DESIGN AND STUDY ON BIO-INSPIRED LATTICE STRUCTURE BY USING SLA 3D PRINTER

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Abstract

Due to their low weight and excellent strength, lattice structures have attracted more attention in recent years. Complex lattice structures may now be accurately and precisely fabricated thanks to the development of 3D printing technology. A common 3D printing technique called stereolithography (SLA) employs photopolymerization to harden liquid resin layer by layer in order to produce 3D objects. Lattice structures may be readily developed and produced with SLA 3D printing thanks to specialised software that enables the fabrication of complex geometry. Due to its low viscosity, which enables the fabrication of thin and delicate structures, the resin used in SLA 3D printing is perfect for generating lattice structure. The resin may also be modified to have certain qualities like high strength, flexibility, or heat resistance. Lattice structures made using resin and SLA 3D printing have applications in aerospace, automotive, and biomedical engineering. Resin-based SLA 3D printing is a powerful technique for creating intricate lattice

structures with great precision and accuracy.

Keywords:

Bio-inspired lattice structure, CAD design, Compression Testing, C scanner , SLA 3D printer

Introduction:

SLA 3D printing, also known as stereolithography, is a popular additive manufacturing techniques that uses photopolymerization to create 3D objects layer-by-layer. One important aspect of SLA 3D printing is the use of a lattice structure which is complex internal structure of the printed object that consists of interconnected beams of struts.The lattice structure in SLA 3D printing is crucial for creating lightweight yet strong and stable object. It reduces the amount of material used in the printing process, which in turn reduces the cost and printing time. Moreover, the lattice structure improves the mechanical properties of the printed object, such as stiffness, strength, and impact resistance, while maintaining a high level of porosity for applications that require fluid flow or filtration.[1] In this study, the researchers investigated the mechanical properties of additively manufactured lattice structure using a variety of testing methods, including compression, tension, and bending tests. They also used EA to demonstrate the effect of lattice strictures on the mechanical properties of the lattice structure were highly depended on their geometries and that certain geometries provided superior mechanical properties compared to other. [2] This study proposed a method for generating lattice structure with varying densities and thickness to achieve a balance between strength and porosity. The researchers used topology optimization and FE analysis to design and evaluate the mechanical properties of the lattice structure. The study found that the optimized lattice structure exhibited higher stiffness and strength compared to the non-optimized structures.[3] In this study, the researchers designed and fabricated cellular lattice structures with different geometries using SLA 3D printing. They evaluated the mechanical properties of the lattice structure were highly depended on their geometries.[4] This study focused on the design and optimization of cellular lattice structure for additive manufacturing and FE analysis to design and evaluate the mechanical properties of the lattice structures. The study found that the optimized lattice structure exhibited improved mechanical properties compared to the non-optimized structures.[5] This review article provides on overview of lattice structure in additive manufacturing, including SLA 3D printing. The authors discuss the different types of lattice structures and their applications in various industries, including aerospace, automotive and biomedical engineering. The article also discusses the challenges and future directions of research in the field of lattice structures. [6] In this study, the researchers investigated the additive manufacturing of hierarchical porous structures, including lattice structure and their mechanical properties. They used FEA to evaluate the effect of different geometries and material compositions on the mechanical properties of the structure. The study found that the hierarchical porous structures exhibited improved mechanical properties compared to the non-porous structures. [7] In this study investigated the additive manufacturing of functionally graded lattice structure using projection micro-stereolithography. The researchers designed and fabricated lattice structure with varying densities and thicknesses and evaluated their mechanical properties using compression testing. This study found that the functionally graded lattice structures exhibited improved mechanical properties compared to the non-graded structures.

Material and methods

The design strategy for homogeneous bioinspired lattice structures involves choosing a lattice type and optimising its diameter, wall thickness, tube angle, and number of curves in an area while taking into account the total stress and strain of a mechanical element. The structures were created using the Autodesk Fusion 360 programme and have a set diameter of 50 mm and a height of 40 mm. The influencing parameters include the wall thickness, tube angle, spiral angle, and number of tubes.

Resin

Resin used in 3D printers for the SLA(Stereolithography) process isa type of photopolymer resin that solidifies when exposed to light. It is specifically designed for use with SLA 3D printers and is different from the thermoplastic filaments used in FDM 3D printers. Sla 3D printing uses a laser or light source to selectively cure the resin layer by layer to creating a 3D object. The resin used in Sla printing is typically a liquid that can be poured into a resin vat, which is there placed under the SLA printer’s light source. There are several types of resin available for SLA 3D printing, each with different properties and characteristics. Some resins are designed for high-resolution prints with fine details,

Fig 1 Resin

while others are more suited for large, functional parts. Additionally, there are resin available in a wide range of colours, as well as transparent and translucent options. When using resin for SLA 3D printing, it is important to handle it with care as it can be hazardous if ingested or if it comes into contact with skin or eyes. It I also important to follow the manufacturer's instructions carefully, as different resins may require different curing times, temperatures, and other parameters.

In our project we used Anycubic standard Gray 3D printer resin is a type f photopolymer resin designed for using with LCD 3D printers. It is a high-quality resin that is easy to use and produces high resolutions 3D prints with smooth surface and high accuracy. The resin is specifically formulated to cure quality and provide excellent adhesion between layers, resulting in strong and durable prints. It has a low odor and is designed to minimum resin shrinkage during the printing process, which helps to educe the likelihood of warping and cracking.

Main material	Resin monomer & Photo initiator
Viscosity (25°C)	552.0 MPa
Tensile Strength	23.4 MPa
Elongation	14.2 %
Hardness(D)	79.0
Shelf Life	12 months
Solidify wavelength	405 nm

Table.1 Material parameter

Bio-inspired lattice structure

Lattice structures are commonly used in SLA 3D printing due to their lightweight, high strength-to-weight ratio and excellent energy absorption properties. Bio-inspired lattice structure are designed to mimic the cellular structure found in natural materials, such as bone or coral. The design process for bio-inspired lattice structure involves selecting a natural material or structure to use as inspiration, creating a virtual model using computer-aided design (CAD) software, and creating a physical prototype using additive manufacturing techniques. The prototype can then be tested and refined using feedback from mechanical testing and simulations to further optimize the design. The design of bio-inspired lattice structure is a highly iterative process that requires expertise in materials science, mechanical engineering and computer-aided design. By mimicking the structure of natural material, these structures offer a promising avenue for the development of lightweight, high-performance materials for range of applications.

Design of Bio-inspired Cytoplasm of animal cells + Centrosome lattice structure

A bio-inspired cytoplasm and centrosome lattice structure is designed to replicate the physical characteristics and capabilities of natural cytoplasm in animal cells. This involves developing a hydrogel matrix that resembles the cytoplasm's mechanical characteristics and gel-like consistency. To mimic the activities of natural organelles, synthetic organelles or compartments are incorporated into the matrix. The cytoplasmic matrix contains microfluidic channels or networks that help in molecular transport. Synthetic signalling pathways and protein scaffolds can be created to facilitate signal transduction and protein-protein interactions. The centrosome lattice structure contains microtubules placed in a precise way to mimic the structure and organisation of natural centrioles in synthetic centrioles. Potential uses for the bio-inspired cytoplasm and centrosome lattice structure include tissue engineering, drug delivery devices, and cell biology research. Researchers may learn more about cellular processes, create novel treatment approaches, and increase our understanding of complex biological systems by replicating the structure and functions of these cellular components.

Dimensions:

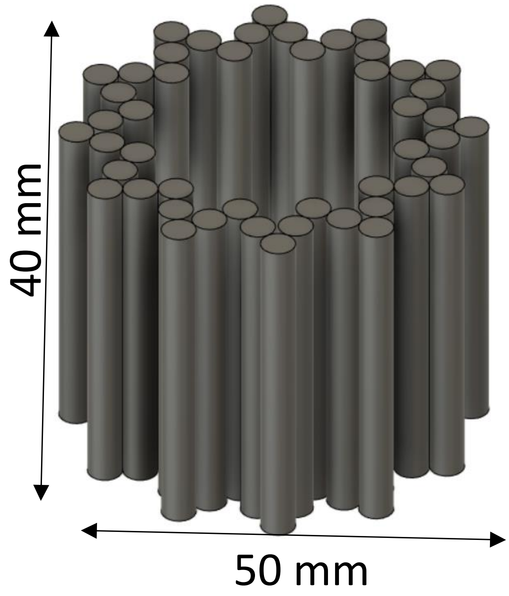

Fig 2

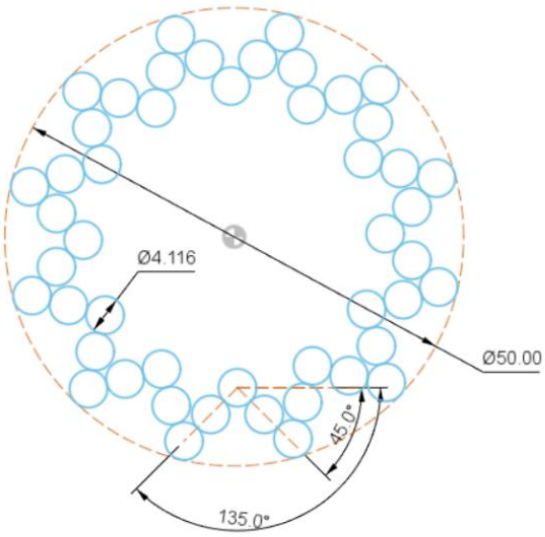

Fig 3

Bio-inspired and lattice structures image:

Fig 4(a)

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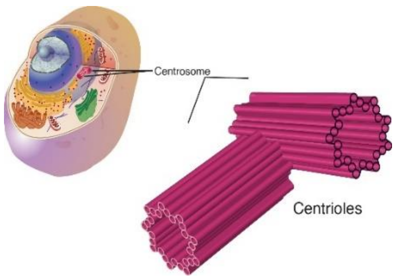

Fig 4(b)

=

Fig 4(c)

Fig 4

(a) Cytoplasm of animal cell

(b) Centrosome ,

(c) combination design of Fig 4 a & b

Design of Bio-inspired Romanesco Broccoli Seeds lattice structure

Romanesco broccoli seeds' unique fractal pattern serves as inspiration for the construction of a lattice structure for bio-inspired Romanesco broccoli seeds. Analysing the fractal pattern and understanding its geometric features is the first step, followed by creating seed-like units that incorporate the distinctive spiral-shaped florets or branches of Romanesco broccoli seeds. Materials must be chosen carefully, and biocompatible solutions such as biodegradable polymers or bio-based materials are recommended due to their adaptability and conformance with the bio-inspired idea. The lattice structure can be used for ornamental elements, architectural designs, and the creation of biomimetic materials. Aesthetics, structural integrity, and manufacturing viability must all be balanced throughout the design process, with iterative refinement and prototyping helping to optimise the design for successful realisation.

Dimensions:

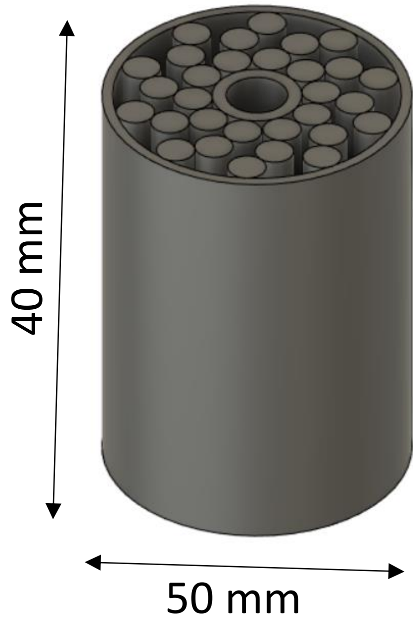

Fig 5

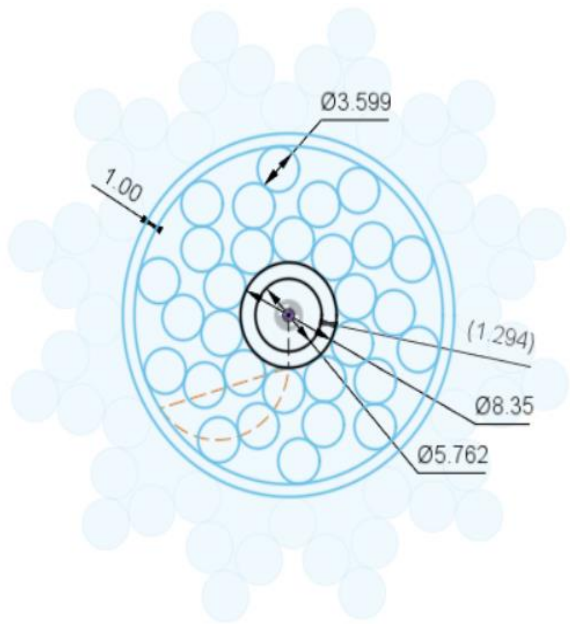

Fig 6

Bio-inspired and lattice structures image:

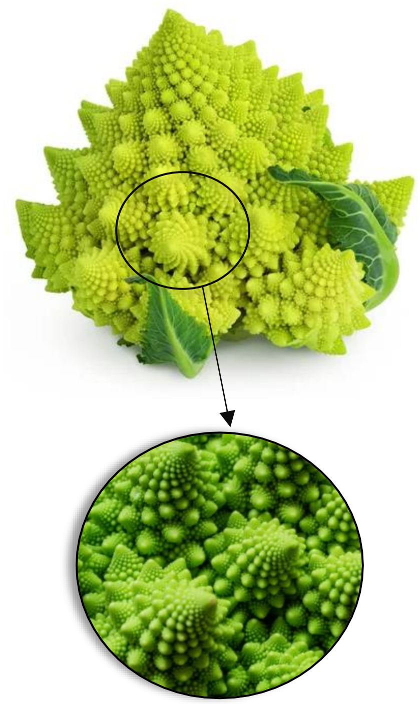

Fig 7(a)

Fig 7(b)

Fig 7

(a) Romanesco Broccoli Seed

(b) Design of Romanesco Broccoli Seed

Design of Bio-inspired Leptasterias aequalis lattice structure

The Bio-inspired Leptasterias aequalis lattice structure offers potential applications in lightweight structures, architectural designs, and biomimetic materials. The design, which takes its cue from the radial symmetry seen in the arms of the Leptasterias aequalis sea star, blends aesthetic appeal with practical efficiency. The lattice structure may be customised to satisfy particular technical needs while using the inherent strength and efficiency of biological forms by utilising cutting-edge manufacturing processes and material choices. The radial symmetry seen in the arms of the Leptasterias aequalis sea star serves as the basis for the Bio-inspired Leptasterias aequalis lattice construction. The arms have a tapered form, beginning broader at the base in the centre and progressively getting narrower as they approach the tip. The centre hub serves as a focal point for the radial arms that make up the unit cell architecture. To mimic the natural form of sea star arms, the arms may have a variety of geometric profiles, such as triangular, trapezoidal, or curved forms. To connect the arms of nearby unit cells, mechanical connections like joints or interlocking features may be used. Materials such as composites or advanced polymers are often favoured to provide the required structural integrity while minimising the structure's total weight.

Dimensions:

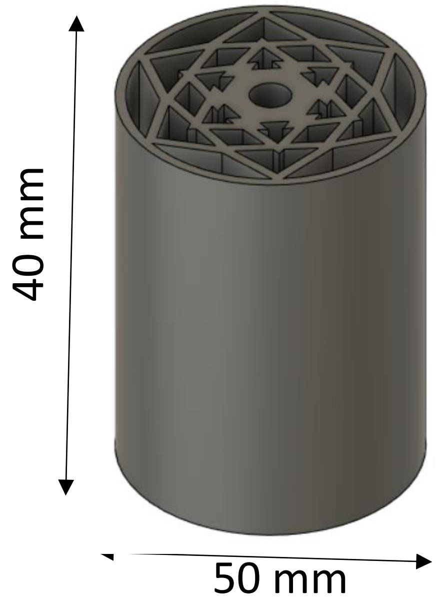

Fig 8

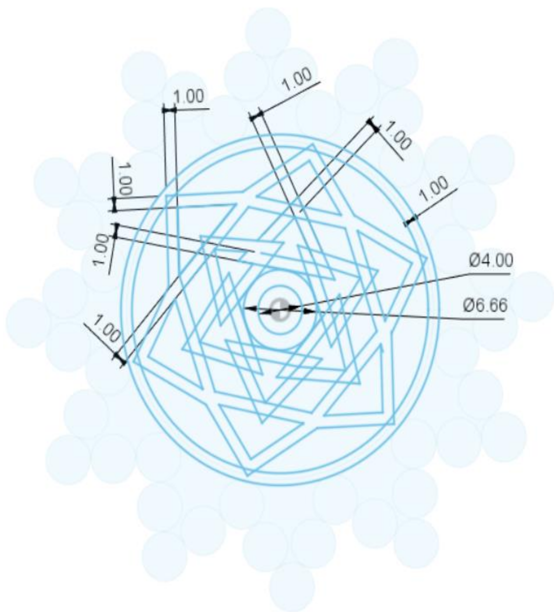

Fig 9

Bio-inspired and lattice structures image:

Fig 10(a)

Fig 10(b)

Fig 10

(a) Leptasterias aequalis

(b) Design of leptasterias aequalis

Combination of both Bio-inspired lattice structure (Cytoplasm of animal cells + Centrosome + Romanesco Broccoli Seeds)

Romanesco broccoli seeds, the centrosome, and bio-inspired lattice structures from the cytoplasm of animal cells may be combined to create an incredibly complex and useful biomimetic system. We may imagine a design that integrates the intricacy and utility of the cytoplasm, the organisational structure of the centrosome, and the captivating fractal pattern of Romanesco broccoli seeds by combining the concepts from these three sources. Designing a hydrogel matrix with characteristics that closely resemble those of real cytoplasm would enable the creation of the bio-inspired cytoplasm lattice structure. Incorporating artificial organelles and compartments, this matrix may perform tasks like energy generation, protein synthesis, and molecular transport. Selective diffusion and molecular interactions can be facilitated via microfluidic channels inside the cytoplasmic matrix, simulating the complex web of cellular communication routes. The centrosome lattice structure can be integrated using synthetic centrioles and a PCM matrix to replicate the role of the centrosome. Synthetic microtubules can be arranged in a manner that resembles the Romanesco broccoli seed fractal to provide an aesthetically pleasing and functional component. The lattice structure is 50mm in diameter and 40mm in length overall.

Final output of Bio-inspired lattice structure

Design 1: (Cytoplasm of animal cells + Centrosome)

Fig 11

Design 2: (Cytoplasm of animal cells + Centrosome + Romanesco Broccoli Seeds)

Fig 12

Experimental procedure:

PARAMETERS	VALUES
Layer thickness (mm)	0.05
Normal Exposure time (s)	2
Off time (s)	0.50
Bottom Exposure Time (s)	28
Z Lift distance (mm)	8
Z Lift speed (mm/s)	2
Z Retract speed (mm/s)	3
Anti-alias	1

Table 2

UV Curing set up image :

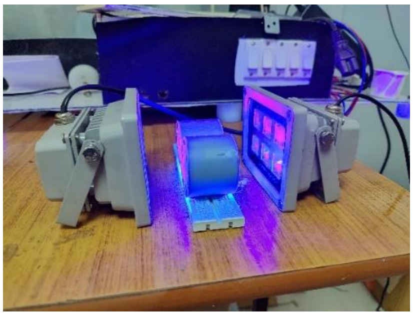

Fig 13(a)

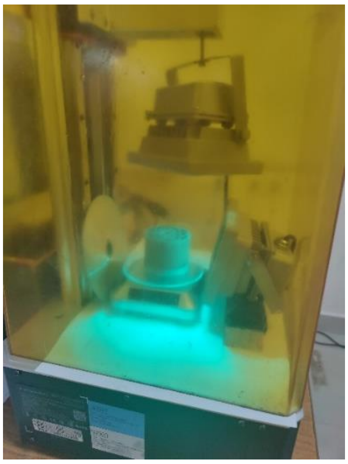

Fig 13(b)

Experimental Produces

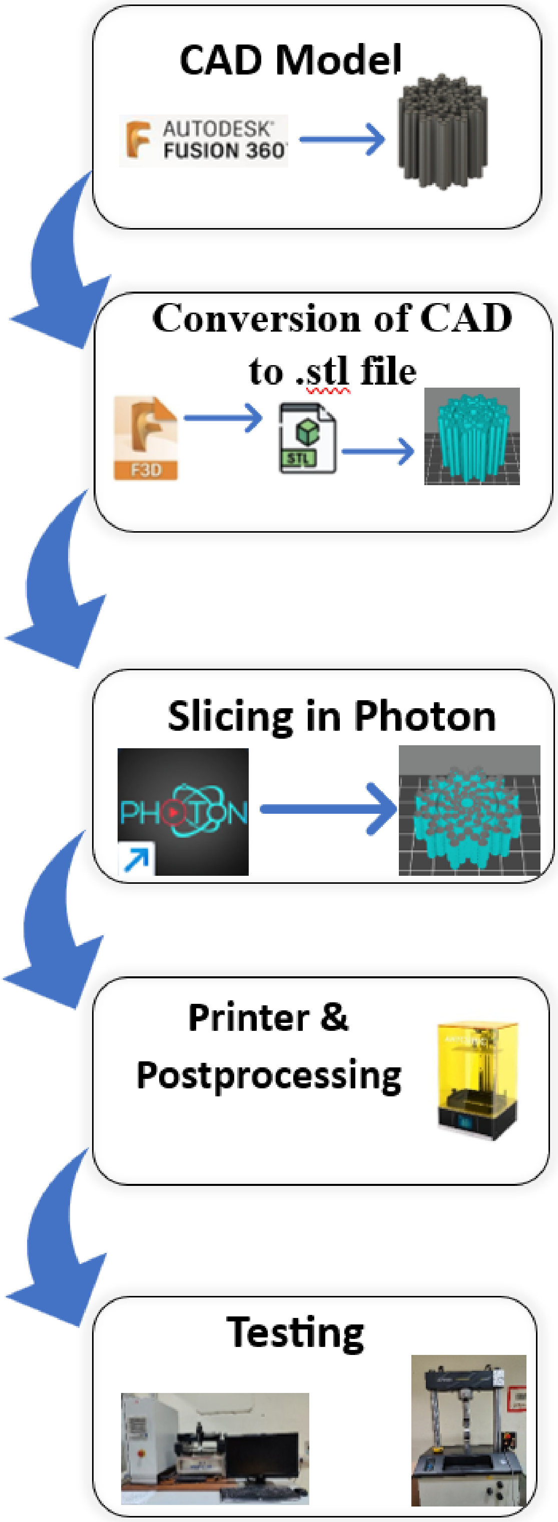

Fig 14

Printer component

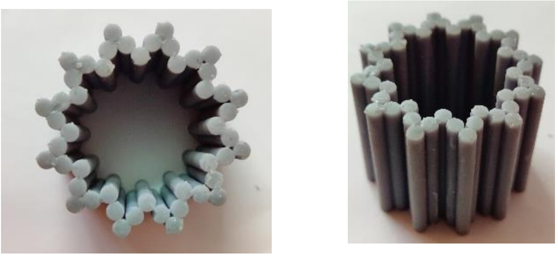

Fig 15 (a)

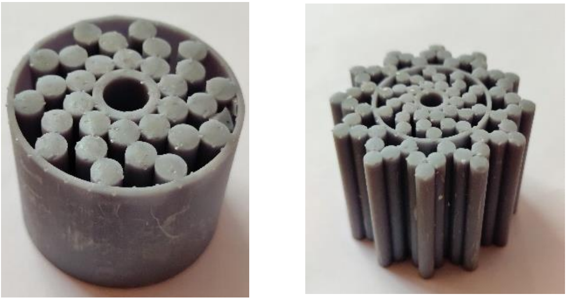

Fig 15(b)

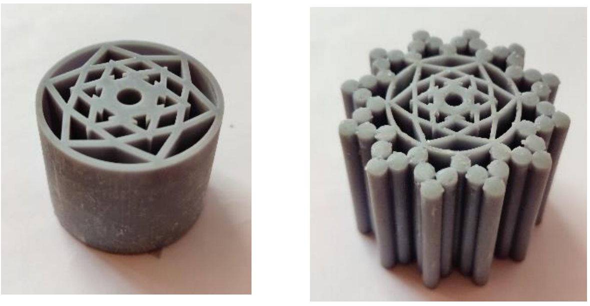

Fig 15(c)

Fig 15

(a) Printing sample of Cytoplasm pf animal cells + Centrosome (Outer)

(b) Printing sample of Overall design-1

(c) Printing sample of Overall design-2

Quasi static process

The compression testing device is a single-axis controller that is completely digital and packaged as a tower. It gathers information during tension, compression and 3-point bend tests using a motor encoder and load cell [8]. For mechanical compressive test a universal mechanical testing machine with a 59KN load capability was used. The design lattice structure in placed in the middle of the bottom plate prior to the experiments. The top plat remained going downward in compression as the bottom plate continued to be constantly pressed and fastened. The crosshead loading rate was set at 0.1mm/s in accordance with ASTM e9-19 and displacement was determined by crosshead movement.

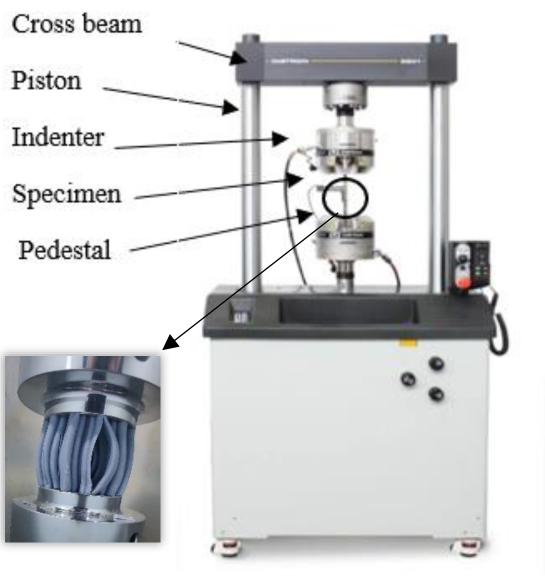

Fig 16

A vice grip device attached to the base plate of the crosshead holds the material specimen is placed during a compression test. A platen connected to the load cell applies a compressive load on the specimen . The platen and load cell won’t move but the crosshead will go higher

Specification

Tower height	1988 mm
Tower width	1106 mm
Tower depth	709 mm
Load capacity	±150 kN
Available Load cell	1. ±150 kN 2. ±1 kN 3. ±10 kN 4. ±100 kN
	5.
Maximum force	±200 kN
Speed	Maximum : 1,200mm/min Minimum: 0.001mm/min
Total crosshead travel	1080mm

Table 3

Additive manufacturing for lattice structure for Quasi statice process

The SLA technology was used for to create the lattice structure. The Photon Mono X Was used to print the specimen and then that specimens are take to the compressive test The lattice structure was printed using Gray resin. Throughout the course of this investigation , a one of a kind design was conceived for each of the bioinspired structure are design and print. The SLA technique of three-dimensional printing will have to be used in order to create this design. The compression test is intended to carry out an in-depth assessment of the material capacity to bear compression and is designed to simulate real world conditions as closely as possible. The printer of each component were subject in quasi-static compression testing, the result value can be seen in **table .** For each component were tester and for each component the stress Vs strain graph were plot .

S.NO	Lattice structure name	Maximum comp. load	Compressive strength (MPa)	Modulus (Automatic) (MPa)
1	Cytoplasm of animal cells + Centrosome	23290.47852	12.74307	356.26332
2	Romanesco Broccoli Seeds	60965.48438	31.52685	694.52721
3	Leptasterias aequalis	43605.98828	22.66843	523.76222
4	Cytoplasm of animal cells + Centrosome + Romanesco Broccoli Seeds	37760.92969	19.51930	387.52000
5	Cytoplasm of animal cells + Centrosome + Leptasterias aequalis	38097.65625	19.66165	397.59909

Table 4

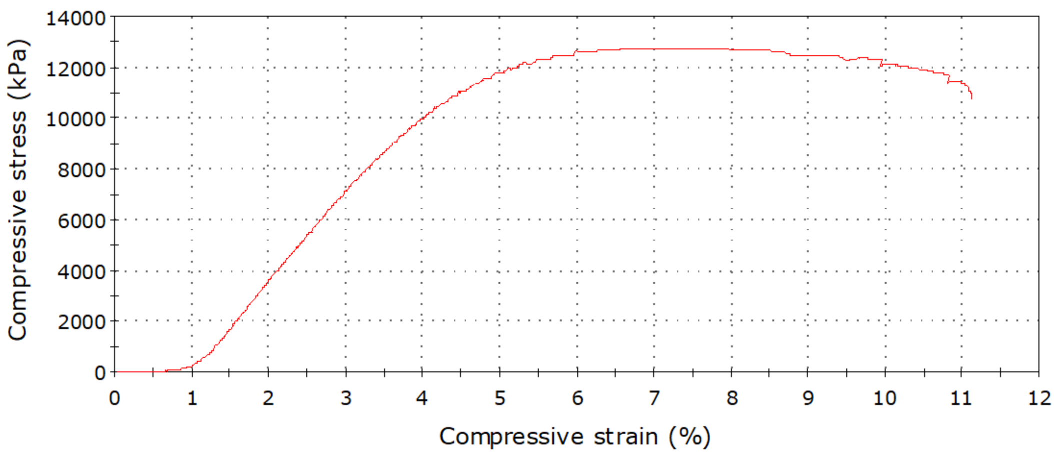

Fig 17 (Cytoplasm of animal cells + Centrosome)

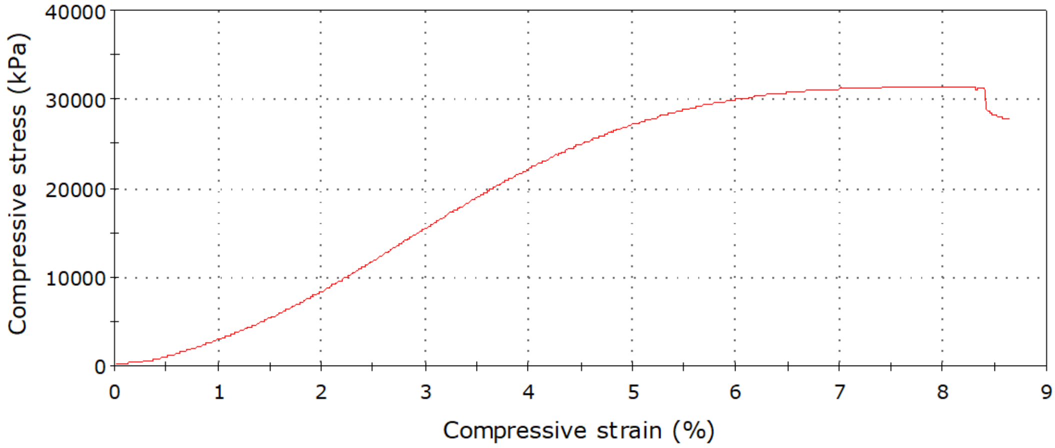

Fig 18 (Romanesco Broccoli Seeds)

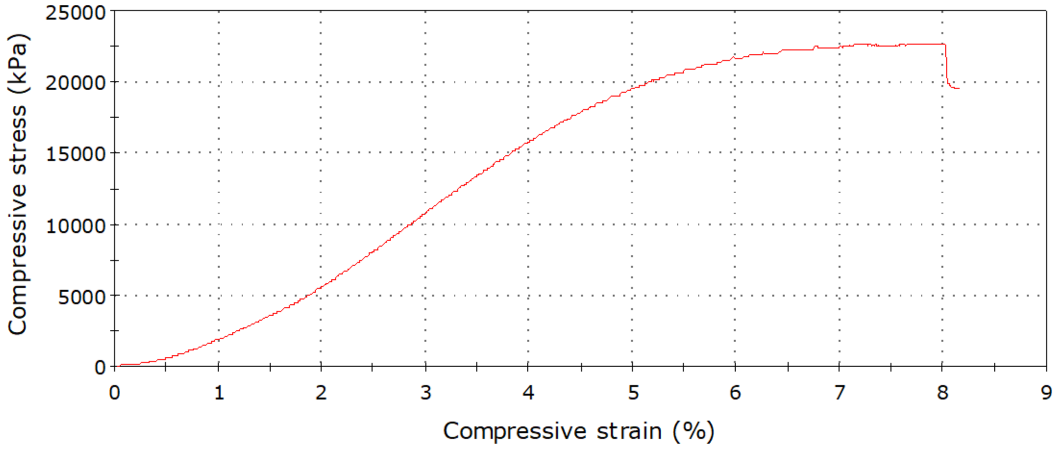

Fig 19 (Leptasterias aequalis)

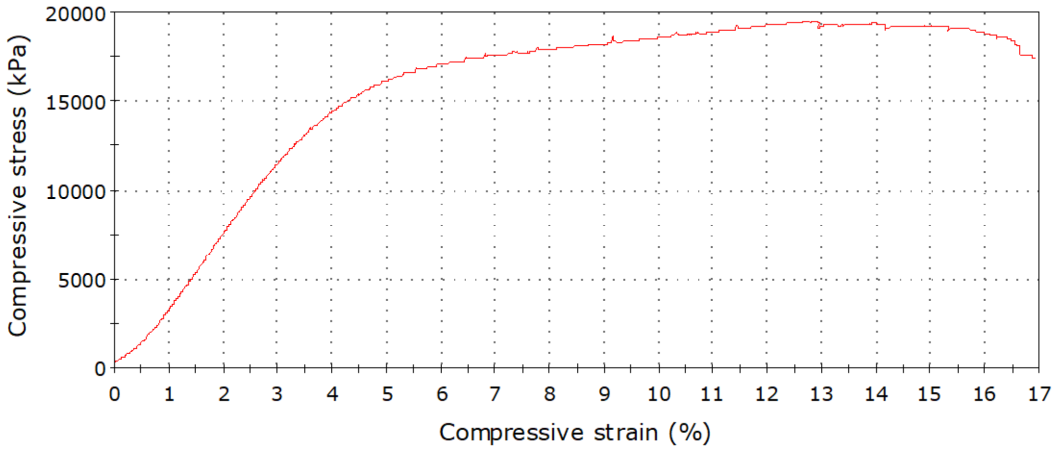

Fig 20 (Cytoplasm of animal cells + Centrosome + Romanesco Broccoli Seeds)

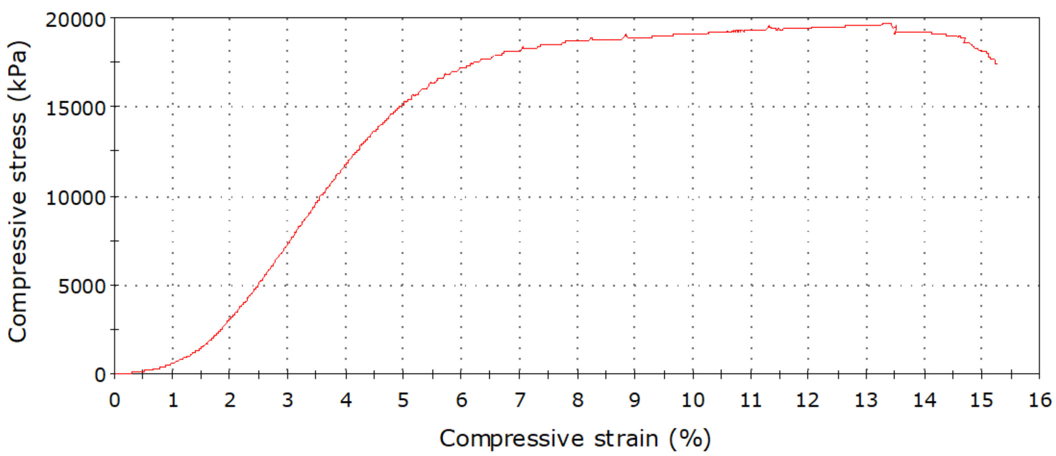

Fig 21 (Cytoplasm of animal cells + Centrosome + Leptasterias aequalis)

C scanner Process

A sort of ultrasonic testing tool called an ultrasonic C-scanner is used to produce two-dimensional pictures of an object's interior structure. It is a non-destructive testing (NDT) technique used to find material faults such inclusions, voids, and fractures. C-scanners operate by sending ultrasonic waves into the target item. The waves pass through the item and return to the scanner as reflected waves. The scanner then measures the power of the reflected waves as well as the time it takes for waves to travel to and from the item. Using this data, a two-dimensional representation of the object's interior structure is produced. C-scanners are used in a broad range of sectors, including oil & gas, aerospace, automotive, and manufacturing. Metals, polymers, composites, and ceramics are just a few of the materials that they are used to check. C-scanners are a useful NDT instrument. Since they are non-destructive, the item being evaluated is not harmed by them. Additionally, they are rather fast and simple to use. Ultrasonic imaging is divided into A-scans, B-scans, and C-scans. A-scans display the amplitude of the ultrasonic signal as a function of time, while B-scans provide inspectors with a visual picture of an object's interior structure. C-scans are planar or volumetric depictions of the region being examined in which the amplitude of the reflected signal has been color-coded to offer a visual indicator of the material's state.

C scan image

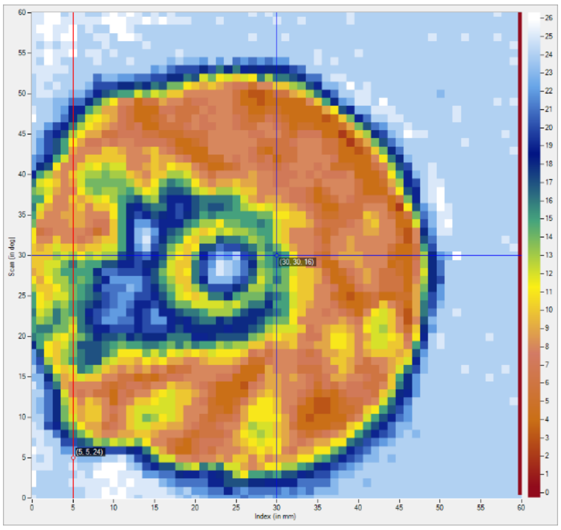

Fig 22 (a)

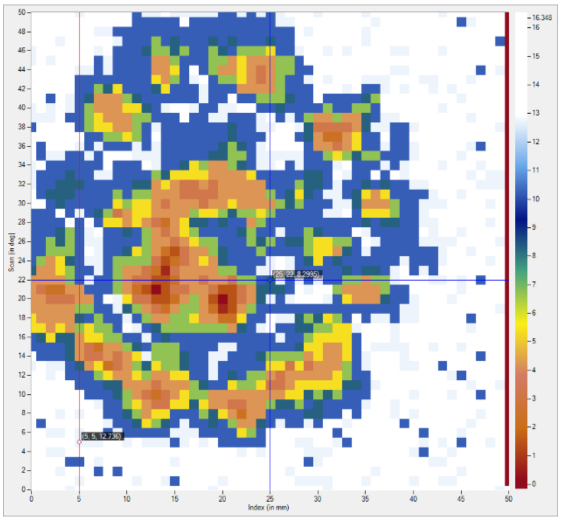

Fig 22(b)

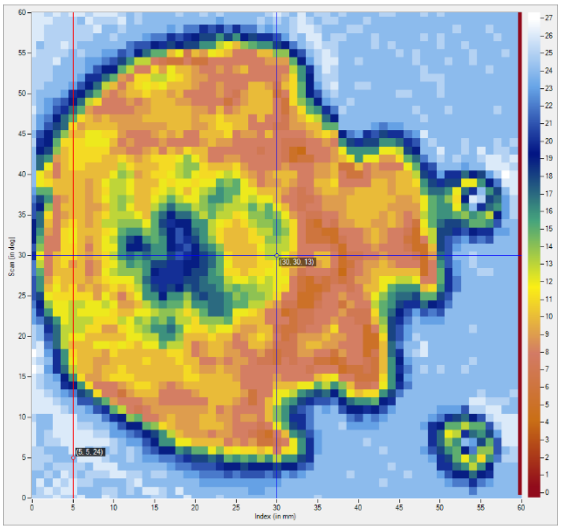

Fig 22(c)

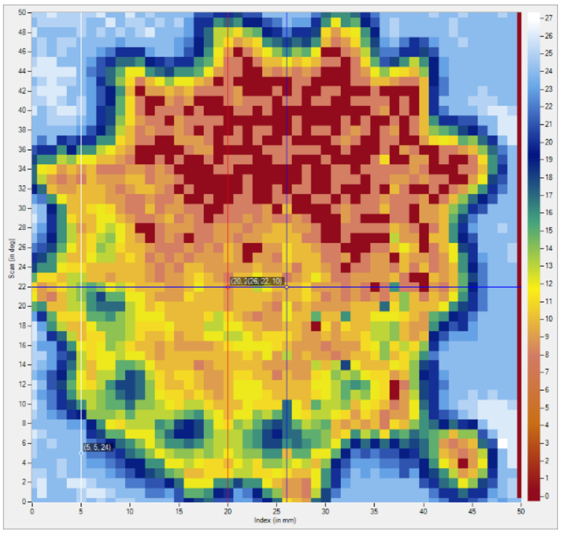

Fig 22(d)

Fig 22

(a) C Scan image of Romanesco Broccoli Seeds design
(b) C Scan image of Leptasterias aequalis
(c) C scan image of Cytoplasm of animal cells + Centrosome + Romanesco Broccoli Seeds
(d) C scan image of Cytoplasm of animal cells + Centrosome + Leptasterias aequalis

Result and Discussion:

During this study we study about the lattice structure according to that , we design the bioinspired structures know as Cytoplasm of animal cell & centrosome, Romanesco Broccoli seeds and Leptasterias aequalis. We design by using fusion 360 software , once we finally the design that file was convert into stl. File formant . That stl file is open with the help of photon workshop , by help of this software the parameters are set and it loaded into the SLA 3D printer, after printing the sample was curved . The compression test is what is used to be carried out the systematic evaluation of the compression strength and c scanner is used to find the crack location before testing and also after testing , by this we can concluded that the design lattice structure can withstand up to certain load . From the quasi statice test , from the result we conclude that the Romanesco Broccoli Seeds lattice structure have the high Maximum compression load (60965.48438) and compressive strength value is (31.52685 MPa) compare to the other lattice structures , the result are in Table 4 and the compression test image are in Fig 17-21. From the C scan image we can see the presence of discontinuities in the material, The nature of the material. It can also be used to assess the quality of the material and to ensure that it meets the required standards.

Conclusion

A study of Bio inspired Lattice Structure by using Stereolithography (SLA) 3d printer. We have design and print different type of lattice structure and two combination of lattice structure and that sample is tester in the C scanner and quasi-static compression testing by comparing the result, Compared to other lattice structures, the Romanesco Broccoli Seeds lattice structure has the highest maximum compression load (60965.48438) and compressive strength value (31.52685 MPa).

Reference:

[1] D. D. Schaefer et al., "Mechanical properties of additively manufactured lattice structures," Materials & Design, vol. 116, pp. 311-319, 2017. (https://www.sciencedirect.com/science/article/pii/S0264127516310915)

[2] J. Wu et al., "Optimization of lattice structures for additive manufacturing," Materials & Design, vol. 168, 107656, 2019. (https://www.sciencedirect.com/science/article/pii/S0264127519308206)

[3] J. Zhang et al., "Design, fabrication and characterization of cellular lattice structures by stereolithography," Rapid Prototyping Journal, vol. 22, no. 1, pp. 30-40, 2016. (https://www.emerald.com/insight/content/doi/10.1108/RPJ-01-2014-0009/full/html)

[4] H. Kang et al., "Design and optimization of cellular lattice structures for additive manufacturing using stereolithography," Journal of Mechanical Science and Technology, vol. 33, no. 1, pp. 67-75, 2019. (https://link.springer.com/article/10.1007/s12206-018-1247-6)

[5] F. Garcia et al., "Lattice structures: a review on their additive manufacturing and mechanical properties," Applied Sciences, vol. 10, no. 1, 203, 2020. (https://www.mdpi.com/2076-3417/10/1/203)

[6] Y. H. Chen et al., "Additive manufacturing of hierarchical porous structures: design, fabrication, and mechanical properties," Materials, vol. 13, no. 11, 2552, 2020. (https://www.mdpi.com/1996-1944/13/11/2552)

[7] S. Y. Huang et al., "Additive manufacturing of functionally graded lattice structures using projection micro-stereolithography," Journal of Materials Research and Technology, vol. 10, pp. 1267-1277, 2021. (https://www.sciencedirect.com/science/article/pii/S2238785420305816)

[8] Yao, Guofeng, et al. "Study on quasi-static mechanical properties of four 3Dprinted bio inspired structures based on functional relationship" Composite Structures 274 (20121) 114304 .(https://www.researchgate.net/publication/353284430_Study_on_quasi-static_mechanical_properties_of_four_3D-printed_bio-inspired_structures_based_on_functional_relationship)