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Analysis of the Effects of Fused Deposition Modeling 3D Printing Process Parameters on the Tensile Strength of Thermoplastic Materials

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Abstract

Fused Deposition Modeling (FDM) is one of the most widely used additive manufacturing technologies; however, the effects of process parameters on tensile strength are still often investigated separately for each material. This study aims to analyze and compare the effects of layer height, nozzle temperature, print speed, and infill density on the tensile strength of PLA, ABS, and PETG materials within a uniform analytical framework. The research data were obtained through the compilation of 96 experimental data points from 11 scientific publications, with each material represented by 32 data points. The analysis was conducted using descriptive statistics and Pearson correlation at a significance level of 5%. The results showed that PLA had the highest average tensile strength of 48.65 MPa, followed by PETG at 32.98 MPa and ABS at 21.41 MPa. For PLA, infill density showed the strongest and most significant relationship with tensile strength, followed by print speed and nozzle temperature. For PETG, nozzle temperature was the only parameter that showed a significant relationship and the highest correlation compared with the other parameters. In contrast, all parameters analyzed for ABS did not show statistically significant relationships, indicating that the tensile strength of ABS is more influenced by other factors such as printing orientation and raster angle, which are beyond the scope of this study. These findings indicate that the response of materials to FDM process parameters is material-dependent; therefore, process parameter optimization strategies need to be adjusted according to the characteristics of each material to achieve optimal tensile strength.

Keywords: *Fused Deposition Modeling; tensile strength; PLA; ABS; PETG.*

1. Introduction

Additive Manufacturing (AM) has developed rapidly over the past few decades and has become one of the manufacturing technologies widely used in product development, prototyping, and the production of functional components. The development of this technology has been driven by its ability to produce complex geometries with relatively short production times compared with conventional manufacturing methods [1]. Among the various AM technologies, Fused Deposition Modeling (FDM) is one of the most popular methods because it has relatively low cost, is easy to operate, and is supported by the availability of a wide range of materials [2]. The increasing use of FDM technology has also increased the demand for the quality of printed products. The products produced must not only meet dimensional accuracy requirements but also possess mechanical properties that are suitable for their intended applications. The mechanical properties of FDM-printed products are influenced not only by the type of material used but also by the process parameter settings during printing [3]. Various studies have shown that parameters such as layer height, nozzle temperature, print speed, and infill density affect the quality of the deposited layers and ultimately determine the mechanical performance of the printed products [4]. Therefore, understanding the effects of process parameters is important for achieving optimal print quality [5].

Among the various mechanical properties used to evaluate the quality of FDM-printed products, tensile strength is one of the most commonly used parameters. Tensile testing provides an indication of a material's ability to withstand applied loads before failure occurs [6]. In addition to evaluating the mechanical performance of materials, tensile testing is also widely used to assess the effectiveness of the process parameters applied during printing [7]. Various thermoplastic materials have been widely used in the FDM process, including Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), and Polyethylene Terephthalate Glycol (PETG). PLA is widely used because it has good tensile strength, high dimensional stability, and ease of printing [8]. On the other hand, ABS is known to have better impact resistance and toughness than PLA, making it widely used in engineering applications [9]. Meanwhile, PETG has become an increasingly popular alternative because it combines the ease of printing of PLA with toughness comparable to that of ABS [10]. Several studies have reported the effects of process parameters on the mechanical properties of these materials. Studies on PLA have shown that variations in layer height, nozzle temperature, and infill density can produce considerable variations in tensile strength [11]. Other studies have also shown that each material responds differently to changes in process parameters, so the optimal printing conditions for one material do not necessarily produce the best performance for other materials [12]. Although many studies on the FDM process have been conducted, most have focused on a single material under different experimental conditions, making the results difficult to compare directly. This condition makes it difficult to understand the differences in material responses to the same process parameters. In addition, comparative studies investigating the effects of process parameters on the tensile strength of various thermoplastic materials using a consistent analytical method remain scarce.

Unlike previous studies, which generally investigated a single material separately, this study integrates experimental data from various scientific publications to analyze the three materials simultaneously within a uniform statistical analysis framework. This approach enables a direct and quantitative comparison of the responses to the process parameters. Therefore, this study aims to analyze and compare the effects of layer height, nozzle temperature, print speed, and infill density on the tensile strength of these three materials. The results of this study are expected to provide a more comprehensive understanding of the differences in the responses of each material to changes in process parameters and to serve as a reference for determining appropriate printing conditions to achieve more optimal mechanical performance.

2. Materials and Methods

This study was conducted to analyze the effects of Fused Deposition Modeling (FDM) process parameters on the tensile strength of PLA, ABS, and PETG materials using secondary data obtained from various scientific publications. The research stages used in this study are shown in Figure 1.

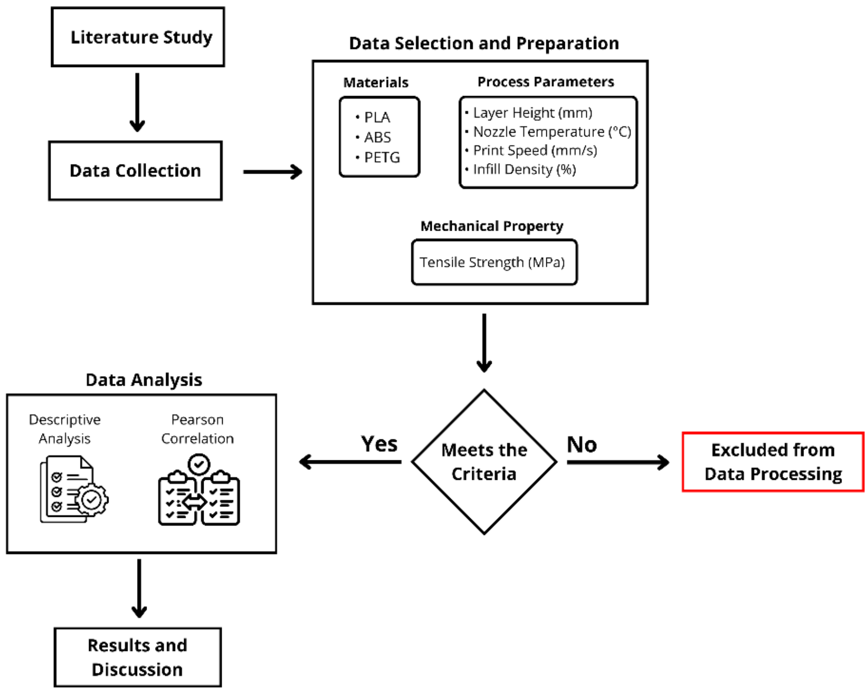

Figure 1. Research workflow.

This study is a quantitative study based on secondary data that aims to analyze the effects of FDM process parameters on the tensile strength of thermoplastic materials. The analysis was conducted by compiling and evaluating tensile test data reported in various scientific publications, thereby enabling comparisons of material characteristics and the relationships between process parameters and tensile strength. The research data were obtained through a literature review of scientific articles discussing the relationship between FDM process parameters and the tensile strength of printed materials. Data were collected by searching articles from various academic databases. The publications were selected based on their relevance to the objectives of this study, namely those that applied the FDM process, used PLA, ABS, or PETG materials, and quantitatively reported the printing parameters and tensile strength values. The data selection process was carried out in stages by applying consistent inclusion and exclusion criteria. Articles were included in the dataset if they used FDM as the printing method, used one of the three materials without reinforcing fibers or special additives, and quantitatively reported layer height, nozzle temperature, print speed, infill density, and tensile strength for each experimental condition. In addition, the tensile strength data had to be reported in MPa according to the ASTM D638 or ISO 527 testing standards and use a print speed of less than 100 mm/s. Articles that did not meet any of these criteria were excluded from the research dataset.

Although the selection process was conducted rigorously, this study acknowledges the potential variability among data sources that should be considered when interpreting the results. Differences in the type of FDM machine, filament brand and quality, ambient temperature during printing, and other printing parameters such as build orientation, raster angle, and air gap, which were not always reported consistently across the studies, may have influenced the obtained tensile strength values. In addition, although all data were selected based on compatible tensile testing standards, differences in specimen geometry and testing procedures that were not entirely identical across the studies may still have introduced variations in the results. Therefore, the relationships obtained in this study should be interpreted as general trends in the relationships between process parameters and tensile strength. Accordingly, the resulting correlation coefficients are descriptive and indicative in nature and are not intended to represent strict causal relationships between process parameters and tensile strength. This study analyzes the relationships between FDM process parameters and the tensile strength of materials. The independent variables include layer height (mm), nozzle temperature (°C), print speed (mm/s), and infill density (%), whereas the dependent variable analyzed is tensile strength (MPa).

These four process parameters were selected because they are the most commonly used parameters in optimizing the quality of FDM-printed products and have been widely reported to influence the mechanical properties of the printed products. All variables were obtained from tensile test data reported in scientific publications that met the research criteria. The data were analyzed using descriptive analysis, Pearson correlation analysis, and data visualization. Descriptive analysis was used to describe the characteristics of the data through the minimum, maximum, mean, median, and standard deviation values. Subsequently, Pearson correlation analysis was used to evaluate the direction and strength of the relationship between the process parameters and tensile strength. The Pearson correlation coefficient was calculated using the following equation 1.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})\,(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{1}$$

where $r$is the Pearson correlation coefficient, x_i and y_i represent the i-th observation values of variables $x$and y, respectively, $\bar{x}$ and $\bar{y}$ are the mean values of variables x and y, respectively, and $n$denotes the number of data points used in the analysis. The Pearson correlation coefficient ranges from -1 to 1. A positive value indicates a positive relationship between two variables, whereas a negative value indicates an inverse relationship [13]. The significance of the relationship was evaluated using the p-value at a significance level of 5%.

The Pearson correlation method was selected in this study because all variables analyzed were continuous numerical data, namely the FDM process parameters and tensile strength values, making this method suitable for measuring the direction and strength of the linear relationship between variables. In addition, the Pearson correlation coefficient allows the degree of relationship between each process parameter and tensile strength to be compared directly and quantitatively for each material investigated. This method has also been widely used in additive manufacturing research to evaluate the relationship between process parameters and the mechanical properties of materials. Nevertheless, Pearson correlation has limitations because it can only describe linear relationships between variables and is sensitive to the presence of outliers. In the FDM process, the relationship between process parameters and tensile strength is not always linear because it is often influenced by interactions among printing parameters and other experimental factors. Therefore, the results of this analysis are interpreted as a descriptive and indicative representation of the relationships among the variables and are not intended to demonstrate definitive cause-and-effect relationships. To support the interpretation of the analysis results, the data were subsequently visualized using distribution plots and relationship plots between the process parameters and tensile strength.

3. Results and Discussion

Before analyzing the effects of FDM process parameters on tensile strength, it is first necessary to understand the characteristics of the dataset used in this study. The dataset was compiled from 11 scientific publications reporting tensile test results for PLA, ABS, and PETG materials under various printing process conditions. The characteristics of the studies used as data sources are presented in Table 1.

Table 1. Characteristics of studies included in the dataset.

No	Material	Number of Data	Experimental Design	Reference
1	PLA	25	Taguchi L27	[14]
2	PETG	16	Taguchi L16	[15]
3	ABS, PETG	15	Taguchi L9	[16]
4	PLA, ABS	11	Factorial experiment	[17]
5	ABS	9	Taguchi L9	[18]
6	ABS	9	Taguchi L9	[19]
7	PETG	6	Taguchi L9	[20]
8	ABS	2	Single-factor experiment	[21]
9	PETG	1	Taguchi L9	[22]
10	PETG	1	Taguchi L16	[23]
11	PLA	1	Taguchi L9 (validation)	[24]

The data sources used in this study were derived from various experimental designs, with the Taguchi method being the most widely used approach. The number of data points obtained from each study varied, ranging from one to twenty-five experimental data points. The diversity of these data sources provides a sufficiently broad range of printing conditions, thereby supporting a more representative analysis of the relationships between FDM process parameters and tensile strength. The distribution of the data based on material type is presented in Figure 2.

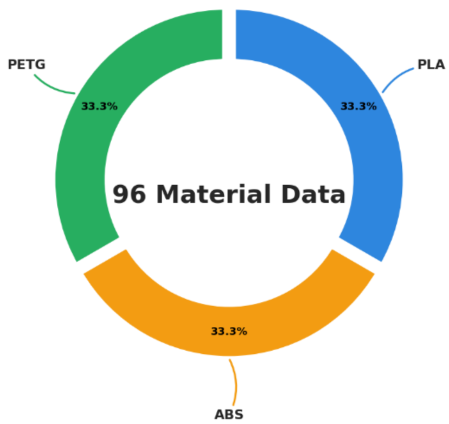

Figure 2. Distribution of material data.

Overall, the dataset consisted of 96 data points divided equally into the three material groups, with each group accounting for 33.3% of the total data. This balanced composition provides an advantage in the analysis process because it allows comparisons to be conducted more objectively without the dominance of data from any particular material group. In addition to its balanced distribution, the dataset also covers a sufficiently wide range of process parameters. The layer height values ranged from 0.05 to 0.30 mm, nozzle temperatures ranged from 200 to 270°C, print speeds ranged from 30 to 90 mm/s, and infill densities ranged from 20% to 100%. The diversity of these parameters provides a sufficiently broad range of printing conditions, thereby supporting a more representative analysis of the relationships between FDM process parameters and tensile strength.

3.1 Comparison of Material Tensile Strength

After understanding the characteristics of the dataset used, the next step is to compare the tensile strength of each material analyzed. This comparison is important for providing an initial overview of the mechanical performance of the three materials before conducting further analysis of the effects of FDM process parameters. A summary of the tensile strength statistics for each material is presented in Table 2.

Table 2. Descriptive statistics of tensile strength.

Material	Mean	SD	Min	Median	Max
PLA	48.65	8.45	27.63	51.11	59.53
ABS	21.41	8.14	3.15	20.77	38.95
PETG	32.98	11.77	19.76	31.50	60.76

Based on the table, PLA showed the highest average tensile strength of 48.65 MPa, followed by PETG at 32.98 MPa and ABS at 21.41 MPa. A similar pattern was observed for the median values, where PLA had the highest median value of 51.11 MPa, whereas PETG and ABS had median values of 31.50 MPa and 20.77 MPa, respectively. These results indicate that, in general, PLA has a better ability to withstand tensile loads than PETG and ABS within the analyzed dataset. In terms of data variability, PETG exhibited the largest standard deviation, at 11.77 MPa, indicating that the tensile strength values of this material are more variable than those of the other materials. In contrast, PLA and ABS had relatively lower standard deviations of 8.45 MPa and 8.14 MPa, respectively. These differences in variability indicate that the consistency of the mechanical performance is not the same for each material; therefore, the distribution of tensile strength values needs to be analyzed further. The distribution of tensile strength values for each material is presented in Figure 3.

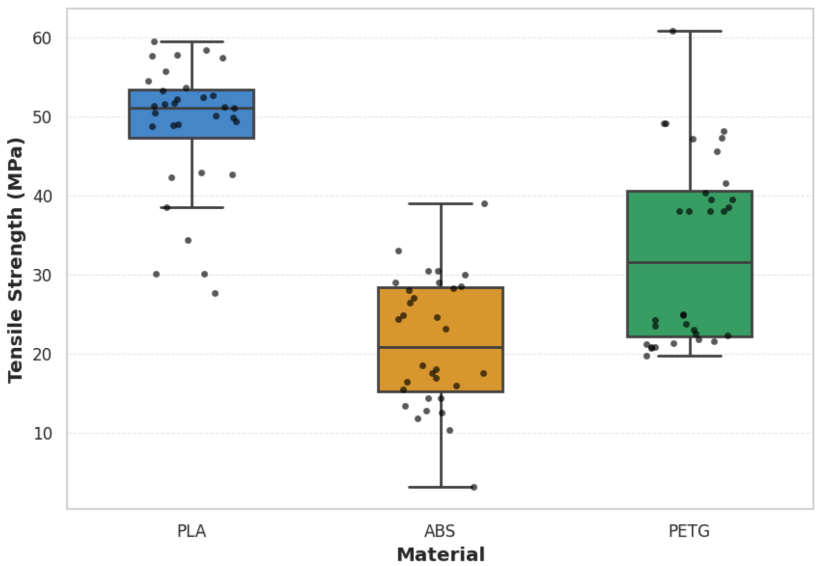

Figure 3. Distribution of tensile strength values.

PLA exhibited a distribution concentrated within a relatively high range of values, indicating that most samples achieved good tensile strength. In contrast, ABS tended to be concentrated within a lower range of values, resulting in the lowest average tensile strength among the three materials. Meanwhile, PETG exhibited a wider distribution range, indicating greater variation in tensile strength among the samples. These differences in distribution patterns indicate that the mechanical characteristics of each material differ not only in terms of tensile strength but also in the consistency of their performance. The predominance of PLA within the higher tensile strength range can be attributed to its relatively high stiffness and mechanical strength compared with other FDM materials [25]. Similar findings were also reported by [26], who showed that FDM-fabricated ABS components tend to exhibit lower tensile strength due to their anisotropic nature and high dependence on interlayer bonding quality. Meanwhile, the broader distribution of PETG indicates that this material exhibits a more variable response to different printing conditions. This finding is consistent with the study reported in [27], which showed that PETG is capable of providing a good combination of strength and toughness, although its mechanical performance is highly influenced by the processing conditions. Therefore, the differences in the intrinsic characteristics of each material contribute to the tensile strength distribution patterns observed in this study.

3.2 Effects of Process Parameters on Tensile Strength

After comparing the tensile strength characteristics of each material, the subsequent discussion focuses on the effects of FDM process parameters on tensile strength. To identify the degree of relationship between the process parameters and tensile strength, Pearson correlation analysis was conducted. The results of the correlation analysis are presented in Figure 4.

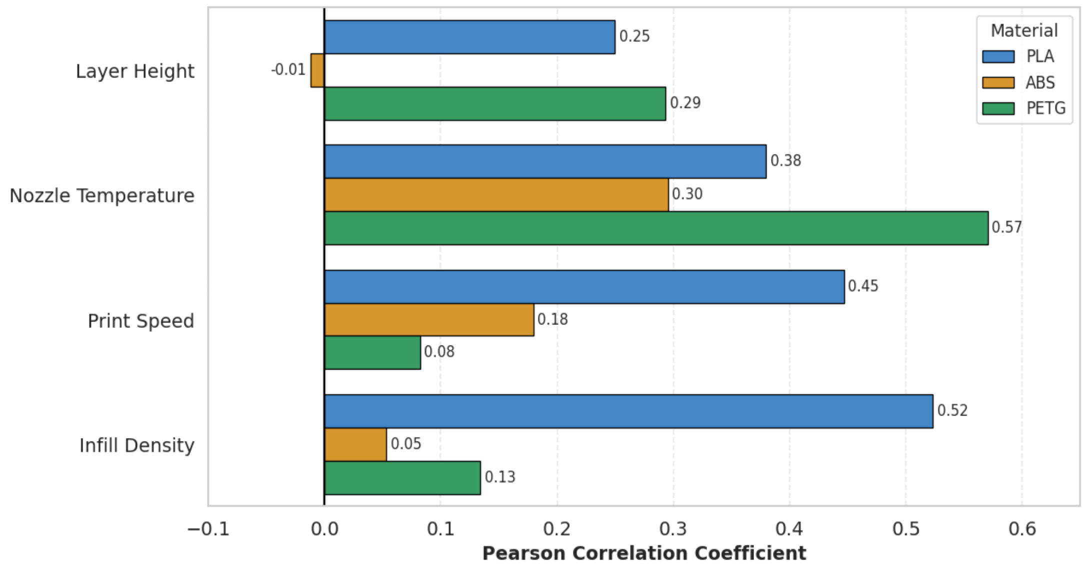

Figure 4. Comparison of Pearson Correlation Coefficients Between FDM Process Parameters and Tensile Strength.

The Pearson correlation coefficients ranged from −0.01 to 0.57, indicating that the degree of relationship between the process parameters and tensile strength differed across the materials. Some parameters showed a positive relationship with tensile strength with varying correlation strengths, whereas the others exhibited very weak or almost no relationship. These differences in the Pearson correlation coefficients indicate that the response of each material to changes in the FDM process parameters is not uniform. To obtain a more comprehensive understanding of these relationship patterns, further analysis was conducted using scatter plots and linear regression lines, as presented in Figure 5.

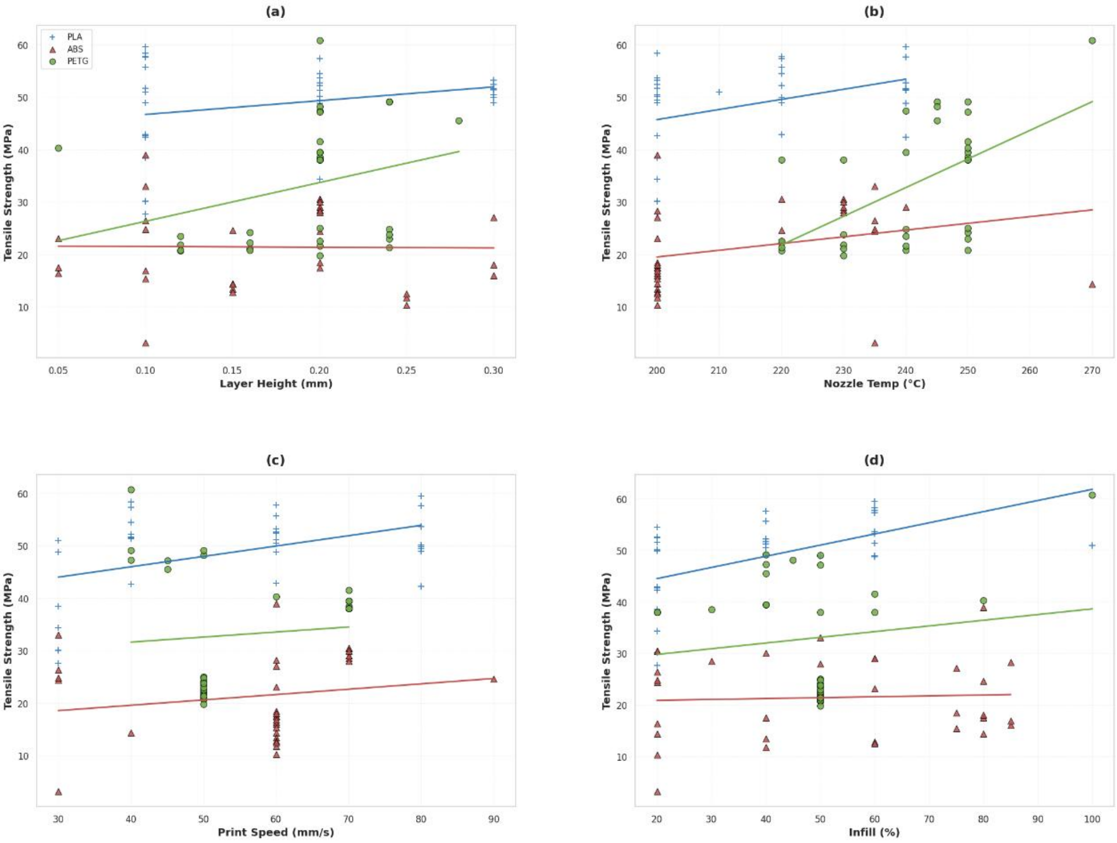

Figure 5. Relationship between process parameters and tensile strength.

The analysis results show that the tensile strength response to changes in the FDM process parameters differs for each material. For layer height, the relationship with tensile strength tends to be weak across all three materials, indicating that the effect of this parameter does not act independently but depends on its interaction with other parameters, such as build orientation, raster angle, and air gap [28]. Theoretically, the smaller the layer height, the greater the number of layers formed, resulting in more uniform interlayer contact. However, this effect is highly dependent on the quality of material melting, which is determined by the nozzle temperature and other printing conditions. A more pronounced effect was observed for nozzle temperature, particularly for PETG. The results show that an increase in nozzle temperature tends to be followed by an increase in tensile strength. This finding is consistent with previous studies [29] and [30], which reported that increasing the nozzle temperature can improve interlayer bonding quality by reducing the viscosity of the molten filament and enhancing polymer chain diffusion at the layer interfaces. These conditions allow stronger interlayer bonding to be formed, thereby increasing tensile strength. PETG exhibits greater sensitivity to this parameter because the quality of its interlayer bonding is strongly influenced by the thermal history during the printing process. In contrast, the relationship is relatively weaker for ABS, which is likely associated with its higher thermal shrinkage, making the material more susceptible to warping and the development of residual stresses during the cooling process.

For print speed, PLA showed a tendency for tensile strength to increase as the printing speed increased. This condition indicates that the range of printing speeds used was still capable of producing adequate material deposition. In contrast, changes in print speed exhibited a less consistent relationship for ABS, which is likely influenced by its interaction with warping and residual stress during the printing process. This finding is consistent with [31], which stated that the effect of print speed cannot be separated from its interaction with other process parameters, particularly nozzle temperature. Infill density showed the clearest positive relationship for PLA. An increase in infill density tended to be followed by an increase in tensile strength, as also reported by [32]. Theoretically, increasing the infill density reduces internal voids, thereby increasing the effective cross-sectional area that resists the applied load and resulting in a more uniform stress distribution. In contrast, this relationship was relatively weak for ABS, which is likely associated with the material's ability to undergo plastic deformation, allowing stress redistribution to occur despite the presence of internal voids. For PETG, the results showed that the relationship between infill density and tensile strength was weaker than the effect of nozzle temperature, suggesting that interlayer bonding quality is a more dominant factor.

Overall, the analysis results indicate that the effects of FDM process parameters are material-dependent. Variations in thermal characteristics, melt flow behavior, shrinkage, and interlayer bonding mechanisms cause the parameters that effectively improve tensile strength in one material not necessarily to produce the same response in other materials. Therefore, the optimization of FDM process parameters should be tailored to the characteristics of each material to achieve optimal mechanical performance. Nevertheless, several limitations should be considered when interpreting the results of this study. The data were compiled from 11 independent publications with different machine conditions, filament brands, and testing procedures that were not entirely consistent. Therefore, the obtained correlation coefficients represent the trends in the relationships between variables rather than definitive cause-and-effect relationships. In addition, the Pearson correlation method only describes linear relationships, so potential non-linear relationships cannot be identified. The amount of data for each material was also relatively limited; therefore, the analysis results should be interpreted with caution. Several other parameters known to influence tensile strength, such as build orientation, raster angle, bed temperature, and filament moisture, could not be controlled because they were not consistently reported across all data sources.

4. Conclusion

This study analyzed the effects of four Fused Deposition Modeling (FDM) process parameters, namely layer height, nozzle temperature, print speed, and infill density, on the tensile strength of PLA, ABS, and PETG using a dataset compiled from 11 scientific publications. Based on the results of the descriptive statistical analysis and Pearson correlation analysis, three main conclusions were obtained. First, PLA exhibited the highest average tensile strength of 48.65 MPa, followed by PETG at 32.98 MPa and ABS at 21.41 MPa. PETG showed the greatest data variation, with a standard deviation of 11.77 MPa, whereas PLA exhibited a relatively consistent tensile strength distribution within the higher value range, and ABS was concentrated within the lower value range. Second, the parameter showing the strongest relationship with tensile strength differed for each material. For PLA, infill density showed the strongest positive relationship, followed by print speed and nozzle temperature. For PETG, nozzle temperature showed the clearest relationship compared with the other parameters. In contrast, all parameters analyzed for ABS showed relatively weak relationships, indicating that its tensile strength is more strongly influenced by other factors, such as build orientation, raster angle, and air gap. Third, the results of this study indicate that the optimization of FDM process parameters is material-dependent. The parameter showing the strongest relationship with tensile strength for one material does not necessarily produce the same response in other materials. Therefore, infill density should be given primary consideration when printing PLA, whereas nozzle temperature control is the most important factor for PETG. For ABS, tensile strength optimization requires a more comprehensive approach by considering build orientation and other geometric parameters. For future research, it is recommended to use a larger dataset and include additional variables, such as build orientation, raster angle, and air gap, so that the effects of FDM process parameters on tensile strength can be understood more comprehensively.

Authors' Contributions

YPK: Conceptualization, Methodology, Software, Formal Analysis, Writing (Original Draft). DW: Investigation, Data Curation, Validation, Visualization. YV: Supervision, Resources, Writing (Review and Editing), Project Administration. All authors have read and approved the final manuscript.

References

[1]. Zhou, L., Miller, J., Vezza, J., Mayster, M., Raffay, M., Justice, Q., ... & Bernat, J. (2024). Additive Manufacturing: a Comprehensive Review. *Sensors*, *24*(9), 2668.

[2]. Țisari, V., Mihalache, M. A., Nagîț, G., Ermolai, V., Irimia, A. I., Grădinaru, C. G., ... & Slătineanu, L. (2026). The Influence of Certain Operating Conditions of the FDM Process on the Mechanical Properties of Polymeric Materials A Review. *Polymers*, *18*(10), 1183.

[3]. Megersa, G. K., Sitek, W., Nowak, A. J., & Tomašić, N. (2024). Investigation of the Influence of Fused Deposition Modeling 3D Printing Process Parameters on Tensile Properties of Polylactic Acid Parts Using The Taguchi Method. *Materials*, *17*(23), 5951.

[4]. Sultan, M. M., Aized, T., Farooq, M., Anwar, S., Ahmad, N., Tauseef, A., & Riaz, F. (2025). Optimization of PETG 3D Printing Parameters for The Design and Development of Biocompatible Bone Implants. *Frontiers in Bioengineering and Biotechnology*, *13*, 1549191.

[5]. Leni, D., Rosa, Y., Sunitra, E., Muharni, R., & Kusuma, Y. P. (2026). Analysis of the Effect of Fused Deposition Modeling Process Parameters on the Tensile Strength of PLA Material. International Journal of Mechanical Engineering and Smart Technology, 1(1), 53-61

[6]. Dizon, J. R. C., Espera Jr, A. H., Chen, Q., & Advincula, R. C. (2018). Mechanical Characterization of 3D-Printed Polymers. Additive manufacturing, 20, 44-67.

[7]. Popescu, D., Zapciu, A., Amza, C., Baciu, F., & Marinescu, R. (2018). FDM Process Parameters Influence over The Mechanical Properties of Polymer Specimens: A review. Polymer Testing, 69, 157-166.

[8]. Plamadiala, I., Croitoru, C., Pop, M. A., & Roata, I. C. (2025). Enhancing Polylactic Acid (PLA) Performance: a Review of Additives in Fused Deposition Modelling (FDM) Filaments. Polymers, 17(2), 191.

[9]. Eyri, B., Gul, O., Yilmaz, S., Karsli, N. G., & Yilmaz, T. (2025). Characterization of ABS/PETG Multi-Material Composites 3D Printed by Print-Pause-Print Method. Polymer Engineering & Science, 65(5), 2353-2369.

[10]. Aslan, E., Akıncıoğlu, G., & Şirin, E. (2025). A Comparative Study on Friction Performance and Mechanical Properties of Printed PETG Materials with Different Patterns. Journal of Applied Polymer Science, 142(27), e57136.

[11]. Hong Vi, N., Chuong, C. K. B., My, L. T. T., Hieu, D. H. M., & Thanh, T. T. (2022, November). Effects of Infill Density, Layer Thickness and Raster Angle on Weight and Tensile Strength of PLA Products Fabricated by Fused Deposition Modeling (FDM). In International Conference on Material, Machines and Methods for Sustainable Development (pp. 87-98). Cham: Springer Nature Switzerland.

[12]. Albaşkara, M., & Yıldız, İ. (2025). A Comparative Study On The Tensile Properties Of Pla, Petg, and ABS in FDM 3D Printing: Effects of Infill Geometry and Build Orientation. International Journal of 3D Printing Technologies and Digital Industry, 9(3), 688-697.

[13]. Leni, D., Sumiati, R., Haris, H., Karudin, A., Kusuma, Y. P., & Afriyani, S. (2026, January). Application of Machine Learning Algorithms for Predicting Mechanical Properties of Stainless Steel. In AIP Conference Proceedings (Vol. 3337, No. 1, p. 040004). AIP Publishing LLC.

[14]. Ekşi, S., & Karakaya, C. (2025). Effects of Process Parameters on Tensile Properties of 3D-Printed PLA Parts Fabricated with The FDM Method. Polymers, 17(14), 1934.

[15]. Ali, H. B., Oleiwi, J. K., & Othman, F. M. (2022). Compressive and Tensile Properties of ABS Material as a Function of 3D Printing Process Parameters. Revue des composites et des matériaux avancés, 32(3), 117.

[16]. Awad, A. H., Sayed, R. A. E., & Atef, M. (2025, October). Enhancing Mechanical Properties of PETG by Optimization of Process Parameters Using The Taguchi Method. In The International Conference on Applied Mechanics and Mechanical Engineering (Vol. 22, No. 22, pp. 1-11). Military Technical College.

[17]. Chen, D. C., Zheng, Q. D., & Chen, C. H. (2024). Optimization of Tensile Strength and Cost-Effectiveness of Polyethylene Terephthalate Glycol in Fused Deposition Modeling Using the Taguchi Method and Analysis of Variance. Polymers, 16(22), 3133.

[18]. Khusheef, A. S., Hashemi, R., & Shahbazi, M. (2024). Optimizing FDM Process Parameters: Predictive Insights Through Taguchi, Regression, and Neural Networks. Physica Scripta, 99(6), 066005.

[19]. Winarso, R., Hidayat, T., Gunawan, B., Nugraha, F., & Mulyani, S. (2026). Preliminary Prototyping and Parameter Optimization of FDM-Based Custom Bone Plates: A Feasibility Study For Orthopedic Fixation. International Journal on Interactive Design and Manufacturing (IJIDeM), 1-20.

[20]. Mishra, V., Bharat, N., Kumar, V., Veeman, D., & Vellaisamy, M. (2024). Assessment of Physio-Mechanical Characteristics of Abs/Petg Blended Parts Fabricated by Material Extrusion 3D Printing. Physica Scripta, 99(12), 125033.

[21]. Rodríguez-Panes, A., Claver, J., & Camacho, A. M. (2018). The Influence of Manufacturing Parameters on The Mechanical Behaviour of Pla and ABS Pieces Manufactured by FDM: A Comparative Analysis. Materials, 11(8), 1333.

[22]. Saini, M. (2019). Optimization The Process Parameter of Fdm 3D Printer Using Taguchi Method for Improving The Tensile Strength. Int. J. All Res. Educ. Sci. Methods, 7, 16-24.

[23]. Ulkir, O., Ertugrul, I., Ersoy, S., & Yağımlı, B. (2024). The Effects of Printing Temperature on The Mechanical Properties of 3D-Printed Acrylonitrile Butadiene Styrene. Applied Sciences, 14(8), 3376.

[24]. Zakaria, S., Stighfarrinata, R., & Maghfiroh, A. M. R. (2022). Optimasi Parameter Proses 3D Printing Terhadap Kuat Tarik Filament PETG Menggunakan Metode Taguchi. JUSTI (Jurnal Sistem Dan Teknik Industri), 3(4), 538-545.

[25]. Gaal, G., Gaal, V., Braunger, M. L., Riul Jr, A., & Rodrigues, V. (2020). FDM 3D Printing in Biomedical and Microfluidic Applications. In 3D Printing in Biomedical Engineering (pp. 127-145). Singapore: Springer Singapore.

[26]. Ahn, S. H., Montero, M., Odell, D., Roundy, S., & Wright, P. K. (2002). Anisotropic Material Properties of Fused Deposition Modeling ABS. Rapid prototyping journal, 8(4), 248-257.

[27]. Kopar, M., & Yildiz, A. R. (2023). Experimental Investigation of Mechanical Properties of PLA, ABS, and PETG 3D Printing Materials Using Fused Deposition Modeling Technique. Materials Testing, 65(12), 1795-1804.

[28]. Mardlotila, M. J., Trifiananto, M., Dwilaksana, D., Basuki, H. A., Kustanto, M. N., & Hardiatama, I. (2022). Effect of Layer Height, Infill Geometry, Nozzle Temperature, and Fan Speed on Tensile Strength of 3D Printing Petg Specimens. INVOTEK: Jurnal Inovasi Vokasional Dan Teknologi, 22(3), 149-158.

[29]. Zeng, Y. S., Hsueh, M. H., Lai, C. J., Fang, T. H., Hsieh, T. H., & Lin, T. K. (2025). Mechanical Behavior of Fdm-Printed Petg Under Temperature–Speed Coupling and Sequential Annealing/Uv: Implications for Process Design. Journal of Reinforced Plastics and Composites, 07316844251414909.

[30]. Dolzyk, G., & Jung, S. (2019). Tensile and Fatigue Analysis of 3D-Printed Polyethylene Terephthalate Glycol. Journal of Failure Analysis and Prevention, 19(2), 511-518.

[31]. Gültekin, M. Ş. (2026). Prediction of Tensile Strength of Pla Parts Produced With Fdm Using Taguchi L27, Anova, and Large-Scale Machine Learning Models and Optimal Parameter Design. Journal of Thermoplastic Composite Materials, 08927057261429023.

[32]. Agrawal, A. P., Kumar, V., Kumar, J., Paramasivam, P., Dhanasekaran, S., & Prasad, L. (2023). An Investigation of Combined Effect of Infill Pattern, Density, and Layer Thickness on Mechanical Properties of 3D Printed ABS by Fused Filament Fabrication. Heliyon, 9(6).