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Investigation of the Influence of the k-Factor Parameter on the Quality of Printed Parts Using Ingeo Biopolymer 4043D

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Abstract

This study examines the influence of the dynamic pressure control parameter in the nozzle during melt deposition onto the build platform (k-Factor), also known as Linear Advance or Pressure Advance in different firmware implementations, on the quality of parts produced using the Fused Deposition Modeling (FDM) technology. The investigation was conducted based on printed test specimens made from Ingeo Biopolymer 4043D, with k-Factor values varied in the range of 0.01 to 0.20 under comparable process conditions. Dimensional measurements were performed along the X and Y axes, and visual analysis was carried out to identify defects in the specimens. The results from statistical analysis and visual inspection reveal a clear correlation between the k-Factor value and part quality. An optimal balance between dimensional and geometric stability was achieved at k-Factor = 0.04, identifying it as a suitable value for the material and process conditions used.

Keywords: additive manufacturing; fused deposition modeling; FDM; k-factor; linear advance; pressure advance

1. Introduction

Additive manufacturing represents a production paradigm based on the layer-by-layer deposition of material to create geometrical objects with a high degree of customization. Among the numerous technologies, Fused Deposition Modeling (FDM) is one of the most preferred due to its cost-effectiveness, accessibility, and flexibility with regard to the thermoplastic materials used. Various sectors such as automotive engineering, education and science, medicine, aviation, and others employ FDM technology for the creation of prototypes or functional components [1,2].

The improvement of the quality of parts produced through FDM remains one of the key factors for enhancing the industrial applicability of the technology. Due to the numerous parameters influencing the printing process, it is essential to select them appropriately in order to achieve optimal results [3–6].

In an effort to reduce production time, increased printing speeds are often employed, which can lead to a deterioration in geometric accuracy and mechanical properties, and in some cases, even to print failure. This occurs due to a disruption in the synchronization between the time required to melt the plastic filament, the speed of the material feed system, and the time lag between the application of force and the response of the fluid flow, the movement of the extruder head, and the resulting inertial effects within the various systems.

Most manufacturers prefer the use of direct-drive extrusion systems over Bowden systems due to the improved control over the generated pressure. In direct-drive extruders, the shorter distance between the motor and the nozzle (typically between 5 and 15 cm) minimizes the elastic buildup in the filament, which is commonly observed in Bowden extruders, where the longer distance between the feeding mechanism and the nozzle (usually between 30 and 60 cm) delays pressure changes [7–9].

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Most widely known firmware implementations include a compensation parameter (k-Factor, also known as Linear Advance in Marlin Firmware or Pressure Advance in Klipper Firmware), which controls the buildup of pressure inside the nozzle by adapting to the printing parameters [10–13]. When the printing speed changes, the pressure in the nozzle does not adjust instantaneously due to the inertial effects within the material feeding system. This necessitates compensation through correction mechanisms, such as:

- During acceleration of linear movements, the amount of extruded material is preemptively increased;
- During deceleration, the amount of extruded material is reduced, preventing excessive extrusion.

Proper calibration of the k-Factor is essential for achieving high print quality, especially in complex geometries with frequent changes in movement direction and translational speeds.

Its influence is significant on the quality of printed parts, as its effects can manifest in various ways—including the shape and dimensional accuracy of the part, surface irregularities or increased porosity, poor interlayer adhesion, reduced mechanical strength, susceptibility to thermal deformation, the emergence of internal localized stresses, and more [14–16].

2. Materials and Methods

This study aims to determine the changes in the quality of 3D-printed parts made from PLA material Ingeo Biopolymer 4043D, produced by NatureWorks, as a result of varying the value of the k-Factor parameter. Dimensional values and the geometric shape of the printed test specimens have been selected as the control parameters

2.1. Analysis Parameters

All specimens were printed on a Prusa MK3S+ 3D printer equipped with a direct-drive extruder (Figure 1), using firmware version 3.14.1-8237 and a compensation parameter (k-Factor) of 1.5. This algorithm allows for more precise extruder operation compared to version 1.0, in which pressure fluctuations could be observed. Printing was carried out at an ambient temperature of 20 °C (±1 °C). The dimensions of the test specimens are 20×40×0.40 mm, selected in accordance with the technical specifications of the stepper motors used in the Prusa model—specifically, NEMA17 with 1.8° step angle. These dimensions are intended to ensure the extruder head reaches the designated maximum movement speed. The range of k-Factor values examined in this study spans from 0.01 to 0.20, with increments of 0.01. Table 1 presents the manufacturer's recommended printing temperature values, while Table 2 outlines the process parameters defined for the investigation.

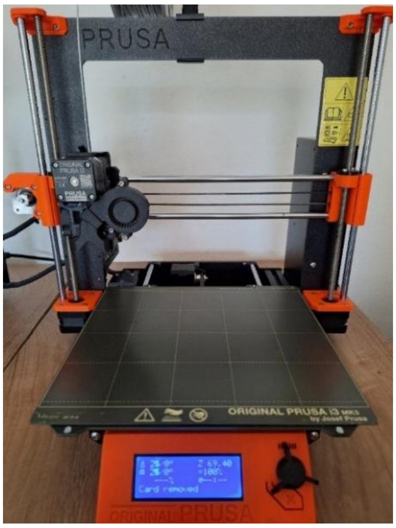

Figure 1. Prusa MK3S+ 3D printer [17].

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Table 1. Recommended temperature settings [18].

Parameters	Value
Nozzle temperature	190 - 230 °C
Bed temperature	50 - 60 °C

Table 2. Process parameters for analysis.

Parameters	Value
Nozzle	
Material	Brass
Diameter	0.4 mm
Temperature	
Nozzle	200 °C (±0.5 °C)
Bed	60 °C (±0.5 °C)
Fan speed (disable fan for the fist layer)	100%
Maximum acceleration	
X	1000 mm/s^2
Y	1000 mm/s^2
Maximum feed rate	
X	200 mm/s
Y	200 mm/s
Speed of print moves	
Perimeters	100 mm/s
Small perimeters	100 mm/s
External perimeters	100 mm/s
Infill	100 mm/s
Solid infill	100 mm/s
Top solid infill	100 mm/s

2.2. Methodology

For each value of the k-Factor parameter, 10 test specimens were printed and measured using a caliper with a Maximum Permissible Error of ±0.02 mm.

The parameters examined in this study include the geometric dimensions and shape of the printed parts, specifically the deviation from nominal dimensions along the X and Y axes and the absolute error. Regarding shape, visual changes or defects on the printed parts were monitored. Three measurements were taken for each test specimen—two along the X direction and one along the Y direction (Figure 2). Averaged values were used in the analysis to eliminate random measurement errors.

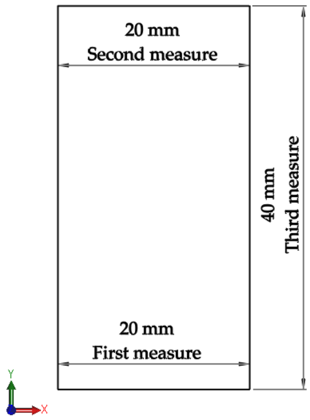

Figure 2. Sequence of measurements.

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After performing the measurements and recording the data along the different axes for each group of test specimens, the information was consolidated into a summary table. This table contains the sum of the averaged absolute errors and the combined standard deviation.

3. Results

The conducted study found that when the k-Factor value exceeds 0.04, an increase in problematic areas becomes evident. Figures 3 and 4 show test specimens with k-Factor values of 0.05 and 0.06, where zones of reduced quality are clearly visible. These defects are also observable in Figure 5, which presents test specimens covering the entire range of k-Factor values examined in the study.

Figure 3. Specimen with k-Factor 0.05.

Figure 4. Specimen with k-Factor 0.06.

Figure 5. Specimens with different k-Factor values.

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Table 3 presents the averaged measurement results for the specimen groups along the X direction, while Figure 6 shows a diagram visualizing these results.

Table 3. The average results of the measurements of the groups in direction X.

k-Factor Value	Mean Deviation from Nominal (20 mm)	Mean Absolute Error
0.01	0.0575	0.0605
0.02	0.0835	0.0835
0.03	0.0675	0.0825
0.04	-0.0265	0.0265
0.05	-0.0760	0.0760
0.06	-0.0260	0.0260
0.07	-0.0010	0.0490
0.08	-0.0475	0.0475
0.09	-0.0335	0.0335
0.10	-0.0210	0.0250
0.11	-0.0260	0.0260
0.12	-0.0125	0.0295
0.13	-0.0420	0.0420
0.14	-0.0275	0.0275
0,15	-0.0480	0.0480
0.16	-0.0095	0.0125
0.17	-0.0200	0.0200
0.18	-0.0055	0.0055
0.19	0.0135	0.0135
0.20	-0.0040	0.0160

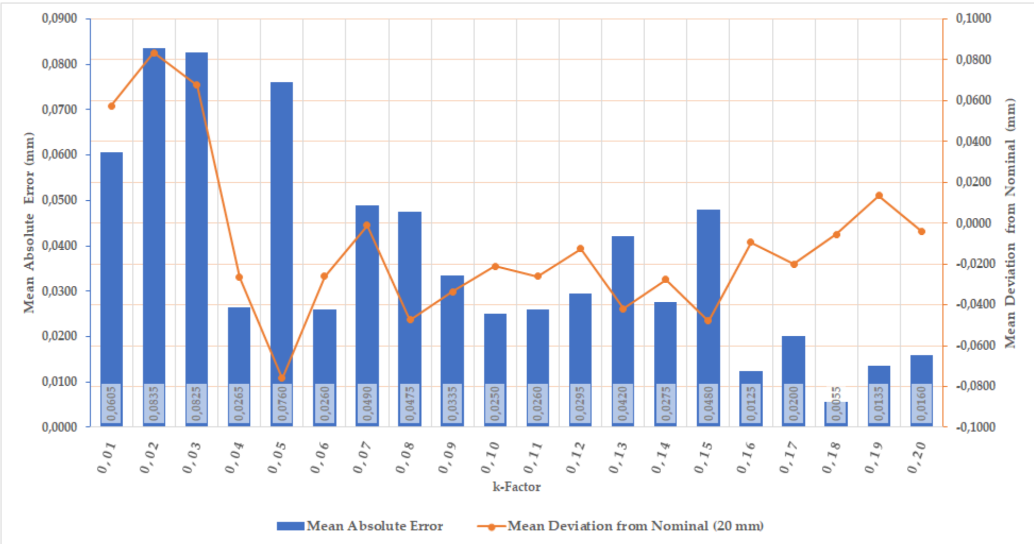

Figure 6. Diagram with visualization of the measurement results along.

The results indicate that the specimens with a k-Factor value of 0.04 exhibit the best performance among the tested range, showing no visible defects or changes in appearance.

Table 4 presents the measurement data along the Y direction, with the corresponding results visualized in the diagram shown in Figure 7. The data indicate that the lowest deviation along the Y axis was observed at a k-Factor value of 0.03.

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Table 4. The average results of the measurements of the groups in direction Y.

k-Factor Value	Mean Deviation from Nominal (40 mm)	Mean Absolute Error
0.01	-0.1310	0.1310
0.02	-0.0420	0.0420
0.03	-0.0070	0.0070
0.04	0.0570	0.0570
0.05	-0.1050	0.1050
0.06	-0.0710	0.0710
0.07	-0.0470	0.0470
0.08	-0.0950	0.0950
0.09	-0.0770	0.0770
0.10	-0.0520	0.0520
0.11	-0.0410	0.0410
0.12	-0.0340	0.0340
0.13	-0.0560	0.0560
0.14	-0.0370	0.0370
0.15	-0.0650	0.0650
0.16	-0.0180	0.0180
0.17	-0.0050	0.0050
0.18	0.0280	0.0280
0.19	0.0080	0.0080
0.20	-0.0010	0.0010

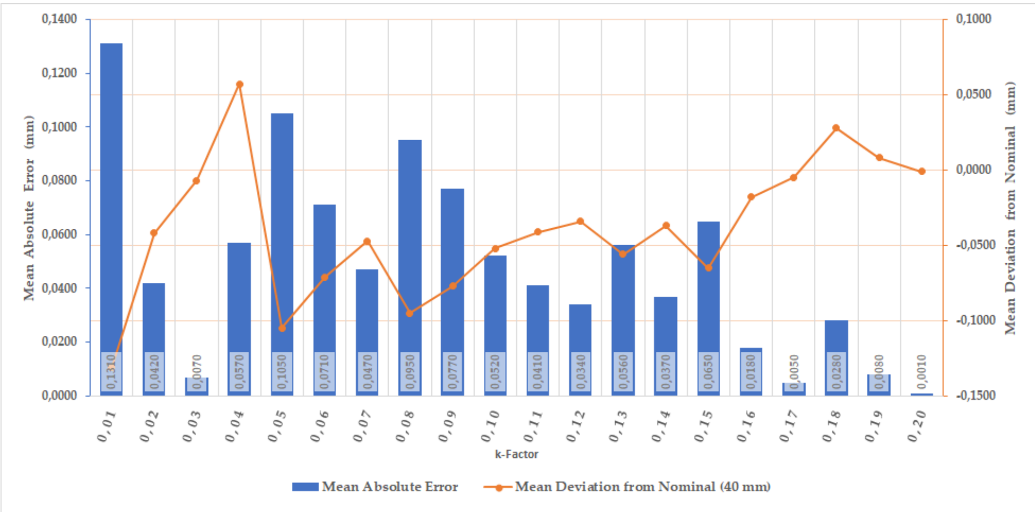

Figure 7. Diagram with visualization of the measurement results along Y.

To summarize the results, the data were consolidated, and the resulting values are presented in Table 5 and Figure 8.

Table 5. Combined measurement results.

k-Factor Value	Combined Standard Deviation from Nominal (20x40)	Combinated Mean Absolute Error
0.01	0.143	0.192
0.02	0.093	0.126
0.03	0.068	0.090
0.04	0.063	0.083

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0.05	0.130	0.181
0.06	0.076	0.097
0.07	0.047	0.096
0.08	0.106	0.143
0.09	0.084	0.111
0.10	0.056	0.077
0.11	0.049	0.067
0.12	0.036	0.064
0.13	0.070	0.098
0.14	0.046	0.064
0.15	0.081	0.113
0.16	0.020	0.031
0.17	0.021	0.025
0.18	0.029	0.034
0.19	0.016	0.022
0.20	0.004	0.017

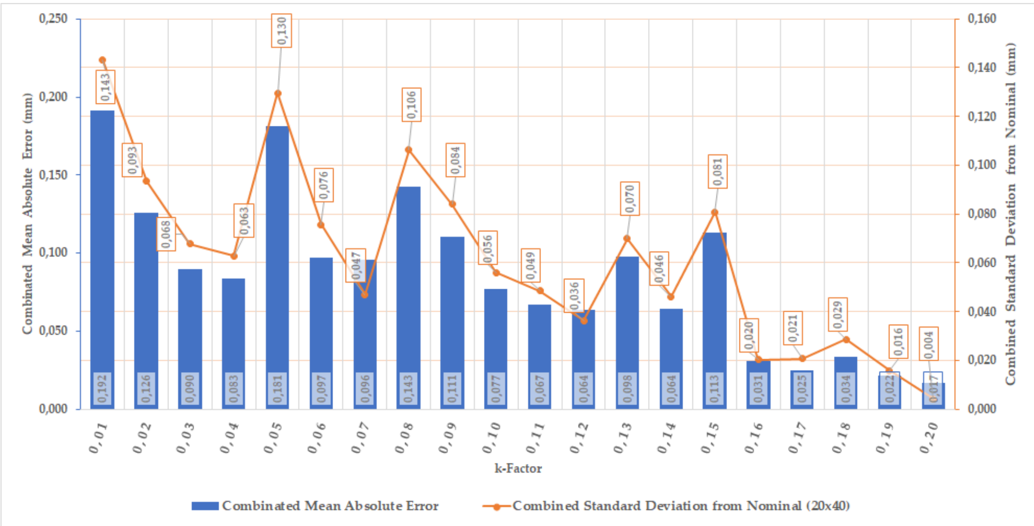

Figure 8. Diagram with visualization of the measurement combined results.

Upon examining the test specimens that yielded the best results—specifically those with k-Factor values of 0.03 and 0.04—it was found that a value of 0.03 resulted in excessive extrusion at the starting position (Figure 9). In contrast, no such issue was observed at a k-Factor value of 0.04, leading to improved part geometry (Figure 10).

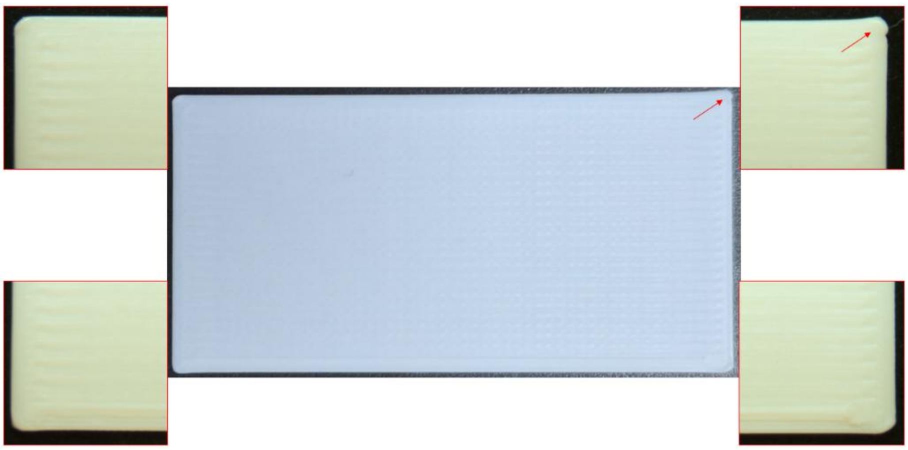

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Figure 9. Specimen with a k-Factor value of 0.03 and the occurrence of over extrusion.

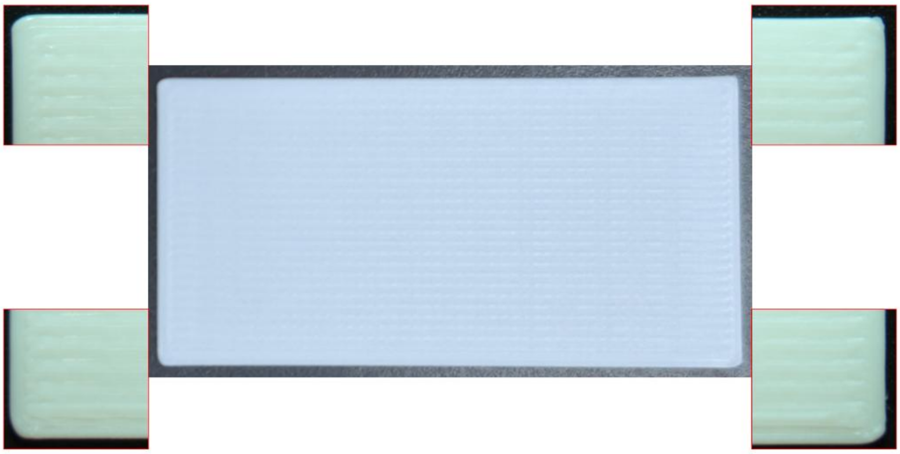

Figure 10. Specimen with a k-Factor value of 0.04.

Figures 11 and 12 display all test specimens with k-Factor values of 0.03 and 0.04, respectively. It is evident from the images that the specimens with a k-Factor of 0.03 exhibit a clearly raised area in one of the corners, while no such defect is observed in the specimens with a k-Factor of 0.04.

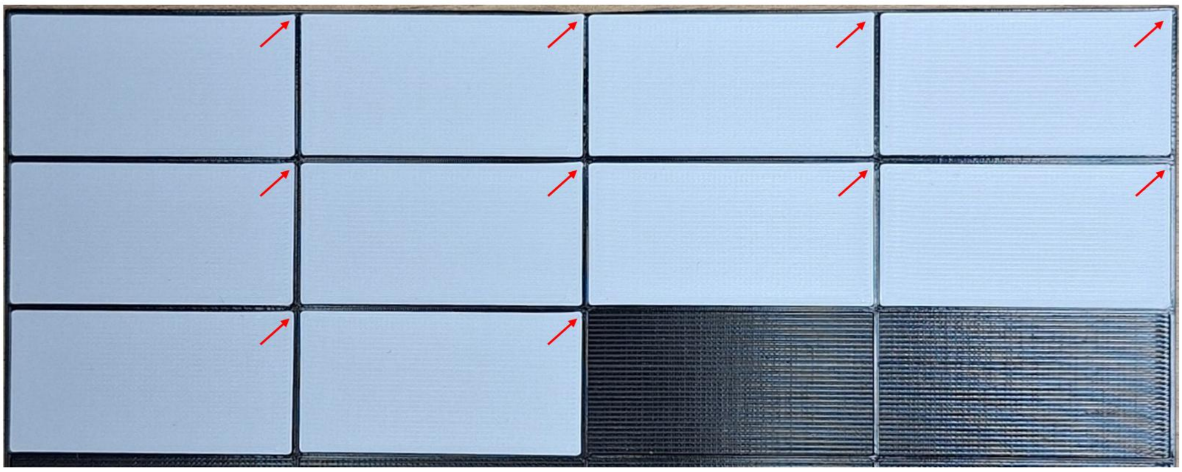

Figure 11. All 10 specimens with a k-Factor of 0.03.

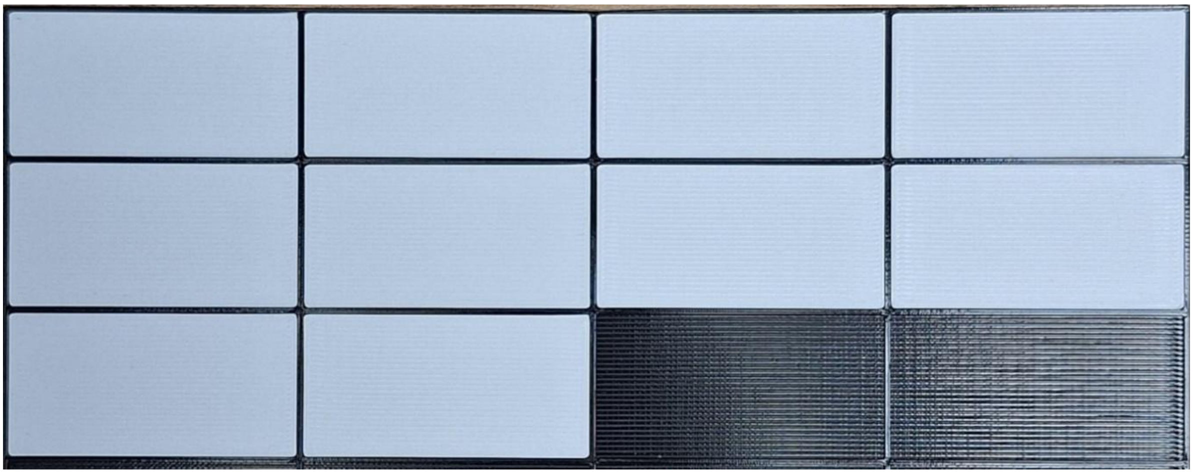

Figure 12. All 10 specimens with a k-Factor of 0.04.

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4. Discussion

The comparative results demonstrate that, under the specific process parameters defined in the study, a compensation parameter (k-Factor) value of 0.04 significantly improves the quality of the printed parts compared to other values. This research may contribute to the enhancement of algorithms used for calculating optimal k-Factor values in FDM technology.

Due to the complexity of the processes involved in printing, a hypothesis can be proposed that the k-Factor value depends on the combination of multiple parameters, with key influencing factors likely being print speed, melting temperature, and nozzle diameter. These relationships will be examined in future studies.

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References

1. Todorov, T.; Todorov, G.; Romanov, B. Design and Simulation of Mould Tools with Multi-Material Structure for Plastic Injection Moulding Based on Additive Technology. In *2019 International Conference on Creative Business for Smart and Sustainable Growth (CREBUS)*; IEEE: Sandanski, Bulgaria, **2019**; pp 1–6. https://doi.org/10.1109/CREBUS.2019.8840061
2. Todorov, T.; Bineva, K.; Romanov, B. Validation of Design and Ergonomics of a Protective Mask by Creating a Silicone Replication in a 3D Printed Mold Tool. In *Machine and Industrial Design in Mechanical Engineering*; Rackov, M., Miltenović, A., Banić, M., Eds.; Mechanisms and Machine Science; Springer Nature Switzerland: Cham, **2025**; Vol. 174, pp 335–344. https://doi.org/10.1007/978-3-031-80512-7_33
3. Mani, M.; Karthikeyan, A. G.; Kalaiselvan, K.; Muthusamy, P.; Muruganandhan, P. Optimization of FDM 3-D Printer Process Parameters for Surface Roughness and Mechanical Properties Using PLA Material. *Materials Today: Proceedings* **2022**, *66*, 1926–1931. https://doi.org/10.1016/j.matpr.2022.05.422
4. Ng, N. Y. Z.; Abdul Haq, R. H.; Marwah, O. M. F.; Ho, F. H.; Adzila, S. Optimization of Polyvinyl Alcohol (PVA) Support Parameters for Fused Deposition Modelling (FDM) by Using Design of Experiments (DOE). *Materials Today: Proceedings* **2022**, *57*, 1226–1234. https://doi.org/10.1016/j.matpr.2021.11.046
5. Zagorski, M.; Sofronov, Y.; Ivanova, D.; Dimova, K. Investigation of Different FDM/FFF 3D Printing Methods for Improving the Surface Quality of 3D Printed Parts; Plovdiv, Bulgaria, 2022; p 060001. https://doi.org/10.1063/5.0090805
6. Sahoo, S.; Sutar, H.; Senapati, P.; Shankar Mohanto, B.; Ranjan Dhal, P.; Kumar Baral, S. Experimental Investigation and Optimization of the FDM Process Using PLA. *Materials Today: Proceedings* **2023**, *74*, 843–847. https://doi.org/10.1016/j.matpr.2022.11.208

7. Moetazedian, A.; Budisuharto, A. S.; Silberschmidt, V. V.; Gleadall, A. CONVEX (CONtinuously Varied EXtrusion): A New Scale of Design for Additive Manufacturing. *Additive Manufacturing* **2021**, *37*, 101576. https://doi.org/10.1016/j.addma.2020.101576
8. Patel, A.; Taufik, M. Extrusion-Based Technology in Additive Manufacturing: A Comprehensive Review. *Arab J Sci Eng* **2024**, *49* (2), 1309–1342. https://doi.org/10.1007/s13369-022-07539-1
9. Azhar, M. A. M.; Sukindar, N. A.; Ani, M. H.; Anuar, H. B.; Kamaruddin, S. B.; Shaharuddin, S. I. S.; Mustafa, M. Y.; Adesta, E. Y. T.; Arief, R. K.; Sulaiman, M. H. Review on Fused Deposition Modelling Extruder Types with Their Specialities in Filament Extrusion Process. In *Proceeding of 5th International Conference on Advances in Manufacturing and Materials Engineering*; Maleque, Md. A., Ahmad Azhar, A. Z., Sarifuddin, N., Syed Shaharuddin, S. I., Mohd Ali, A., Abdul Halim, N. F. H., Eds.; Lecture Notes in Mechanical Engineering; Springer Nature Singapore: Singapore, **2023**; pp 407–413. https://doi.org/10.1007/978-981-19-9509-5_54
10. Pressure advance - Klipper documentation. Available online: https://www.klipper3d.org/Pressure_Advance.html (accessed 03.12.2025)
11. Sineos, S. *Linear Advance*. Marlin Firmware. Available online: https://marlinfw.org/docs/features/lin_advance.html (accessed 03.12.2025)
12. Tronvoll, S. A.; Popp, S.; Elverum, C. W.; Welo, T. Investigating Pressure Advance Algorithms for Filament-Based Melt Extrusion Additive Manufacturing: Theory, Practice and Simulations. *RPJ* **2019**, *25* (5), 830–839. https://doi.org/10.1108/RPJ-10-2018-0275
13. Kazmer, D.; Peterson, A. Compressibility in Fused Deposition Modeling. Society of Plastics Engineering Annual Technical Conference, Additive Manufacturing Division **2022**
14. Zimenko, K. V.; Afanasev, M. Ya.; Kolesnikov, M. V. Pressure Control in Material Extrusion Additive Manufacturing. *Naučno-teh. vestn. inf. tehnol. meh. opt.* **2022**, *22* (5), 929–940. https://doi.org/10.17586/2226-1494-2022-22-5-929-940
15. Kámán, A.; Meszlényi, A.; Jakab, M.; Kovács, A.; Egedy, A. Effect of Geometry and Size on Additively Manufactured Short-Fiber Carbon-Nylon Composite Under Tensile Loading. *Polymers* **2025**, *17* (3), 401. https://doi.org/10.3390/polym17030401
16. Lendvai, L.; Fekete, I.; Rigotti, D.; Pegoretti, A. Experimental Study on the Effect of Filament-Extrusion Rate on the Structural, Mechanical and Thermal Properties of Material Extrusion 3D-Printed Polylactic Acid (PLA) Products. *Prog Addit Manuf* **2025**, *10* (1), 619–629. https://doi.org/10.1007/s40964-024-00646-5
17. Bankov, B.; Todorov, T. T.; Todorov, G. A Functional Model Printing Approach Optimized for Cost-Efficiency Using FDM Technology. In *The 14th International Scientific Conference TechSys 2025—Engineering, Technologies and Systems*; MDPI, **2025**; p 53. https://doi.org/10.3390/engproc2025100053
18. Ingeo Biopolymer 4043D Technical Data Sheet. Available online: https://www.natureworksllc.com/~/media/Files/NatureWorks/Technical-Documents/Technical-Data-Sheets/TechnicalDataSheet_4043D_3D-monofilament_pdf.pdf (accessed 03.12.2025)