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Simulation for Design and Evaluation of a Bending Beam-based Lattice for Manufacturing

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ABSTRACT

Lattice structures are two- or three-dimensional micro-architectures made composed of beams, struts, or nodes. They're bio-inspired arrangements consisting of trusses with honeycomb and octagonal patterns. In nature, any lattice-like structure adds strength and flexibility to otherwise a lightweight material. In this paper, an analysis of four lattice specimens - triangle, hexagon, concentric cube, and regular cube - was carried out. A comprehensive examination of the main parameter's sheds light on their mechanical behavior under applied loads. The mass and volume of the samples vary, reflecting differences in geometric configurations. The cube with the center has the least mass, followed by the regular cube, hexagon, and triangle. All samples share a constant density, indicating a uniform material composition across the network structures. Weight corresponds to mass, with a centered cube being the lightest and a regular cube being the heaviest. The stress values increase serially from triangle to regular cube, indicating a relationship between geometric complexity and internal stress. The concentric cube and the regular cube show higher displacements and strains, indicating greater structural flexibility or deformation under applied loads. Reaction forces vary, supporting the idea that different network configurations respond uniquely to external forces. Von Mises stress values are related to geometric complexity, highlighting the influence of composition on mechanical behavior. Pressure-to-weight analysis shows that the concentric cube and the regular cube show superior structural efficiency, outperforming the others in pressure-to-weight ratios. Displacement-to-weight analysis reveals that the centered cube and the regular cube show superior deformation properties, with higher displacements relative to their weights. Stress-to-weight analysis shows that the concentric cube and the regular cube exhibit superior material deformation properties, with higher strains compared to their weights. Observations indicate that the centered cube and regular cube exhibit superior structural efficiency and deformation properties, while the triangle and hexagonal specimens balance lower stress, displacement, and strain with lower weights. These results can guide lattice design optimization to improve performance in various applications. This research provides a quantitative basis for understanding the structural performance of mesh specimens, provides insights into their response to applied loads and informs future investigations and simulations of optimal mesh design.

1. INTRODUCTION

It is yet, another technological innovation made feasible by the transition from analog to digital processes. In recent decades, communications, imaging, architecture, and engineering have all undergone their own digital revolutions. Now, AM can provide digital flexibility and efficiency to production operations. Additive manufacturing employs data computer-aided design (CAD) software or 3D object scanners to command hardware to deposit material, layer upon layer, in precise geometric patterns. As its name implies, additive manufacturing adds material to make an object.

By contrast, when you construct an object by traditional techniques, it is often essential to remove material through milling, machining, carving, shaping, or other means. Although the terms "3D printing" and "rapid prototyping" are casually used to discuss additive manufacturing, each method is essentially a subset of additive manufacturing. While additive manufacturing seems new to many, it has actually been around for several decades. In the right applications, additive manufacturing delivers a perfect trinity of better performance, complicated geometry and easier fabrication. As a result, opportunities abound for individuals who aggressively adopt additive manufacturing. Nowadays, it has become necessary to make light metal and non-metallic structures using additive manufacturing processes AM to reduce weight and thus reduce the manufacturing cost, as models called Lattice structures manufactured using additive manufacturing technology have begun to appear in many industrial applications. The lattice structure is a desirable material for many design applications (aerospace, biological engineering, mechanical engineering, etc.) because of the great qualities including the light-weighting, high specific strength and stiffness, disperse heat, and so on. As porous materials, before the lattice structure developed, the name of cellular structure was more generally adopted. The concept of “cellular structure” was originally introduced by Gibson and Ashby Evans, Hutchinson, et al. [1–2]. May explain that in an easy-to-understand fashion that, lattice structures are repetitive patterns that fill a volume or conform to a surface. In engineering design, lattices are cellular materials generally inspired by nature that consist of beams, surfaces, or plates that fit together following an ordered or stochastic pattern. Figure 1 displays many forms of lattice structures.

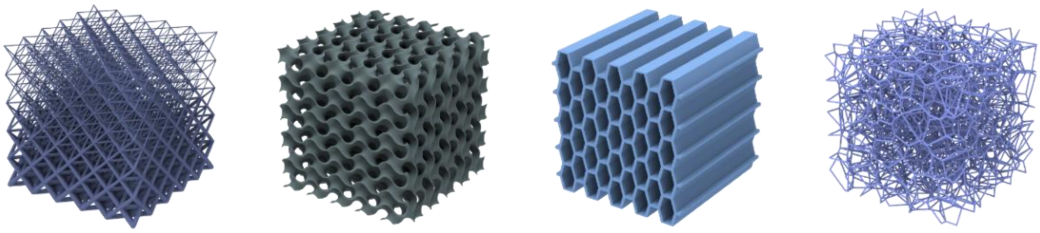


Fig. 1 Different types of cellular structures.

The remarkable features of lattice structures fill in the blank of the manufacturing industry and create unprecedented prospects for structures with superior manufacturing performance. The features of lattice structures dictate their extensive application sectors. Because of its lightweight and high strength, lattice structures are extensively utilized in the structural design of airplanes, rockets, and other aerospace disciplines [3], and automotive applications [4]. In addition, lattice structures have bio-compatibility and great strength, which can be fashioned into the shape of human tissue and bone to replace sick organs. Lattice structures have been widely used in the medical profession because of their flexible mechanical qualities and structural characteristics, which can satisfy specific criteria [5]. The specific applications of lattice structures are depicted in Figure 2.

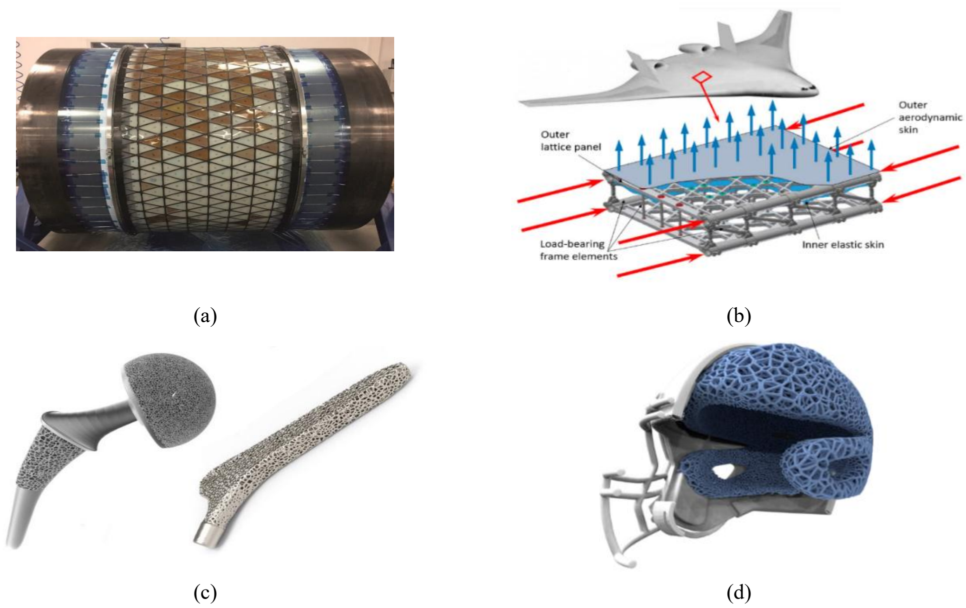


Fig. 2 Applications of lattice structures: (**a**) Cylindrical lattice structures for satellite applications; (**b**) aerial vehicle wing structure; (**c**) Medical implant; (**d**) hockey helmet.

Due to searching and collecting some scientific works on the topic of this paper, it was revealed that there are few references related to the lattice structure topic. It was noted that all works published in scientific journals and conferences are fairly up-to-date references.
In this part of the literature review, some information and statistics about the design and manufacture of lattice structures were presented.
A lattice structure is an architecture formed by an array of spatial periodic unit cells with edges and faces. There are two- and three-dimensional lattice structures, and they are often linked to cellular solids [10], see Figure 3 It is also known as lattice material because the micro architecture allows it to be viewed as a monolithic material with its own set of effective properties.

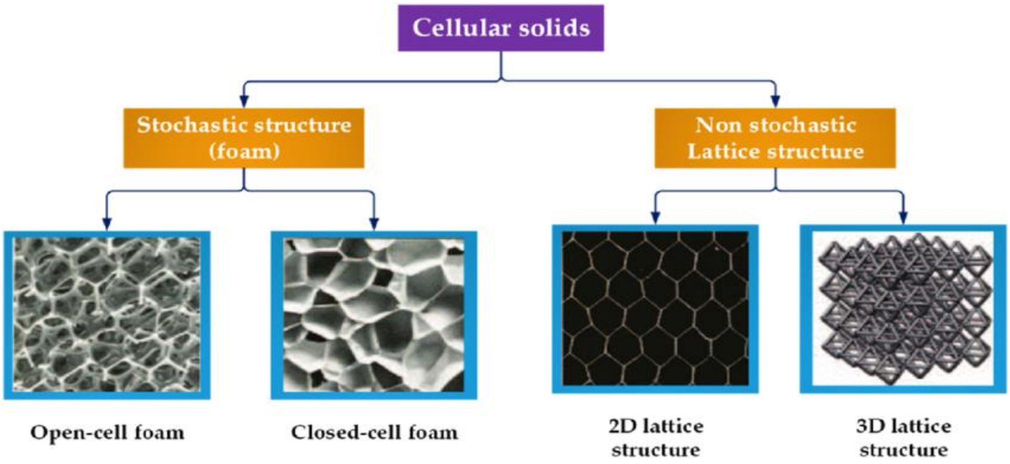


Fig. 3 Categories of cellular solids.

In one of the works published which related to an overview of the Design, analysis, and manufacturing of lattice structures in the International Journal of Computer Integrated Manufacturing [7], it was discovered that more than eighty articles were first assessed. After careful study, forty-five of them were selected and examined to establish the diverse unit cell designs, manufacturing procedures, and materials utilized. Literature was located through the use of the Scopus database as well as thorough Google Scholar searches to guarantee literature from a wide range of study topics was employed, stretching from the previous 5 decades to the present. The literature was categorized into distinct categories depending on their main topic of research Figure 4.
In other parts of the published research which exhibits the manufacturing procedures of lattice structures the same paper [7] concluded that there presently exist no techniques to produce a lattice structure using regular manufacturing methods without requiring assembly or post-production treatment. The electrodeposition manufacturing procedure, involving the coating of hollow lattice structures, there exists a lack of alternate materials being electrode posited on cells. Further, there is a lack of comparison between the testing of hollow lattice structures, notably in the comparison of hollow tubes being braised and sophisticated manufacturing method such as Selective laser sintering (SLS) and Selective laser melting (SLM).
The main additive manufacturing procedures applied in the fabrication of lattice structures are powder bed fusion technologies such as SLS and SLM, as can be seen in Figure 5, Both SLS and SLM procedures have been able to be used to materials such as bronze, steel, titanium and aluminum.

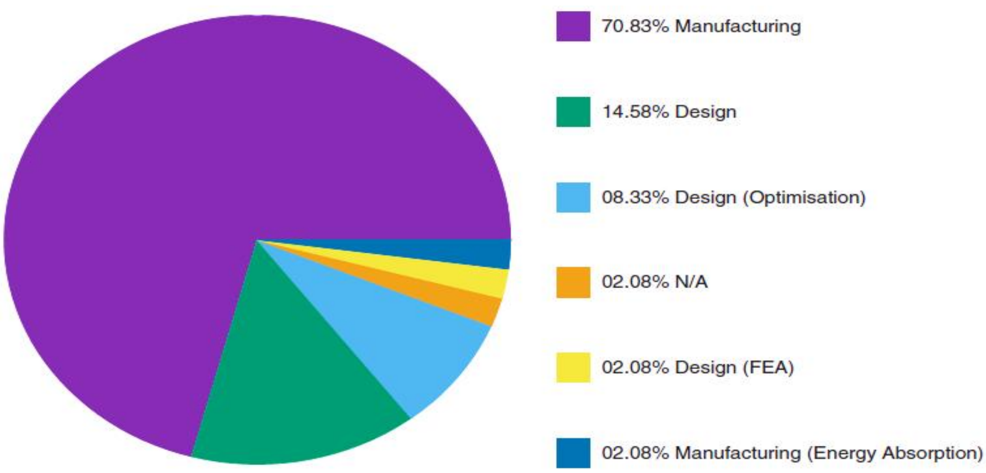


Fig. 4 Classifications of literature areas that lattice structures.

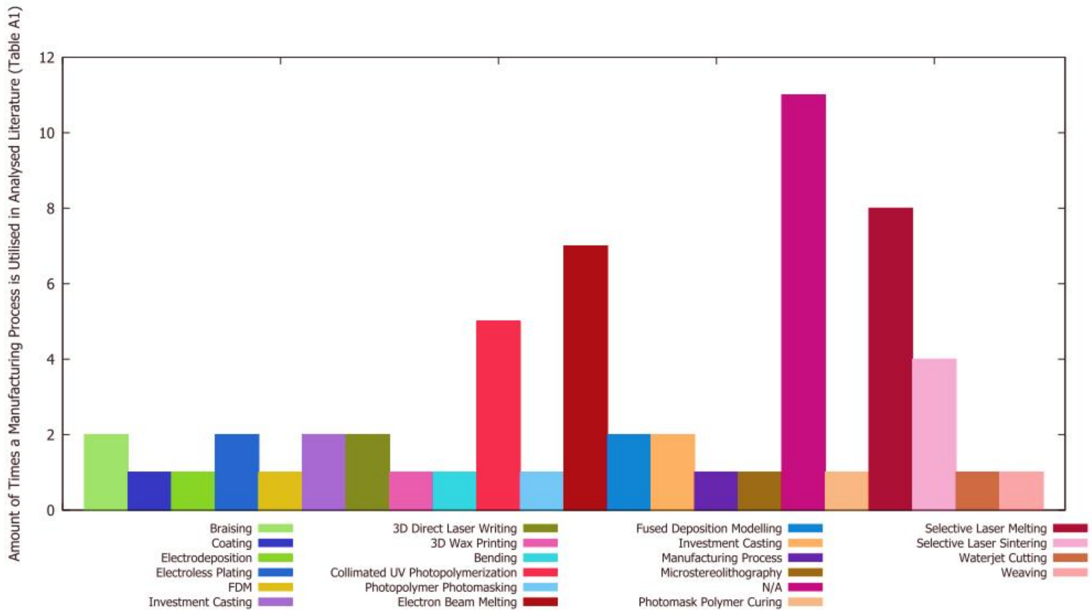


Fig. 5 The methods utilized in lattice structures manufacturing. [7]

Researchers from China and Taiwan has been published an important topic connected to kinds, design, optimization, and additive manufacturing of cellular structures in the International Journal of Advanced Manufacturing Technology (Springer Nature) [8]. This publication detailed numerous investigations that have been made to build various sorts of cellular structures with distinct features. Many most widely explored lattice structures are presented in Figure 6. All lattice structures obtained in this illustration are named as: a Kagome. b Octet truss. c MS1 lattice structure. d Stochastic foam. e Pillar textile. f Square collinear/cubic. g Re-entrant auxetic. H Spatially varied self-collimating lattice. i Body-centered cubic (BCC). j BCC with vertical strut in z-axis (BCCZ). k Face-centered cubic (FCC). l FCC with vertical strut in z-axis (FCCZ). m Octahedron. n Honeycomb. o Square. p Diamond. q TPMS P-type. r TPMS gyroid. s TPMS D-type. t TPMS I-WP type.

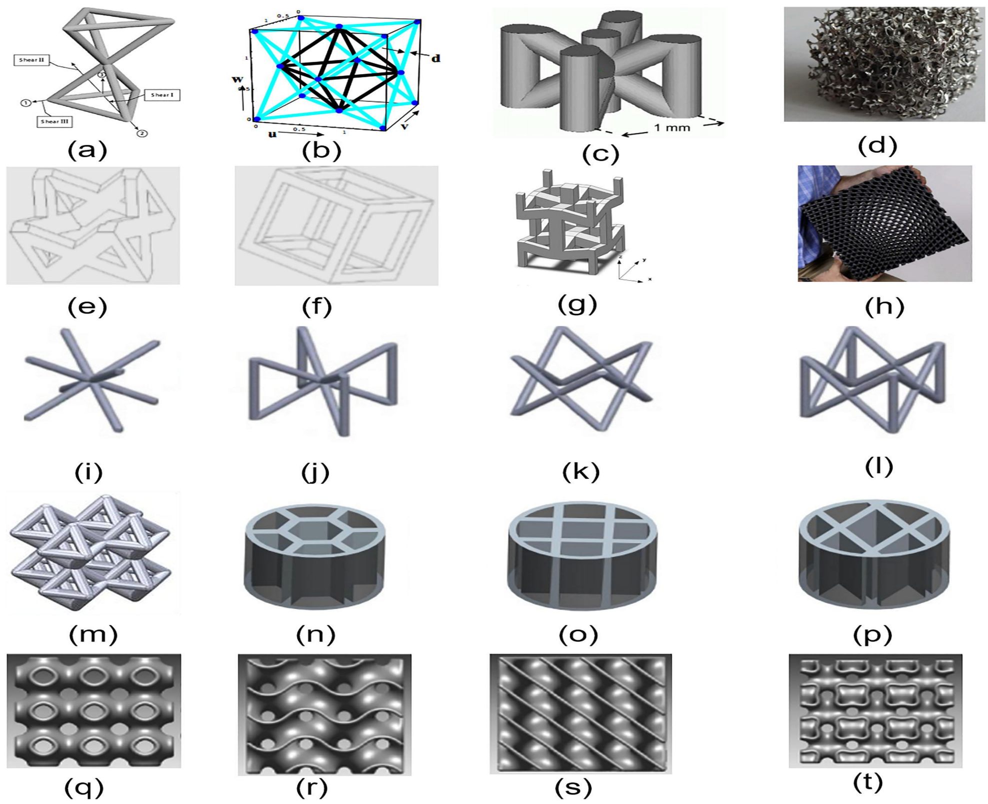


Fig. 6 Various topologies of lattice structures.

According to a published study which give a review design and optimization of lattice structures, the lattice structures are classed into uniform lattice structures and non-uniform lattice structures. The design and optimization of uniform lattice structures are largely described from three aspects: (1) unit cell structure design, (2) mathematical algorithm, and (3) unit cell topology optimization. For the definition of lattice structure, the lattice structure is formed by arrangement of unit cells in space. Different types of unit cells have their individual features, which can reflect and impact the performance of the complete lattice systems. [9].

Most of academic work on the attributes of lattice structures are based on the design of unit cell structures, the change of unit cells arrangement, and the optimization. With the application of various modeling software, it is easy to construct alternative unit cell structures. Designers can freely utilize CAD software to create the geometric structure of unit cells, and then study the performance of the unit cells using finite element or experimental methods, and finally form a uniform lattice structure according to a given arrangement of unit cells. For the design of unit cell shape, three authors from the University of Southern California [17] proposed a 3D texture mapping method, which enabled designers to select the unit cell structure that satisfied the design requirements from cell structure library See Figure 7, and then the internal structure was generated and defined in the Extensible Markup Language (XML) file combined with the selected unit cell structure. System can automatically transform the unit cell structure file into a CAD model. Finally, all the unit cells created a lattice structure. The basic idea of 3D texture mapping is shown in Figure 8. For example, the designer, knows in advance the stress state of solid cube structure on the left of plus sign, and then selects the lattice structure on the right side of the plus sign to map into the cube, forming a lattice structure by Boolean on the right side of the equal sign that can be made by additive manufacturing.

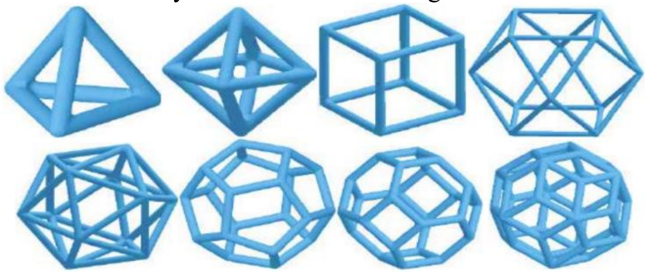


Fig. 7 3D Unit cell structure library [17]: tetrahedron, octahedron, cube, vector (top row, from left to right); icosahedral, dodecahedron, tetrakaidecahedron, triacontahedron (bottom row from left to right).

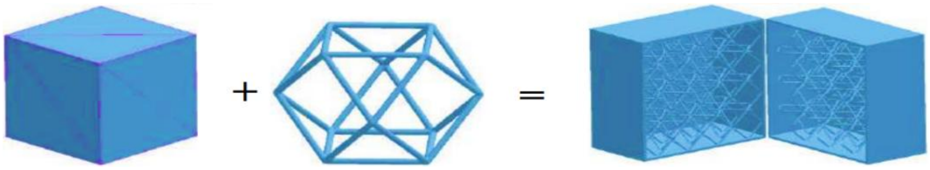


Fig. 8 3D texture mapping method [17].

It is an accurate approach to describe lattice structures by utilizing mathematical algorithms to create unit cell. Triply periodic minimum surface (TPMS) is one of the mathematical strategies that may successfully turn the theoretical mathematical model into the actual lattice structures. TPMS can be generated in numerous ways including Weistreass formula assessments, nodal approximations of the Weistreass formula, and numerical production. Figure 9 illustrates Unit cell based on TPMS.

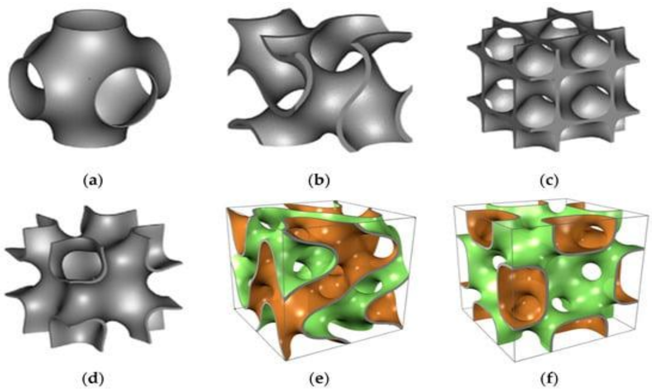
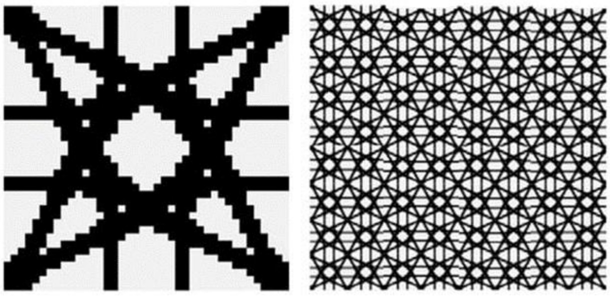


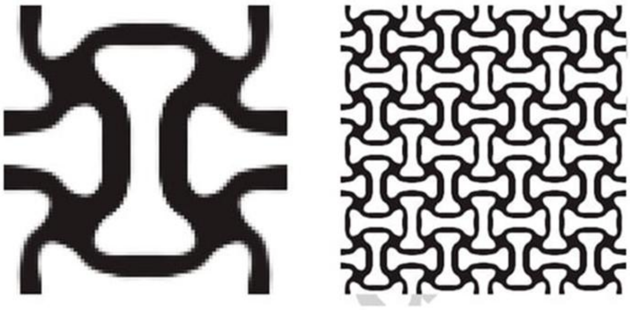
Fig. 9 Unit cell based on TPMS: (a) Schwartz P; (b) Schoen G (c) Schwarz D; (d) Schoen IWP; (e) Fischer - Koch S; (f) Schoen FRD.

Academic literature show that topology optimization is one of the ways to obtain uniform lattice designs. By optimizing unit-cell struts' sizes (i.e., thickness, length and diameter, etc.) and geometries, topology optimization effectively obtains lattice structures with specific performance, that is under condition of the specific constraints, the unit cells can be optimized to obtain specific performance requirements, and then unit cells can be arranged periodically to get the uniform lattice structures. Figures 10 and figure 11 presents design, optimal material, and Topology optimization of uniform lattice construction.



(a) (b)

Fig. 10 Design and optimal material: (**a**) optimal unit cell; (**b**) lattice structure.



(a) (b)

Fig. 11 Topology optimization of uniform lattice structure: (a) unit cell; (b) lattice structure.

EXPERIMENTAL WORK

In this paper, a design and simulation of some samples of lattice structures are obtained. To enhance the aim of this paper, It must check and validate the SolidWorks software by designing and manufacturing standard samples made from Acrylonitrile butadiene styrene ABS, these samples were tested by a tensile test machine to get the actual mechanical properties of the material used.

The actual results of the tensile test were compared to the behavior and results that we can get from the software, this step is needed to check and validate the SolidWorks software.

The other step of this experimental work is to design four sandwich samples of lattice structures and simulate these samples to study the mechanical behavior during their resistance to bending and exposure to shear forces.

Sstandard samples design

The initial step is the design of test specimens by one of the additive manufacturing techniques which is Fused Deposition Modeling (or FDM for short), this method is one of the most common 3D printing techniques available.

The test specimen to be built through by 3D printing process will undergo mechanical properties testing such as tensile test. The specimens should be designed as per ASTM standards, i.e., standard dog bone-shaped specimens for tensile tests of the specimens. these samples were implemented as 3D drawings in SolidWorks as shown in the figure below.

The test specimen has a gripping head or a holding head so that the test specimen can be easily fixed on the work holding jaws of the Universal Tensile Testers (UTM) on both ends. This gripping head has a length of 156mm and a breadth of 19 mm and thinks 3 mm. The test specimen has a gauge length of 75 mm and a gauge breadth of 13 mm where the properties of the polymers can be found subject to the respective test as shown in Figure 12.

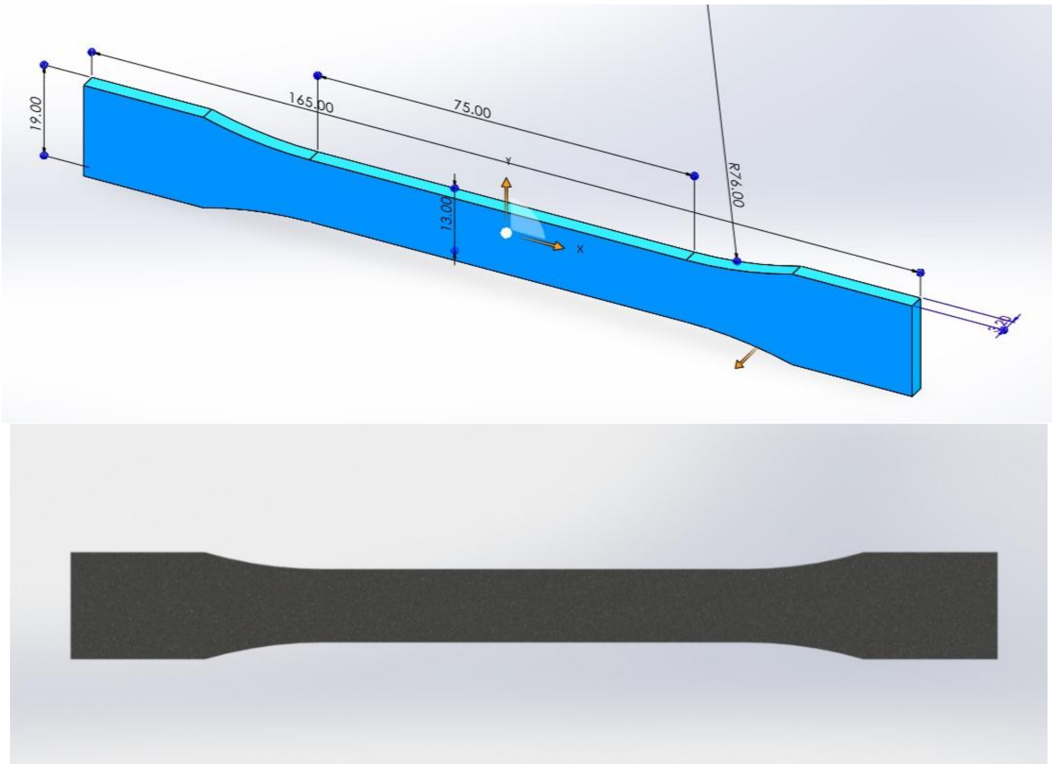


Fig. 12 The shape and geometry of the tensile test specimen.

The samples were manufactured using a Kingroon KP3S 3D Printer shown in Figure 13. This printer is available at the Center for Printing Plastic Crafts in Tripoli city. Figure (4.4) presents a picture from the laboratory in which the study samples were manufactured and the 3d printer.
The specimens are made from Acrylonitrile butadiene styrene ABS, and the printer was set according to the following data in Table 1. [30]

Table. 1 Printing parameters.

Layer thickness	Printing temperature	Infill density	Printing speed
0.1mm	250 C	40 mm/s	100%

Fig. 13 The shape and type of printer and samples used in this study.

Tensile test

Tensile test specimens were manufactured according to the American Society for Testing and Materials (ASTM) D638-02a (3.2 mm thick V-type specimens). In total, 4 samples of the same material were printed in one stage. The samples were manufactured using additive manufacturing technology using a Kingroon 3D printer (Intamsys Technology Co. Ltd., Shanghai, China). Tensile test was performed using a device from Deepak Poly plast (Shivalik Shilp, ISKCON Cross Road, SG Highway, Ahmedabad - Gujarat, India) and the test was conducted in the Misurata Plastic Pipe Factory laboratory. Figure 14 shows the tensile testing machine used in this work.

Fig. 14 The polymer sample being installed on the jaws of the tensile testing machine.

Tensile testing results are tabulated in stress-strain curve graphical representations are shown in Figure 15. Yield Force ranged between 671.76 and 761.00 N. Obtained ultimate tensile strength (UTS) varied from 16.75 to 18.98 N/mm².

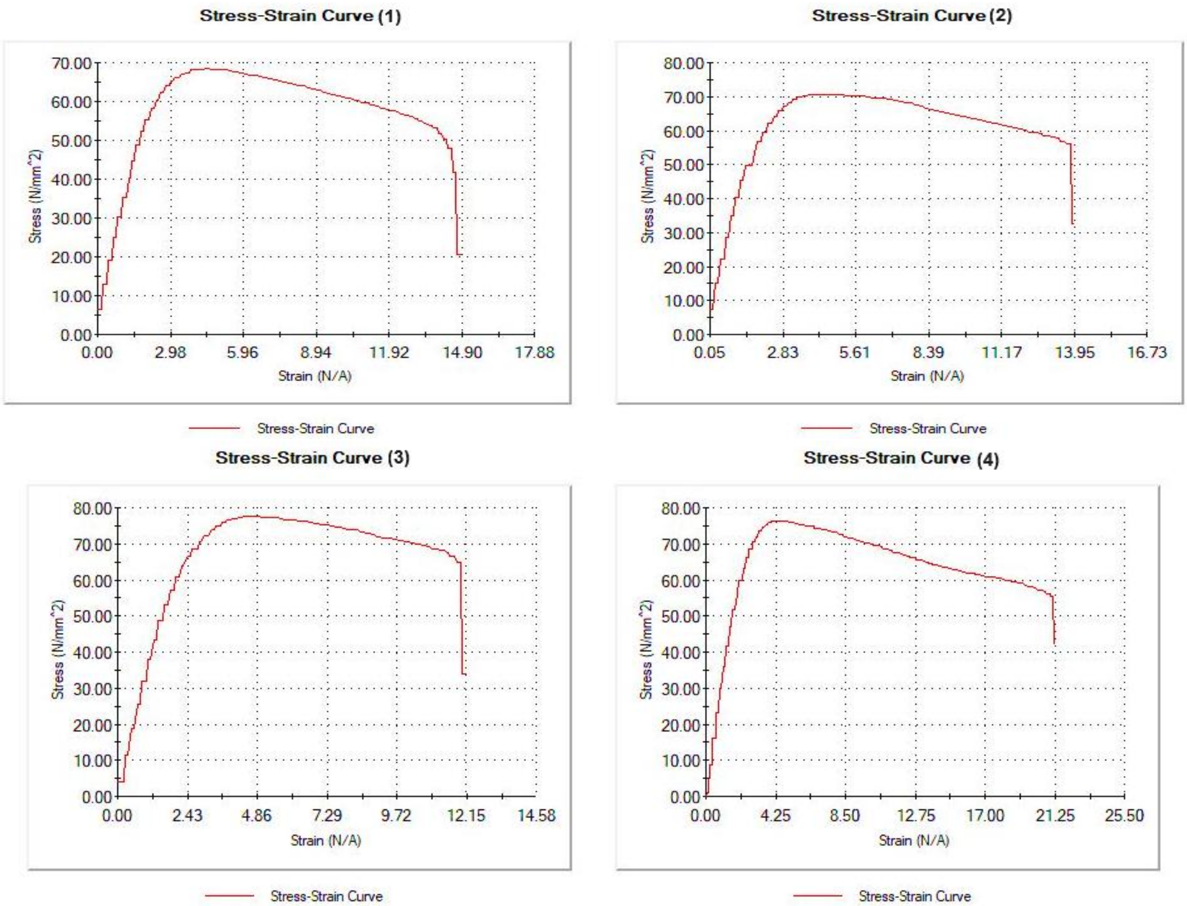


Fig. 15 The stress-strain curve for the samples

Actual and Simulation results

A tensile test simulation of a standard I sample using SolidWorks Simulation is implemented and the material selection from the program's material library is obtained, this material as mentioned before is ABS material. The results of the computer simulation are shown in the following Figure 16 and 17.

Name	Type	Min	Max
Stress1	VON: von Mises Stress at Step No: 146(1 Seconds)	4.175N/mm^2 (MPa) Node: 15412	24.959N/mm^2 (MPa) Node: 14824

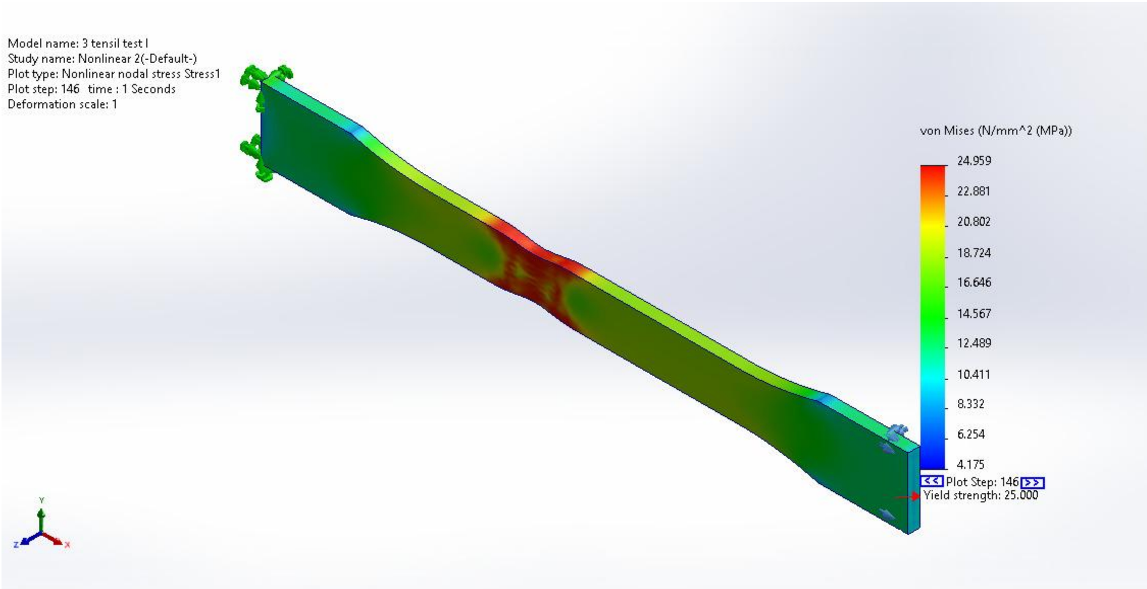


Fig. 16 The resulting stress plots.

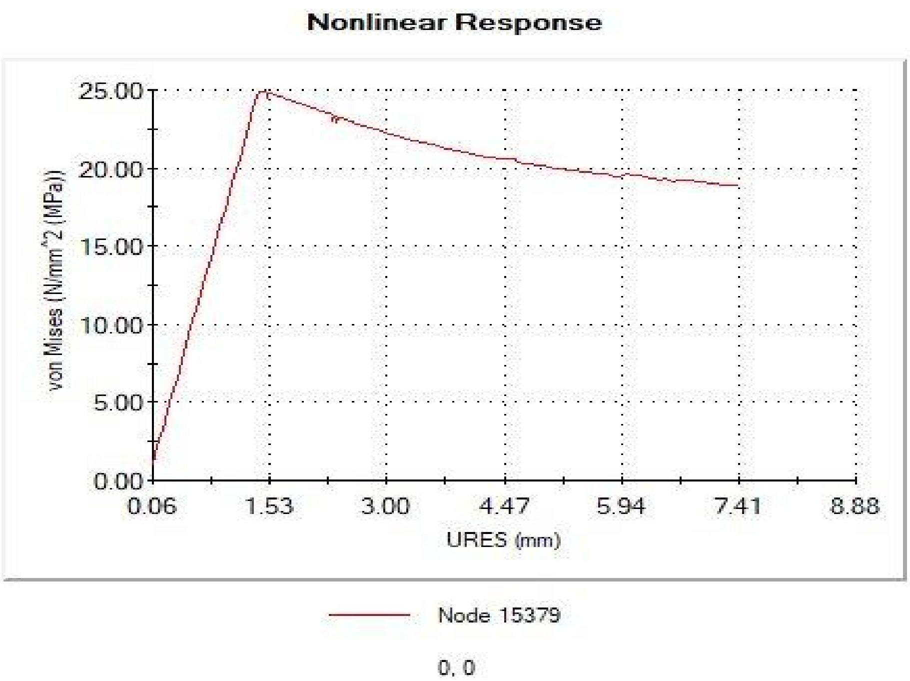


Fig. 17 Trend tracker graphs for stress with displacement.

It is obvious that the maximum stress value for the laboratory test is less than the simulation, as it was **18.7** MPa in the laboratory test and **25** MPa in the simulation. This is because manufacturing with 3D printing can affect the durability of the product, as thermal stress and changes in environmental temperature can lead to Reducing product durability.

Calibrate the SolidWorks Simulation program.

SOLIDWORKS Simulation uses material properties as the foundation to study designs. The default SOLIDWORKS material has many pre-defined material properties; however, users may need to define some of the material properties of default and custom materials before running a particular simulation study. For example, you may find that Mass Density and Yield Strength are pre-populated in a specific material but Specific Heat and Thermal Conductivity are not. This article defines the custom material properties and the studies they are used in.

To enhance the results of any design process, it should compare the actual results with the results that obtained by simulation software.

Figure 18. shows the material properties dialog box in the SolidWorks Material Library. It’s possible to create and edit custom materials, libraries, and favorites from the materials dialog box.

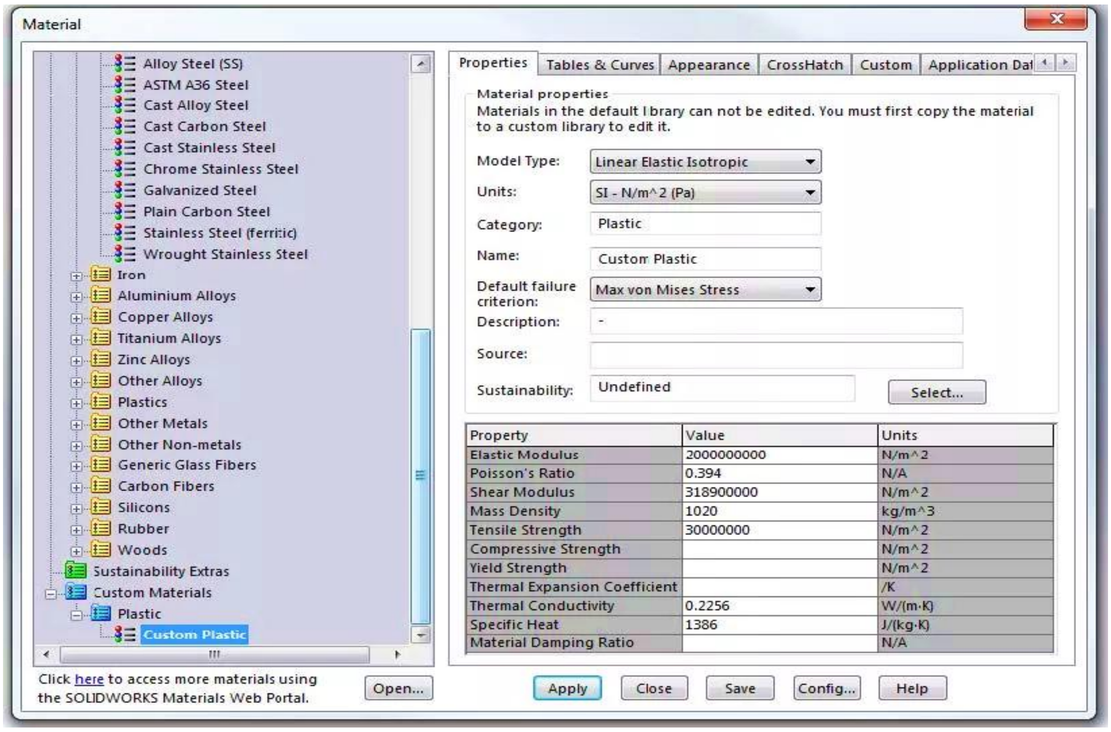


Fig. 18 Material Properties Dialogue Box.

Editing of Material properties in SOLIDWORKS Simulation

With a 3D model in SolidWorks, it’s simple to find out how strong or durable your design is using Simulation .But for a Simulation to be accurate, the virtual evaluation needs to reflect its real behavior, physical counter part .This is why the material properties is the foundation of a Simulation’s accuracy .When setting up a Simulation it’s crucial to use the correct material properties to ensure the results are as accurate as possible. However, when scrolling through the predefined library of 260 materials you might not find what you’re searching for .Here’s how to use your own, custom material in SOLIDWORKS Simulation.

The biggest distinction between the material library in SOLIDWORKS CAD and in SOLIDWORKS Simulation is the color code. In the side-by-side comparison below you’ll observe that they are identical except for properties highlighted in red and blue in Simulation This is your method of knowing which properties you’ll need to know. Red is unquestionably required; blue might be required as shown in Figure 19. [32]

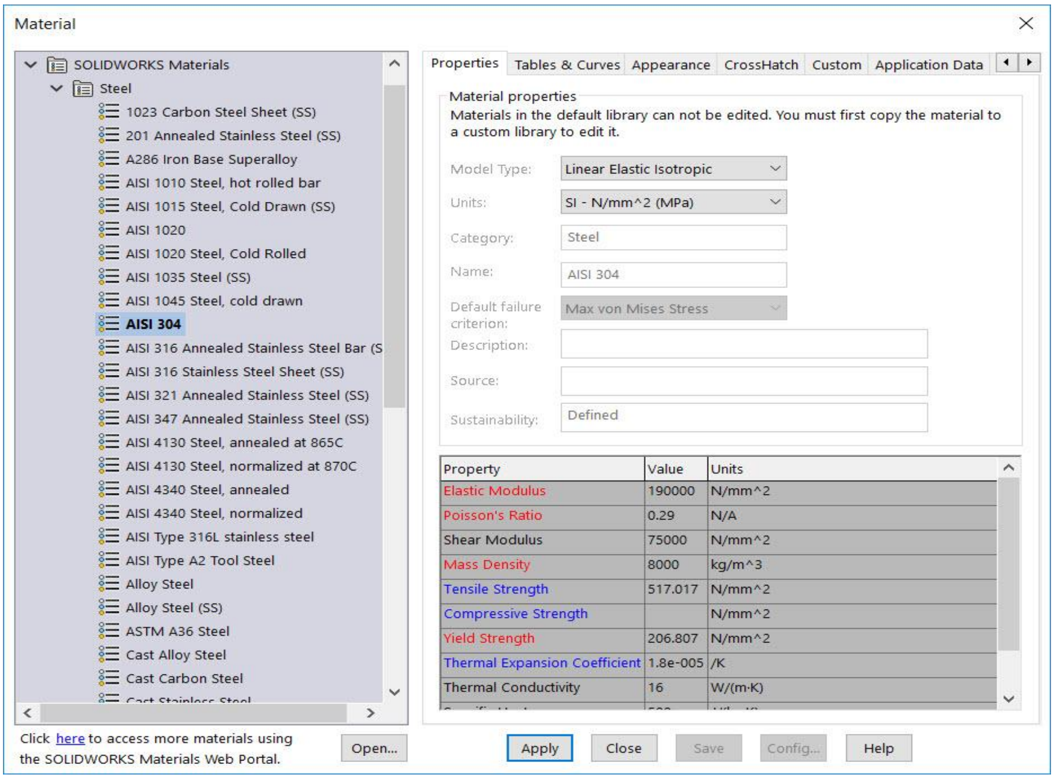


Fig. 19. Mechanical and physical properties of materials.

Results of editing the material library

After adding a custom value of the ABS material in the material library and retesting these values, the results will be appear as shown in the following figures of Figure 20 and 21.

Name	Type	Min	Max
Stress1	**VON: von Mises Stress at Step No: 110(1 Seconds)**	3.42N/mm^2 (MPa) Node: 10288	18.9N/mm^2 (MPa) Node: 16495

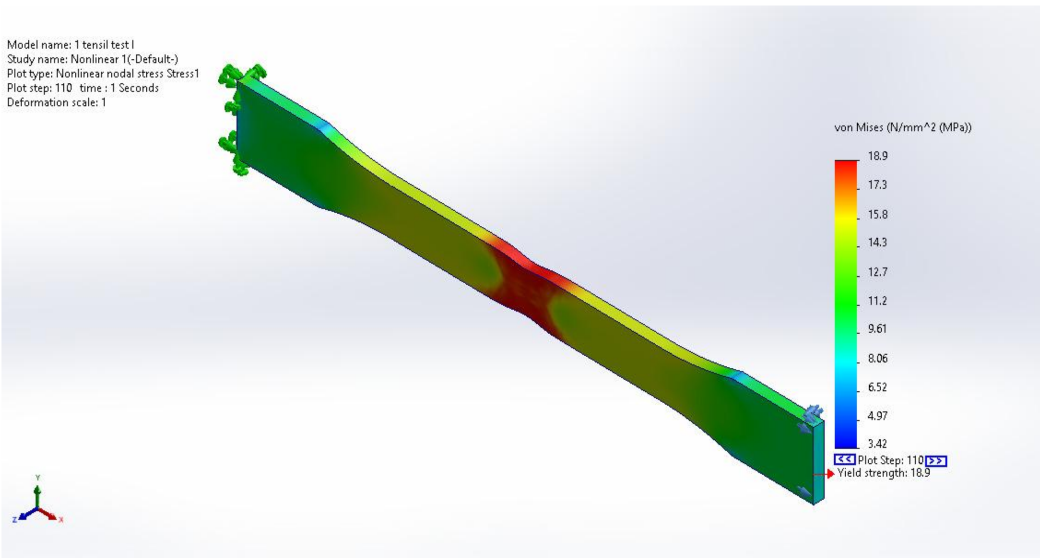


Fig. 20 Stress distribution plot.

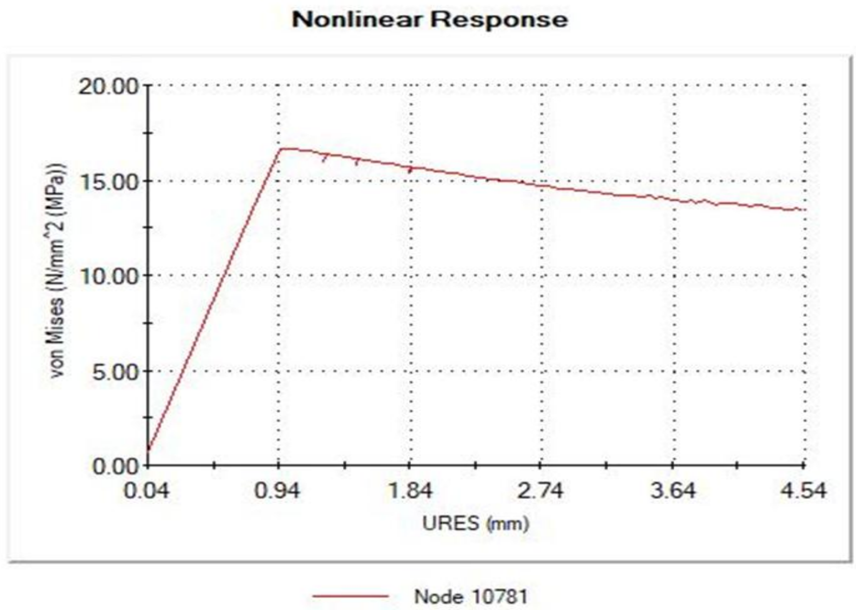


Fig. 21 Trend tracker graphs for stress with displacement.

The new material was saved as ABS FDM in the SolidWorks materials library to conduct tests on mesh samples using this modified material.

Design and evaluation of lattice structures samples

In this work, design of a lattice sandwich structure is created as shown in Figure 22. It is a composite structure consisting of a body substructure and a face substructure. Its total size is 160 mm length x 40 mm width x 10 mm height and the thickness of the outer layer is 2 mm. The inner filling process of the lattice structure will be in four different shapes.

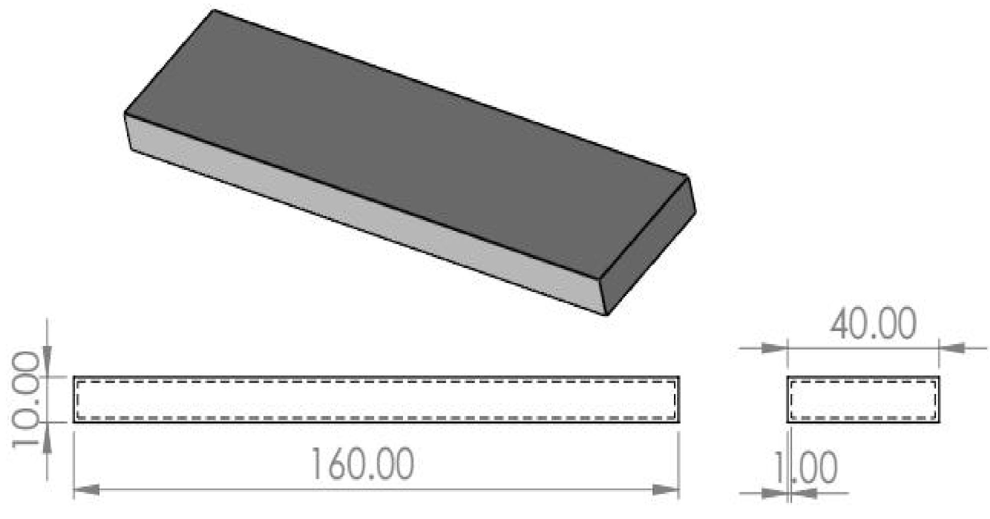


Fig. 22 The proposed sandwich structure.

In this paper, four samples are designed, each sample has a different lattice structure pattern, and SpaceClim software is used in the design process. This software is used in the design process because it has a library with a set of grid structures and allows to fill in any empty object with specific proportions and values. It possible to save the design in STEP format and export it to any other program.

Figures 23to 30 show the proposed lattice structures in this work in addition to Data used in the fill pattern of each sample.

1- 3D Hexagonal pattern "Hex"

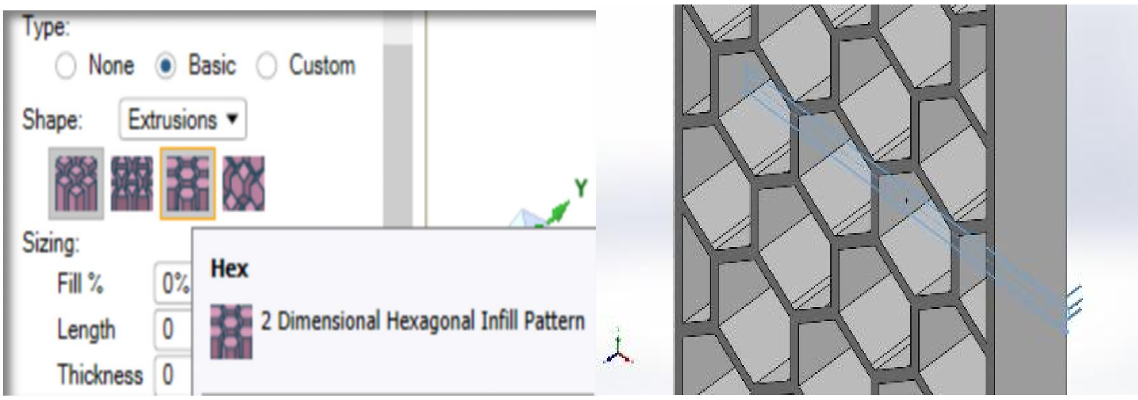


Fig.23 The hexagonal filling patterns

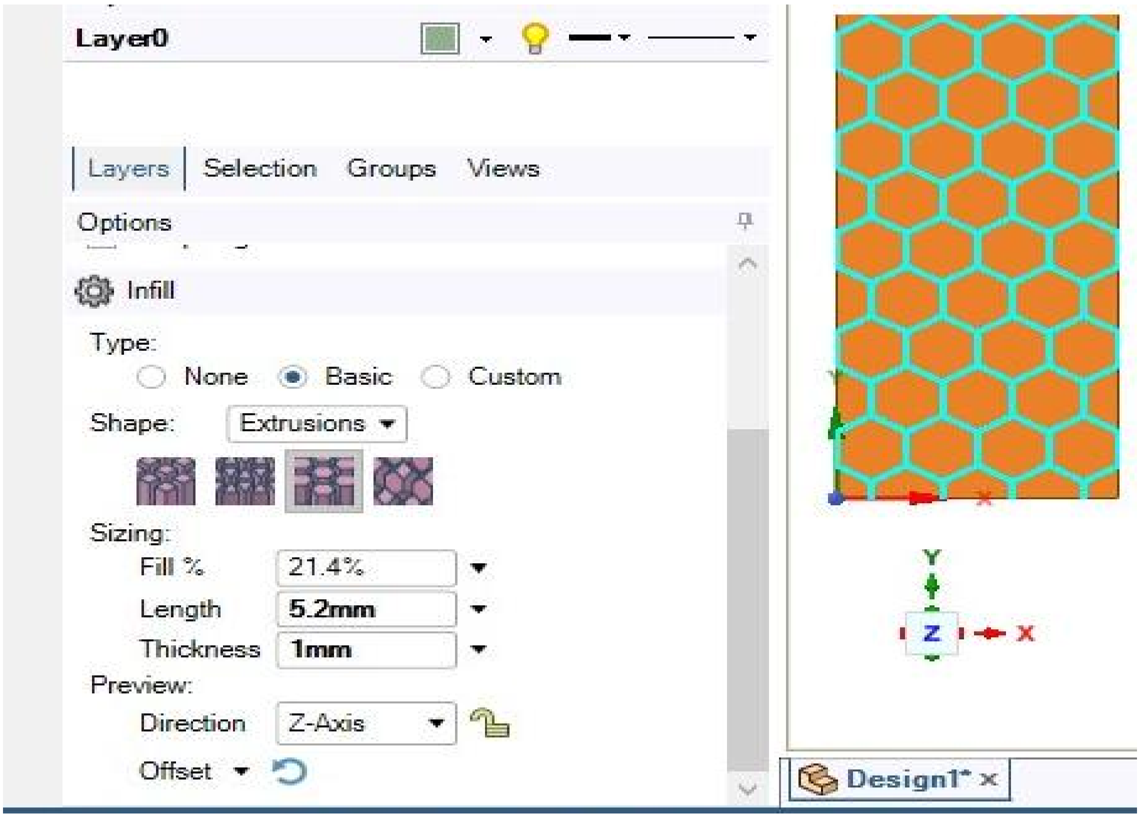


Fig. 24. Data used in the hexagon fill pattern.

2- 3D triangle pattern

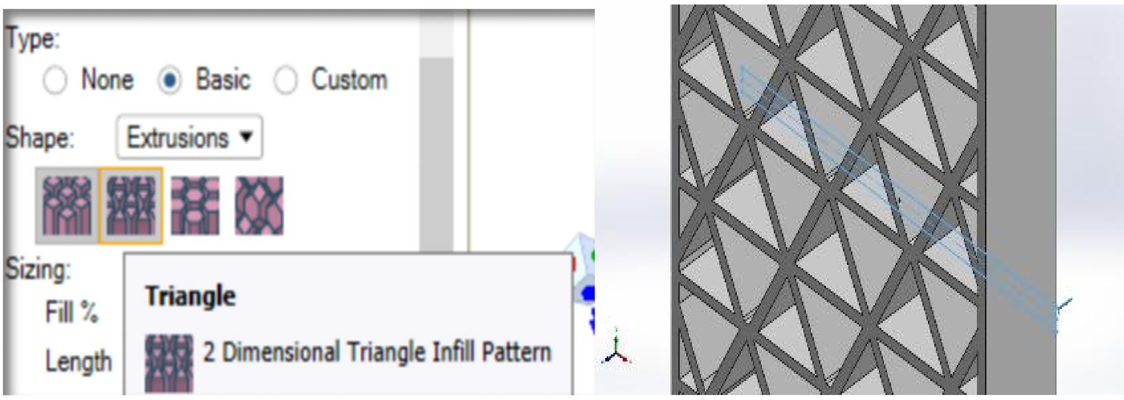


Fig. 25. The triangle-filling patterns.

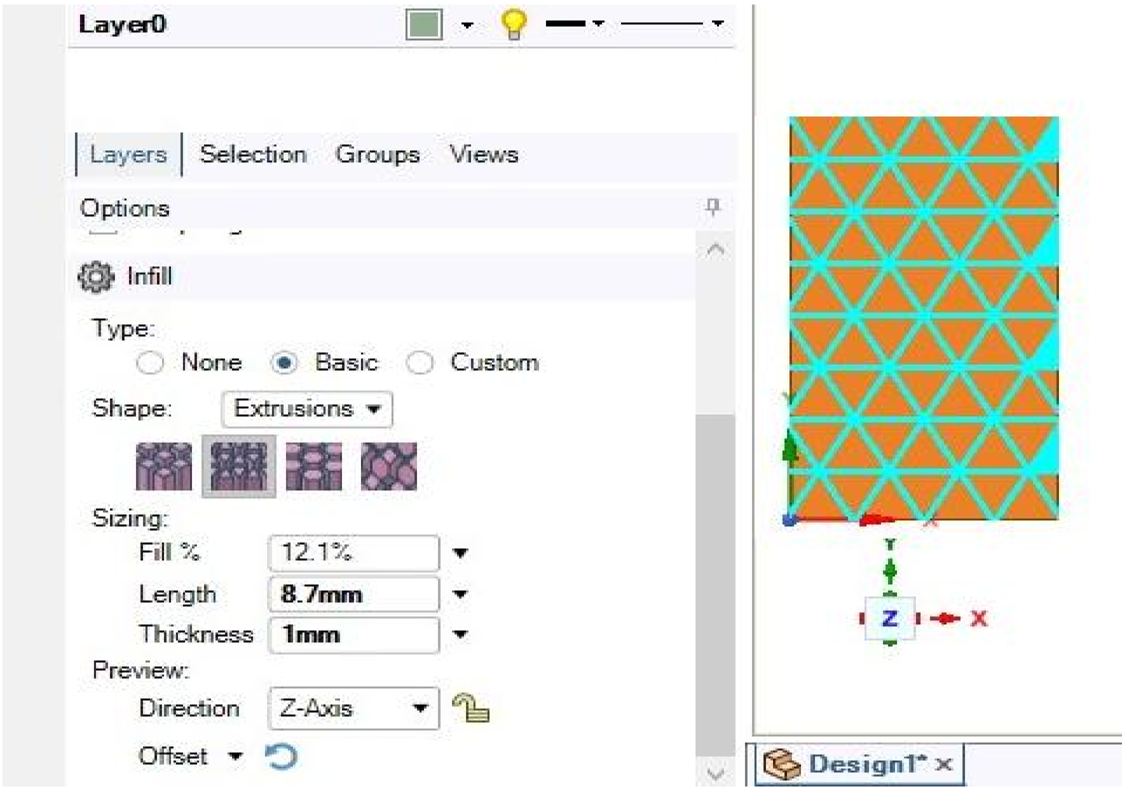


Fig. 26. The data used in the triangle filling patterns.

3-Regular cube lattice

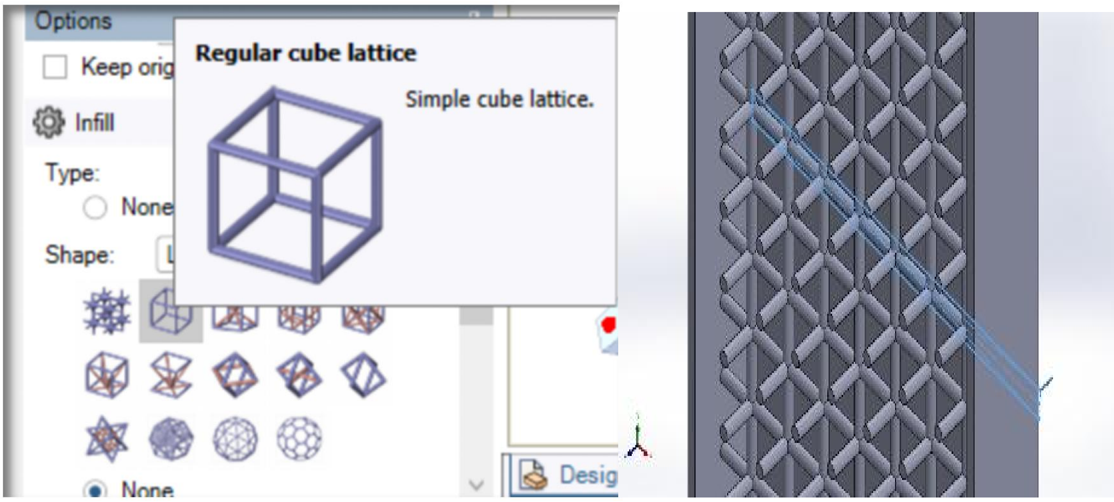


Fig. 27. The Regular cube lattice.

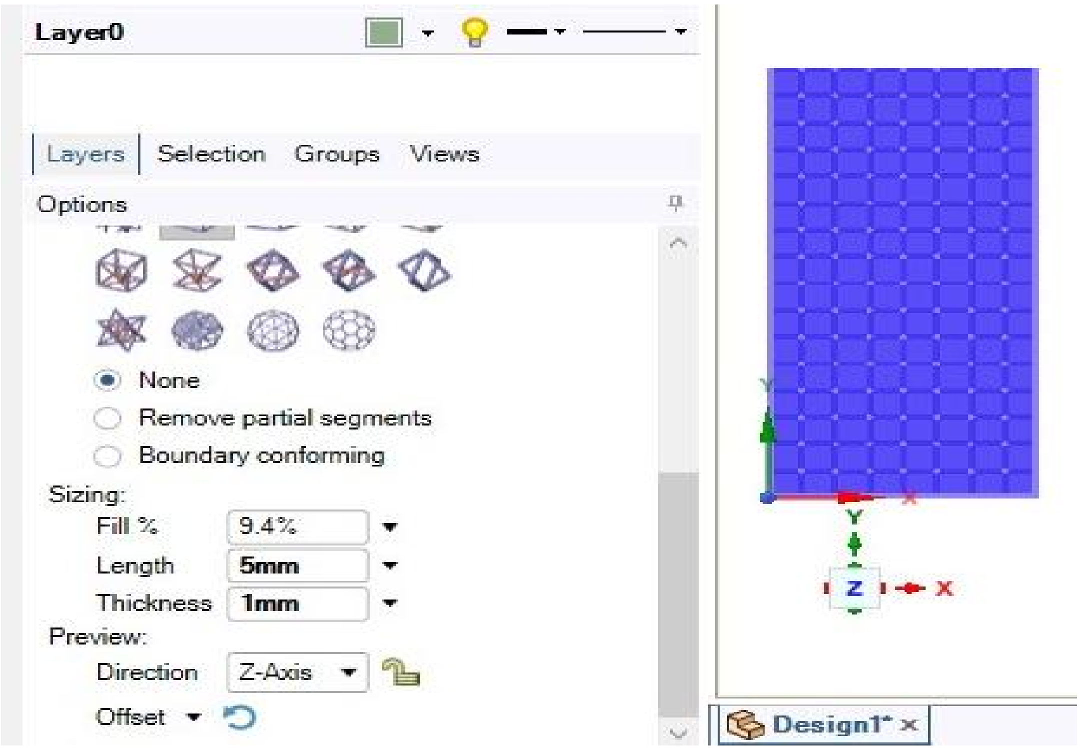


Fig. 28. The data used in the Regular cube lattice.

4-. Cube lattice with center supports

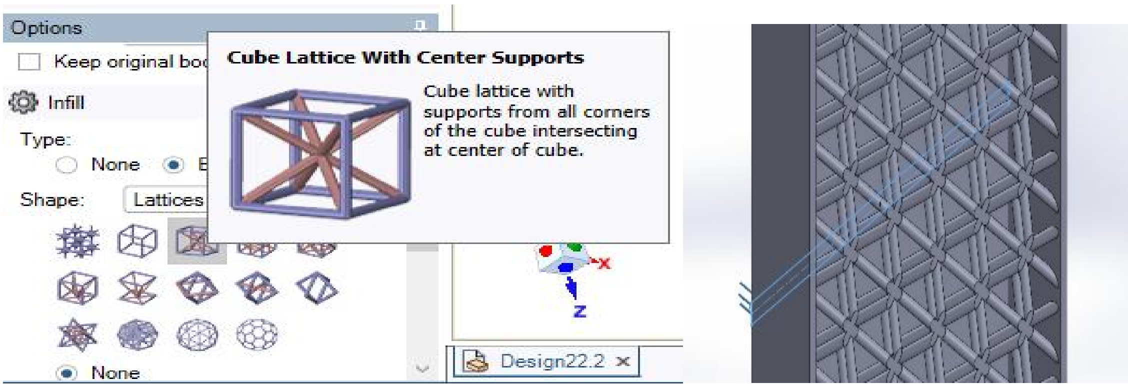


Fig. 29. The Cube lattice with center supports.

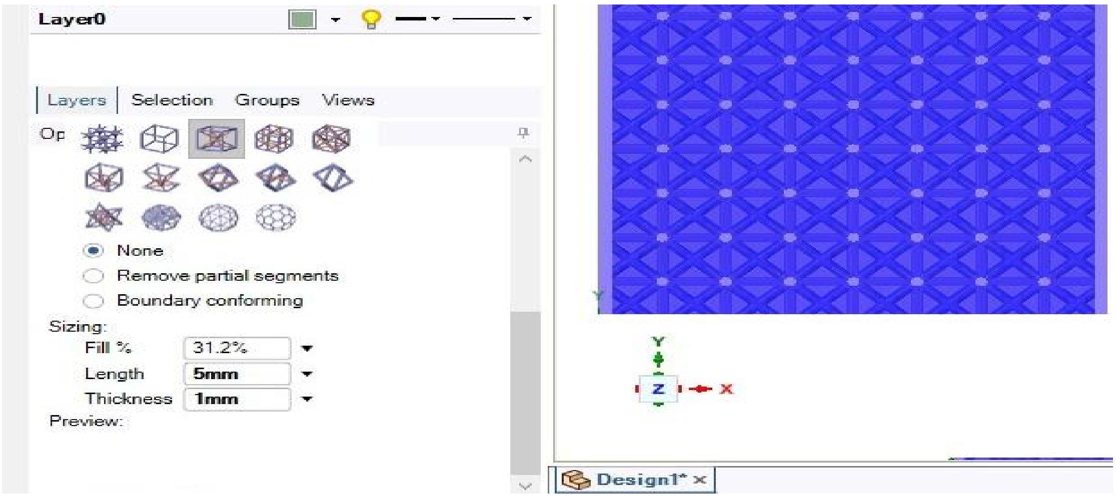


Fig. 30 The data used in the Cube lattice with center supports.

RESULTS AND DISCUSSION

In this section, the design details data of the proposed lattice structures from SpaceClim software are imported to SolidWorks Simulation to check the behavior and the mechanical properties of the four samples.

The pre-processed ABS FDM was selected as a raw material and carried out a Static test on it, fixing both ends of the plate and shedding a load from the middle by 500 N for all samples. When analyzing the four lattice specimens—triangle, hexagon, centered cube, and regular cube—several key parameters provide insight into their mechanical behavior under applied loads. Table 2 shows the data of static test results for von Mises, Displacement, Strain and Reaction force.

Table 2. Results data.

Unit	Triangle	Hex	Cube With Center	Regular Cube
Mass **Volume** **Density** **Weight**	0.0259964 kg 2.42957e-05 m^3 1,070 kg/ m^3 0.254765 N	0.0197261 kg 1.84356e-05 m^3 1,070 kg/ m^3 0.193316 N	0.0132877 kg 1.24184e-05 m^3 1,070 kg/ m^3 0.130219 N	0.0156586 kg 1.46356e-05 m^3 1,069.9 kg/ m^3 0.153455 N
Von Mises tress **Displacement** **Strain** **Reaction force**	102.805 N/mm² 5.005 mm 0.029 491.842 N	132.949 N/mm² 7.053 mm 0.041 489.943 N	217.834 N/mm² 10.001 mm 0.068 102.288 N	242.563 N/mm², 9.660 mm 0.077 168.466 N

A comparison of the results for the four design cases of the lattice structure approach and the corresponding values of the mass, Von Mises stress, and the displacement for each case is presented next. Two quantities are overplotted in Figure 31: mass vs maximum von Mises stress for the four different designed lattice structure.

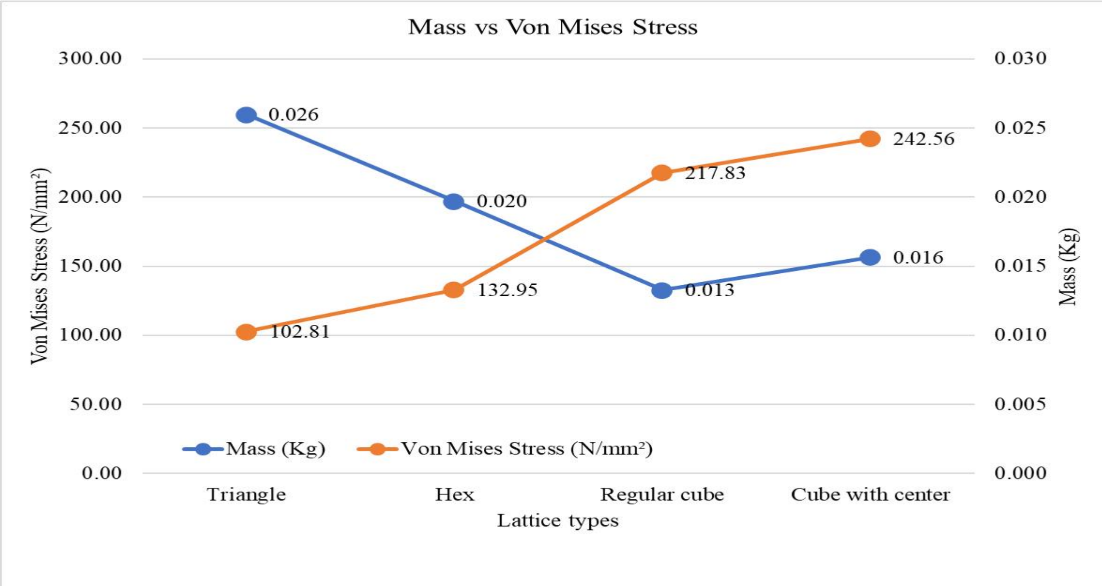


Fig. 31 Mass vs Von Mises stress.

According to the above figure, the mass variation between the four designed approaches is accompanied by an increase in the maximum von Mises stress. For instance, the highest maximum von Mises stress (242.56 N/mm^2) was associted with the most complicated design (Cubic with center). This was because the complexity of the configurated internal lattice structure increases the concentrated stress on the trusses of the centered cubic as can be noted in the. Figure 32.

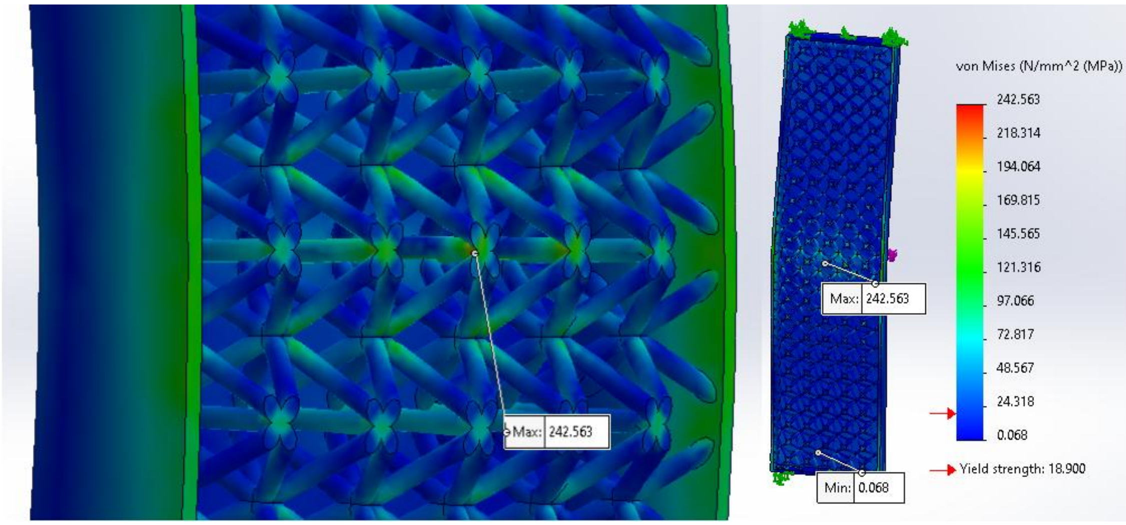


Fig. 32 Equivalent stress.

Regarding the weight reduction, the regular cubic has the lowest value of 0.013 kg. However, the cubic with center has higher value in comparison with the regular cubic by 18.75 %. The simplest designed structure was the triangle structure, which has the lowest maximum von Mises stress amounting to 102.81 N/mm^2, when compared to the other three cases. However, the mass of this design was relatively major than the other designs.

It is worth mentioning that the limitation of the mesh generation could lead to an increase in the stress of the lattice structure. Whereas, by the best of the author's experience and the available facilities, a very fine mesh was generated.

The graph correlates mass variation and displacement among the four designed lattice approaches. As seen in the figure 33. Indicating a proportional relationship between mass and displacement.
The results presented in the graph offer valuable insights into the interplay between mass and displacement, providing a basis for further refinement and optimization of lattice designs for specific engineering applications.

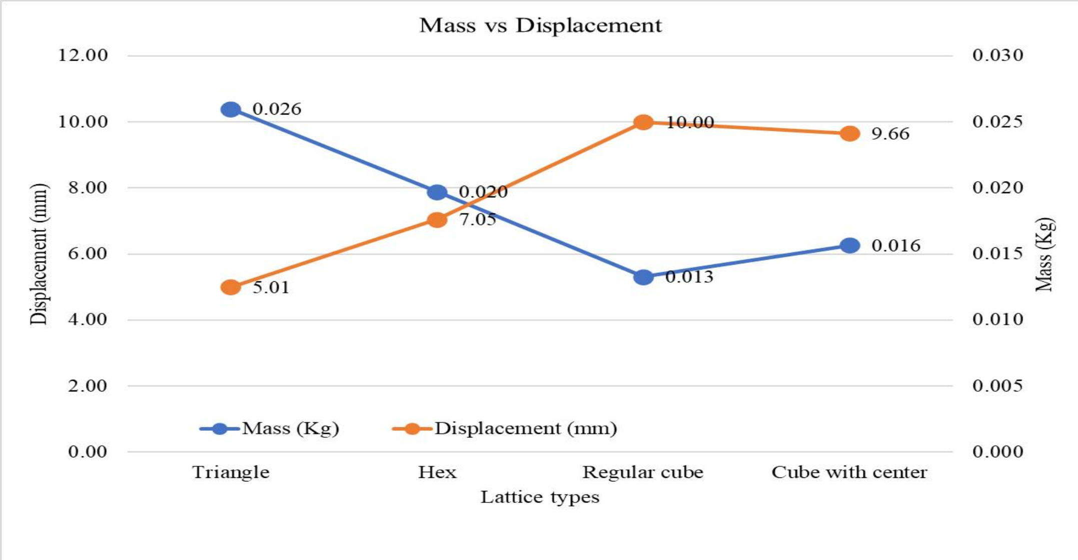


Fig. 33 Mass vs displacement.

Upon analysis, it is evident that the Cube with center exhibits the highest displacement at 10.001 mm, indicating substantial structural deformation under applied loads. Remarkably, it also boasts the lowest mass, underscoring its efficiency in weight distribution. Contrastingly, the Regular cube, with a slightly lower displacement of 9.660 mm, features a higher mass of 0.0156586 kg, suggesting a nuanced balance between deformation and mass in its design.
The Triangle and Hex samples fall within this spectrum, with the Triangle having the lowest displacement but a relatively higher mass, while the Hex displays a moderate displacement and mass. These observations illuminate the trade-offs between displacement and mass in lattice structures, providing valuable insights into their deformation characteristics and weight efficiency under external forces.

CONCLUSION

In this thesis, a comprehensive analysis of lattice sandwich structures, with a specific focus on design, simulation, and mechanical behavior evaluation, was conducted. The following conclusions can be drawn from this study:

- Design and Structure Configuration: a lattice sandwich structure was successfully designed with specific dimensions, comprising both a body substructure and a face substructure. This design showcased the versatility of incorporating different lattice filling shapes within the structure.
- Pattern Variability: Four different lattice structure patterns were designed, each offering its own properties and characteristics. The utilization of SpaceClim software enabled the creation of diverse patterns with specific proportions and values.
- Simulation Capabilities: To investigate the structural performance of the lattice samples, SolidWorks Simulation was employed. This simulation facilitated subjecting the samples to non-linear and static tests, offering valuable insights into their mechanical responses under the applied load.
- Deformation Analysis: Detailed analyses of deformation behavior, including resultant deformation and plastic strain, were conducted. These analyses offered visual representations of the structural response under the specified conditions.
- Static Test Results: The static test aimed to determine the stress distribution under tensile loads. All four lattice models exhibited von Mises stress values significantly below the material's yield strength, affirming their structural robustness.
- Resultant Displacement and Equivalent Strain: Resultant displacement and equivalent strain analyses demonstrated minimal displacement and strain values, further affirming the structural integrity of the lattice models.

In conclusion, this work significantly contributes to the understanding of lattice sandwich structures and their mechanical behavior. The incorporation of 3D design software, simulation tools, and systematic testing approaches has provided valuable insights into the robustness and versatility of such structures. These findings hold promise for potential applications across various fields, particularly in engineering and material science. Future research avenues may explore additional lattice patterns, material variations, and real-world applications to further advance the field of lattice structure design and analysis.
Additionally, this thesis addresses a fundamental challenge, namely the variability in material properties resulting from the complexities of 3D printing technology. To overcome this challenge, the study employed a methodology involving material testing, the creation of standard samples using ABS materials via 3D printing, and subsequent tensile testing. The results highlighted the significant differences between laboratory-tested materials and existing library data within SolidWorks, underscoring the need for deliberate material property modifications in simulation software to achieve accurate predictions.
This work expanded its scope to design and analyze vacuum sandwich specimens incorporating a variety of lattice structures using SpaceClim software. The primary focus was on comprehensively evaluating the mechanical response of these designs under a central compressive load of 500 N, with the results presented graphically. In essence, this research emphasizes the critical importance of considering material properties and adjusting them within simulation software when working with 3D printed structures. The findings presented here offer valuable insights for improving lattice structure design and evaluation across a range of applications.

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