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Finite Element Analysis of 3D Printed Block Prepared of Sustainable Acrylonitrile Butadiene Styrene (ABS)

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Abstract. ABS and chain-branched amylopectin exhibit poor processing capabilities, making them unsuitable for 3D printing utilizations. While ABS exhibits excellent mechanical properties with high processing costs, it lacks the practical requirements of PLA, an environment-friendly polymer with poor mechanical performances. Studying the toxicity of 3-D printer emissions and the causes of toxicity both in vivo and in vitro is necessary in light of the rapidly expanding applications of 3-D printing technological advances, the documented emissions, and the possible adverse reactions from exposed to those emissions. Despite these limitations, ABS and PLA continue to be developed for 3D printing applications. Several mechanical behaviors, including tensile strength, creep, and fatigue, are examined in the study to determine the structural integrity and durability of a 3D-printed ABS square block. The results of the safety factor analysis show a minimum value of 0.1823, indicating the presence of potential failure points and the need for design optimization. The material can last long under dynamic loads, as shown by the fatigue study. This study not only improves ABS parts in real-life uses but also helps grasp their strength better. It gives clues for their future design and making. Using experimental and simulation data, the study optimizes 3D printing parameters and improves ABS materials' structural efficiency by integrating finite element methods with practical manufacturing outcomes.

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

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1 Introduction

A mix electrode can be made into any form or size, ideal for making sensors with complex shapes [1]. It has zones of conductors spread out randomly or in a set pattern, with an insulator in between each set [2]. Their resistance is usually higher and their efficiency is less stable than solid conductive parts [3-4]. The rise of conductive filaments [5] and 3D printers has made it cheap to create detectors in complex shapes with good repeatability [6]. Acrylonitrile Butadiene Styrene (ABS) [7] is a strong thermoplastic polymer that can be 3D printed, opening up new uses in the electronics for consumers and auto sectors [8]. Using a twin-screw extruder, researchers have effectively produced thermoplastic starches (TPS) with high processibility through the debranching and the plasticization of polysaccharides [9]. The TPS are then combined with suitable proportions of impact modifiers [10], compatible compounds, acrylonitrile-butadiene-styrene copolymers (ABS), and colors in an extruder with two screws to create TPS/ABS biomass alloy [11].

This advanced technology allows the manufacturing of complicated geometries, layer through way of layer, by using a aggregate of sophisticated additive manufacturing strategies and conventional production strategies. 3D printed ABS gives large flexibility and customization for product format, rapid prototyping, and green mass-manufacturing across numerous industries because of its integration with FDM (Fused Deposition Modeling) and SLA. The accuracy of dimensions, surface exceptional further to sturdiness will increase upon varying printing parameters [12]. A whole study performed in [12-19], which combines laminate-based totally finite-element modelling & experimental facts examines numerous mechanical properties which include tensile strength; creep& fatigue resistance factors that may have an effect on the final output at the same time as producing components the usage of 3-d printed ABS material [20]. On its part, Young’s modulus is the highest; similarly, the zero-axis orientation is ultimate however occurrence of resonance towards creep is most extreme at a degree 90 orientations! Meanwhile, when continually subjected to stress loads up-to-thirty, newton rotational cycles, the sum-of 4 thousand rotations whilst averaging thirty-four-hundredths millimetre.at every joint cycle produced all via flaw analysis trials [21]. As a result, nearly of excellent qualities above makes Acrylonitrile Butadiene Styrene ideal constituent material choice since it delivers over three decades worth-of computing for use in other apps thus the capability as better material existent on the latter market [22].
Tensile strength is the highest stress in which it can undergo stretching before breaking, which is why it serves as a go-to’s for tension materials. In [23] the study of the additive manufacturing of acrylonitrile butadiene styrene was conducted, and a multi-state numerical model is proposed, based on finite elements. A reverse engineering model can be developed alongside this version where impact of infill density is taken into consideration [24-30]. Two approaches are set up for musicale evaluation: a statistical rule of mixtures (ROM) and a numerical framework based totally on representative volume elements (RVE) [31]. The outcomes the research based study's findings can assist AM techniques in an expansion of engineering domains [32].

2 Methodology of 3d Printing of Block

This study used compression testing, static structural analysis, fatigue analysis, for a finite element analysis of a 25 mm x 25 mm block of square construction. The findings displayed safety factor, and overall deformation further to equivalent pressure. The careful preparation of ABS in 3D printing calls for following particular steps mentioned in figure 1, which includes refining the computational version, nicely calibrating gadget and slicing substances into plausible layers. Maintaining a sealed work area at the same time as tracking temperature is important for most desirable effects. After completion of production, it is critical to settle down before handling any printed objects accordingly by elimination from the chamber once cooled sufficiently. For a safe 3-D printing knowledge, safety precautions include adequate airflow and careful management of filaments and prints.

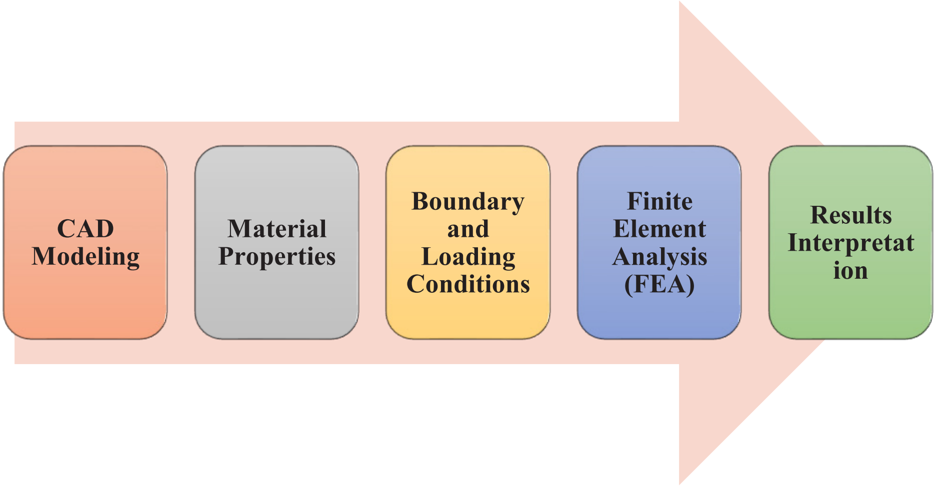

Fig. 1: Proposed methodology flow chart

An important component of engineering simulation is CAD modeling, a process that relies on computer-aided design software to generate detailed digital models of actual systems or components. It is critical for ensuring that simulations accurately represent real-world conditions and has an impact on the dependent nature of the analysis process. Next, the characteristics of the material in terms of their response to expansion due to heat and insulating values must be specified in the FEA model. Indeed, such a step is key in providing valid predictions for the performance of materials simulation against mechanical loads and environmental conditions clarify its use cases for FEA results for real-world applications of such simulations. Another critical aspect of FEA preparations is setting boundary and loading conditions that represent the virtual world of the model and solution methods to external force, pressure, and temperature influences. If applied correctly, the findings of the FEA simulation are indicative, i.e., relevant of the object use and operation in the desired environment or extreme conditions that could structurally exhibit unsafe behavior. A CAD model can be broken down into smaller, simpler pieces using a fundamental analytical technique called finite element analysis, which also helps to simplify complex equations. By calculating the reactions in each element, this approach offers comprehensive insights into the material's or structure's performance. The interpretation of results, the last phase in the FEA process, entails data analysis to ascertain the model's performance and structural integrity. Engineers evaluate component safety and make well-informed decisions about design enhancements, material modifications, or safety aspects by examining stress distribution, deformation patterns, and other responses.

3 Result and Discussion

In the present work finite element analysis have been conducted on Simple structure of square block with dimensional parameter 25 mm x 25 mm x 25 mm, this FEM analysis includes compression test using static structural analysis, fatigue analysis and model analysis. 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 ABS at 12200 N Applied in vertical direction

When analyzing Acrylonitrile Butadiene Styrene (ABS) squares under a vertical load of 12,200 N, we focus on total deformation, fatigue analysis, and factor of safety to assess its structural integrity can maintain its structural integrity effectively Fatigue analysis requires the number of cycles of the section before failure, important for applications requiring durability under cyclic loads A factor of safety calculated by comparing material strength to applied stress ensures that the section has adequate safety to will prevent failure under normal operating conditions for, thus helping engineers make informed decisions about the suitability of ABS for a particular application, especially where reliability and longevity are important.

After performing compression test structural analysis on square block for ABS at 12200 N applied in vertical direction, the total deformation of 0.21256 mm has been observed as shown in Table 1**.** After performing compression test structural analysis on square block for ABS 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 ABS at 12200 N Applied in vertical direction

Parameter	Description	Minimum Value	Maximum Value
Total Deformation	Deformation under vertical load (mm)	0.023618 mm	0.21256 mm
Fatigue Life	Cycles until failure under vertical load	0 cycles	5.391e6 cycles
Safety Factor	Factor of safety against vertical fatigue failure	0.18239	0.74355

After performing fatigue analysis on square block for ABS at 12200 N applied in vertical direction, the maximum fatigue life of 5.391E+6 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 ABS at 12200 N applied in vertical direction, the minimum safety factor of 0.18239 based on the design life of a product and the probability of fatigue failure at a given time at the corner of the square block had been observed as shown in Table 1. Values less than one indicate failure before the design life is reached.

After performing fatigue analysis on square block for ABS at 12200 N applied in vertical direction, the minimum available life is zero cycle on Log-Log scaling with respect to a fatigue failure at a given design life has been observed.

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

When analyzing the structure of a square-shaped block made of acrylonitrile butadiene styrene (ABS) under a peak load of 12,200 N, in horizontal direction, attention to total deformation, fatigue analysis and factor of safety yields several aspects attitude towards its mechanical strength. Fatigue analysis examines the endurance of a component under repeated loading, determines the number of load cycles before failure. This analysis is important where monitored allow the object to move or be loaded at all times. Finally, the safety factor calculates the ultimate strength rating of the part, ensuring that the system adds sufficient margin to prevent failure under expected load. This detailed analysis helps confirm that whether ABS is suitable for specific applications that require durability and reliability under high pressure conditions. After performing compression test structural analysis on square block for ABS at 12200 N applied in horizontal direction, the total deformation of 0.21261 mm has been observed as shown in Table 2. After performing compression test structural analysis on square block for ABS at 12200 N applied in horizontal direction, the equivalent stress ranging from 41.016 MPa at bottom layer to 20.01 MPa of at bottom layer of square block has been observed.

Table 2. Comparative Analysis of square block for ABS at 12200 N Applied in horizontal direction

Parameter	Description	Minimum Value	Maximum Value
Total Deformation	Deformation under horizontal load (mm)	0 mm	0.21261 mm
Fatigue Life	Cycles until failure under horizontal load	0 cycles	6.8432E+6 cycles
Safety Factor	Factor of safety against horizontal fatigue failure	0.18687	0.76184

After performing fatigue analysis on square block for ABS at 12200 N applied in horizontal direction, the maximum fatigue life of 6.8432E+6 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 ABS at 12200 N applied in horizontal direction, the minimum safety factor of 0.18687 based on the design life of a product and the probability of fatigue failure at a given time at the corner of the square block has been observed as shown in Fig. 8. Values less than one indicate failure before the design life is reached. After performing fatigue analysis on square block for ABS at 12200 N applied in horizontal direction, the maximum available life of 1027.2 cycle on Log-Log scaling with respect to a fatigue failure at a given design life has been observed.

4 Comparative Results

Comparative studies of acrylonitrile butadiene styrene (ABS) under different loading conditions yield insightful observations of mechanical behavior. The results show that the ABS has a gradual increase in total deformation when subjected to vertical and horizontal loads, up to about 0.25 mm. This refers to changes in the response of the material depending on the magnitude and direction of the load, as well as other experimental parameters. Maximum equivalent stress recorded for ABS shows higher strain response under horizontal than vertical load, indicating directional sensitivity of material Besides, the fatigue life of ABS can withstand more cycles under horizontal load compared to vertical distribute effectively against such loads that there is little room for error in the operational safety of the conditions shown below.

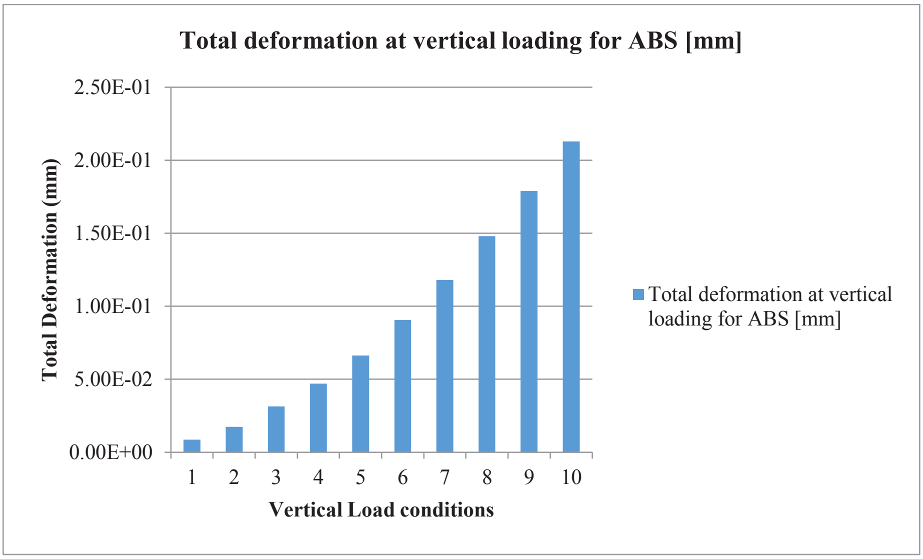

Fig. 3: Comparative result of Total deformation at vertical loading for ABS

ABS material deformation measured in millimeters when subjected to vertical loading. As shown in Fig. 3, the horizontal axis identifies ten different tests or conditions. There are approximately 0.25 millimeters of deformation on the vertical axis. As the values rise from test 1 to test 10, the deformation graph shows a gradual increase in deformation.

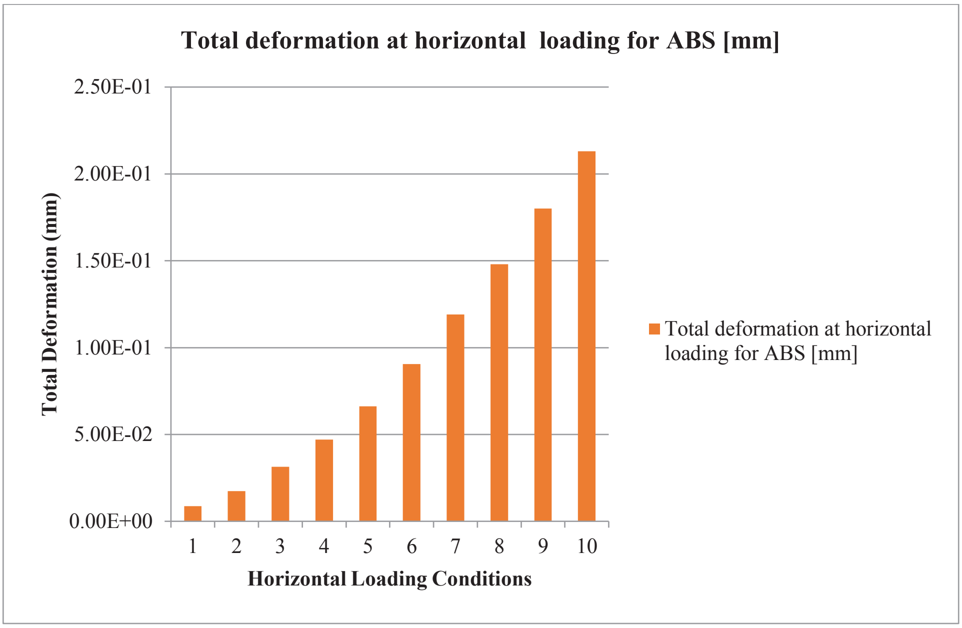

Fig. 4: Comparative result of Total deformation at horizontal loading for different materials

According to Fig. 4, the vertical axis quantifies the deformation, ranging from 0 up to about 0.25 mm. Loading conditions applied in between 1220 units to 12200 units .Tests 1 to 5 show a rapid increase in deformation; test 6 shows a slight dip, and test 7 shows another surge in deformation leading to test 10. As a result of this pattern, ABS material's physical response may vary depending on loading magnitudes, material structure, or other experimental conditions.

Table 3: Comparative result of maximum equivalent stress for different materials

Materials	**ABS**
Maximum equivalent stress at load on vertical Layer [MPa]	30.425
Maximum equivalent stress at load on horizontal Layer [MPa]	40.016

The maximum equivalent stress experienced by acrylonitrile butadiene styrene (ABS) in different load specifications provided in Table 3, reflects an important aspect of the mechanical properties of the material when vertical loading occurs: ABS is subjected to tension a maximum equivalent of 30.425 MPa. This strain rate increases as the load is applied horizontally, with the material experiencing a strain of more than 40.016 MPa. This variation in the strain response in different loading directions indicates that ABS exhibits abnormal behavior, its strength and durability can vary significantly depending on the direction of the applied force Such information is important to engineers and designers when considering ABS for applications where directional pressure is a factor .

Table 4: Comparative result of Fatigue life for different materials

Materials	**ABS**
Fatigue life at load on vertical Layer	5.391E+6
Fatigue life at load on horizontal Layer	6.8432E+6

The extent of acrylonitrile butadiene styrene (ABS) fatigue life varies depending on the applied load as depicted in Table 4. When subjected to a vertical load, the ABS exhibits a fatigue life of approximately 5.391 million cycles. This endurance increases with direct application of the load, with a material withstanding 6.8432 million cycles. This difference in fatigue life under vertical versus horizontal loading conditions indicates that ABS is more resistant to fatigue when stress is applied horizontally, an important consideration for applications where product stability is expected repetitive loading or cyclic loading edges in specific orientations Understanding these variables helps to optimize ABS design and its application to industrial applications critical to durability.

Table 5: Comparative result of safety factor for different materials

Materials	**ABS**
Safety factor at load on vertical Layer	0.18239
Safety factor at load on horizontal Layer	0.18293

Safety factors under load guidelines for acrylonitrile butadiene styrene (ABS) exhibit an important feature in its mechanical performance as presented in Table 5. When under vertical load, the ABS factor of safety is 0.18239, indicating that the actual material strength is slightly more than 18% of the required strength to avoid failure under these conditions and the factor of safety increases slightly to 0.18293 under high load . These values indicate that the ABS has a very small margin of safety under both load conditions, indicating that it performs close to its failure limit. This lower level of protection means that ABS may not be suitable for applications where high levels of protection are required, especially critical components carrying loads with significant consequences in the event of failure.

6 Conclusion

Following an exhaustive compression test structural analysis conducted on a square ABS block subjected to a vertical load of 12,200 N, several key findings have emerged. Moreover, the equivalent stress distribution within the block ranged between 30.425 MPa at the outer layer and 21.872 MPa at the middle layer, indicating a total deformation of 0.21256 mm. Notably, the study provided crucial insights into the block's fatigue behavior, estimating a maximum fatigue life of 5.391E+6 cycles before potential failure, primarily concentrated at the corner of the structure. The key findings from the research was as follows:

- In the work conducted, a structural safety analysis was performed that thereby revealed a minimum safety factor of 0.18239 regarding fatigue failure at the corner. The study also did an extensive structural analysis of an ABS square block subjected to 12,200 N that has revealed several significant results.
- The work also found a total deformation of 0.21261 mm. Research followed the distribution of equivalent stress within the block that defined the values ranging from 41.016 MPa at the bottom layer to 20.01 MPa at the top layer.
- Moreover, from this analysis, we gained important insights into the block's fatigue behavior, with the most vulnerable point of the structure located at the corner, meaning that the block has a maximum fatigue life of 6.8432E+6 cycles before it may fail. The structural safety parameters were also evaluated, and a minimum safety factor of 0.18687 was determined, especially in terms of fatigue-induced failures at corners, within the specified design life.

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