Advances In Multidisciplinary & Scientific Research
AIMS Research Journal
A Multidisciplinary & Interdisciplinary Journal
Volume 9, No 3, September 2023 Series

Comparative study of Mechanical Properties of 3D Printing Materials (Polylactic acid and Acrylonitrile Butadiene Styrene) via Simulations Using COMSOL Multiphyisics.

[1]Oyetunji O.R., [2]Ajayi A, S., [1]Amuda B. A & [1]Morawo I.I.
[1]Department of Mechanical Engineering
Ladoke Akintola University of Technology, Ogbomoso, Oyo state, Nigeria.
[2]Department of Mechanical Engineering
Faculty of Engineering, Hanbat National University, South Korea.
Corresponding Author's Email: oroyetunji@lautech.edu.ng

ABSTRACT

Fused Deposition Modeling used in most 3D printing makes use of Polylactic acid and Acrylonitrile Butadiene Styrene as filament materials. The properties of these materials affect printing parameters, such as layer height, printing orientation, infill type and density. In order to have improved output, this study is aimed at determining and comparing the mechanical properties of the Polylactic acid and Acrylonitrile Butadiene Styrene 3D printing material via simulations using COMSOL Multiphysics software. A flat plate was modeled using the modeling tool in the software (10m x 100m x 1m), The Polylactic acid and Acrylonitrile Butadiene Styrene mesh was studied under the Solid Mechanics physics with cantilever and simple supported as case study. The displacements of both specimens were studied after simulation. Simulations results show a maximum displacement of 670mm and 1100mm in the cantilever and simply supported models respectively The results showed that the support at both ends of the model, there was reduction in the ductility property of the Polylactic acid compare to the Acrylonitrile Butadiene Styrene from the stress analysis result, Factor of safety analysis revealed that the Polylactic acid is more safer than that of Acrylonitrile Butadiene Styrene and also Polylactic acid will experience more strength properties compare to that of Acrylonitrile Butadiene Styrene which is seen by the displacement analysis study.

Keywords: 3D printing, Acrylonitrile Butadiene Styrene, Additive Manufacturing,COMSOL Multiphysics, Fused Deposition Modeling Polylactic acid,

Aims Research Journal Reference Format:
Oyetunji O.R., Ajayi A, S., Amuda B. A & Morawo I.I. (2023): Comparative study of Mechanical Properties of 3D Printing Materials (Polylactic acid and Acrylonitrile Butadiene Styrene) via Simulations Using COMSOL Multiphyisics. Advances in Multidisciplinary and Scientific Research Journal Vol. 9. No. 3. Pp 21–34. www.isteams.net/aimsjournal. dx.doi.org/10.22624/AIMS/V9N3P3

1. INTRODUCTION

3D printing is also known as Additive Manufacturing (AM) adopts the technology of Fused Deposition Modeling (FDM) in producing a 3D object for prototyping. It uses Polylactic acid (PLA) or Acrylonitrile Butadiene Styrene (ABS) as the filament for printing of object in layer by layer. 3D printing is an innovative manufacturing process that builds parts layer by layer adopting a varied range of material such as plastics, ceramics and metals [1,3].

With rise in the application of plastics and polymer composite material in many fields, polymers have become one of the most usually used materials for 3D printing [8]. Various methods have been adopted in AM of which Fused Deposition Modeling (FDM) has presented great potential because of its capability to print parts with complicated geometry [15]. The uncomplicatedness of its operation and cost efficacy is part of the deliberation when applying AM in manufacturing [1]. There is dimensional inexactness and decrease in mechanical properties due to build-up of residual stresses during printing process. The thermal residual stresses are reliant on temperature variations, changes in the printing conditions which have important impact on the quality and dimensions of the printed parts. Also the structural integrity of the part is negotiated if high amounts of residual stresses are induced during 3D-printing.

Hence the final mechanical properties are also affected by warpage and the threshold for cracking/breaking of the part is reduced under external load. Residual stresses and warpage undesirably affect the dimensional accuracy and performance of 3D-printed semi-crystalline polymers in FDM. One of the main challenges in FDM is to understand and relate the impact of printing conditions on part distortion for optimizing the 3D-printing process to achieve good print quality [1]. Samy et al.,(2021) reported from the simulation results that it is observed that a decrease in layer thickness from 0.5mm to 0.1mm results in a 89% drop in warpage and a reduction in residual stress of 24%. When line raster pattern was used it reduces warpage and residual stresses by 16% and 36%, respectively in comparison with a zigzag raster pattern.

An agreement was observed between simulation and experimental results for warpage under various printing conditions. Japrin et al (2021) showed that the tradition infill is much more cost-effective in terms of material cost compared to the solid infill. The study also discovers that different material filaments produced different displacements. ABS filament gives longer displacement compared to PLA filament because it is a bit bendable and therefore less brittle than PLA. Even though ABS material had higher displacement but in the real life industry, PLA filament is convenient to be printed because PLA nozzle temperatures are lower related to ABS filament.

Modeling and simulation will play a vital part today, which changes conventional approaches of trial and error including for the design as well as the optimization of the components and materials. In additive manufacturing, known modeling and simulation techniques used to simulate materials production are being expanded. Due to the extreme variations in FDM technology, the strength of the components made using this technology must be tested which is the effect of two controllable variables such as the pattern and density of the infill [8]. Honeycomb structures are also used to provide the layer with physical stability and the object with mechanical integrity. The properties of FDM produced objects are influence by layer thickness, build orientation, raster distance and print speed parameters. Also the mechanical qualities of 3D printed parts can be influenced by the printing parameters [9].

Optimizing the infill design is important to satisfy the industry standard which produces a product high mechanical performance using low material usage. Using different filament materials produced almost similar results in von mises stress which the maximum stress for PLA and ABS filaments are 1.18 GPa and 1.19 GPa respectively. There is a difference in displacement for using different filament materials. The ABS filament had higher durability and less brittle compared to PLA filament material.

Even though ABS material had higher displacement, but it not user-friendly thermoplastic with higher stiffness and strength compared to PLA material. In real life industry, PLA filament is easier to be printed because PLA nozzle temperatures are lower compared to ABS filament. The PLA material is recyclable and biodegraded which is able to meet the element of sustainability. In addition, ABS and PLA are great materials but for different reasons [9].

In AM printing parameters, such as layer height, printing orientation, infill type and density, number of outline perimeters, have a high influence on mechanical properties of finished parts [2].3D printing has grown in popularity as a method of developing tools and functional parts, particularly in industries requiring extensive customization, such as medical and aerospace [6]. However, current 3D printing techniques, such as used FDM, Stereolithography (SLA), and Multi-Jet Fusion (MJF), introduce a variety of uncertainties to the outcome prediction based on mechanical engineering ideas [7,10]. In general, 3D-printed parts manufactured using various techniques differ in terms of strength, stiffness, microstructure, and material properties, necessitating investigation of their behaviours using both experimental tests and Finite Element Analysis (FEA) [11.16].

The optimization of extrusion deposition trajectories and FDM, 3D printing has shown promise in improving specific mechanical qualities of products, such as fracture toughness [12]. The filament direction optimization is said to have led to a broad deformation zone, which resulted in "ductile-like behaviour" and a slow fracture propagation rate [14]. In addition, when compared to traditionally manufacture of composite parts, using 3D printing to generate co-continuous composite or interpenetrating phase composite parts resulted in a considerable increase in damage tolerance and fracture toughness [13]. The use of various crack-deflection and crack-bridging strategies to improve fracture resistance in 3D-printed composites was made possible by rationally designed interpenetrating architectures. Mechanical dependability is critical in a wide range of engineering applications.

Since catastrophic failures are frequently caused by unstable crack propagation, studying component fracture is an important part of engineering design. Catastrophic failures often occur due to unstable crack propagations and therefore, study of fracture of components is a vital component of engineering design. This study is essential to know and compare the properties of PLA and ABS materials used in 3D printing. COMSOL software was used for the analysis at an isothermal coupling temperature of 293.15 K

2. METHODOLOGY

The modeling of the PLA and ABS was done by the in-built modeling part of the COMSOL software and thus simulated via the simulating interface of the software. The von Mises stress analysis and displacement was studied at two different direct load application cases. The simple supported and cantilever cases were the two cases taking into consideration. The cantilever supported technique involved the application of a similar magnitude of load at one free end of the material, as only one end of the material were made fixed. All studies were conducted at an isothermal coupling temperature of 293.15K (room temperature).

The COMSOL Multiphysics is computer software and is the research medium for this research process. The following are the chronological steps to be followed to meet the objectives of this study;

2.1 The model environment

The COMSOL Multiphysics application is opened, selecting the 3D mode and launching into the Multiphysics window.

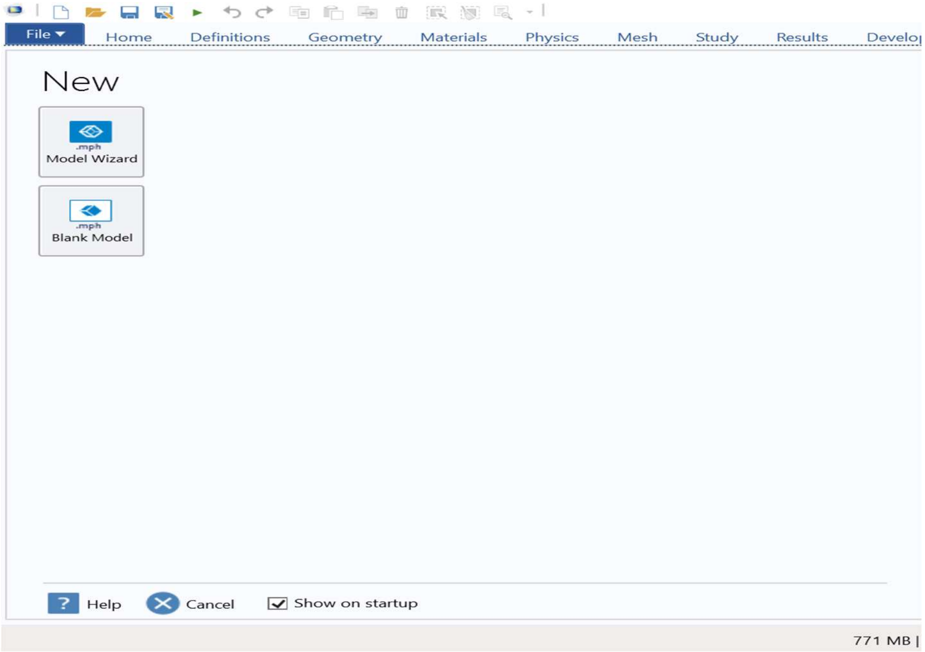


Figure 2.1: Multiphysics software interface

2.2 Building required Geometry

It is the use of Solidworks to turn model into a flat plate of dimension 100mm x 10mm with thickness 0.5mm

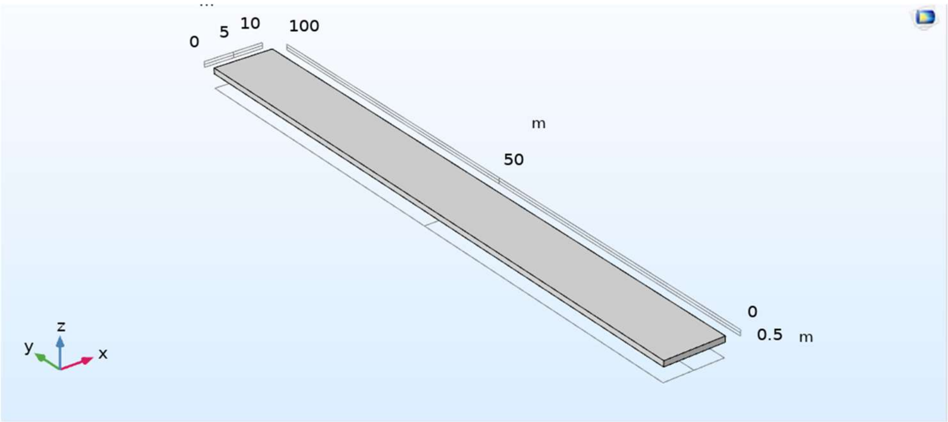


Figure 2.2: Model of a flat plate of dimension 100mm x 10mmx 0.5mm

2.3 Creating Adequate Definitions

The parameters of the components to be modeled strictly in the parameter window were adequately created.

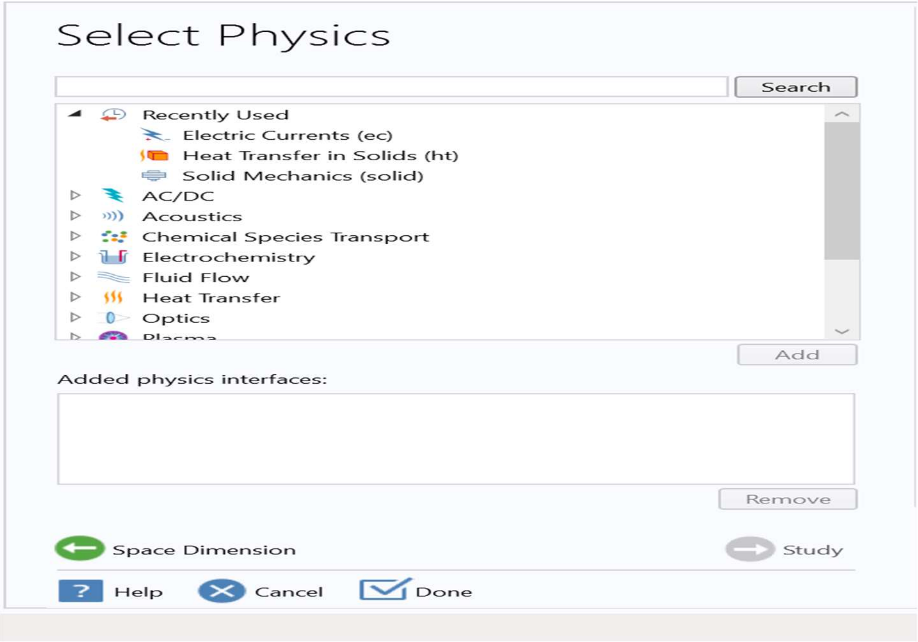
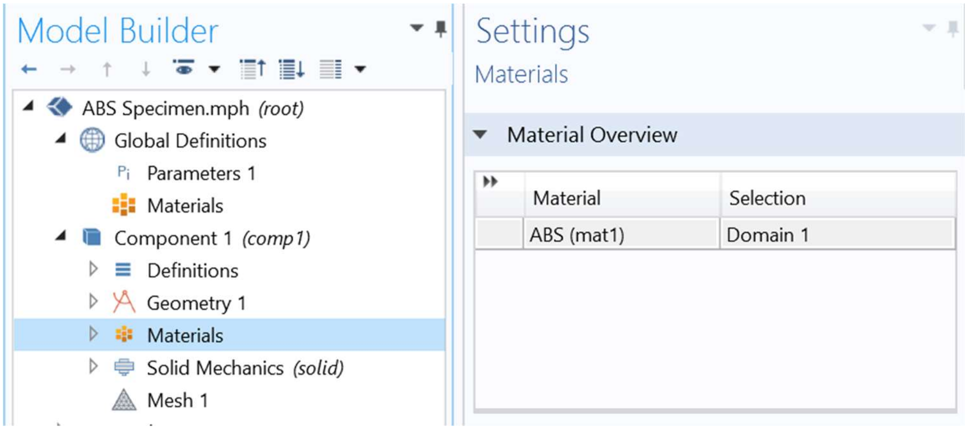


Figure 2.3: Parameter Creation

2.4 Specification of Research Material Properties

This involved the use of built-in parameters or via creating a new material using the blank material option

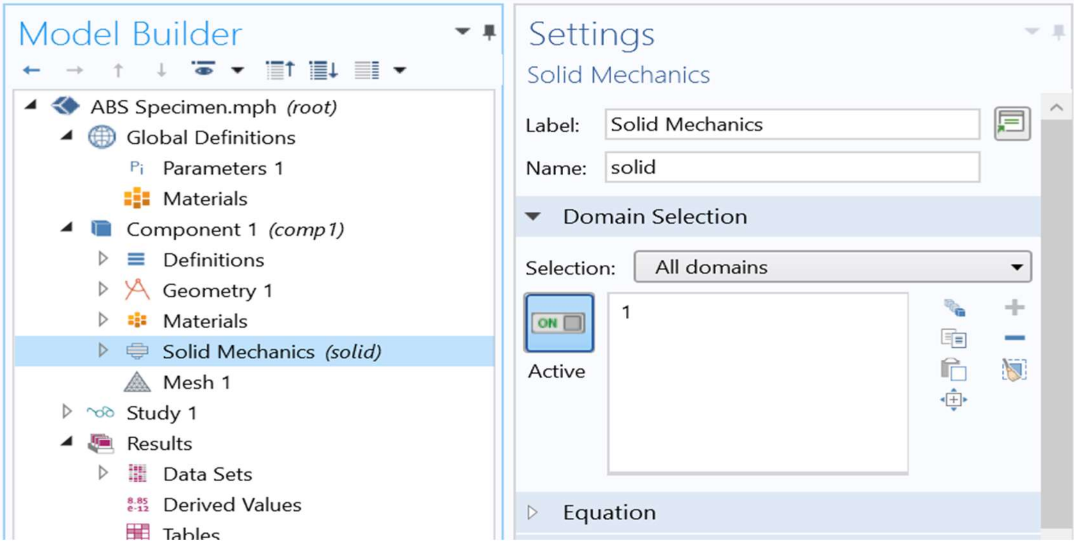


Material	Selection
ABS (mat1)	Domain 1

Figure 2.4: Research materials specified

2.5 Specification of Physical Boundaries

It entails the use of built in parameters in the user physics window or user defined parameters.



Label: Solid Mechanics
Name: solid
Selection: All domains
1

Figure 2.5: User defined parameters

2.6 Meshing

This involves the use of user defined or built in meshing option, it is basically for expressively seeing the geometry for both the PLA and ABS.

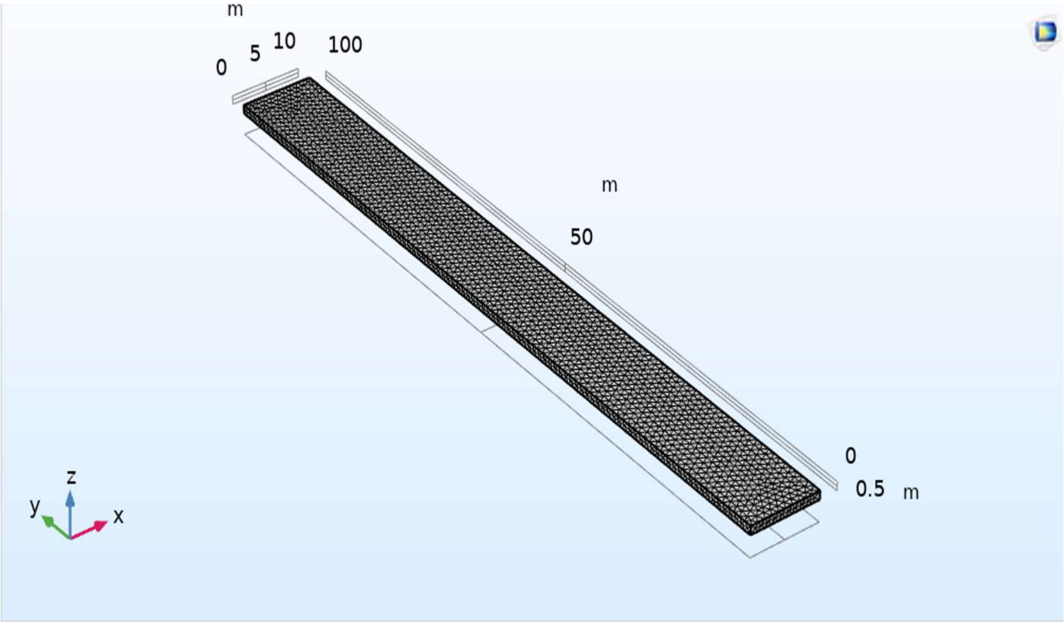


Figure 2.6: User defined or built in meshing option

2.7 Running Simulation Result

It is the process of running the post simulations result via the result window and expressively showing each and every result for all the cases study

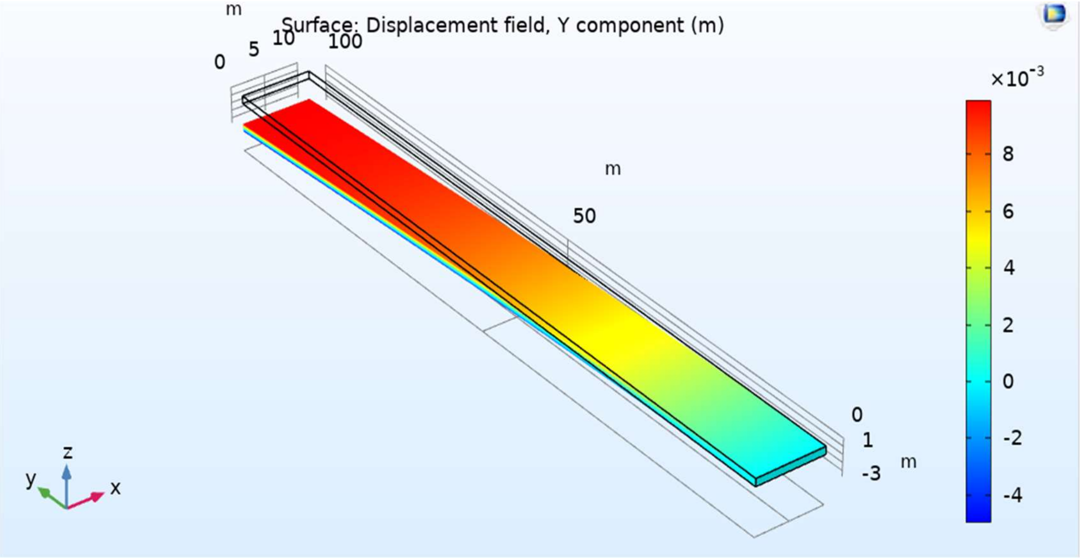
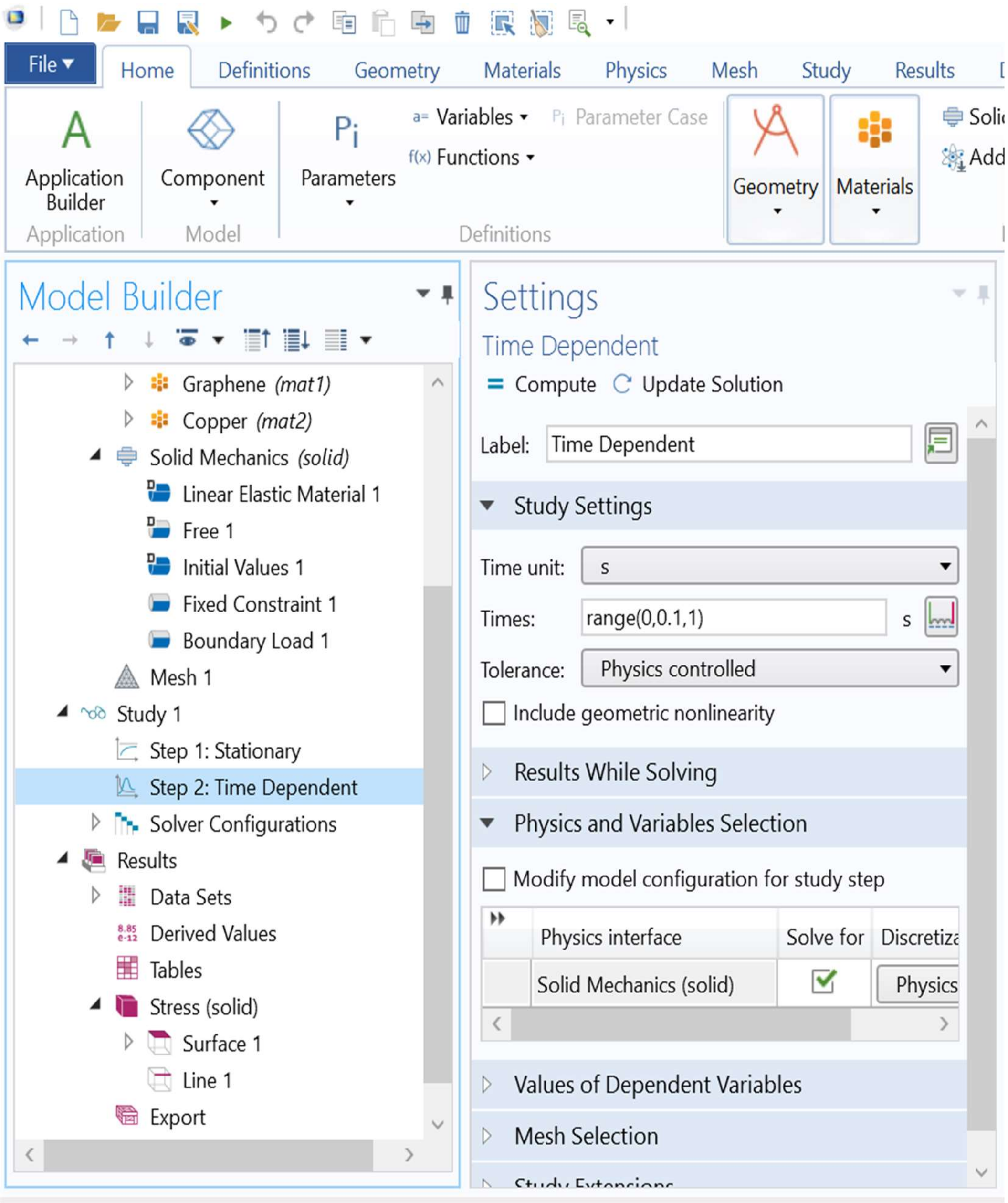


Figure 2.7: Running simulation result

2.8 Repetition of Design Process

The use of this process for each of the Solid mechanics physics to be studied.



Label: Time Dependent

Time unit: s

Times: range(0,0.1,1) s

Tolerance: Physics controlled

☐ Include geometric nonlinearity

☐ Modify model configuration for study step

Physics interface	Solve for	Discretiza
Solid Mechanics (solid)	☑	Physics

Figure 2. 8: Repetition of design process

2.9 Process Flow Chart

The operation flow chart is shown in figure 2.9.

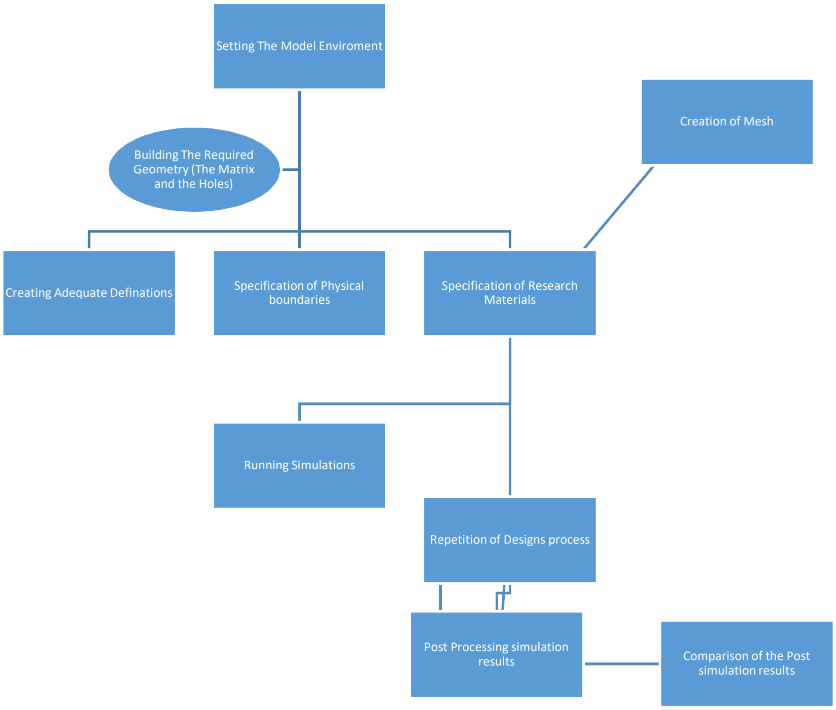


Figure 2.9 : Operation Flowchart

3. RESULTS AND DISCUSSION

3.1 Comparative Study of Stress

Figures 3.1 and 3.2 shows the simulated model results for the von misses stress values of the simply supported and cantilever supported PLA models respectively. The maximum stress values of the simply supported and cantilever supported models are 50 KPa and 370 KPa respectively. The lower stress value of the simply supported model shows that it would undergo lesser yielding before fracture due to the constraints induced by fixing both ends of the model.

Figure 3.3 and 3.4 represents the simulated von misses stresses of simply supported and cantilever supported ABS copper models respectively. The maximum stress values are deduced to be 47 KPa and 350 KPa for the simply supported and cantilever supported models respectively. Similar to the PLA models, the cantilever supported solid copper model witnesses a higher stress value because there are no constraints of being fixed at both ends like the simply supported model, and as such will undergo more yielding before fracture.

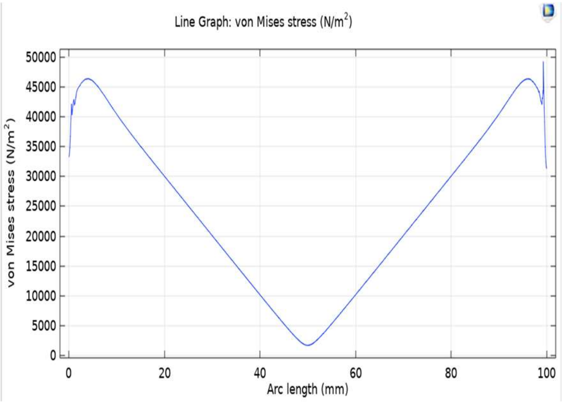


Figure 3.1 : PLA simple supported model

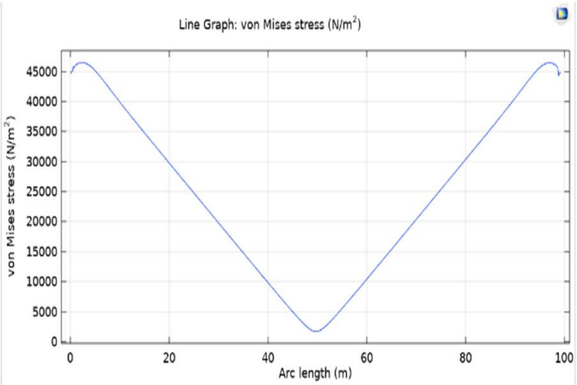


Figure 3.3 : ABS simple supported model

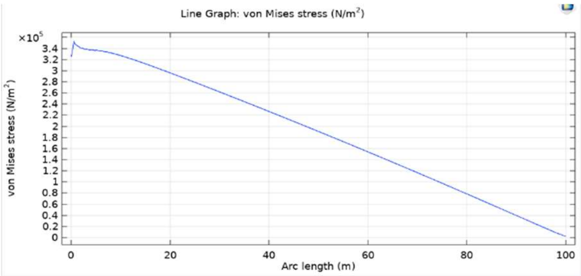


Figure 3.2 : PLA cantilever supported model

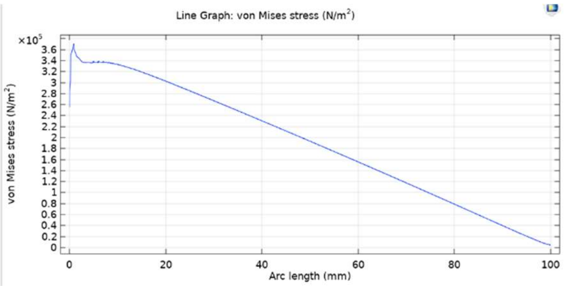


Figure 3.4 : ABS cantilever supported model

A comparative study of the stress values of PLA and ABS models shows a higher stress values in the PLA models for both techniques of support. This is explained as the improvement in ductility of the PLA over ABS material, but at the expense of the fracture strength of the PLA. Table 3.1 highlights the stress results of all studies models.

Table 3.1: Von Misses stress results for all studied models

	PLA		ABS	
	Max (KPa)	Min (KPa)	Max (KPa)	Min (KPa)
Simply Supported	50	2.5	47	2.3
Cantilever Supported	370	0.01	350	0.02

3.2 Comparative Study of Displacement

Figure 3.5 and Figure 3.6 show the simulated displacement results of simply supported and cantilever supported PLA models respectively. Simulations results show a maximum displacement of 670mm and 1100mm in the cantilever and simply supported models respectively.

The higher displacement experienced in the cantilever supported model is due to the non presence of constraints that could have been experienced due to fixing of both ends of the models as in the simply supported model. As such, the cantilever supported PLA model is able to undergo more displacement before necking, fracture or failure. Also, figure 3.8 and figure 3.9 represent the simulated displacement values of simply supported and cantilever supported ABS models respectively. On application of the constant force of 1000N, simulation results show maximum displacement values of 0.32mm and 0.55mm in the simply supported and cantilever supported models respectively. Similar to the PLA model, a higher displacement value is experienced in the cantilever supported model due to the absence of restraints of supports at both ends of the model, causing it to experience greater displacement before fracture.

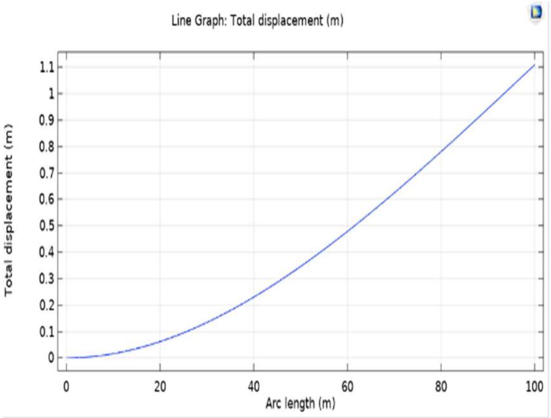


Figure 3.5 : PLA cantilever supported model

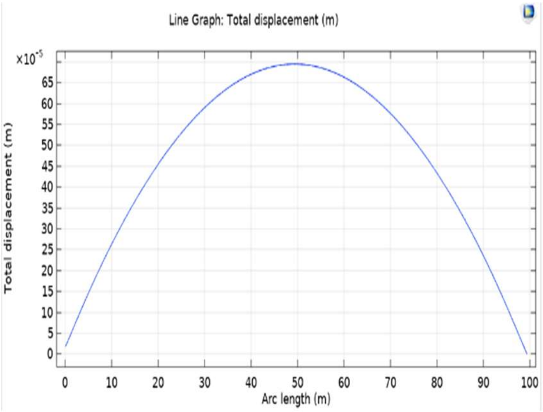


Figure 3.6 : PLA simple supported model

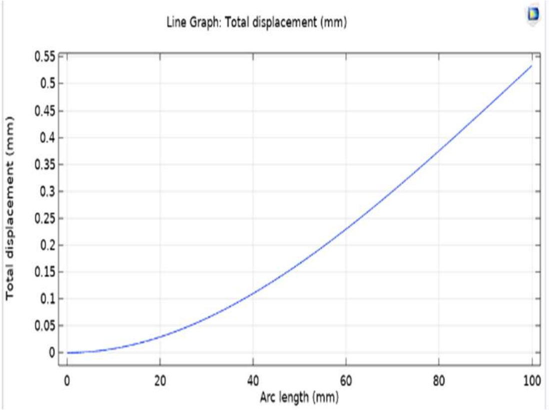


Figure 3.7 : ABS cantilever supported model

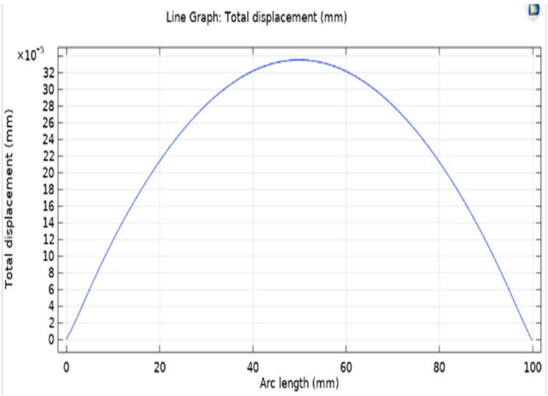


Figure 3.8 : ABS simple supported model

Comparing the displacement values of the PLA and ABS models, higher displacement value results are shown in the PLA models for both techniques of support. This can be explained as the improvement in ductility of copper by introduction of graphene, at the expense of the strength property. Table 4.2 represents a highlight of all displacement results.

Table 3.2: Displacement Results of all Studied Models

	PLA		ABS	
	Max (mm)	Min (mm)	Max (mm)	Min (mm)
Simply Supported	670	0.0	0.32	0.0
Cantilever Supported	1100	0.0	0.55	0.0

3.3 Examination of Factor of Safety

The Factor Of Safety (FOS) is examined analytically as;

$$\text{FOS} = \frac{\text{Ultimate Load}}{\text{Maximum Allowable Stress}}$$

Where, Ultimate Load = 1000N/m^2
FOS (cantilever supported ABS) = 1000/0.37 = 2702
FOS (cantilever supported PLA) = 1000/0.35 = 2860

Analytical results show a greater factor of safety for use of the PLA model than the ABS model, on field. This corroborates the results of previous studies that the PLA model possesses more ductility property and will undergo greater yielding before necking than the ABS model.

4. CONCLUSIONS

The following conclusions were gotten via the simulation of the result, PLA and ABS models supported at several ends (one or two) will experience poor ductility and are liable to break easily on application of a low stress, Also, the use of PLA provides more ductility property than ABS and finally there is an adverse effect on the strength property of ABS when use over PLA which was fully seen via the stress analysis study.

REFERENCES

1. Antony Samy, A., Golbang, A., Harkin-Jones, E., Archer, E., & McIlhagger, AT. (2021). Prediction of part distortion in Fused Deposition Modelling (FDM) of semi crystalline polymers via COMSOL: Effect of printing conditions. CIRP Journal of Manufacturing Science and Technology, 33, 443-453. https://doi.org/10.1016/j.cirpj.2021.04.012
2. Aleksa Milovanovića., Aleksandar Sedmakb., Aleksandar Grbovićb., Zorana Golubovića., Goran Mladenovićb., Katarina Čolića., and Miloš Miloševića (2020).Comparative analysis of printing parameters effect on mechanical properties of natural PLA and advanced PLA-X material, Procedia Structural Integrity 28 (2020) 1963–1968
3. Bikas, H., Stavropoulos, P and Chryssolouris, G (2016) Additive manufacturing methods and modeling approaches: A critical review, Int. J. Adv. Manuf. Technol. 83 (2016) 389– 405. https://doi.org/10.1007/s00170-015-7576-2.
4. Libonati, F.; Gu, G.X.; Qin, Z.; Vergani, L.; Buehler, M.J.(2016) Bone-Inspired Materials by Design: Toughness Amplification Observed Using 3D Printing and Testing. Advance Engineering Material. 2016, 18, 1354–1363.
5. Papon, E.A.; Haque, A.(2019) Fracture toughness of additively manufactured carbon fiber reinforced composites. Additive Manufacturing. , 26, 41–52.
6. Zolfagharian, A.; Kaynak, A.; Kouzani, A.(2020) Closed-loop 4D-printed soft robots. Mater. Des. 2020, 188.
7. Mitsouras D, Liacouras PC. 3D printing technologies. In 3D Printing in Medicine; Springer: Berlin, Germany, 2017; pp.5–22.
8. Penumakala P. K,m Sonto J and Thomas A (2020) A critical review on the fused deposition modeling of thermoplastic polymer composite , ScienceDirect. Vol.201,(2020) 108336 https : // doi.org/10.1016
9. Sabri Japrin and Mustaffa Ibrahim (2021)Fused Deposition Modeling(FDM) Custom Internal Filling Structural Mechanics Simulation, Research Progress in Mechanical and Manufacturing Engineering Vol. 2 No. 2 (2021) p. 1-9
10. Zolfagharian, A.; Kouzani, A.Z.; Khoo, S.Y.; Moghadam, A.A.A.; Gibson, I.; Kaynak, A. Evolution of 3D printed soft actuators. Sensors Actuators A: Phys. 2016, 250, 258–272.
11. Zhou, Y.; Zou, J.; Wu, H.; Xu, B. Balance between bonding and deposition during fused deposition modeling of polycarbonate and acrylonitrile-butadiene-styrene composites. Polym. Compos. 2019, 41, 60–72.
12. Turner, B.N.; Strong, R. Gold, S.A. A review of melt extrusion additive manufacturing processes: I. Process design and modeling. Rapid Prototyp. J. 2014, 20, 192–204.
13. Thrimurthulu, K.; Pandey, P.M.; Reddy, N.V. Optimum part deposition orientation in fused deposition modeling. Int. J. Mach. Tools Manuf. 2004, 44, 585–594.
14. Zhou, Y.-G.; Su, B.; Turng, L.-S. Deposition-induced effects of isotactic polypropylene and polycarbonate composites during fused deposition modeling. Rapid Prototyp. J. 2017, 23, 869–880.

15. 15. Zhang Y and Chou K (2009) A parametric study of part distortions in fused deposition modeling using 3 D finite element analysis, Material science Proceedings of the institution of mechanical engineers, www.semanticsscholar.org/pa
16. Zolfagharian, A.; Kouzani, A.Z.; Khoo, S.Y.; Gibson, I.; Kaynak, A. 3D printed hydrogel soft actuators. In Proceedings of the 2016 IEEE Region 10 Conference (TENCON), Singapore, 22–25 November 2016.