STRENGTH ANALYSES OF FDM PRODUCTS FROM ADDITIVELY STRENGTHENED PLA MATERIALS

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This paper investigates the mechanical properties of products manufactured using Fused Deposition Modeling (FDM) technology from additively reinforced polylactic acid (PLA) materials. With the growing popularity of 3D printing technology, it is necessary to increase and improve the performance of PLA, which is known for its brittleness and limited durability. The aim of this study is to analyze the influence of various additives on the physical and mechanical properties of printed samples. Also, the part of research is to optimize printing parameters to improve overall strength and durability. The basic idea and reason for the observation is to compare regular PLA, which can withstand temperatures of 60°C, and additive PLA, which can withstand temperatures up to 110°C, and its properties in tensile tests exceed those of commonly available PLA. Such additive PLA is not extruded in regular printing and is often excluded from the production process precisely because of insufficient thermal resistance. The results indicate that the use of additives and adjustment of processing parameters leads to a significant improvement in mechanical properties, which highlights the potential of reinforced PLA materials for a wide range of industrial applications. These findings offer valuable insights into research and development in the field of additive manufacturing and may contribute to better optimization of future prints.

KEYWORDS

FDM, PLA, Strength Analysis, Durability, Materials

1 INTRODUCTION

The production of polymeric materials has undergone a substantial transformation with the advent of additive manufacturing (AM), commonly known as 3D printing. Among the various AM techniques, FDM stands out as one of the most widely used due to its cost-effectiveness, design flexibility, and relatively simple process control.

FDM operates by extruding thermoplastic filament through a heated nozzle and depositing it layer by layer, allowing the fabrication of geometrically complex and customized components. This layer-wise construction, combined with the possibility of adjusting slicing parameters, enables the tailoring of internal structures and material distribution. This advantage is making FDM suitable for both industrial applications and scientific research [Gibson et al. 2020]. PLA is one of the most used thermoplastics in FDM due to its affordability, ease of processing and environmentally friendly nature, as it is biodegradable and derived from renewable resources [Tymrak et al. 2014]. Compared to conventional PLA filaments, PLA Blaster exhibits significantly improved heat resistance, as confirmed by both experimental results and practical observations. It maintains dimensional stability at temperatures where standard PLA materials begin to deform, making it suitable for technical applications where elevated temperatures are a factor — such as in the automotive industry or for functional engineering parts.

However, the mechanical limitations of standard PLA, such as its brittleness and relatively low impact and tensile strength, hinder its use in applications requiring higher performance. Moreover, standard PLA does not tolerate elevated temperatures well, which significantly limits its thermal stability. Therefore, it is beneficial to modify PLA with the aim of maintaining its ease of printing while enabling it to compete with other, non-biodegradable materials such as ABS or PETG. As a result, significant research efforts have been directed toward enhancing PLA's mechanical properties through various additive strategies. To address these challenges, reinforcing PLA with additives—such as natural fibres, inorganic nanoparticles, or synthetic polymeric fillers—has become a promising approach. Due to this unique combination of enhanced thermal performance and low printing requirements, PLA Blaster presents itself as a viable alternative to more demanding engineering plastics, while preserving the user-friendly nature of PLA. This makes it a distinct material with no direct equivalent currently available in the mainstream filament market. One notable example is the incorporation of poly(3-hydroxybutyrate) (PHB), which has been demonstrated to enhance PLA's crystallinity and improve its thermal and mechanical performance [Farah et al. 2016]. Furthermore, post-processing techniques such as annealing can be used to refine the microstructure of PLA, thereby increasing its thermal resistance and impact toughness [Wang et al. 2019]. In addition to material modifications, the mechanical behaviour of FDM-printed parts is significantly influenced by printing parameters, including nozzle temperature, layer height, infill density, print orientation, and printing speed. These parameters affect interlayer bonding and internal stress distribution, which in turn determine the structural integrity of printed components [Mohamed et al. 2015]. Poor parameter selection may result in weak layer adhesion, voids, or internal defects that compromise the part's load-bearing capability [Popescu et al. 2018].

This study focuses on the strength analysis of FDM-printed samples in accordance with ISO 527-2, using PLA materials that have been additively reinforced to enhance their mechanical properties. At the same time, the material retains the ease of printing characteristic of regular PLA. It can be processed on standard FDM/FFF printers without the need for a heated chamber, unlike materials such as ABS, ASA, or PC, which typically require more controlled conditions to avoid warping and layer separation. For testing elongation and calculating tensile properties, the samples had a width of 10 mm, a thickness of 4 mm, and a gauge length of 80 mm, while the total length of each sample was 150 mm. The objective is to evaluate how various material reinforcements and printing parameters influence the tensile performance of printed parts. Through this investigation, the research aims to contribute valuable insights into the optimization of FDM processes and material formulations to achieve improved durability and functional reliability in PLA-based components [Fontana et al. 2022].

2 MATERIALS AND METHODS

The production process itself is being greatly expedited by the advancement of additive technologies, particularly FDM 3D printing. But this development also raises the bar for printed component quality; the increased speed needs to be weighed against the prints' accuracy, strength, and dependability. For this reason, there is a growing emphasis on the necessity of standardizing mechanical property testing to guarantee an unbiased comparison of outcomes. Uniform (unified) test specimen formats that satisfy globally accepted standards are necessary for this [Khosravani a Reinicke 2020].

2.1 3D printer

The Bambu Lab X1C is considered one of the most advanced FDM printers currently available, offering exceptional print quality and a wide range of innovative technological features. This system is particularly suitable for applications requiring high dimensional accuracy and fine surface quality. The printer's CoreXY kinematic architecture, reinforced carbon fiber rods, and active vibration compensation contribute significantly to the achievement of high-speed printing while maintaining excellent precision and repeatability [Lu et al. 2025].

Advanced functionalities, including AI-based first layer inspection, automatic bed levelling, and active cooling management, enhance process reliability and reduce the risk of print failure. The Bambulab X1C utilizes LIDAR (Light Detection and Ranging) technology as part of its advanced functionalities to enhance the printing process e.g. see Fig. 1. The unique operating system of the printer offers print settings that are tuned to allow for effective control of the parameters required to produce goods with the highest possible strength and integrity. When creating intricate geometric constructions out of PLA materials that have been additively reinforced, this skill is especially crucial since precise processing and robust outcomes are needed [Lu et al. 2025].

Figure 1. Bambulab X1C printing testing samples of Generic PLA JAYO

2.2 Material selection – PLA BLASTER, PLA JAYO, PLA KINGROON and ABS

The primary benefits of PLA over ABS are its increased stiffness and strength, which guarantee the creation of more robust goods [Dhinesh et al. 2021; Arockiam et al. 2021].

PLA also offers the advantage of easy processing. In contrast to ABS, which requires strict manufacturing conditions to avoid warping and cracking, PLA is generally easier to print and less demanding in terms of temperature control. This ease of processing enables the production of more complex and often heavier parts. PLA types with improved thermal resistance approaching that of ABS, are becoming more universal in their application. It is meaningful to manufacture them in larger spools. As a result, industrial use often involves filament rolls weighing up to five times more than the standard 1 kg spools [Roy a Mukhopadhyay 2021; Arockiam et al. 2021].

For comparison, three types of PLA were utilized in this study: generic PLA YAYO with a Heat Deflection Temperature (HDT) of 55 °C, generic PLA KINGROON with an HDT of 50 °C, and an additively strengthened PLA BLASTER, which has HDT up to 110°C as stated by the manufacturer. The PLA Blaster material used in this study is not a commonly available filament in standard retail outlets or mainstream 3D printing material suppliers. It is a specialized type of modified PLA, typically distributed through selected channels or directly by the manufacturer, rather than being widely accessible to general consumers. In our study, we compared the mechanical properties of PLA specimens produced according to ISO 527-2 with those of ABS, a material that is more demanding in terms of printing conditions. Unlike ABS, PLA exhibits significantly lower shrinkage during cooling, which typically results in better dimensional stability and less warping of printed parts.

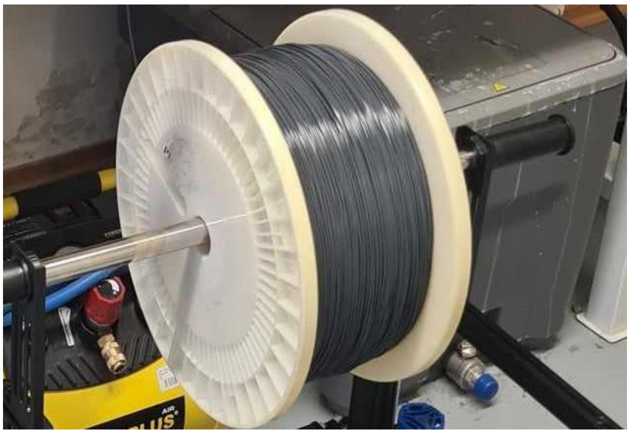

Figure 2. PLA Blaster by Filamentree

Manufacturers are focusing on adding various natural fillers to PLA to further improve its mechanical properties. Increased strength, flexibility and impact resistance are achieved by adding bio-based fillers [Singh et al. 2020; Arockiam et al. 2021].

2.3 PLA Blaster usage

1. Nozzle settings

Nozzle temperature and print speed are crucial factors to consider while maximizing print parameters for PLA material in FDM process [Popović et al. 2023]. In our study, the nozzle temperature was set according to the specifications and requirements of each tested material. For PLA Blaster, the nozzle temperature was adjusted to 265 °C to accommodate its enhanced formulation and higher thermal resistance. For PLA JAYO and PLA Kingroon, the nozzle temperature was set to 230 °C, as recommended by their respective manufacturers. For ABS was set to 270°C. In addition, the layer height was consistently set to 0.2 mm for all four tested filaments to maintain uniformity in sample fabrication. The maximum volumetric speed was set to 18 mm^3/s for all specimens

2. Cooling settings

To guarantee solid adherence to the substrate and stability of the base layers, the fan should be entirely turned off during the first three layers. To guarantee that the layers stabilize rapidly, the fan is gradually turned up to 50% starting with the fourth layer and set to 100% for large layers with short print periods (up to 8 seconds To ensure consistent printing conditions and reduce variability related to surface adhesion and thermal behavior, all specimens except those made of ABS were printed on a Bambu Lab Cool Plate. In the case of ABS, printing was carried out on an Engineering Plate, as recommended by the material manufacturer. From the fourth layer onward, the fan must be turned on permanently. At the same time, the forced cooling of bridges and overhangs must be initiated. This configuration will reduce the chance of warping and produce excellent print quality.

3. Standardization of testing samples

According to J. Török and colleagues, the necessity to standardize the guidelines for the shape of test samples has gradually emerged on the international market. In Central Europe, Slovak Technical Standards (STS) frequently adopt ISO norms, either through direct translation or with necessary modifications, while in the United States, ASTM standards are preferred. Although testing standards for plastics have existed for some time, the rapid development of additive manufacturing (AM) technologies—especially in metal, polymer, and composite 3D printing—has highlighted inadequacies in current specifications [Török et al. 2021].

As printing rates rise and FDM technology advances, consistent product quality becomes more and more crucial. To guarantee mechanical performance at these accelerated circumstances, systematic testing using consistent sample geometries is required. Thus, for an objective evaluation of how print parameters impact the mechanical characteristics of FDM-printed parts, standardization of test procedures and samples is essential, enabling greater dependability and comparability in research and production processes. The forms of the test samples are described in the pertinent standards, but the machine path is not exactly specified. Like this, there is no set orientation for the print bed; however, multiple studies have indicated that the vertical position, as seen in Figure 3. on the left, is not advised. Our comparative research will focus on the middle sample, whose horizontal orientation was determined to be the most appropriate by J. Török et al. Similarly, the infill density in our study was set to 100%, as also applied by J. Török, since using a fixed infill parameter is a common standard in tensile testing. This approach facilitates consistent testing conditions and enables meaningful comparisons across different studies. A third orientation option, edgewise, in relation to the heat bed is also shown in Figure 3 [Török et al. 2021; Hwang et al. 2015; Der Klift et al. 2016].

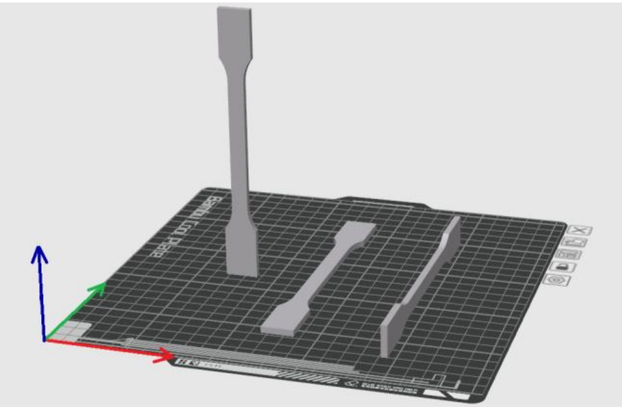

Figure 3. PLA test sample orientations in the Cartesian coordinate system

2.4 ISO 527-2

According to Rawabe Fatima Faidallah, the ISO 527-2 standard defines the testing parameters for extruded and molded Plastics and outlines the tensile properties of plastics. It specifies the specimen geometries suitable for tensile testing of various material types. Numerical analysis performed using the finite element method (FEM) revealed that higher stresses were localized in the narrow-gauge section of the specimens, away from the clamping points, while ISO 527-2 samples exhibited minimal to no stress concentrations near the gripping areas. These findings suggest that specimens prepared according to ISO 527-2 offer greater mechanical stability during tensile testing, making them well-suited for reliable strength evaluation. According to Faidallah et al. ISO 527-2 specimens exhibit greater stability during testing compared to other specimen types, as they are subjected to lower mechanical stress, resulting in more accurate and reliable measurements [Faidallah et al. 2023].

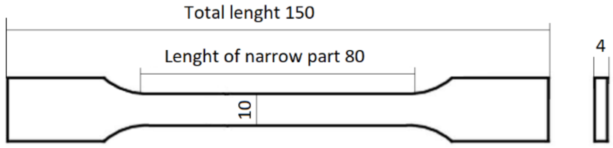

Figure. 4. Parameters of ISO 527-2

Based on the study of material testing by Aaron M. Forster, this work employs tensile test specimens designed according to the ISO 527-2 standard. ISO 527-2, an internationally recognized standard, specifically focuses on the tensile testing of plastics, providing comprehensive guidelines for the preparation, testing, and evaluation of mechanical properties. The adoption of ISO 527-2 in this study thus ensures methodological rigor and facilitates the generation of comparable and reproducible mechanical performance data for additively manufactured PLA-based materials [Forster 2015; Bajpai et al. 2019].

Forster reports that Ahn observed premature failure in ASTM D638 type I specimens due to stress concentrations near the gauge section, where the ends of printed filaments caused excessive shear [Ahn et al. 2002; Forster 2015].

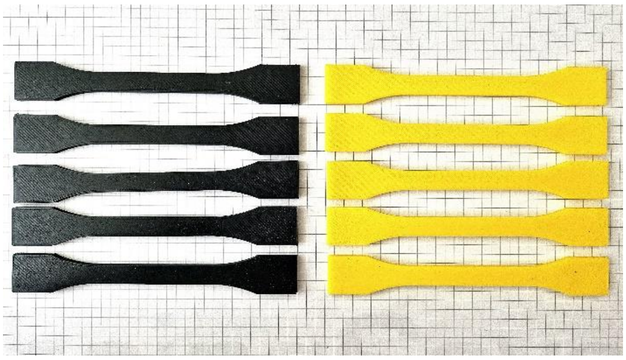

Figure 4. ISO 527-2 1B PLA BLASTER AND PLA JAYO

The ISO 527-2 Type 1B tensile test specimen is designed with a total length of 150 mm and a nominal thickness of 4 mm. Its geometry is specifically engineered to ensure uniform stress distribution within the narrow-gauge section, which has a width of 10 mm and a length of 80 mm. The gripping sections, located at both ends of the specimen, each measure 20 mm in width and provide the necessary interface for secure clamping during mechanical testing. A transition radius of R60 mm facilitates a smooth reduction in width from the gripping area to the gauge section, effectively minimizing stress concentrations and enhancing the reliability of test results. This specimen configuration adheres to standardized testing requirements and is widely utilized for the accurate determination of tensile properties in polymeric materials.

2.5 Testometric x350-5

One key area of focus is the strength analysis of products fabricated from additively strengthened PLA materials. In this study, mechanical testing was conducted using a tabletop, two-column, computer-controlled universal testing machine, the Testometric X350-5. This device is designed for a wide range of material testing applications, including tensile, compression, bending, cyclic loading, adhesion, shear, hardness, and spring tests. The Testometric X350-5 has a load capacity of 5 kN and allows a feed rate range from 0.00001 to 2000 mm/min, making it highly suitable for the controlled deformation of polymer specimens. Its dimensions (without jaws) are 1100 mm in height and 320 mm in width, and it offers a measurement range from 0.4% to 100% of the nominal load value, ensuring accurate force detection across a wide spectrum of loads. Control and data acquisition are performed through the WinTest Analysis software, a fully configurable platform that enables the definition of custom testing programs in accordance with ISO, EN, ASTM, and other international standards. The combination of precise mechanical control and advanced software integration ensures that testing conditions comply with the requirements necessary for reliable evaluation of the tensile properties of PLA-based materials produced FDM [Marticek et al. 2024].

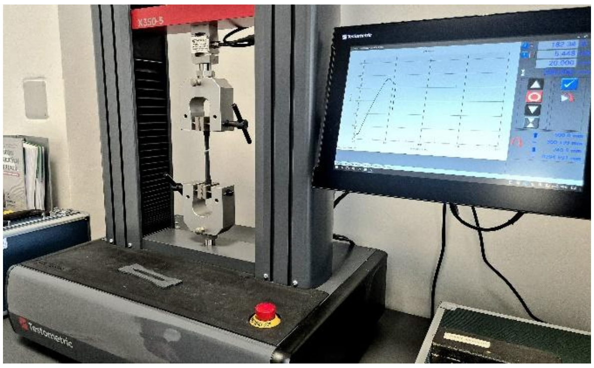

Figure 5. Testing PLA Blaster on Testometric x350-5

The PLA samples used in our tests were weighed immediately after performing the tensile test to minimize weight discrepancies that could arise from variations in moisture content. This procedure is crucial, as the moisture level can affect the weight of the samples and their mechanical properties, potentially leading to inaccuracies in the results. Additionally, I also utilized the laboratory scale KERN EG 420, like the equipment used in the study observing the drying process of maize. This scale is capable of weighing with an accuracy of 0.001 grams, ensuring precise measurements. By accounting for these factors, we aimed to ensure the accuracy and reliability of our measurements, which is essential for further evaluation and comparison of results [Vitazek a Veres 2013].

Figure 6. Weighting of PLA Blaster samples

3 RESULT AND DISCUSSION

The tensile testing research was conducted in the Laboratory of Technical Materials at the Faculty of Manufacturing Technologies, with seat in Prešov. During the tensile measurements of the ISO 527-2 1B samples, the laboratory maintained a room temperature of 21.5 °C, under which conditions the samples were also stored.

To improve first-layer adhesion and minimize warping, 3DLAC Original adhesive was applied to both the Cool Plate and Engineering Plate surfaces prior to printing. The printing of five test specimens made from additively modified PLA Blaster material took 1 hour and 14 minutes, with a final weight after tensile testing of 52.96 g. Printing five specimens from Generic PLA by JAYO required 1 hour and 28 minutes, resulting in a total weight of 54.11 g. Kingroon-branded Generic PLA specimens were printed in 1 hour and 17 minutes, with a combined weight of 51.41 g. The longest print time was recorded for ABS specimens, which took 1 hour and 39 minutes to complete, and their total post-test weight was 42.55 g. All samples were stored in the same laboratory environment where subsequent mechanical testing was conducted. For a direct and valid comparison between ABS and additively enhanced PLA materials, it is essential to evaluate all material types under consistent printing and testing conditions, as differences in composition, shrinkage behavior, and thermal stability significantly influence performance.

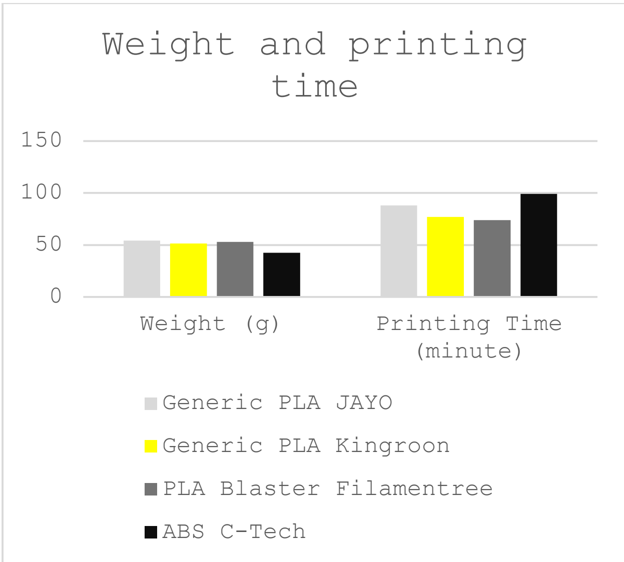

Figure 7. Comparison of the weight and printing time

Tensile testing was used to measure the mechanical qualities of the materials under test, and Table 1. summarizes the results of this study.

With the highest peak Force and Stress values among the materials examined, the PLA BLASTER specimens showed the best mechanical performance. The PLA BLASTER showed noticeably higher tensile strength than Generic PLA JAYO, showing the beneficial impact of material modification with additions. PLA BLASTER, however, showed greater brittle fracture behavior in tensile tests. Without any visible plastic deformation, the specimen quickly and completely separated, causing the collapse. The PLA JAYO and Kingroon PLA specimens, on the other hand, showed more ductile behavior, showing partial extension and necking before ultimate failure.

Test	Testing Material	Maximum Force (N)	Ultimate Tensile Strength (MPa)	Elong. Peak (mm)	Elongation at Break (%)
1	PLA JAYO	1935.5 (-16.67)	48.388 (-0.432)	4.16 (+0.196)	5.210 (+0.255)
2	PLA JAYO	1974.62 (+22.25)	49.365 (+0.545)	3.883 (-0.081)	4.853 (-0.102)
3	PLA JAYO	1940.08 (-12.69)	48.502 (-0.318)	3.864 (-0.1)	4.832 (-0.123)
4	PLA JAYO	1939.58 (-12,79)	48.489 (-0.331)	3.864 (-0.1)	4.832 (-0.123)
5	PLA JAYO	1974.08 (-21Pe.71)	49.352 (+0.532)	4.051 (+0.087)	5.063 (+0.108)
6	PLA Blaster	2384.21 (+49.36)	59.605 (+0.835)	4.335 (+0.107)	5.419 (+0.134)
7	PLA Blaster	2323.99 (-10.76)	58.1 (-0.67)	4.179 (-0.049)	5.224 (-0.061)
8	PLA Blaster	2366.15 (+31.04)	59.154 (+0.384)	4.276 (+0.048)	5.345 (+0.06)
9	PLA Blaster	2284.6 (-50.15)	57.115 (-1.165)	4.099 (-0.129)	5.124 (-0.161)
10	PLA Blaster	2314.8 (-19.95)	57.87 (+0.9)	4.25 (-0.022)	5.313 (+0.028
11	PLA Kingroon	2125.88 (-4.45)	53.147 (-0.113)	4.299 (+0.023)	5.373 (+0.029)
12	PLA Kingroon	2173.42 (+43.09)	54.335 (+1.075)	4.304 (+0.028)	5.381 (+0.037)
13	PLA Kingroon	2079.38 (-50.95)	51.984 (-1.276)	4.271 (-0.005)	5.339 (-0.003)
14	PLA Kingroon	1708.76 (-421.57)	42.719 (-10.541)	3.764 (-0.512)	4.706 (-0.638)
15	PLA Kingroon	2142.64 (+12.31)	53.566 (+0.306)	4.228 (0.048)	5.284 (-0.06)
16	ABS C-Tech	1486.83 (+34.59)	37.171 (+0.861)	3.865 (+0.166)	4.832 (+0.207)
17	ABS C-Tech	1466.47 (+14.23)	36.662 (+0.352)	3.724 (+0.025)	4.654 (+0.029)
18	ABS C-Tech	1414.93 (-37.31)	35.373 (-0.937)	3.727 (+0.028)	4.658 (+0.033)
19	ABS C-Tech	1386.51 (-66.23)	34.663 (-1.647)	3.602 (-0.097)	4.503 (-0.122)
20	ABS C-Tech	1506.44 (54.2)	37.661 (+1.351)	3.581 (-0.118)	4.476 (-0.149)

Table 1. Results of all Tension testing samples

Kingroon PLA filament was used for additional testing. The red color in Table 1 highlights the PLA Kingroon 14 sample where an operator error occurred during testing. A technical problem occurred during the testing of one Kingroon specimen; operator mistake caused the grips to loosen due to the grips not being properly tightened before the test. Since inaccurate measurements cannot be considered when evaluating statistics, the impacted specimen was not included in the computation of the average results. The remaining Kingroon specimens, however, offered consistent and trustworthy information for comparison. This explanation is also provided in the manuscript for clarity.

The average results for each material group confirmed that PLA BLASTER achieved the highest resistance to tensile forces, followed by Kingroon PLA and JAYO PLA.

To calculate the Ultimate Tensile Strength (MPa) during the tensile tests, the Maximum Force (N) and the cross-sectional area of each specimen were utilized. The relationship between stress and force is given by the following equation:

$$Stress_{\ Peak}(MPa) = \frac{Force\ (N)}{Cross\text{-}section\ Area\ (mm^2)} \qquad (1)$$

In our testing, PLA Blaster demonstrated the highest average strain values, ranging from 5.12% to 5.42%, confirming its ability to undergo greater deformation before failure. This suggests improved elasticity and potential for use in applications requiring more stretchability. PLA JAYO showed slightly lower strain values, between 4.83% and 5.21%, indicating moderate flexibility and a more gradual failure mode compared to PLA Blaster. Despite its higher stretch capacity, PLA Blaster tended to fail more abruptly—suggesting a brittle fracture behavior—whereas PLA JAYO showed more controlled deformation prior to failure. These differences in deformation behavior are reflected in Figure 8, where PLA Blaster exhibits both higher stress (up to 59 MPa) and strain, but with a sharper failure transition compared to the more ductile performance of Generic PLA.

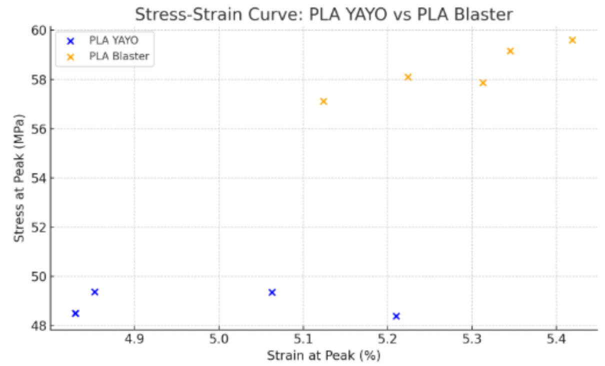

Figure 8. Tensile test of Generic PLA (YAYO) and ADDITIVELY STRENGTHENED PLA (Filamentree)

As shown in Figure 9, both PLA Kingroon and PLA Blaster reached comparable strain at peak values, ranging from 4.71% to 5.38% and 5.12% to 5.42%, respectively. While PLA Blaster exhibited higher stress at peak (up to 59.6 MPa) compared to Kingroon (averaging around 52–54 MPa), the failure mechanism differed significantly.

PLA Blaster, despite its enhanced tensile strength, displayed a more brittle failure behavior, failing abruptly at peak strain. In contrast, PLA Kingroon, although slightly weaker in terms of peak stress, demonstrated a more ductile response with a more gradual material failure.

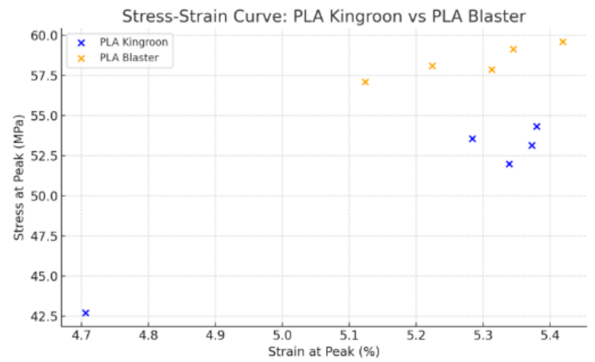

Figure 9. Tensile test of Generic PLA (Kingroon) and ADDITIVELY STRENGTHENED PLA (Filamentree)

This suggests that while additively strengthened PLA Blaster is mechanically superior in strength, its tendency toward brittle fracture under load may limit its use in applications requiring controlled deformation or energy absorption. Generic PLA Kingroon presents a more balanced mechanical profile, offering reasonable strength with better post-yield flexibility.

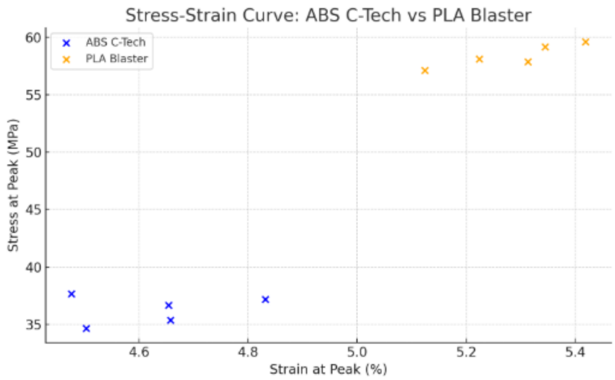

Figure 10. Tensile test of ABS C-tech and ADDITIVELY STRENGTHENED PLA (Filamentree)

As illustrated in Figure 10, ABS C-Tech reached peak stress values in the range of 34.7–37.7 MPa, with corresponding peak strain values of 4.48–4.83%. In contrast, PLA Blaster exhibited significantly higher peak stress levels, reaching up to 59.6 MPa, while maintaining a comparable strain at peak in the range of 5.12–5.42%.

4 CONCLUSIONS

The results of this research confirm the superior mechanical properties of PLA Blaster, an additive-enhanced filament produced by Filamentree. This material meets the requirements for higher strength while maintaining high-quality standards within the PLA category. During testing, PLA Blaster demonstrated excellent printability, with no issues or defects observed during the printing process. Its relatively easy printability, combined with higher resistance and the ability to withstand temperatures exceeding 110°C, positions this additive-enhanced PLA as a viable competitor to materials in other filament categories. In addition to its excellent performance, PLA Blaster is environmentally friendly, with low emissions during production compared to other materials.

Filamentree's use of high-quality polymers from NatureWorks LLC, a leading American producer, as the base material for PLA Blaster, ensures exceptional mechanical performance and reliability. The test results show that PLA Blaster outperforms other materials in terms of peak force and stress, as illustrated in Table 2, where PLA Blaster demonstrates the highest values for both peak force and stress. This study also compared PLA JAYO, PLA Kingroon, and PLA Blaster. It was found that while PLA JAYO exhibited significant ductility with greater elongation before failure, PLA Blaster showed a more brittle failure mode despite its higher elongation capacity. In contrast, Generic PLA Kingroon provided a balanced performance, offering a compromise between flexibility and brittleness, making it a suitable middle ground. Typically, PLA is not used for applications requiring high thermal resistance due to its relatively low heat tolerance. However, PLA Blaster's thermal resistance is approximately double that of standard PLA, eliminating the need to use materials like PETG, ABS, or ASA for applications requiring high thermal performance. This makes PLA Blaster a highly attractive alternative for applications that demand both strength and heat resistance, all while maintaining the environmental benefits of PLA. A similar study on PLA tensile strength testing was conducted by Dhinesh S.K. et al., who examined various PLA/ABS blends. Their results showed that the composition with 80% PLA and 20% ABS achieved the highest tensile strength, with an *extension at break* value of 6.74632 mm. However, the addition of ABS results in a loss of biodegradability and increased environmental burden, as ABS is a petroleum-based plastic that does not degrade naturally and is more difficult to recycle. In contrast, the tested PLA Blaster sample in this study achieved an *extension at break* of 4.228 mm, while maintaining full biodegradability, low production emissions, and excellent printability. This demonstrates that PLA Blaster offers enhanced mechanical and thermal properties without compromising environmental responsibility. The data supports its potential to compete with more specialized filaments, highlighting its promising future in the 3D printing industry [Dhinesh et al. 2021].

This data clearly demonstrates that PLA Blaster not only outperforms ABS in tensile strength by a margin exceeding 50%, but also maintains similar or slightly improved ductility under tensile loading conditions. Despite ABS being known for better toughness, the tested specimens showed no notable elongation advantage over the PLA Blaster. From a structural design perspective, this indicates that PLA Blaster offers a viable alternative to ABS, particularly in applications where higher tensile load resistance and dimensional stability are critical.

Material	Maximum Force ((N)	Average Ultimate Tensile Strength (MPa)	Average Elongation Peak (mm)	Elongation at Break (%)
PLA JAYO	1952.37	48.82	3.964	4.955
PLA Blaster	2334.75	58.77	4.228	5.285
PLA Kingroon	2130.33	53.26	4.276	5.344
ABS C-Tech	1452.24	36.31	3.699	4.625

Table 2. Average parameters of Tension testing results

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