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Evaluation of Infill Type Effect on Strength of Thermoplastic Components

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Abstract: Additive manufacturing is one of the latest growing approaches that gives the ability to rapid design, test and improve concepts, as well as mass-production. In the present work, the effect of the infill patterns on tensile strength of thermoplastic components are studied. Computer-Aided-Design (CAD) software is used to develop the required specimens, which are then imported into ANSYS Workbench for the stress-strain simulation. The materials selected for the analysis are PLA, ABS thermoplastics. The infill patterns selected for the analysis are honeycomb, triangle, square-grid. For each infill pattern, the specimens were designed with an infill density value of 50%. Static Structural analysis is carried out to predict the stress and elastic strain generated during the tensile test in each specimen.

I. INTRODUCTION

The design of any engineering component involves three interrelated problems: selecting a material, specifying a shape, and choosing a manufacturing process. Getting this selection right the first time by selecting the optimal combination for a design has enormous benefits to the production of any engineering product. It leads to lower costs, shorter production times, a reduction in the number of in-service failures and, sometimes, many other significant advantages relative to other competitions. There are often an infinite number of possibilities and combinations which exist and, while they may all be viable options, it stands to reason that there exists an optimal solution. The recent development and advances in the field of rapid prototyping technology provides the engineer with a more innovative approach to combating this complex issue. First becoming visible in the late 1980's. Rapid Prototyping (RP) technologies were originally developed as a quicker, more cost-effective method for creating prototypes within industry. Progress was achieved throughout the 1990's and early 2000's with a host of new technologies emerging in the industry. Most of these technologies were still focused almost entirely on industrial applications with much focus being placed on how this rapid production technology could be applied to the tooling and manufacturing sectors. 3D printing/fabrication did not begin to show significant possibility in terms of a stand-alone means of production. However, until the mid-90's. At this time, two main areas of emphasis emerged. The first was considered more as high-end 3D printing and was mainly geared towards the production of highly engineered complex parts. This development is still ongoing, but the results are only now really starting to become visible in production applications such as the aerospace, medical, and automotive sectors. At the other end of the spectrum, machines dubbed "concept modelers", were being developed.

A quick Google search for "3D printing" shows some very interesting concepts. Most of the retrieved results, however, are related to small toys and other objects whose purposes are quite vague. While there is a time and place for producing fun and aesthetically attractive objects, the motivation is fueled by the potential that one can see 3D printing in terms of its potential contributions to the field of engineering. While some older tried and true materials and manufacturing processes are still viable options, 3D printing has some negative connotations surrounding it for which there might be some invalidated reasons. Some say it is too unpredictable or lacks consistent strength, quality, or reliability. Most of the time, the potential use of this technology is often dismissed before it is given a chance. In recent years, however, those passionate or just curious about this technology have been in the quest of helping to develop a series of viable quality assurance processes that will hopefully help solve some of these problems. It is really an engineer's dream to be able to take an idea and turn it into something tangible. 3D printing makes this dream a reality and the number of enthusiasts, both engineers and non-engineers alike, is growing rapidly. Today, anyone can buy a desktop printer and learn to model, and 3D print their designs relatively quickly and cost effectively due to the vast array of 3D printing websites available in the online community. The potential of the rapid prototyping industry is far from its peak. The main motivation for this study was to see how relevant parts were printed on an entry-level, desktop 3D printer in terms of real-world applicability.

II. LITERATURE REVIEW

Bogrekci et al. [1] studied the effect of infill type and density with rapid prototyping technique on hardness of 3-D printed part. Harpool [2] identified the effects of infill shapes on the tensile characteristics of 3D Printed plastic parts. Pandzic et al. [3] identified the effect of infill type and density on tensile properties of PLA material for FDM process. Johnson and French [4] studied the evaluation of infill effect on mechanical properties of consumer 3D printing materials. Ajay Kumar et al. [5] studied the effect of machine parameters on strength and hardness of FDM printed PETG thermoplastics. The factors selected for 3D printed of the specimen are print speed, infill density and layer height. The results of tensile and hardness are obtained by using Taguchi L9 experimental approach. It is observed that print speed and infill density have individual and simultaneous effect on tensile strength and hardness. Hussin et al. [6] studied the bio-inspired 3D infill patterns for additive manufacturing and structural applications. Cabreira and Santana [7] studied the influences of the infill patterns in the mechanical response of printed parts. Using poly lactic acid (PLA), a widely used polymer in FFF process, the mechanical responses of parts printed with different infill patterns were analysed. Lalegani Dezaki and Mohd Ariffin [8] combined the infill patterns on mechanical properties in FDM Process. It investigates the effects of combined infill patterns in 3D printed products. Five patterns (solid, honeycomb, wiggle, grid, and rectilinear) were combined in samples to analyse their effects on mechanical properties for tensile strength analysis. Dudescu and Racz [9] Three-dimensional printing is an additive manufacturing process that allows rapid design and manufacture of complex component based on computer-aided design models. Hanon et al. PLA filaments with three different colors (white, grey, and black) are utilized in [10] to produce the required test pieces. The dimensional accuracy for cylindrical (diameter and length) and dog-bone (width and thickness) samples have been evaluated. The nominal values are considered the reference to determine the accuracy percentage for each specimen. Harpool et al. [11] focused on investigating the percentage infill with respect to the cross-sectional area of the investigated samples. The mechanical properties, i.e., modulus of toughness, ultimate tensile stress, yield stress, and percent elongation, were explored for each sample having a different geometrical infill design. John et al. [12] characterized the effect of infill percentage, printing orientation and raster angle on ABS samples prepared with 3D printing technology. Letcher [13] a preliminary effort was undertaken to represent the mechanical properties of a 3D printed specimen as a function of layer number, thickness and raster orientation by investigating the correlation between the mechanical properties of parts manufactured out of ABS using Fused Filament Fabrication (FFF) with a commercially available 3D printer, Makerbot Replicator 2x, and the printing parameters, such as layer thickness and raster orientation, were considered. From this literature it has been identified that thermoplastic composites have many applications and the effect of infill ratio, infill type, orientation angle etc. such parameters on 3D printed components have significant impact on strength of the particular specimen. However, research on these materials is just started a decade ago so that there is lot of scope for conducting numerous studies and investigations in this area.

In this work, the effect of the infill patterns on tensile strength of the 3D-Components are studied. Computer-Aided-Design (CAD) software is used to develop the required specimens, which are then imported into ANSYS Workbench for the stress-strain simulation. A static structural analysis is carried out to predict the stress and elastic strain generated during the tensile test in each specimen. Post-process the data acquired from the testing and compare/contrast various calculated values related to the mechanical performance of each sample through this study of PLA and ABS materials for different infill patterns.

III. MODELLING OF TENSILE TEST SPECIMEN

Using CATIA V5 design software, the specimens are developed [14], the basic design of the tensile test specimen with 100% infill density and the dimensions taken are as shown in Table 1.

Table 1 Tensile test specimen specifications

Dimensions	Value (mm)
Width	6
Thickness	3
Radius of fillet	6
Overall length	100
Length of reduced parallel section	32
Width of grip section	10

The tensile test model is generated is shown in Fig. 1. The volume of the model is found to be 2541.66mm³. In this work, only 50% infill density is considered. So, the volume of specimens with different infill patterns should be close to 1270.83mm³.

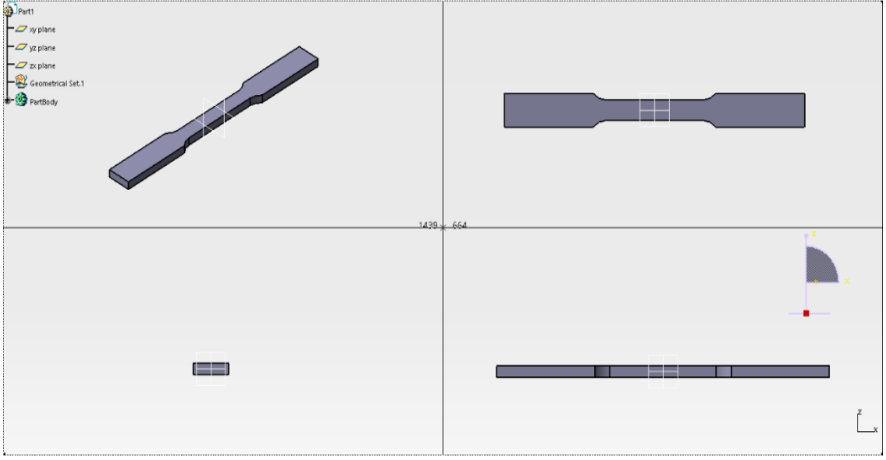

Fig 1 Tensile test specimen

3.1 Design of Basic Structure of Patterns

All basic structures are drafted in wire frame surface modelling in CATIA V5. This is the main repeating element in every pattern and they are shown in Figs. 2(a), 2(b) and 2(c).

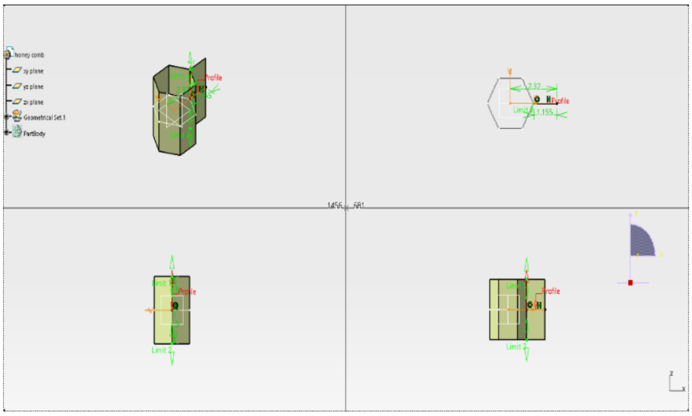

Fig. 2(a) Honeycomb basic structure

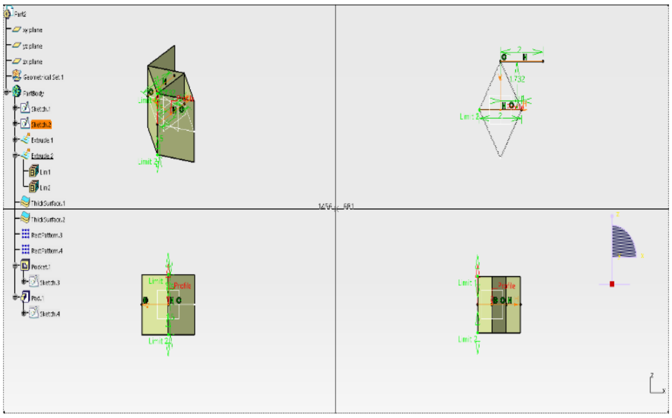

Fig. 2(b) Triangular basic structure

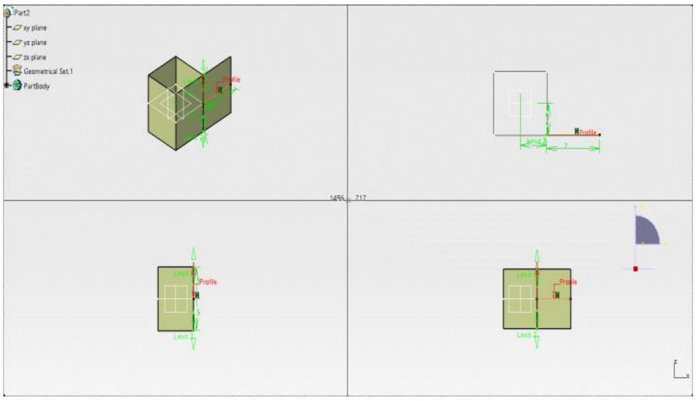

Fig. 2(c) Square grid basic structure

The infill patterns are generated from the basic structures in ‘wireframe and surface design’ to a height of 3mm and the extruded structure is given a surface thickness of 0.27mm (for Fig. 2(a)); 0.3mm (for Fig. 2(b)); 0.175mm (for Fig. 2(c)) in first, second off-set values; then using the ‘rectangular pattern’ tool in part design to create the honeycomb infill structure. After, that reverse pocketed the tensile test specimen profile and providing the thin thickness 0.2mm along the outer profile, then the specimen is generated as shown in Figs. 3(a), 3(b) and 3(c) in Multiview. (All the above dimensions are taken for 50% infill density).

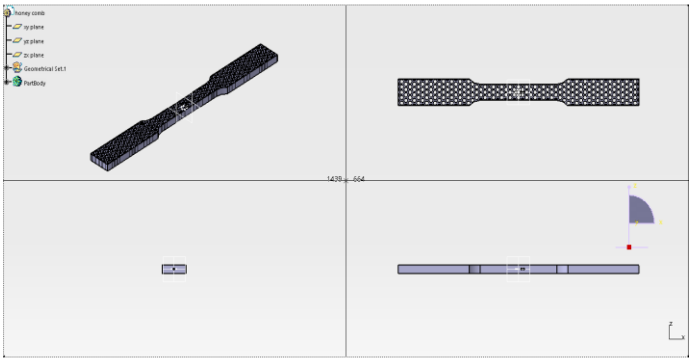

Fig. 3(a) Tensile specimen with honeycomb infill pattern

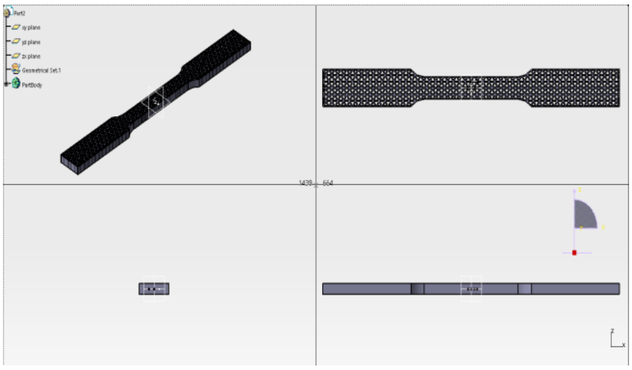

Fig. 3(b) Tensile specimen with Triangle infill pattern

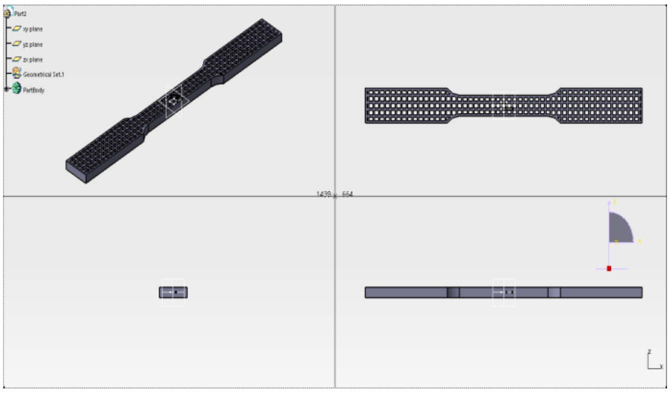

Fig. 3(c) Tensile specimen with square grid infill pattern

3.2 Static Structural Analysis

Static structural analysis of the six specimens with different infill patterns; materials and analyzed the factors like stress, elastic strain. The aim is to study the equivalent stress and equivalent elastic strain developed in the specimen until the initiation of permanent deformation. The material property values used for this analysis are described in Table 2.

Table 2 Material properties

Material	PLA	ABS
Density (kg/m³)	1230	1070
Young's Module's (GPa)	2.34	2.06
Poisson's Ratio	0.36	0.37
Yield Stress (MPa)	40	38.8

The meshing size is one of the main factors during the analysis so that it can be have a minimal runtime for solution and an optimal skewness of the mesh elements to avoid any errors in calculation process. Here, a 2mm element size is selected for honeycomb infill specimen and Triangular specimen and a 1.2mm element size is selected for square gird specimen. The meshed models are shown in Figs. 4(a), 4(b) and 4(c).

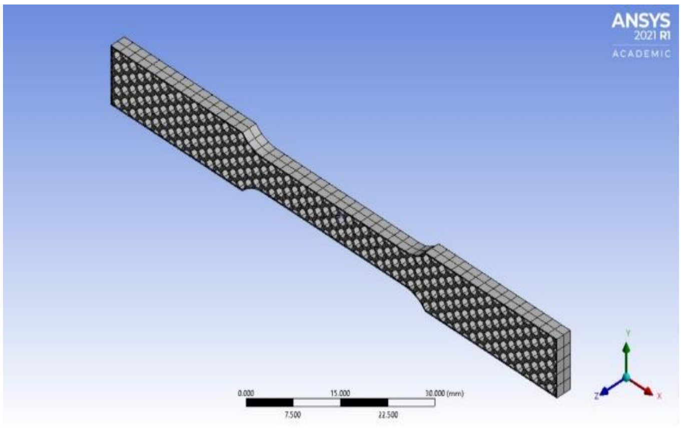

Fig. 4(a) Meshed honeycomb infill model

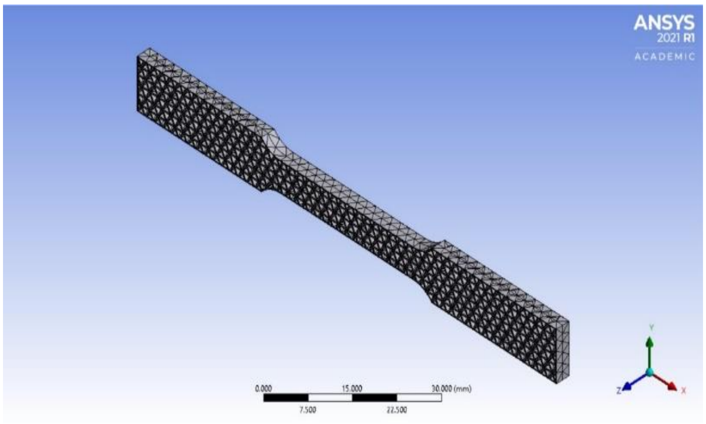

Fig. 4(b) Meshed triangle infill model

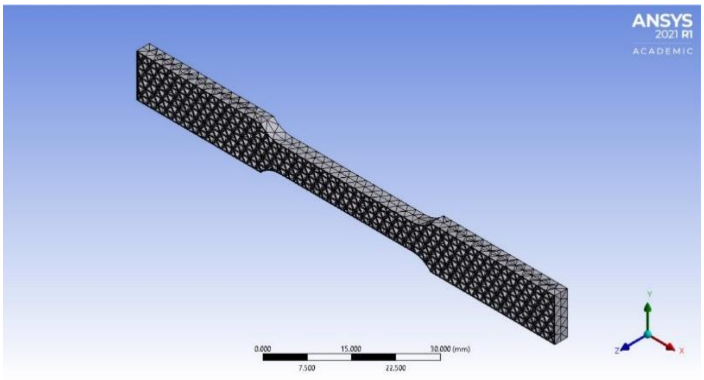

Fig. 4(c) Meshed square grid infill model

In this analysis, the opposite rectangular surfaces of grip section on top and bottom of the left side on the specimen is fixed, while the faces on the right side are selected for the application of load. The load acting on the specimen is varied for different infill types and different materials (PLA, ABS) and is considered based on the initiation of the permanent deformation using trial and error method. The loads considered for the honeycomb, triangular and square grid infill are 325 N, 320 N and 250 N respectively.

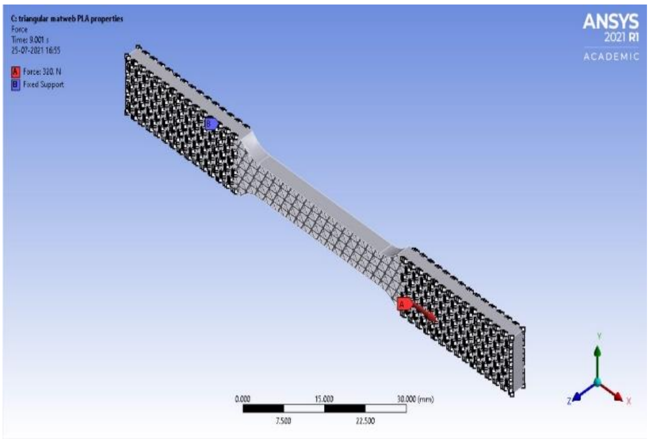

Fig. 5(a) Boundary conditions for triangular infill

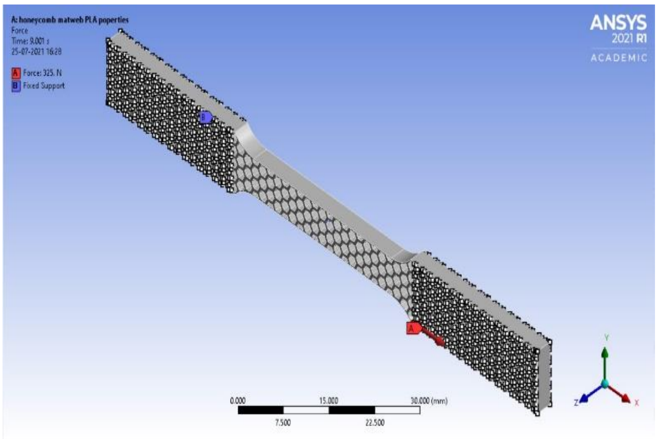

Fig. 5(b) Boundary conditions for honeycomb infill

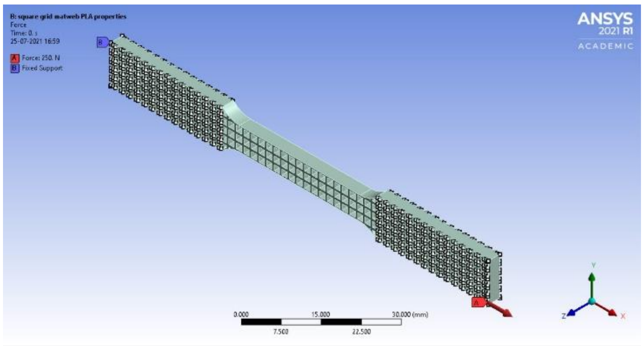

Fig. 5(c) Boundary conditions for square grid infill

IV. RESULTS AND DISCUSSION

In the present work, 6 specimens of PLA, ABS material with different infill pattern are tested. Influence of infill pattern and material on structural strength are tested, and all results are analysed. The results obtained from the ANSYS simulation showed the difference between different parameters of infill pattern and material, of specimen. The static structural analysis is performed based on the given boundary conditions; from the analysis it is observed that the maximum stresses occur at the middle part of the specimen. The maximum stress obtained for the infill model of honeycomb of PLA is 71.014MPa and ABS is 56.338MPa. It means for the load of 325N the tensile strength of PLA is 26% greater than the ABS material.

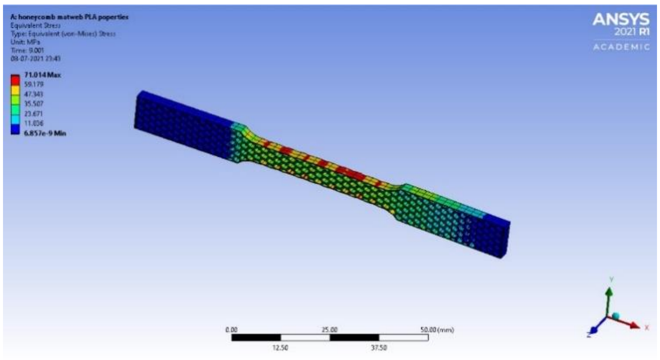

Fig. 6(a) Stress contour for honeycomb with PLA material

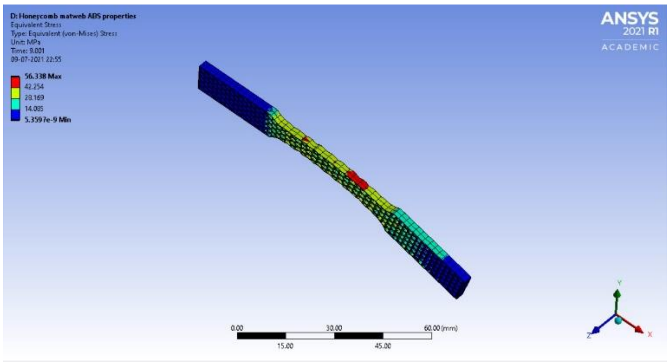

Fig. 6(b) Stress contour for honeycomb with ABS material

The maximum stress obtained for the triangular infill of PLA is 54.048MPa and ABS is 49.283MPa. The tensile strength of PLA is 9.7% greater than the ABS material for the load of 320N. These stresses are 15-30% less compare to honeycomb structure.

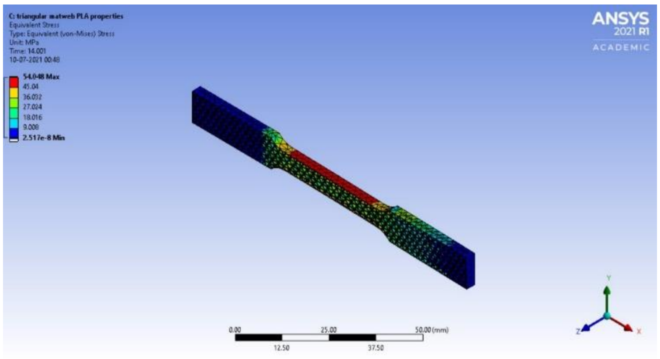

Fig. 7(a) Stress contour for triangular with PLA material

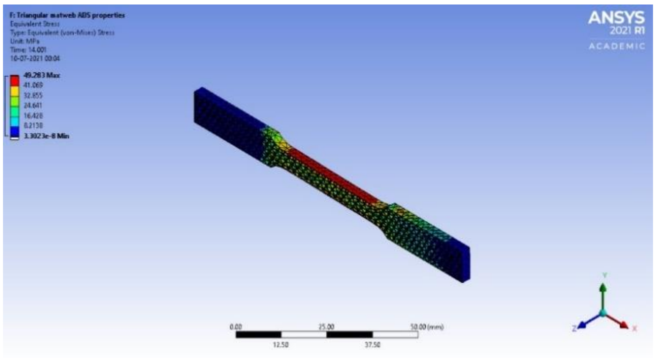

Fig. 7(b) Stress contour for triangular with ABS material

The maximum stress obtained for the square grid infill of PLA is 16.946MPa and ABS is 16.994MPa. The tensile strength of PLA and ABS material for the load of 250N. These stresses are 70-76% less compare to honeycomb structure.

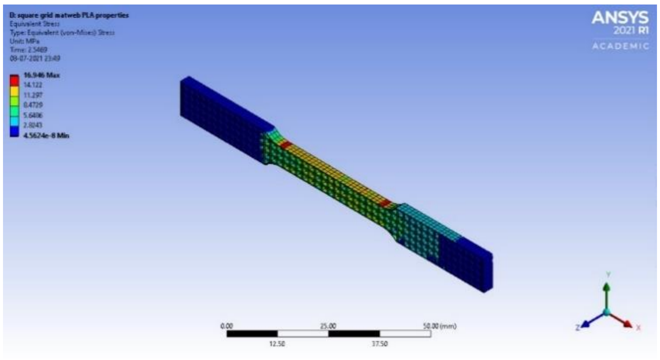

Fig. 8(a) Stress contour for square grid with PLA material

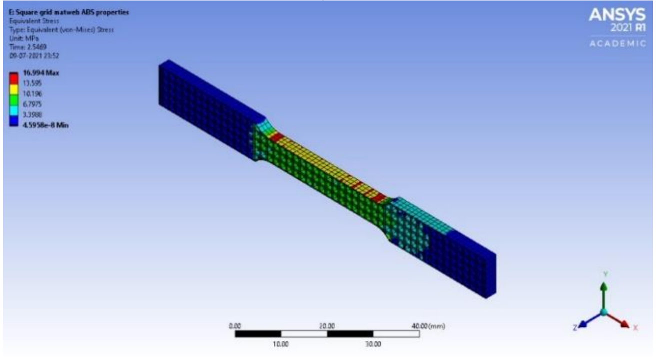

Fig. 8(b) Stress contour for square grid with ABS material

The maximum strain obtained for the infill model of honeycomb of PLA is 0.0308MPa and ABS is 0.0283MPa. It means for the load of 325N the strain of PLA is 8% greater than the ABS material.

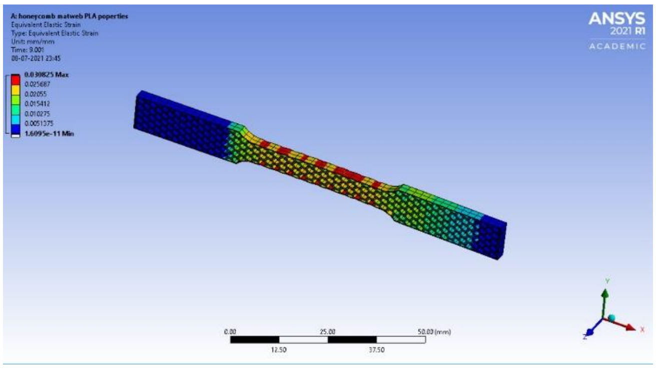

Fig. 9(a) Strain for honeycomb with PLA material

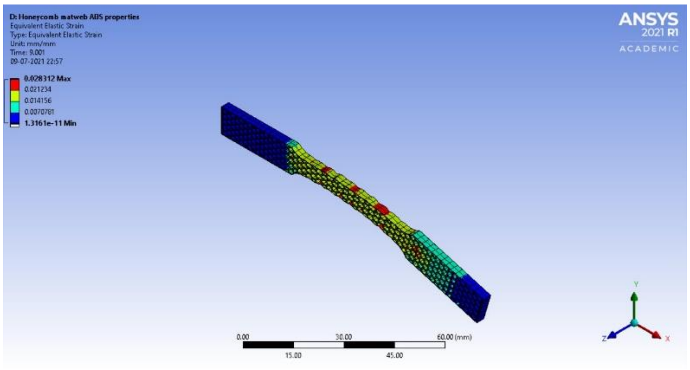

Fig. 9(b) Strain for honeycomb with ABS material

The maximum strain obtained for the triangular infill of PLA is 0.024 and ABS is 0.025 The strain of PLA and ABS material for the load of 320N are almost same.

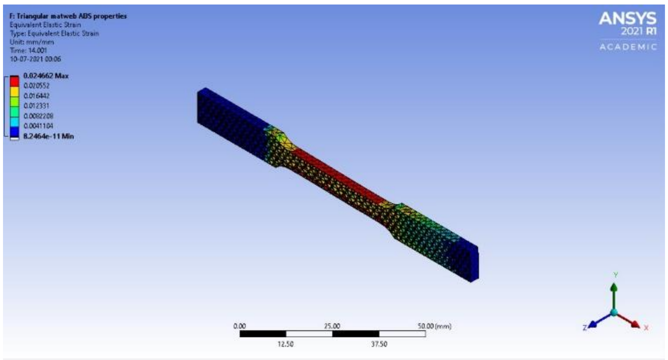

Fig. 10(a) Strain for triangle with ABS material

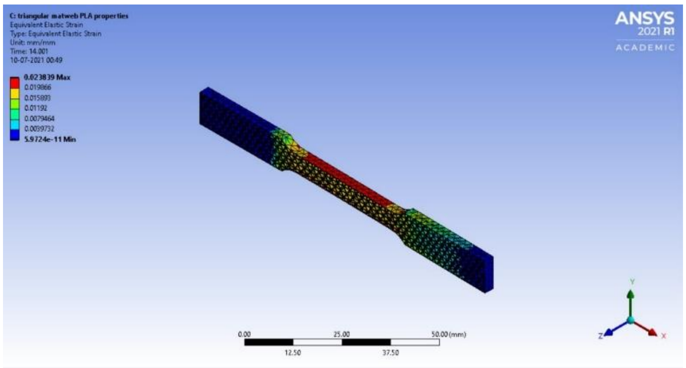

Fig. 10(b) Strain for triangle with PLA material

The maximum strain obtained for the square grid infill of PLA is 0.021 and ABS is 0.025 The strain of PLA and ABS material for the load of 250N are almost same.

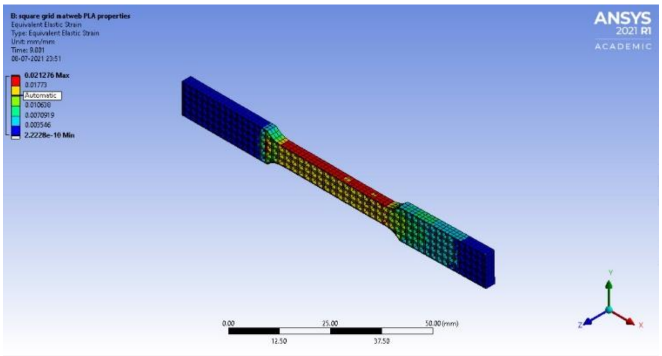

Fig. 11(a) Strain for square grid with PLA material

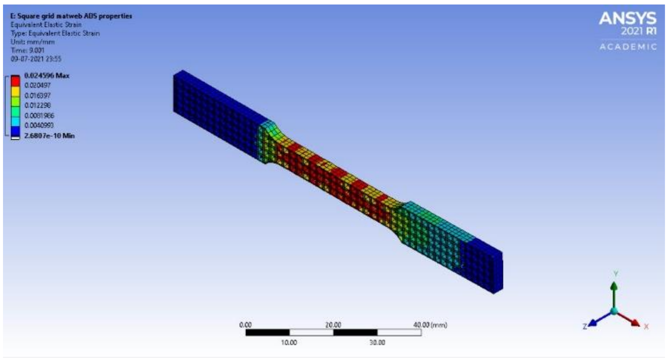

Fig. 11(b) Strain for square grid with ABS material

Fig. 12 presents the typical stress–strain curve for each test method. All curves displayed a similar trend of increased tensile stress with increased strain until the peak stress is reached, after which stress rapidly dropped to zero.

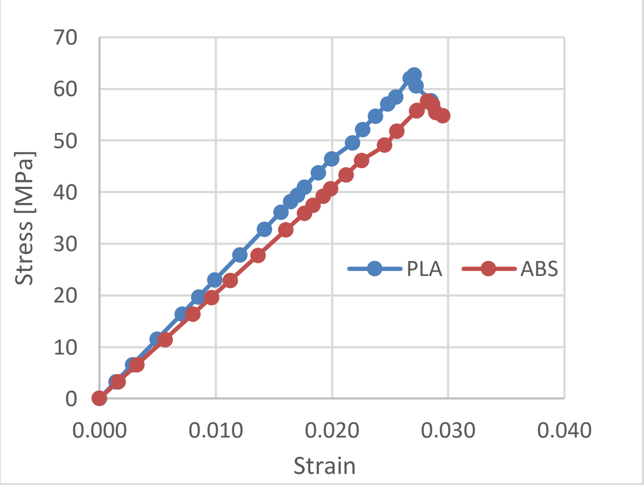

Fig. 12(a) Effect of material on strength for honeycomb infill

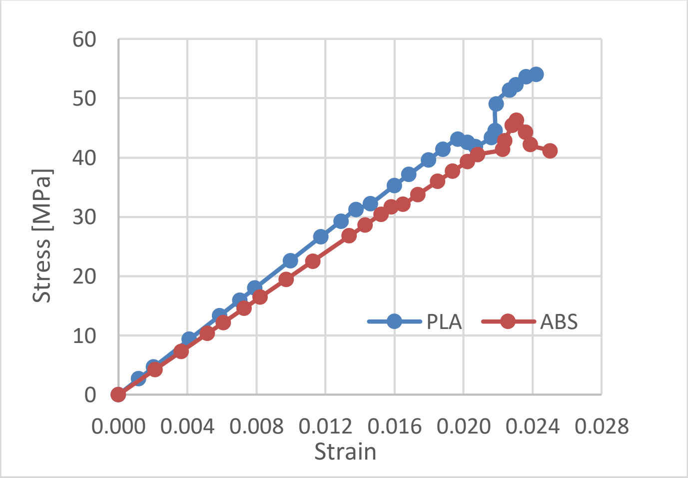

Fig. 12(b) Effect of material on strength for triangular infill

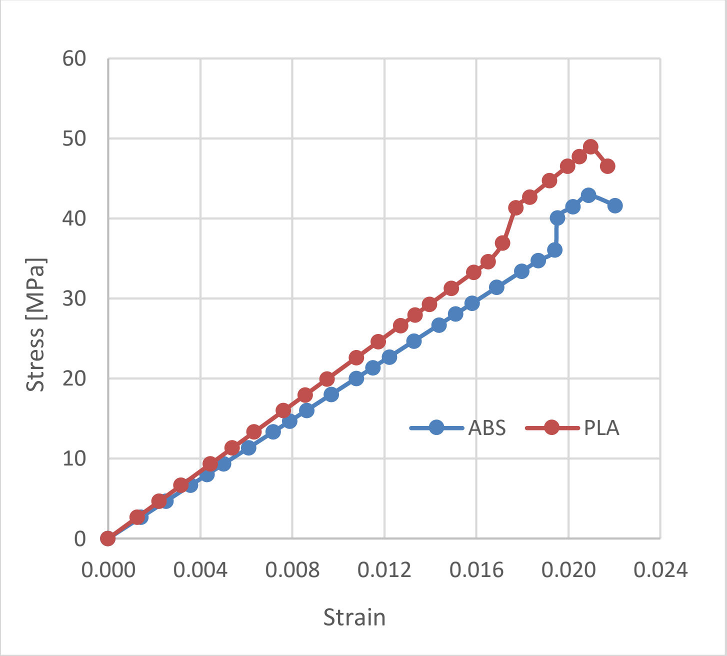

Fig. 12(c) Effect of material on strength for square grid infill

The stress–strain relationship is nearly linear for all infill shapes of PLA and ABS materials. A large strain developed before the occurrence of failure, and all curves clearly indicate the brittle nature of the tensile failure. The tensile strengths for the PLA and ABS materials of honeycomb infill obtained the highest value, followed by triangular and square grid infill structures.

V. Conclusion

In the present work, the effects of infill type and material on tensile strength of thermoplastic components have been studied. The specimen with honeycomb infill has the maximum tensile strength for both materials used in range of 71.064-56.338MPa. The minimum strength is obtained for the square-grid infill is around 16MPa. The classification among the different infill patterns related to tensile strength was Honeycomb > Triangle > Square Grid. The results obtained in this study agreed with the investigation regarding the infill pattern and strength. Infill type have effect on strength for thermoplastic components. Here, the influence of infill pattern on material properties is examined only for tensile testing in one direction. It can be further examined the other factors in 3 directions. Also, the influence of infill pattern on other mechanical properties (bending, pressure and hardness etc.) should be examined. This analysis identifies material behavior with different infill pattern and density for various applications.

REFERENCES

[1] İ. Bogrekci, P. Demircioglu, H. S. Sucuoglu, and O. Turhanlar, “The Effect of the Infill Type and Density on Hardness of 3D Printed Parts,” *Int. J. 3D Print. Technol. Digit. Ind.*, vol. 3, no. 3, Art. no. 3, Dec. 2019.

[2] T. D. Harpool, “Observing the Effects of Infill Shapes on the Tensile Characteristics of 3D Printed Plastic Parts,” Wichita State University, 2014.

[3] A. Pandzic, D. Hodzic, and A. Milovanovic, “Effect of Infill Type and Density on Tensile Properties of PLA Material for FDM Process,” in *DAAAM Proceedings*, 1st ed., vol. 1, B. Katalinic, Ed., DAAAM International Vienna, 2019, pp. 0545–0554. doi: 10.2507/30th.daaam.proceedings.074.

[4] G. A. Johnson and J. J. French, “Evaluation of Infill Effect on Mechanical Properties of Consumer 3D Printing Materials,” *Adv. Technol. Innov.*, vol. 3, no. 4, Art. no. 4, Jul. 2018.

[5] M. Ajay Kumar, M. S. Khan, and S. B. Mishra, “Effect of Machine Parameters on Strength and Hardness of FDM Printed Carbon Fiber Reinforced PETG Thermoplastics,” *Mater. Today Proc.*, vol. 27, pp. 975–983, Jan. 2020, doi: 10.1016/j.matpr.2020.01.291.

[6] M. S. Hussin *et al.*, “Experimental and Finite Element Modeling of Partial Infill Patterns for Thermoplastic Polymer Extrusion 3D Printed Material using Elasto-plastic Method,” *AIP Conf. Proc.*, vol. 2278, no. 1, p. 020011, Oct. 2020, doi: 10.1063/5.0014978.

[7] V. Cabreira and R. M. C. Santana, “Effect of Infill Pattern in Fused Filament Fabrication (FFF) 3D Printing on Materials Performance,” *Matér. Rio Jan.*, vol. 25, no. 3, p. e-12826, 2020, doi: 10.1590/s1517-707620200003.1126.

[8] M. Lalegani Dezaki and M. K. A. Mohd Ariffin, “The Effects of Combined Infill Patterns on Mechanical Properties in FDM Process,” *Polymers*, vol. 12, no. 12, Art. no. 12, Dec. 2020, doi: 10.3390/polym12122792.

[9] M. Dudescu and L. Racz, “Effects of Raster Orientation, Infill Rate and Infill Pattern on the Mechanical Properties of 3D Printed Materials,” *ACTA Univ. Cibiniensis*, vol. 69, Dec. 2017, doi: 10.1515/aucts-2017-0004.

[10] M. M. Hanon, L. Zsidai, and Q. Ma, “Accuracy investigation of 3D printed PLA with various process parameters and different colors,” *Mater. Today Proc.*, vol. 42, pp. 3089–3096, Jan. 2021, doi: 10.1016/j.matpr.2020.12.1246.

[11] T. D. Harpool *et al.*, “Evaluation of the Infill Design on the Tensile Response of 3D Printed Polylactic Acid Polymer,” *Materials*, vol. 14, no. 9, Art. no. 9, Jan. 2021, doi: 10.3390/ma14092195.

[12] J. John, D. Devjani, S. Ali, S. Abdallah, and S. Pervaiz, “Optimization of 3D Printed Polylactic Acid Structures with Different Infill Patterns using Taguchi-Grey Relational Analysis,” *Adv. Ind. Eng. Polym. Res.*, vol. 6, no. 1, pp. 62–78, Jan. 2023, doi: 10.1016/j.aiepr.2022.06.002.

[13] T. Letcher, B. Rankouhi, and S. Javadpour, “Experimental Study of Mechanical Properties of Additively Manufactured ABS Plastic as a Function of Layer Parameters,” presented at the ASME 2015 International Mechanical Engineering Congress and Exposition, American Society of Mechanical Engineers Digital Collection, Mar. 2016. doi: 10.1115/IMECE2015-52634.

[14] M. Derise and A. Zulkharnain, “Effect of Infill Pattern and Density on Tensile Properties of 3D Printed Polylactic acid Parts via Fused Deposition Modeling (FDM),” *Int. J. Mech. Mechatron. Eng.*, vol. 20, pp. 54–62, Aug. 2021.