# Finite Element Analysis of 3D Printed Sustainable Polylactic Acid (PLA) Square Blocks

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**Abstract.** The processing of eco-friendly materials and goods from sustainable resources is becoming more and more important worldwide; the production of bioplastics is expected to expand by 30% annually. By building materials layer by layer, additive manufacturing (AM) processes like fused deposition modeling (FDM) have the potential to lower greenhouse gas emissions and pollution from plastics. This study endeavors to bridge the space between technique of additive manufacturing and structural engineering principles, offering a complete analysis framework for assessing the viability and performance of 3-d printed PLA square block below varying operational conditions. The purpose of this study is to provide a complete analysis of the structural assessment of a Polylactic Acid (PLA) square block on applied significant loads in vertical as well as horizontal direction, revealing important findings about its deformation and stress distribution. Deformations were referred to inside the block, and strain various notably between layers. Furthermore, this become recognized because the most prone point for structure failure in the analysis, based totally on its fatigue assessment. Moreover, the study examined the structural analysis parameters, which highlighted fatigue-induced screw ups inside the block's design lifestyles at important factors. PLA materials beneath similar stress situations can gain from these insights for his or her layout and protection.

**Keyword-:** 3D printing, PLA, square blocks, CFD simulation, manufacturing.

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# 1 Introduction

The development of additive manufacturing (AM) in 1986 revolutionized manufacturing. Fused deposition modeling (FDM) is a popular 3D printing technique for complex geometric objects. Nozzles used to extrude polymeric materials and assemble them into 3D objects as FDM performs material extrusions. Because it can create complex designs by layering the desired shape over an already laid layer and controlling the temperature, this approach is becoming more and more popular in the industry [1]. 3D printing now enables the development of unique products such as biotechnology or biomedical solutions that are rapidly developed and tailored to individual patients [2-5]. It allows tissue preparation for individual patients and high print resolution. Commonly used materials like PLA and ABS, however, might not be able to produce low surface roughness or the necessary mechanical qualities [6-8]. Due of PLA's shape memory, heat treatment can cause an item to distort and then regenerate. PLA is recommended because of its affordability, biocompatibility, and simplicity of printing, even though alternative 3D printing polymers have shape-memory qualities as well [99-10]. The pieces produced by standard 3-D printers using fused filament fabrication (FFF) are made of thermopolymers, like polylactic acid (PLA). A fresh selection of PLA composites with metal bases is now accessible, offering a unique array of possible engineering materials for these kinds of 3-D printers. There is currently a dearth of material data on these composites, particularly in terms of thermodynamic property assessment. Consequently, these materials cannot be used to functionally designed systems [11-13]. A finite element analysis (FEA) model for internal partial discharge (PD) in solid dielectrics' air-filled cylindrical gaps is presented in [14-17]. Allografts as well as autografts are now the gold standard for treating bone lesions; nonetheless, they have drawbacks such as infection risk and morbidity [18-19]. For reconstruction of bones, synthetic grafts and scaffolds show promise, and fused deposition modeling is a useful technique for creating intricate forms. A research assessed whether PLA/nanoHA composites could be manufactured using 3D printing, verifying the nano HA content of the composites and enhancing PLA mechanical characteristics while maintaining rheological performance [20-22]. Experiments are used in the model's development to estimate parameters and forecast PD behavior in scenario two. The results demonstrate a reasonable degree of agreement regarding the recorded and anticipated PD activities, indicating that PD behavior may be accurately predicted using simulation, which is a time- and money-efficient method of evaluating the dependability of insulating systems [23]. Both case studies may be used with the model. The design of porous scaffolds with tetragonal, hexagonal, and wheel-like structures was the main goal of [24]. Three-dimensional printing was employed to create the matching PLA scaffolds. strong mechanical strength and strong interconnectivity were proven by high-resolution micro-computed tomography [25-27]. The hexagonal and wheel-like structures showed reduced viscoelasticity, but the tetragonal shape demonstrated superior anti-fatigue performance. Using a melt mixing approach, PLA biocomposites including calcined seashell (CSh) particles were created [28], and their morphological, thermal, and mechanical properties were assessed in [29]. 3D printing is a viable replacement for subtractive processing since it provides processing flexibility and minimal material waste. Three materials are utilized in 3D printing: polylactic acid (PLA), polyamide (PA), and acrylonitrile butadiene styrene (ABS) [30-33]. These materials are employed in the automotive, aerospace, and medical industries. Nevertheless, their usefulness is limited by significant surface roughness, requiring pre- and post-processing enhancements to improve surface quality [34]. The superior mechanical and physical qualities of porous structural materials have led to their widespread adoption in the medical area. The creation of porous structures is made possible by the advances in 3D printing technology. However, repeated quick heating and cooling cycles during the 3D printing of porous structures result in residual tension [35-36].

## 2 Methodology of 3D Printing Block

An essential engineering field that aids in understanding how structures behave under various loads and circumstances is structural analysis. It offers thorough understanding of how a building reacts to external pressures, guaranteeing functioning, stability, and safety. Engineers can make well-informed judgments and optimize designs for a variety of applications, including buildings, bridges, airplanes, and mechanical components, thanks to structural analysis, which functions under stable loading and reaction conditions. The process of damage building up cycle after cycle in a material subjected to varying loads and strains is known as fatigue. The inability of the load to produce early failure or widespread plastic deformation is a key characteristic of fatigue. Rather, a component fails after it has undergone a certain amount of load variations, or when the cumulative damage reaches a critical point. A 3D printed square block product of Polylactic Acid (PLA) with Finite detail analysis (FEA) includes several steps,

As shown in Fig. 1. CAD software have to be used to correctly model the square blocks, making sure that everyone dimensions and features are correctly depicted.

After figuring out or obtaining PLA's mechanical properties which include young's modulus, Poisson's ratio, and remaining tensile energy, the following step is to determine its properties. Once the CAD version and material homes are hooked up, the next step is to create a finite element mesh of the square blocks. To approximate the conduct of the structure under various loading situations, the geometry is dividing into finite numbers of smaller, interconnected factors. Care ought to be taken to make certain that the mesh is sufficiently delicate to seize the critical functions of the geometry even as also being computationally green. The boundary situations and loading situations should be defined once the finite detail mesh is in area. Supporting and constraining the rectangular blocks in addition to making use of loads and pressures mimicking actual-world conditions are component of this procedure. For structural analysis, regular loading situations may also include static loads, dynamic masses, or thermal loads, relying on the supposed software of the blocks.

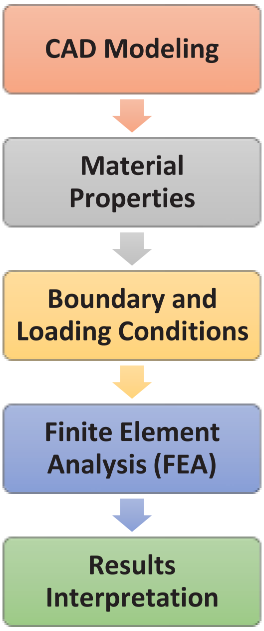


**Fig. 1:** Flow chart of the proposed methodology

Inside the case of boundary and loading conditions, ANSYS, Abacus, or COMSOL software program programs can be used to perform a finite element analysis. Taking into account cloth properties, geometric constraints, and boundary situations, a gadget of equations is solved to determine how every finite detail behaves in reaction to the applied loads.
The output of the analysis generally includes stress distribution, deformation, and other relevant parameters that provide perception into the structural integrity of the square blocks. The durability of 3-d revealed blocks also can be accessed through fatigue evaluation in addition to structural analysis. This includes making use of cyclic hundreds to the model and predicting the variety of cycles required for failure to occur, based on fatigue criteria which include the S-N curve or fatigue life estimation techniques.
To ensure 3D published square blocks meet the specified overall performance and protection specs, the structural and fatigue analysis outcomes can be interpreted and compared towards relevant standards. Any important layout modifications can then be implemented iteratively, and the analysis procedure may be repeated until pleasant consequences are done.

# 3 Result and Discussion

This FEM analysis encompasses compression tests using static structural analysis, fatigue analysis, and model analysis on a simple square block with dimensional parameters 25 mm x 25 mm x 25 mm. The total deformation and equivalent stress layer wise have been found by compression test, whereas the design life and safety factor of the material is determined by the fatigue analysis and the natural frequency of the square block has been found in the modal analysis**.** For the compressive test perform structural analysis by keep lower side fixed and apply a compressive load of 12200 N on top layer of the square block. Check fatigue life and safety factor by using fatigue tool and for the natural frequencies need to perform model analysis with six possible modes.

## 3.1 Structure analysis of square block for PLA at 12200 N applied in vertical direction

Total Deformation -: Using 12,200 N as a vertical load, Polylactic Acid (PLA)'s total deformation reveals how much it compresses or changes shape when under stress. For applications where dimensional stability under load is crucial, this deformation is crucial to evaluating PLA's structural integrity. It is important to understand PLA's deformation behavior under such loading conditions in order to determine its performance limitations and ensure it can withstand operational stresses without significant distortion, given its rigidity and brittleness compared to more flexible thermoplastics. After performing compression test structural analysis on square block for PLA at 12200 N applied in vertical direction, the total deformation of 0.10185 mm has been observed as shown in Table 1. After performing compression test structural analysis on square block for PLA at 12200 N applied in vertical direction, the equivalent stress ranging from 30.425 MPa at outer layer to 21.872 MPa of at middle layer of square block has been observed.

**Table 1.** Comparative analysis of square block for PLA at 12200 N applied in vertical direction

| Parameter | Description | Minimum Value | Maximum Value |
|---|---|---|---|
| **Total Deformation** | Deformation under vertical load (mm) | 0 mm | 0.010185 mm |
| **Fatigue Life** | Cycles until failure under vertical load | 1,250.4 cycles | 1.75925E+5 cycles |
| **Safety Factor** | Factor of safety against vertical fatigue failure | 0.040283 | 0.16423 |

**Fatigue analysis:-** Concentrate on how many stress cycles the material can withstand before exhibiting signs of failure such as cracking or complete fracture Fatigue life is critical where the material is subjected to repeated loads, because the soft PLA has the presence can facilitate fatigue failure over time , providing the data needed to establish the life and safety of materials made of PLA in dynamic loading environments If PLA fatigue life is observed under specific loading conditions , ensures that the system can be designed properly to avoid premature failures and increase reliability. After performing fatigue analysis on square block for PLA at 12200 N applied in vertical direction, the minimum fatigue life of 1250.4 numbers of cycles until the part will fail due to fatigue at the corner of the square block has been observed as shown in Table 1. After performing fatigue analysis on square block for PLA at 12200 N applied in vertical direction, the minimum safety factor of 0.04028 with respect to a fatigue failure at a given design life at the corner of the square block has been observed as shown in Table 1. Values less than one indicate failure before the design life is reached.

### 3.2 Structure analysis of square block for PLA at 12200 N applied in horizontal direction

Total deformation -: In this case, the total deformation measures the extent to which the PLA block moves or sinks. This material displacement is important in analyzing the ability of a material to maintain structural integrity under lateral loads, which can be a significant challenge for PLA and other less ductile materials. After performing compression test structural analysis on square block for PLA at 12200 N applied in horizontal direction, the total deformation of 0.10188 mm has been observed as shown in Table 2. After performing compression test structural analysis on square block for PLA at 12200 N applied in horizontal direction, the equivalent stress ranging from 41.016 MPa at bottom layer to 20.01 Mpa of at top layer of square block has been observed.

**Table 2:** Comparative analysis of square block for PLA at 12200 N applied in horizontal direction

| Parameter | Description | Minimum Value | Maximum Value |
|---|---|---|---|
| **Total Deformation** | Deformation under horizontal load (mm) | 0 mm | 0.010188 mm |
| **Fatigue Life** | Cycles until failure under horizontal load | 1,362.3 cycles | 1.91625E+5 cycles |
| **Safety Factor** | Factor of safety against horizontal fatigue failure | 0.014274 | 0.16826 |

Fatigue analysis in horizontal direction -: Fatigue analysis for a polylactic acid (PLA) square block subjected to a horizontal load of 12,200 N focuses on the evaluation of the general resistance of the material to repetitive or cyclic loading. cracks or structural weaknesses. After performing fatigue analysis on square block for PLA at 12200 N applied in horizontal direction, the minimum fatigue life of 1362.3 numbers of cycles until the part will fail due to fatigue at the corner of the square block has been observed as shown in Table 2. After performing fatigue analysis on square block for PLA at 12200 N applied in horizontal direction, the minimum safety factor of 0.041274 with respect to a fatigue failure at a given design life at the corner of the square block has been observed as shown in Table 2. Values less than one indicate failure before the design life is reached.

## 4 Comparative results

The analysis of polylactic acid (PLA) under loading conditions provides important insights into its mechanical behavior. When a load is applied vertically, PLA exhibits a number of maximum uniform stresses, which are more pronounced when the load is applied horizontally. This indicates that PLA can withstand more stresses in the horizontal direction on. In addition, PLA fatigue life shows that it can withstand more cycles of horizontal loading compared to horizontal, indicating a slightly better fatigue resistance with lateral loading Safety factor is important for identification reliability and suitability of materials for a particular application are particularly low under vertical and horizontal loads

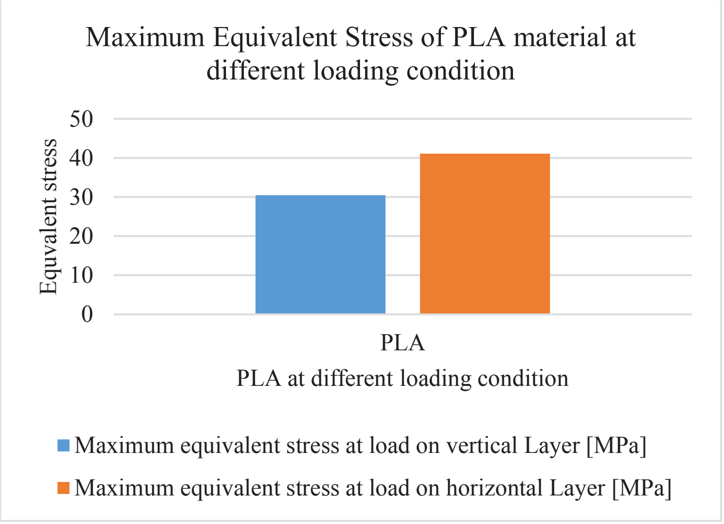


**Fig. 2:** Maximum Equivalent Stress at different loading condition

In the graph provided in Fig. 2, For PLA, when a load is applied on a vertical layer, the maximum equivalent stress it withstands is measured to be 30. 425 megapascals (MPa). Conversely, when the load is applied on a horizontal layer, the maximum equivalent stress that the material can endure is higher, at 41.016 MPa.

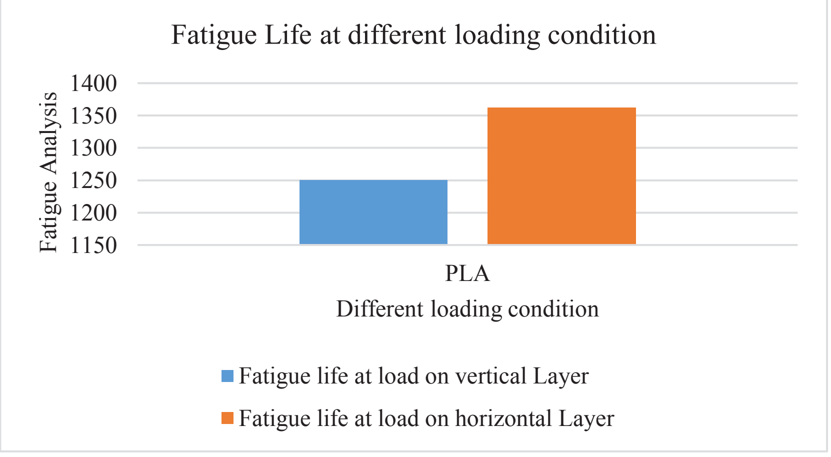


**Fig. 3:** Fatigue Life at different loading condition

The fatigue life of PLA when the load is applied on a vertical layer is 1250.4 cycles. This indicates the number of cycles that PLA can endure before a fatigue failure is likely to occur under this specific loading orientation. In comparison, when the load is applied on a horizontal layer, the fatigue life of PLA is slightly higher at 1362.3 cycles as depicted in Fig. 3. The increased number of cycles suggests that PLA has a marginally greater resistance to fatigue when loaded horizontally than vertically.

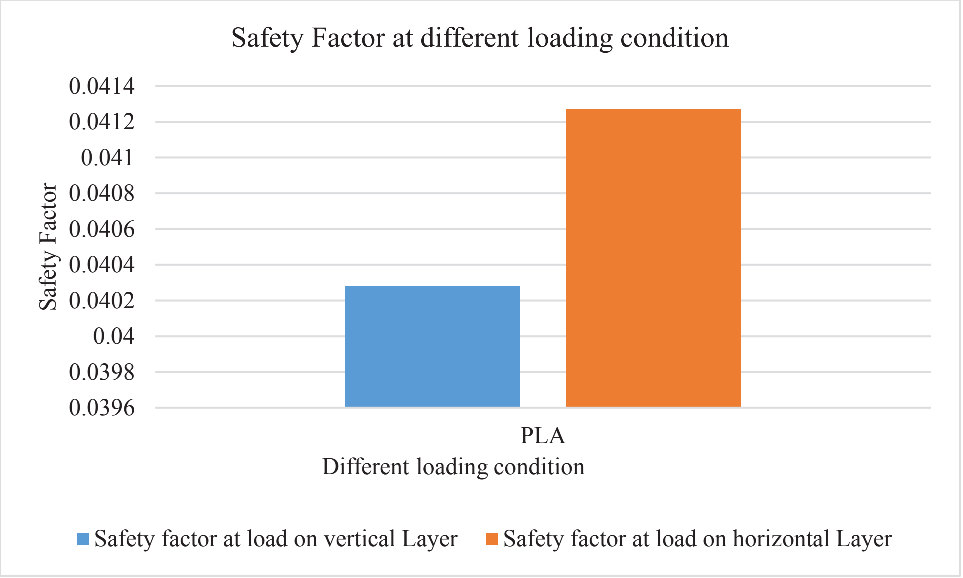


**Fig. 4:** Safety Factor at different loading condition

For PLA, the safety factor when the load is applied on a vertical layer is 0.04028. This is quite low and suggests that the intended load is very close to the material’s limit or breaking strength. A safety factor greater than 1 is typically desired in engineering applications to ensure reliability; hence, according to Fig. 4, a safety factor of 0.04028 indicates that either the material is not suitable for the load it's expected to carry, or the design needs to be revised to reduce the load or increase the material's strength. Similarly, the safety factor for a load on a horizontal layer of PLA is 0.041274, which is also significantly less than 1 but marginally higher than the vertical layer's safety factor.

## 5 Conclusion

This FEM analysis encompasses compression tests using static structural analysis, fatigue analysis, and model analysis on a simple square block with dimensional parameters 25 mm x 25 mm x 25 mm. Following an exhaustive structural analysis post-compression testing of a PLA square block subjected to a vertical and horizontal load of 12,200 N, several noteworthy findings have come to light.

- Total deformation of 0.10185 mm revealed.
- PLA can withstand 30.425 MPa stress under vertical loading, increasing to 41.016 MPa under horizontal loads.
- Its fatigue life sustains 1250.4 cycles under vertical loading and 1362.3 cycles when applied horizontally, indicating marginally better fatigue resistance laterally.
- Safety factors for PLA are 0.04028 for vertical loads and 0.041274 for horizontal loads, below the standard 1.0 for reliability and safety.

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