Journal of Advances in Manufacturing Engineering
Web page info: https://jame.yildiz.edu.tr
DOI: 10.14744/ytu.jame.2025.00012

Original Article

Tensile testing of polylactic acid (PLA) samples produced with a 3D printer and finite element analysis

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ARTICLE INFO

Article history
Received: 29 July 2025
Revised: 07 December 2025
Accepted: 08 December 2025

Key words:
3D printer, finite element analysis, PLA filament, tensile test.

ABSTRACT

Polylactic acid (PLA) is increasingly vital in 3D printing due to its sustainability and versatility in applications ranging from product packaging to medical implants. Ensuring its mechanical reliability under load is critical for expanding its industrial use. This study evaluated the mechanical properties of fully loaded samples produced from PLA filament using a 3D printer, through experimental tensile tests and finite element analysis (FEA). The samples were designed in accordance with the ASTM D638 Type I standard and fabricated using a 3D printer. Unlike prior studies, this work uniquely combines the ANSYS Explicit Dynamics module with the Johnson–Cook material model to simulate high-deformation behavior in fully loaded specimens, addressing gaps in the literature regarding comprehensive mechanical analysis of 3D printed PLA. Fracture zones were examined with a digital microscope. Experimental tensile tests on fully loaded PLA samples accurately simulated the stress distribution using FEA. These findings offer insights into optimizing 3D printing parameters to improve interlayer bonding, reduce defects, and enhance PLA's reliability in industrial applications.

Cite this article as: Turgut, Y. Y., Akıncıoğlu, S., & Akıncıoğlu, G. (2025). Tensile testing of polylactic acid (PLA) samples produced with a 3D printer and finite element analysis. *J Adv Manuf Eng*, 6(2), 111–120.

INTRODUCTION

3D printing, also known as additive manufacturing, is a rapidly developing technology [1–3]. This manufacturing method is based on the principle of melting the material and adding layers on top of each other to produce the object [4]. PLA, acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG) can be used as raw materials [5, 6]. PLA has attracted significant attention in recent years. The growing need for sustainable material solutions, in particular, has led PLA to emerge as a significant alternative in both research and applications. PLA material can be used in product packaging, medical applications such as implants, textile products, as a 3D printing raw material and many other applications [7–14]. However, for PLA material to be used safely, its behavior under load must be examined and defined. Therefore, tensile test results, either experimentally or using the finite element analysis, are important for determining the material's mechanical behavior [15]. FEA stands out as a powerful tool for evaluating the mechanical behavior of 3D printed parts. To enhance the reliability of sustainable materials, particularly PLA, in industrial applications, FEA precisely models stress distributions and deformations, providing results consistent with experimental tests [16]. This analysis enables the simulation of complex geometries and load conditions, contributing to design optimization and material strength prediction.

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Published by Yıldız Technical University Press, İstanbul, Türkiye

Kumar and Narayan [17] investigated the mechanical behavior of tensile test specimens made of PLA material in accordance with ASTM D638 Type IV. They compared the results with those obtained using the computer-aided analysis program ANSYS. They concluded that the results were consistent and that the maximum tensile strength was 54.46 MPa. Alharbi et al. [18] performed tensile tests using finite element analysis to simulate the mechanical properties of 3D printed PLA samples. They found that the resulting values deviated from the experimental values by 2% for yield strength and 6.7% for tensile strength. Özmen et al. [19] produced tensile test specimens from PLA material with different infill patterns and different raster angles. They selected grid, concentric, triangular, hexagonal, and zigzag infill patterns, and 0°, 45°, and 90° raster angles. When examining the tensile test results, they determined that higher strength was achieved in the concentric and zigzag patterned specimens with 90° raster angles. These studies establish FEA as a robust analysis for understanding the mechanical performance of 3D printed PLA; however, comprehensive analyses of fully loaded samples using advanced FEA modules such as Explicit Dynamics remain limited and this study aims to address this issue.

When the literature is reviewed, Ganeshkumar et al. [20] produced tensile test specimens with different infill patterns (hexagonal (honeycomb), gyroid, rhombile, circular, truncated octahedron) and infill ratios (20%, 40%, 60%, 80%) using PLA material via 3D printing. These specimens were subjected to tensile testing using experimental and finite element analysis. They investigated the effect of infill pattern and infill ratio parameters on the strength of PLA material. They concluded that the hexagonal infill pattern had better mechanical strength than the other infill patterns examined and that the strength improved as the infill ratio increased. Harpool et al. [21] investigated the effects of different infill patterns on mechanical properties using PLA material. They used tensile testing and finite element analysis in their study. They obtained the highest tensile strength with a hexagonal infill pattern. Auffray et al. [22] investigated the effects of parameters such as infill pattern, infill density, printing speed, and raster angles on mechanical properties using PLA. The experiments were conducted using the Taguchi design of experiments. They noted that the best strength was achieved with a triangular infill pattern, 50% infill density, printing speed of 3 m/min, and a 45° raster angle. They also concluded that layer height and extrusion temperature were less effective than other parameters. Brischetto and Torre [23] conducted compression and tensile tests using PLA material. The test results revealed that PLA exhibits different mechanical behavior in tension and compression. Evlen et al. [24] investigated the effect of infill ratio on mechanical properties using PLA and PET materials. They found that increasing the infill ratio increased the hardness and surface roughness of the materials. Kamer et al. [25] produced tensile test specimens from PLA and ABS materials at different printing speeds. They also conducted hardness and surface roughness tests. They found that as printing speed increased, hardness and tensile strength decreased in PLA samples, while surface roughness increased. When the same parameters were examined for ABS, no clear conclusions were reached. Aloyaydi et al. [26] subjected samples they produced using 3D printing in PLA material with different infill patterns to compression tests. The highest compressive strength was achieved with the grid pattern. Klossa et al. [27] conducted tensile tests using carbon fiber-reinforced nylon samples. The parameters used were carbon fiber content (0%, 10%, 15%, 20%) and infill angle (0°, 45°, 90°). The best results were obtained at a infill angle of 0° with 10% carbon fiber. Öztürk et al. [28] investigated the mechanical behavior of polycarbonate (PC) using both experimental and numerical analysis. They found that the highest strength was achieved at a 0° raster angle. They found the difference between the experimental and numerical results to be 11.98%, which they considered reasonable. In the literature, mechanical tests have been carried out on samples of many different materials produced by 3D printing method [29–34]. These studies establish FEA as a robust method for understanding the mechanical performance of 3D printed PLA; however, comprehensive analyses of fully loaded samples using advanced FEA modules such as Explicit Dynamics have been limited and this study aims to address this issue.

While the literature provides a rich foundation for understanding the mechanical properties of 3D printed PLA samples, it lacks areas such as the extensive use of fully loaded samples and finite element analysis. In this study, we conducted experimental and finite element analysis studies for tensile testing on fully loaded samples produced from 3D printed PLA filament. PLA samples were manufactured in accordance with the ASTM D638 Type I standard for rigid and semi-rigid materials. The ANSYS Explicit Dynamics module was used in the finite element analysis. Our study infills these gaps and makes a unique contribution from both scientific and practical perspectives. Analyses of fully loaded specimens and the integration of Explicit Dynamics and the Johnson-Cook model represent significant advances in better understanding the mechanical behavior of PLA and improving its reliability in industrial applications. By integrating experimental validation with advanced numerical simulations, this study offers significant scientific contributions to the literature and practical insights for enhancing the reliability of 3D printed PLA in industrial applications, paving the way for future research into optimized additive manufacturing processes.

MATERIALS AND METHODS

The workflow diagram for our study, which conducted tensile tests and finite element analyses using PLA filament, is shown in Figure 1. Tensile test specimens were 3D modeled in Solidworks 2024 for use in the production and analysis phases. The solid model was dimensioned in accordance with the ASTM D638 Type 1 standard [35], recommended for rigid and semi-rigid plastics. Figure 2 shows the sample dimensions according to the standard. The sample thickness was 3 mm.

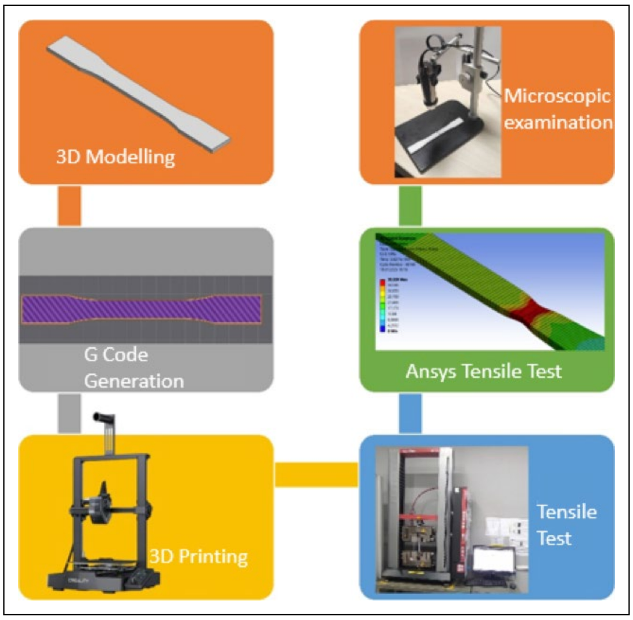

Figure 1. Workflow diagram.

G codes were obtained for the 3D modeled sample using the Creality Print slicing program. The slicing parameters prepared in the Creality Print program are listed in Table 1.

Samples with G codes were prepared using a 3D printer. The prints were obtained using a Creality brand Ender 3 V3 SE model 3D printer (origin: China) (Fig. 3).

Tensile tests of the samples were performed in accordance with the ASTM D638 standard on a Zwick/Roell Z010 tensile tester (Germany). The experimental setup for the tensile test is shown in Figure 4. Tensile tests were conducted at room temperature at a tensile speed of 5 mm/min. The Zwick/Roell Z010 tensile tester with a pneumatic gripper has a test height of 1050 mm, a maximum load capacity of 10 kN, and high-precision measurement with a deviation of 0.5%.

To validate the experimental data and avoid the need for further experiments in future studies, tensile tests were performed in a computer environment using Ansys 2024 R2. The Johnson-Cook material model was used to accurately reflect the plastic deformation and material behavior occurring in the tensile test. The Johnson-Cook material model is preferred in situations with high plastic deformation, such as machining, explosion, and impact. Table 2 shows the Johnson-Cook parameters for PLA material [36, 37].

Table 1. Slicing parameters

Parameters	Values	Unit
Filament type	PLA	
Infill pattern	Grille	
Infill density	100	%
Raster angle	45	°
Layer height	0.2	mm
Wall thickness	0.8	mm
Nozzle diameter	0.2	mm
Print temperature	190	°
Table temperature	50	°
Print speed	180	mm/s

PLA: Polylactic acid.

Table 2. Johnson-Cook parameters [38]

Johnson-Cook parameters	Values
Initial yield stress	40.16 MPa
Hardening constant	16.55 MPa
Hardening exponent	0.374
Strain Rate constant	0.05

Table 3. Information about the mesh structure

Properties	Value	Unit
Element Quality (Average)	0.96	
Element size	1	mm
Nodes	13040	
Elements	9234	

The boundary conditions and mesh structure defined in the Ansys program on the tensile test specimen are shown in Figure 5. The specimen was fixed in the blue section (A). A perpendicular displacement was applied to the specimen section in the yellow section (B). Information on the mesh structure is given in Table 3.

The mesh was generated using tetrahedral elements. The element type used in ANSYS Explicit Dynamics is SOLID168, a 10-node quadratic tetrahedron element suitable for large deformation and explicit analysis.

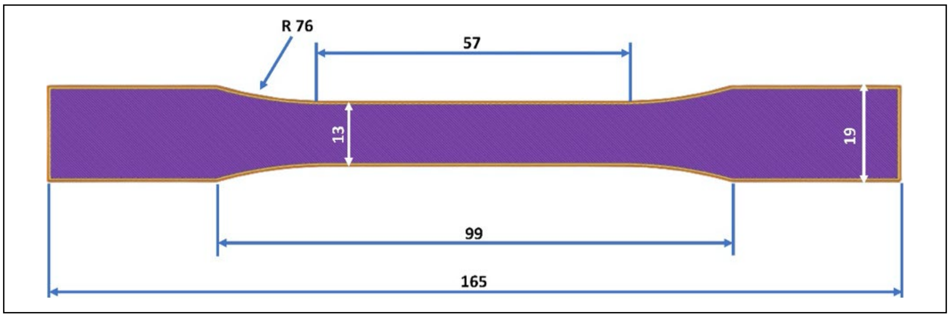

Figure 2. Sample dimensions according to ASTM D638 Type 1 standard.

Figure 3. Obtaining samples using a 3D printer.

A Dino-Lite brand digital microscope (origin Taiwan) was used to examine the fractured areas of the samples (Fig. 6). Images of the fractured areas were obtained using Dino-Lite software.

RESULTS AND DISCUSSION

Table 4 shows the experimental and FEA results of tensile tests performed on fully loaded samples made from PLA (polylactic acid) filament produced with a 3D printer. The table compares the tensile strength values obtained from the experimental and FEA.

According to the data in the table, both the experimental and FEA results are close to each other. Specifically, a tensile strength of around 38 MPa was observed. This reflects the expected mechanical properties of the PLA material. Furthermore, the Explicit Dynamics module used in the FEA is considered a suitable analysis for simulating the dynamic behavior of the material. The standard deviations of the experimental results were calculated according to Formula (1).

Table 4. Comparison of experimental and FEA tensile strength

	Experimental tensile strength values (MPa)	FEA tensile strength values (MPa)
PLA 1	34.845	38.639
PLA 2	37.943	38.639
PLA 3	38.445	38.639
PLA 4	38.126	38.639
Average	37.340	38.639

Table 5. Comparison of experimental and FEA yield strength

	Experimental yield strength values (MPa)	FEA yield strength values (MPa)
PLA 1	29.565	32.773
PLA 2	32.962	32.773
PLA 3	29.629	32.773
PLA 4	32.727	32.773
Average	31.221	32.773

FEA: Finite element analysis.

Standard deviation (σ) measures how far the data deviates from the mean. Its formula is:

$\sigma = \sqrt{[\Sigma(xi - \mu)^2 / N]}$ Formula (1)

Here:
σ: Standard deviation
xi: Each data point
μ: Average
N: Number of data

Confidence interval $= \mu \pm \left(t \text{ x } \frac{\sigma}{\sqrt{n-1}}\right)$ Formula (2)

Here:
μ: Sample mean
t: Degrees of freedom, df = n - 1
σ: Sample standard deviation
n: Sample size
$\frac{\sigma}{\sqrt{n}}$: Standard error

Experimental tensile strenght average ve standard deviation;

Average: 37.340

Standard Deviation: ≈ 1.676

Confidence interval (t-value (n=4, df=3. %95 confidence level) ≈ 34.673 MPa – 40.007 MPa

Margin of Error≈ 2.667%

The experimental tensile test results for PLA samples show a mean of 37.340 MPa and a standard deviation of 1.676 MPa, indicating consistent data. The 95% confidence interval ranges from 34.673 MPa – 40.007 MPa, suggesting that the true mean likely falls within this range. The margin of error of 2.667% indicates minimal deviation from the mean, confirming the reliability of the experimental results.

The tensile test FEA result is approximately 1.299 MPa higher than the experimental average, with an error rate of 3.48%. This indicates that the FEA exhibits little devia-

Figure 4. Tensile test experimental setup.

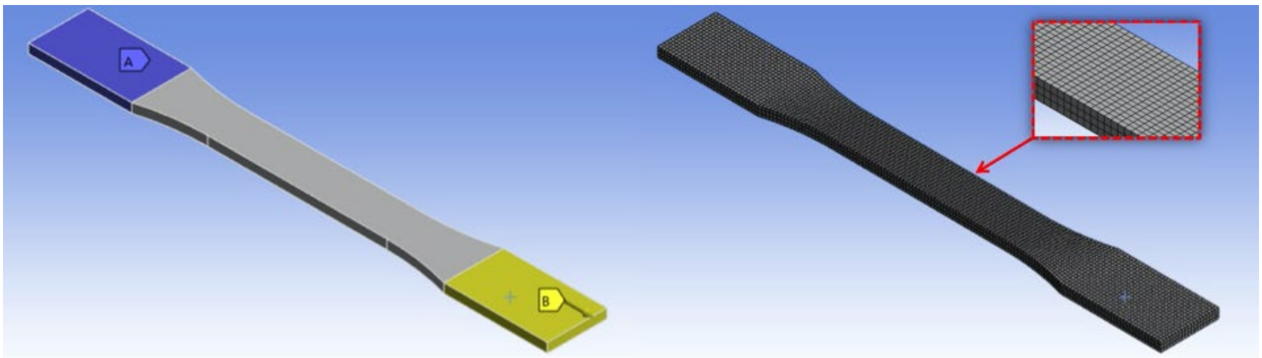

Figure 5. Boundary conditions and mesh image of the test sample.

tion compared to the experimental results and is generally consistent. This study, which used experimental and tensile FEA, achieved successful results in verifying the tensile strength of PLA materials using both experimental and numerical analysis. It can be said that the ANSYS Explicit Dynamics module offers a reliable approach in tensile test analyses, especially since the FEA results are in great agreement with the experimental results.

Table 5 shows the experimental and FEA yield strength results obtained from tensile tests on four different fully loaded samples produced from PLA filament using a 3D printer.

Yield strength represents the maximum stress a material can withstand before beginning plastic deformation and is measured here in MPa. Experiments revealed a yield strength of 30 MPa for PLA1 and PLA3, 33 MPa for PLA2 and PLA4. This suggests that differences between samples may be due to manufacturing or testing conditions. Based on Finite Element Analysis (FEA), the yield strength was calculated as a constant value of 32.773 MPa for all samples. The Finite Element Analysis (FEA) yield strength results are higher than the experimental results for PLA1, PLA3 and PLA4, but slightly lower than for PLA2. Overall, the differences are within an acceptable range (ranging from 0.14% to 10.85%), indicating that FEA is generally reliable, despite showing deviations in samples with manufacturing defects.

Experimental yield strength means and standard deviation values;

Average: 31.221 MPa

Standard Deviation: ≈ 1.877 MPa

Confidence Interval: 28.235 MPa-34.207 MPa

Margin of Error (percentage) ≈ 9.57 %

Yield strength standard deviation results show that the yield strength values of the samples vary from the mean by

Figure 6. Dino-Lite Digital microscope.

±1.877 MPa. The yield strength values clustered into two distinct groups (approx. 30 MPa and 33 MPa). The high consistency within these groups contributed to the reliable data distribution, despite the slight variation between the groups.The Margin of Error indicates a deviation of ±9.57% from the mean. This is acceptable for this type of experimental study. The confidence interval indicates that the average yield strength of the samples could be between 28.235 MPa and 34.207 MPa for the material. The margin of error indicates that the results are reliable with a moderate degree of deviation. The yield test FEA result is approximately 1.552 MPa higher than the experimental average, with an error rate of 4.97%. This indicates that the FEA exhibits little deviation compared to the experimental results and is generally consistent.

Figure 7 shows the experimentally obtained tensile test curves, and Figure 8 shows the tensile test curve obtained with FEA.

Figure 9 shows images of the fracture zones of PLA samples resulting from tensile tests. The fracture surface and surrounding deformation characteristics were analyzed for each sample. Polymeric materials such as PLA generally exhibit brittle fracture behavior; however, due to 3D printing layers, delamination or voids can occur at the fracture surface. The fracture surface of PLA1 appears rough. There is significant delamination between the layers, and small voids are observed at the fracture site. PLA1 exhibited lower tensile strength (34.845 MPa) and yield strength (29.565 MPa) than the other samples. The higher tensile strength of PLA2 indicates that the material has a more homogeneous

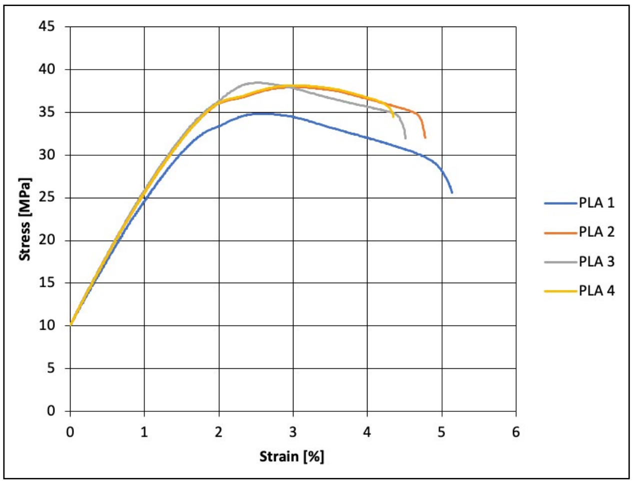

Figure 7. Experimental stress-strain curve.

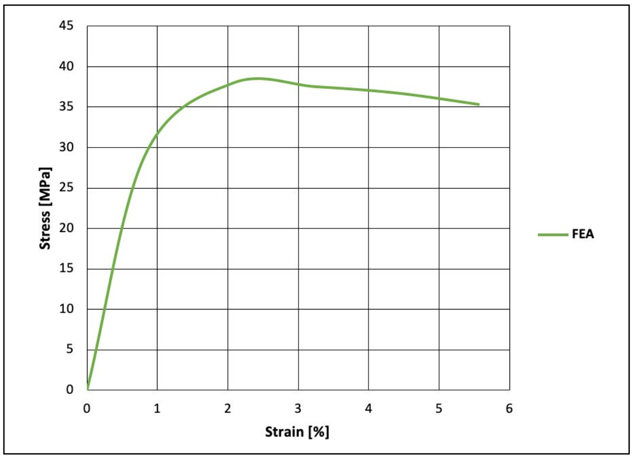

Figure 8. FEA stress-strain curve.

structure and better stress distribution. The layer separation and voids seen in the PLA3 microscope image caused the sample to yield prematurely. However, its high tensile strength indicates that the material can sustain the stress for some time after yielding. This indicates that the sample has localized weaknesses in its internal structure but is generally durable. In PLA4, the microscope image shows strong interlayer bonds and minimal separation.

Layer separation seen in the microscope image indicates a weak bond within the sample's internal structure and insufficient fusion between layers. This can be caused by factors such as low temperature, rapid cooling, or insufficient extrusion during 3D printing. Furthermore, voids reduce the material's strength.

PLA is generally a brittle material, and the images show brittle fracture characteristics (irregular fracture surfaces, cracks) rather than ductile fracture. However, delamination (delamination) at the fracture surface due to the 3D printing layers plays a prominent role.

The FEA results (32.773 MPa for yield, 38.639 MPa for tensile) are generally higher than the experimental results. Microscope images show defects (voids, delamination) not considered in the FEA. These defects are the main reason why the experimental results are lower than the FEA results.

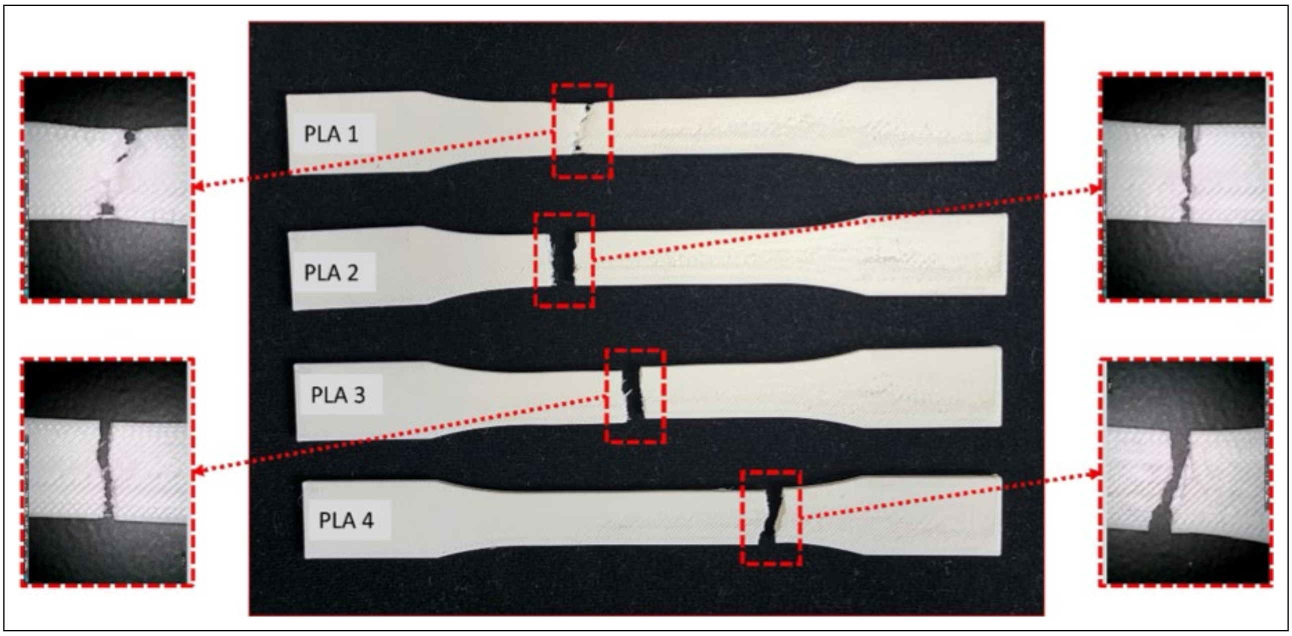

Figure 9. Experimental tensile strength resuts stereo microscop images.

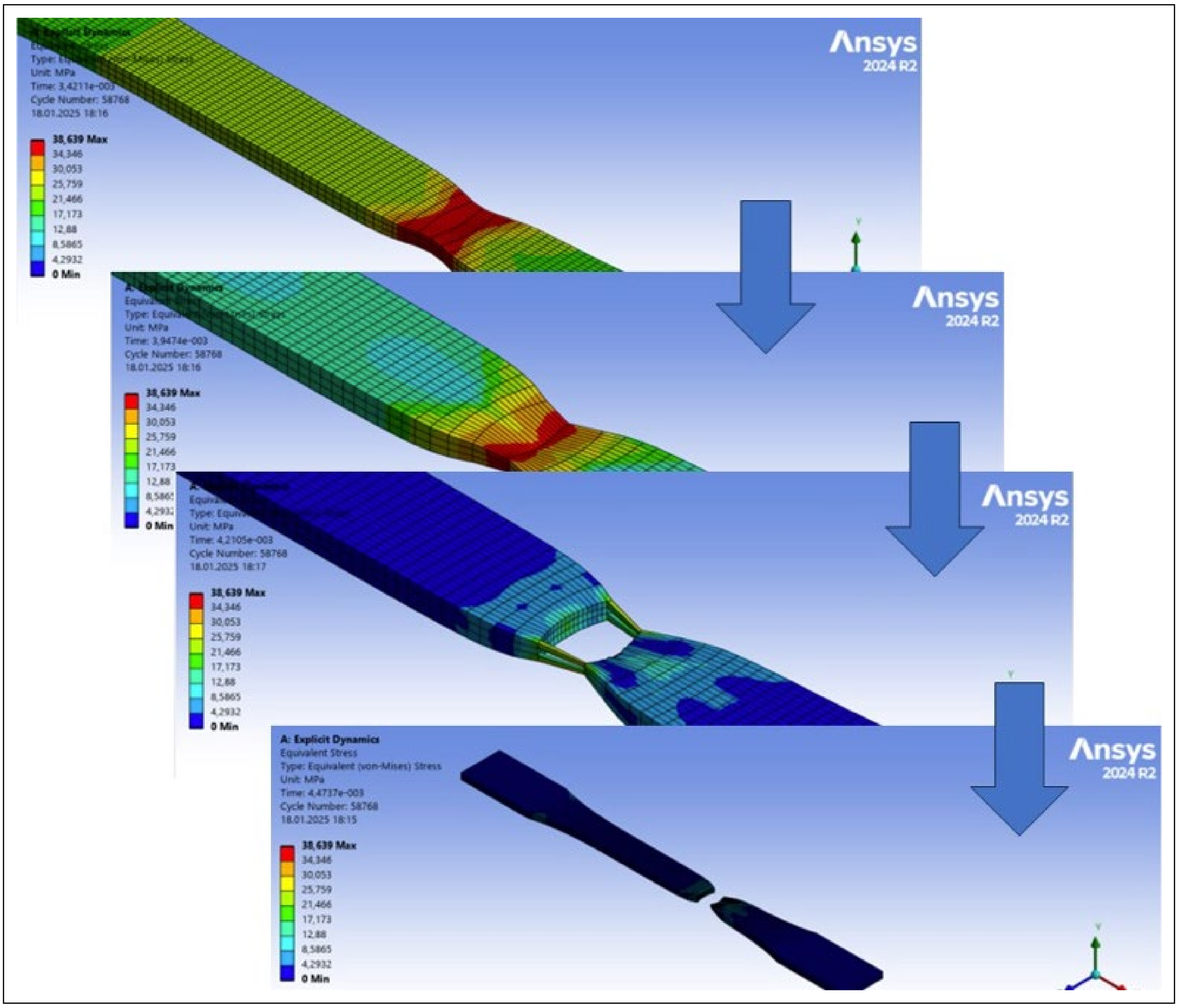

Figure 10. FEA image tensile strenght.

Figure 10 shows the stress distributions of the samples during tensile testing from FEA performed with ANSYS. The same model was used for all samples in the finite element analysis. In the color scale, blue regions represent low stress (0-5 MPa), and red regions represent high stress (36-38.639 MPa). The stress concentration is maximum in the central portion of the specimens (the contraction region), as expected in tensile testing. Fracture typically occurs in this region, where the stress is highest. The ANSYS images clearly show the stress concentration in the contraction region of the specimens. This confirms that the fracture occurred in this region in the microscope images.

The fracture characteristics observed in the PLA samples revealed brittle fracture characteristics in 3D printed PLA samples, with delamination, rough surfaces, and voids primarily resulting from interlayer bonding issues. These brittle fracture features and interlayer delamination observations are also in good agreement with the fracture surface analyses reported by Bacak et al. on FDM-printed PLA specimens produced with different process parameters and infill geometries [33, 34]. Tensile tests using digital image correlation on FDM-printed PLA samples reported similar rough fracture profiles and delamination, attributing these to manufacturing parameters such as infill density and printing speed. They noted a decrease in overall ductility and an increase in brittle behavior. This is consistent with our findings that voids and delamination led to premature yielding in PLA1 and PLA3, while PLA2 and PLA4 exhibited stronger bonds and higher strength. Furthermore, studies of tensile and fracture properties, influenced by parameters such as raster angle and layer height, demonstrate the dependence on print quality. Looking at the experimental and FEA results, the average tensile strength of 37.340 MPa and yield strength of 31.221 MPa are within the commonly reported ranges for 3D printed PLA. This has been seen in extensive characterizations of PLA composites, where variations infillers and additives yield similar mechanical properties. The low error rates between experimental and FEA results (2.667% for tensile strength, 4.97% for yield) support previous comparisons showing 2–6.7% deviations in yield and tensile strengths [18] and stress-strain curve fits with deviations below 5% for architectural cellular PLA composites. These fits validate the use of the Johnson-Cook model in Explicit Dynamics for high-deformation simulations and highlight the need to include microscopic defects such as voids in future FEA models.

CONCLUSION

The present study investigated the tensile behavior of 3D-printed PLA specimens produced with 100% infill according to ASTM D638 Type I standard using both experimental tests and finite element analysis with ANSYS Explicit Dynamics.

The key findings are as follows:

- The average experimental ultimate tensile strength was 37.340±1.676 MPa and the yield strength was 31.221±1.877 MPa.
- FEA using the Johnson–Cook material model in Explicit Dynamics module predicted an ultimate tensile strength of 38.639 MPa and a yield strength of 32.773 MPa, with deviations of 3.48% and 4.97%, respectively, from the experimental mean values.
- The Explicit Dynamics approach successfully simulated stress distribution and correctly predicted the fracture location in the gauge section.
- Microscopic examination of fracture surfaces revealed brittle fracture characteristics accompanied by interlayer delamination and voids, which explain the slightly lower experimental strengths compared to FEA results.

These results confirm that ANSYS Explicit Dynamics combined with the Johnson–Cook model is a reliable tool for predicting the tensile behavior of fully infilled 3D-printed PLA parts. The findings contribute to improving the confidence in using PLA in load-bearing applications through better understanding and optimization of printing parameters.

Data Availability Statement

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

Author's Contributions

Yunus Zübeyir Turgut: Analysis, Writer, Data Collection, Critical Review.

Sıtkı Akıncıoğlu: Supervision, Conseption, Writer, Design.

Gülşah Akıncıoğlu: Literatür Review, Writer, Critical Review.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Statement on the Use of Artificial Intelligence

The authors acknowledge the use of Scite for assistance in drafting parts of the introduction and ensuring language clarity.

Ethics

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Chadha, U., Abrol, A., Vora, N. P., Tiwari, A., Shanker, S. K., & Selvaraj S. (2022). Performance evaluation of 3D printing technologies: a review, recent advances, current challenges, and future directions. *Progress in Additive Manufacturing, 7*(5), 853-886. [CrossRef]

[2] Aslan, E., & Akıncıoğlu, G. (2024). Investigation of the wear and friction profile of TPU-based polymers at different infill ratios. *International Journal of Automotive Science and Technology, 8*(1), 125-131. [CrossRef]

[3] Akıncıoğlu, G., Şirin E., & Aslan, E. (2023). Tribological characteristics of ABS structures with different infill densities tested by pin-on-disc. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 237*(5), 1224-1234. [CrossRef]

[4] Shahrubudin, N., Lee, T. C., & Ramlan, R. J. P. (2019). An overview on 3D printing technology: Technological, materials, and applications. *Procedia Manufacturing, 35*, 1286-1296. [CrossRef]

[5] Iftekar, S. F., Aabid, A., Amir, A., & Baig, M. (2023). Advancements and limitations in 3D printing materials and technologies: a critical review. *Polymers, 15*(11), Article 2519. [CrossRef]

[6] Toktaş, I., & Akıncıoğlu, S. (2025). Investigation of tribological properties of industrial products with different patterns produced by 3D printing using polylactic acid. *Rapid Prototyping Journal, 31*(2), 371-378. [CrossRef]

[7] Jiménez, L., Mena, M. J., Prendiz, J., Salas, L., & Vega-Baudrit, J. (2019). Polylactic acid (PLA) as a bioplastic and its possible applications in the food industry. *Journal of Food Science&Nutrition, 5*(2), 2-6. [CrossRef]

[8] Abd Alsaheb, R. A., Aladdin, A., Othman, N. Z., Abd Malek, R., Leng, O. M., Aziz, R., & El Enshasy, H. A. (2015). Recent applications of polylactic acid in pharmaceutical and medical industries. *Journal of Chemical and Pharmaceutical Research, 7*(12), 51-63.

[9] Avinc, O., & Khoddami, A. (2009). Overview of poly (lactic acid)(PLA) fibre: Part I: production, properties, performance, environmental impact, and end-use applications of poly (lactic acid) fibres. *Fibre Chemistry, 41*(6), 391-401. [CrossRef]

[10] Arockiam, A. J., Subramanian, K., Padmanabhan, R. G., Selvaraj R., Bagal D. K., & Rajesh S. (2022). A review on PLA with different fillers used as a filament in 3D printing. *Materials Today: Proceedings, 50*(5), 2057-2064. [CrossRef]

[11] Hussain, M., Maqsood Khan, S., Shafiq, M., & Abbas, N. (2024). A review on PLA-based biodegradable materials for biomedical applications. *Giant, 18*, Article 100261. [CrossRef]

[12] Aslan, E., & Akıncıoğlu, G. (2026). *3D printing in automotive component development*, in Sustainable Composites for Automotive Engineering (p. 321-338). Elsevier. [CrossRef]

[13] Şirin, Ş., Aslan, E., & Akincioğlu, G. (2023). Effects of 3D-printed PLA material with different filling densities on coefficient of friction performance. *Rapid Prototyping Journal, 29*(1), 157-165. [CrossRef]

[14] Akıncıoğlu, G., & Aslan, E. (2021). Investigation of tribological properties of amorphous thermoplastic samples with different filling densities produced by an additive manufacturing method. *Gazi Journal of Engineering Sciences, 8*(3), 540-546. [CrossRef]

[15] Pezer, D., Vukas, F., & Butir, M. (2022). Experimental study of tensile strength for 3D printed specimens of HI-PLA polymer material on in-house tensile test machine. *Technium, 4*(1), 197-206. [CrossRef]

[16] Ayrilmis, N., Kariz, M., Heon Kwon, J., & Kuzman, M. K. (2019). Effect of printing layer thickness on water absorption and mechanical properties of 3D-printed wood/PLA composite materials. *The International Journal of Advanced Manufacturing Technology, 102*(5), 2195-2200. [CrossRef]

[17] Anand Kumar, S., & Shivraj Narayan, Y. (2019). Tensile testing and evaluation of 3D-printed PLA specimens as per ASTM D638 type IV standard. In *Innovative Design, Analysis and Development Practices in Aerospace and Automotive Engineering (I-DAD 2018) Volume 2*. Chennai, India. [CrossRef]

[18] Alharbi, M., Kong, I., & Patel, V. I. (2020). Simulation of uniaxial stress-strain response of 3D-printed polylactic acid by nonlinear finite element analysis. *J Applied Adhesion Science, 8*(5), 1-10. [CrossRef]

[19] Özmen, Ö., Sürmen, H. K., & Sezgin A. (2023). The effect of infill pattern in 3-dimensional printing on tensile strength. *Journal of Engineering Sciences and Design, 11*(1), 336-348. [CrossRef]

[20] Ganeshkumar, S., Dharani Kumar, S., Magarajan, U., Rajkumar, S., Arulmurugan, B., Sharma, S., Li, C., Ilyas, R. A., & Badran, M. F. (2022). Investigation of tensile properties of different infill pattern structures of 3D-printed PLA polymers: analysis and validation using finite element analysis in ANSYS. *Materials, 15*(15), Article 5142. [CrossRef]

[21] Harpool, T. D., Alarifi, I. M., Alshammari, B. A., Aabid, A., Baig, M., Malik, R. A., Sayed, AM., Asmatulu, R., & Ali EL-Bagory, T. M. A. (2021). Evaluation of the infill design on the tensile response of 3D printed polylactic acid polymer. *Materials, 14*(9), Article 2195. [CrossRef]

[22] Auffray, L., Gouge, P.-A., & Hattali, L. (2022). Design of experiment analysis on tensile properties of PLA samples produced by fused filament fabrication. *The International Journal of Advanced Manufacturing Technology, 118*, 4123-4137. [CrossRef]

[23] Brischetto, S., & Torre, R. (2020). Tensile and compressive behavior in the experimental tests for PLA specimens produced via fused deposition modelling technique. *Journal of Composites Science, 4*(3), Article 140. [CrossRef]

[24] Evlen, H., Özdemir, M. A., & Çalışkan, A. (2019). Effects of filling percentage on mechanical properties of PLA and PET materials. *Journal of Polytechnic, 22*(4), 1031-1037. [Turkish] [CrossRef]

[25] Kamer, M. S., Temiz, Ş., Yaykaşlı, H., Kaya, A., & Akay, O. E. (2022). Comparison of mechanical properties of tensile test specimens produced with ABS and PLA material at different printing speeds in 3D printer. *Journal of the Faculty of Engineering Architecture of Gazi University, 37*(3), 1197-1211. [CrossRef]

[26] Aloyaydi, B., Sivasankaran, S., &. Mustafa, A. (2020). Investigation of infill-patterns on mechanical response of 3D printed poly-lactic-acid. *Polymer Testing, 87*, Article 106557. [CrossRef]

[27] Klossa, C. M., Chatzidai, N., & Karalekas, D. (2023). Tensile properties of 3D printed carbon fiber reinforced nylon specimens. *Materials Today: Proceedings, 93*, 571-574. [CrossRef]

[28] Öztürk, F. H., Marques, E. A. S., Carbas, R. J. C., & da Silva, L. F. M. (2024). Experimental and numerical study on mechanical behavior of 3D printed adhesive joints with polycarbonate substrates. *Journal of Applied Polymer Science, 141*(29), Article e55657. [CrossRef]

[29] Bacak, S. (2022). Investigation of the tensile strength properties of samples produced using different parameters from ABS, PLA, TPU(Flex) materials. *Journal of Yekarum, 7*(2), 58-64.

[30] Alarifi, I. M. (2023). Mechanical properties and numerical simulation of FDM 3D printed PETG/carbon composite unit structures. *Journal of Materials Research Technology, 23*, 656-669. [CrossRef]

[31] Akhoundi, B., Behravesh, A. H., & Bagheri Saed, A. (2019). Improving mechanical properties of continuous fiber-reinforced thermoplastic composites produced by FDM 3D printer. *Journal of Reinforced Plastics Composites, 38*(3), 99-116. [CrossRef]

[32] Shakor, P., Sanjayan, J., Nazari, A., & Nejadi, S. (2017). Modified 3D printed powder to cement-based material and mechanical properties of cement scaffold used in 3D printing. *Construction Building Materials, 138*, 398-409. [CrossRef]

[33] Bacak, S., Özkavak, H. V., & Sofu, M. M. (2021). Comparison of Mechanical Properties of 3D-Printed Specimens Manufactured Via FDM with Various Inner Geometries. *Journal of the Institute of Science and Technology, 11*(2), 1444-1454. [CrossRef]

[34] Bacak, S., Özkavak, H. V., & Tatlı, M. (2021). Investigation of the effect of processing parameters on tensile properties of PLA samples produced by FDM method. *Mühendislik Bilimleri ve Tasarım Dergisi, 9*(1), 209-216. [Turkish]. [CrossRef]

[35] Sola, A., Chong, W. J., Simunec, D. P., Li, Y., Trinchi, Y., Kyraatzis, I. L., & Wen, C. (2023). Open challenges in tensile testing of additively manufactured polymers: A literature survey and a case study in fused filament fabrication. *Polymer Testing, 117*, 107859. [CrossRef]

[36] Sirigiri, V.K.R., Gudiga, V. Y., Gattu, U. S., Suneesh, G., & Buddaraju, K. M. (2022). A review on Johnson Cook material model. *Materials Today: Proceedings, 62*, 3450-3456. [CrossRef]

[37] Burley, M., Campbell, J. E., Dean, J., & Clyne, T. W. (2018). Johnson-Cook parameter evaluation from ballistic impact data via iterative FEM modelling. *International Journal of Impact Engineering, 112*, 180-192. [CrossRef]

[38] Pyka, D., Słowiński, J. J., Kurzawa, A., Roszaki, M., Stachowicz, M., Kazimierczak, M., Stępczak, M., & Grygier, D. (2024). Research on basic properties of polymers for fused deposition modelling technology. *Applied Sciences, 14*(23), Article 11151. [CrossRef]