Velmurugan, C.; Kumar, M. S.; Sivakumar, M. & Asokan, P. (2023). Experimental Investigation on Mechanical Properties of FDM-Based Nylon Carbon Parts Using ANN Approach. Surface Review and Letters, *30*, DOI:10.1142/S0218625X23500282

[15] Zaldivar, R.J.; Witkin, D.B.; McLouth, T.; Patel, D.N.; Schmitt, K. & Nokes, J.P. (2017). Influence of Processing and Orientation Print Effects on the Mechanical and Thermal Behavior of 3D-Printed ULTEM®9085 Material, Additive Manufacturing, Vol. 13, pp. 71–80, DOI:10.1016/j.addma.2016.11.007

[16] Farashi, S. & Vafaee, F. (2022). Efect Of Printing Parameters on the Tensile Strength of FDM 3D Samples: A Meta-Analysis Focusing on Layer Thickness and Sample Orientation, Progress in Additive Manufacturing, 7, pp-565-582, DOI:10.1007/s40964-021-00247-6

[17] Anubhav; Kumar, R.; Nandi, S. K. & Agrawal, A. (2023). Influence of Build Orientation on Tensile and Flexural Strength of FDM Fabricated ABS Component, Advances in Additive Manufacturing and Metal Joining, Lecture Notes in Mechanical Engineering, pp. 177–187, DOI:10.1007/978-981-19-7612-4_15

[18] Brown, D. M. (2019). Moisture Absorption and Desorption Effects on Mechanical Behavior in Specialty Polyamide Products, Theses and Dissertations, 5637, Lehigh University

[19] Gong, H.; Runzi, M.; Wang, Z. & Wu, L. (2022). Impact of Moisture Absorption on 3D Printing Nylon Filament, Proceedings of the 33rd Annual International Solid Freeform Fabrication Symposium – An Additive Manufacturing Conference, DOI:10.26153/tsw/44131

[20] https://www.luvocom.de/en/products/3d-printing-materials/luvocom-3f/, (2023). Lehmann&Voss&Co – LUVOCOM 3F – Materials for Extrusion Based Processes, Material Technical Data Sheet, Accessed on: 2023-09-05