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Modeling And Fabracation Of Auxetic Structures

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ABSTRACT: Auxetic structures, which have a negative Poisson's ratio, display distinct lateral expansion when under tension and become denser when compressed, in contrast to typical structures. Examples of these include honeycomb, chiral, and S-shaped designs with star patterns. Their characteristics can be assessed through techniques such as uniaxial tension, compression, and low-velocity impact tests. This mini-project focuses on modeling and creating auxetic structures using SOLIDWORKS and 3D printing. Renowned for their enhanced strength and rigidity, auxetic structures are widely used in armor, military applications, and protective gear.

KEYWORDS: Poisson’s ratio, auxetic structure.

1. INTRODUCTION

Auxetic structures are types of materials that possess a distinct mechanical characteristic referred to as a negative Poisson's ratio. In contrast to traditional materials that shrink perpendicular to the direction of tension, auxetic materials expand sideways when pulled and contract when pressure is applied. The idea of auxetic materials has its origins in the early 1900s but attracted considerable interest in the 1980s when the initial designs showcasing a negative Poisson's ratio were systematically developed and examined.

2.LITERATURE REVIEW

Shivangi Shukla et.al.[1]: Auxetic textiles are intriguing materials with unusual capabilities. These materials exhibit negative Poisson’s ratio with extraordinary performance in toughness, resilience, shear resistance, and acoustic properties mainly due to their special structure and associated deformation mechanics.

Yaozhong Wu et.al.[2]: Lightweight materials and structures have been extensively studied for a wide range of applications in design and manufacturing of more environment-friendly and more sustainable products, such as less materials and lower energy consumption, while maintaining proper mechanical and energy absorption characteristics.

Rafael Augusto Gomes et.al.[3]: Auxetic materials and structures have been attracting attention due to their extraordinary mechanical properties that stand out due to their high capacity to absorb energy. Some types of auxetic tubular structures have been studied and designed in diverse engineering fields such as mechanical, aerospace and medical.

Jianjun Zhang et.al.[4]: Different from conventional materials, materials with negative Poisson's ratios expand laterally when stretched longitudinally. Known as ‘auxetic’ materials, the effect means they possess particularly fascinating properties, which have recently attracted considerable attention in the literature. A range of auxetic materials has been discovered, theoretically designed and fabricated.

Jinfei Fan et.al.[5] : Bone defect is a highly prevalent disorder. Given that many people, especially the elderly are suffering from it, there’s an urgent need for the development of bone tissue regeneration engineering. Multifarious artificial bone substitute biomaterials such as metals, bioceramics and polymers have been favored over autologous and allogeneic bone grafts because of their ease of sampling and good biocompatibility. The advent of the age of big data has enabled artificial intelligence to provide fresh insights for materials discovery. Machine learning is a branch of AI, which can complete complex calculations and data analysis accurately and efficiently, so as to realize the discovery and reuse of materials

Ying Zhou et.al.[6]: Flexible materials and structures, mainly including nonmetallic and nonceramic materials, are being increasingly applied in the field of blast mitigation to prevent collateral damage by secondary debris. This paper outlines the load characteristics of typical explosions and the modern trend of using flexible materials and structures for blast mitigation. An attempt is made to interpret blast waves, fragments, and their combined load characteristics and discuss the loading and testing methods used at different explosion scales. The findings can help develop tailored approaches for property evaluation and optimized designs of flexible materials and structures according to specific loadings.

A. Lorato et.al.[7]: This work describes the out-of-plane linear elastic mechanical properties of trichiral, tetrachiral and hexachiral honeycomb configurations. Analytical models are developed to calculate the transverse Young's modulus and the Voigt and Reuss bounds for the transverse shear stiffness. Finite Element models are developed to validate the analytical results, and to identify the dependence of the transverse shear stiffness vs. the gauge thickness of the honeycombs. The models are then validated with experimental results from flatwise compressive and simple shear tests on samples produced with rapid prototype (RP)-based techniques.

Chao Quan et.al.[8] : Continuous fiber reinforced thermoplastic composite (CFRTPC) auxetic honeycomb structures were fabricated using the 3D printing technology with a specific printing path planning. For comparison, auxetic honeycombs were also fabricated with pure polylactic acid (PLA). In-plane compression tests were conducted, with corresponding damage types explored using Scanning Electron Microscopy (SEM) images. A printing path-based finite element (FE) method was developed to mimic both small and large deformations of CFRTPC auxetic honeycombs, while analytical model was proposed to predict their 25 effective stiffness and Poisson ratio. Good agreement was achieved among analytical predictions, FE simulation results and experimental measurements. A systematic parametric study was subsequently carried out to quantify the dependence of in-plane mechanical properties on geometrical parameters.

Chang Qi et.al.[9]: Honeycombs are ultra-light materials with outstanding mechanical properties, which mainly originate from their unit cell configurations rather than the properties of matrix materials. Honeycombs are triggering in numerous promising applications in the fields of architecture, automotive, railway vehicle, marine, aerospace, satellite, packaging and medical implants, etc. Here we provide an indepth overview of some important advances in basic structural design to obtain novel honeycombs with various improved mechanical properties. Firstly, the review introduces the classical honeycomb configurations. Then, a clear classification of advanced designs is established and discussed according to the design scale. The designs on the macro scale are divided into hierarchical, graded and disordered, while the designs on the meson scale are grouped as hybrid, curved ligament and reinforced strut. Moreover, the effects of different designs on the mechanical properties of honeycomb are discussed quantitatively. Finally, we summarize the important potential designs to improve the mechanical properties of honeycombs and the challenges in further research

.Jianjun Zhang et.al.[10]: Different from conventional materials, materials with negative Poisson's ratios expand laterally when stretched longitudinally. Known as 'auxetic' materials, the effect means they possess particularly fascinating properties, which have recently attracted considerable attention in the literature. A range of auxetic materials has been discovered, theoretically designed and fabricated. Developments in additive manufacturing (AM) techniques enable fabrication of materials with intricate cellular architectures. This paper outlines recent progress in the development of auxetic materials and structures, and their mechanical properties under quasi-static and dynamic loading are analysed and summarized. Limited experimental studies on 3D printed auxetic materials and structures are given more attention, ahead of extensively finite element (FE) simulations. A special focus is dedicated to their large, plastic deformation behavior and energy absorption performance, which should be stressed in their engineering applications; no review paper has yet been found regarding this. Finally, this paper provides an overview of current study limitations, and some future research is envisaged in terms of auxetic materials and structures, nanoauxetics and additive manufacturing. In this paper, design methods and advanced manufacturing technologies of auxetic tubular structures are extensively reviewed, including various types of cellular auxetic tubes, nonporous and porous auxetic tubes, macro and micro auxetic tubes. Furthermore, auxetic behavior, mechanical properties and potential applications of auxetic tubular structures are elaborated. Finally, the challenges and opportunities on the auxetic tubes are discussed to inspire future research work.

3.METHODOLOGY

The basic building blocks of anloT System are Sensors, Processors and applications. So the block diagram below is the proposed model of our project which shows the interconnection of these blocks. The sensors are interfaced with Microcontroller, data from the sensor is displayed on the mobile app of the user. Mobile app provides an access to the continuous data from sensors and accordingly helps farmer to take action to fulfil the requirements of the soil.

3.1 Selection of auxetic structures

Selection of Auxetic Structures involves choosing the most appropriate type of auxetic pattern based on the desired performance characteristics, material properties, and manufacturing constraints. Here are the key factors to guide the selection.

3.1.1. Auxetic Geometry/Pattern Type:

• Re-entrant Structures have a "U" or "V" shaped unit cell that leads to negative Poisson's ratio behavior. They are commonly used in applications where flexibility and energy absorption are critical.

• Chiral Structures involve patterns where the unit cells are twisted or rotated, giving them unique deformation characteristics under stress. They are useful in applications requiring enhanced shear resistance or torsional strength.

3.1. 2. Material Properties:

• Polymers and Elastomers are flexible and lightweight polymers (like PLA, TPU) are ideal for applications where flexibility and energy absorption are required, such as in protective padding, medical implants, or shock-absorbing packaging.

• Metallic Materials like aluminum, titanium, or steel can be used for auxetic structures in applications requiring high strength and durability, such as in aerospace and automotive industries.

3.1. 3. Manufacturing Constraints:

• Additive Manufacturing (3D Printing) method is ideal for creating complex auxetic geometries with precise control over design and material properties. Technologies such as SLA, FDM, and SLS can fabricate intricate auxetic structures with high customization and rapid prototyping.

• Subtractive Manufacturing (CNC Machining, Laser Cutting) traditional manufacturing techniques like CNC machining or laser cutting can be used to create auxetic patterns, particularly for simple 2D patterns that are cut from sheets of material.

• Moulding and Casting for large-scale production or when working with polymers and elastomers, injection moulding and casting are effective methods to create auxetic structures with consistent properties.

3.1. 4. Performance Requirements:

• Energy Absorption and Impact Resistance if the application requires energy dissipation, such as in protective padding, helmets, or automotive bumpers, auxetic structures with higher flexibility and deformation are ideal.

• Stiffness and Strength are for structural applications in construction or aerospace, auxetic structures that balance strength and stiffness while maintaining low weight may be selected. Materials and geometries that provide improved tensile strength and resistance to buckling should be prioritized.

• Biocompatibility in biomedical applications such as implants or prosthetics, the auxetic structure must be designed with materials that are biocompatible, non-toxic, and capable of withstanding biological environments.

3.1. 5. Cost and Feasibility:

• Material Cost selection affects both the initial cost and the long-term performance of the structure. Low-cost materials like plastics may be chosen for disposable or consumer products, whereas higher-cost materials like composites might be selected for high-performance applications.

• Fabrication Costs are complex geometries or small-scale, customized designs can increase fabrication costs, especially when using 3D printing or advanced Moulding techniques. For mass production, simpler designs or more efficient manufacturing processes may be preferred. This restricts the types of applications that can benefit from auxetic structures, particularly in industries requiring specific material properties like high temperature resistance or electrical conductivity

3.2Design and manufacture of auxetic structures:

3.2.1 Designing Auxetic Structures:

• Topological Design: Auxetic can be achieved through the geometry or arrangement of a material's internal structure, such as in honeycomb-like structures, lattice frameworks, or grid patterns.
• Metamaterials: These are artificial structures engineered to have properties not found in naturally occurring materials. Auxetic metamaterials can be designed by adjusting the arrangement of repeating units in the material.
• Unit Cells: In 2D or 3D auxetic structures, repeating unit cells (geometrical arrangements that define the material's overall behavior) are used to control the mechanical response. Common types include re-entrant structures, chiral structures, and rotating squares.

3.2.2Manufacturing Techniques:

• 3D Printing (Additive Manufacturing): This technique allows for precise control over the geometry of auxetic structures. It enables the creation of complex internal structures with intricate geometries that would be impossible or difficult to achieve with traditional manufacturing methods. 35
• Laser Cutting: Laser cutting is often used for creating 2D auxetic structures that can be expanded into 3D forms using folding techniques.
• Moulding: Auxetic materials can also be fabricated using Moulding processes, such as injection moulding, where the auxetic design is incorporated into the mold to shape the material.
• Textile and Composite Fabrication: Auxetic structures can be integrated into textile materials and composites, often used in protective clothing, sportswear, and medical devices, where the material's stretching and energy-absorbing capabilities are beneficial.
• Shape Memory Alloys and Polymers: Some auxetic behaviors are achieved by integrating materials like shape memory alloys or polymers that change shape in response to external stimuli like temperature or stress.
• Auxetic structures, which possess a negative Poisson's ratio, have gained significant attention in material science due to their unique mechanical properties. Unlike conventional materials, which contract when stretched, auxetic materials expand perpendicular to the direction of applied force. This counterintuitive behavior enhances properties such as impact resistance, energy absorption, and toughness. The design and modelling of auxetic structures are essential steps in developing materials with tailored mechanical properties for applications in aerospace, medicine, automotive, and protective equipment. This essay explores the design principles and modelling techniques used to create auxetic structures.

4.DESIGN AND MODELING:

4.1Design of Auxetic Structures: The design of auxetic structures is driven primarily by the geometric arrangement of their constituent cells. The structure's overall behaviour is dictated by the shape, connectivity, and interaction of these cells. Several geometries and design principles are commonly employed to achieve auxetic behavior.

4.1.1.Geometric Arrangements

The fundamental aspect of auxetic design is the geometry of the material at the cellular or lattice level. The most widely used geometric configurations for auxetic structures include:

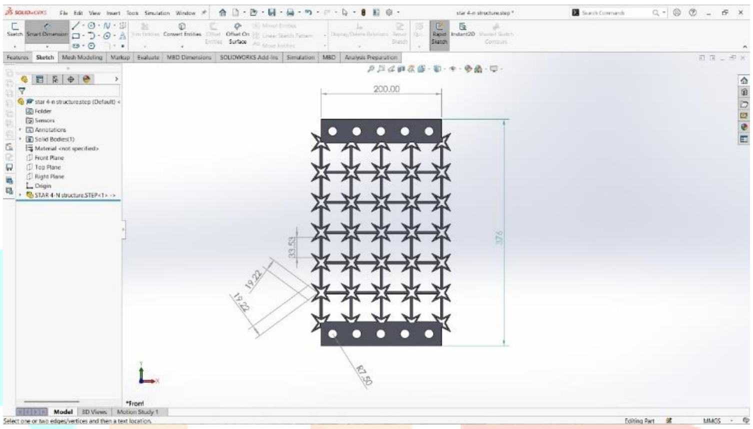
Re-entrant Honeycombs: These are lattice structures where each cell has inward-facing walls. When stretched, the angle of the wall's changes, causing the structure to expand in the perpendicular direction. Reentrant honeycombs are one of the most commonly studied auxetic designs due to their simple and effective auxetic behavior.

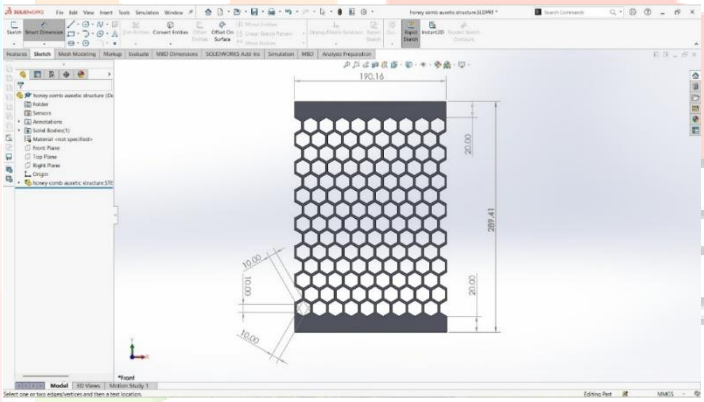
Chiral Structures: These are twisted or spiral geometries where the cells are designed with a specific angular rotation. The helical shape of chiral structures results in auxetic behavior when subjected to tensile forces. The twist in the structure leads to expansion in the transverse direction, similar to the behavior seen in reentrant honeycombs but through a more complex cellular arrangement.

Star-Shaped and Prismatic Cells: These cells are often designed with angled connections that deform in a way that results in auxetic behavior. These types of lattices are particularly useful in applications where specific stiffness and strength characteristics are required.

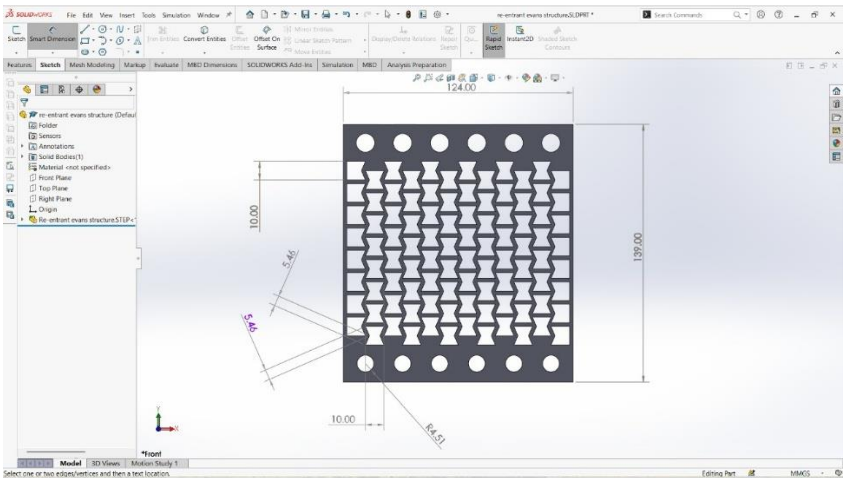
4.1.2.Topological Considerations In addition to geometric arrangements, the topology of auxetic structures plays a critical role in their behaviour. Topology refers to the connectivity and spatial relationship between cells within the lattice. Different topological configurations can be designed to optimize certain mechanical properties like Absorption or stress distribution. For example, the connectivity of cells in an auxetic structure can influence how forces are transferred through the material, which is crucial for applications like shock absorption or impact resistance.

4.1 DESIGNING OF HONEYCOMB AUXETIC STRUCTURE





4.2 DESIGING OF S-STAR AUXETIC STRUCTURE



4.3 DESIGING OF RE-ENTRANT AUXETIC STRUCTURE

4.1.3.Modelling of Auxetic Structures

Modelling auxetic structures involves simulating their mechanical behaviour and predicting how they will perform under various loading conditions. This process is vital for understanding the material's properties and optimizing the design before physical fabrication. There are several approaches to modelling auxetic structures, including geometrical modelling, computational simulations, and analytical methods. For simpler auxetic structures, analytical models can provide quick insights into their mechanical properties. These models rely on basic principles of material mechanics, such as elasticity theory and straindisplacement relations. Analytical models are often used to calculate the Poisson’s ratio and Young’s modulus for auxetic materials, offering a more efficient way to estimate the material's properties without extensive computational resources.

5.FABRICATION

Auxetic structures can be fabricated through various methods, often relying on clever geometric designs or specific materials that exhibit this unusual behavior. Here are some common approaches to the fabrication of auxetic structures:

5.1.GEOMETRIC DESIGN:

Poisson's ratio and energy absorption capacity. Examples of Auxetic Structures and 3D Printing Methods: **Re-entrant cell structures:** These are common auxetic designs that can be easily 3D printed using FDM or SLA.
Lattice structures: Lattice structures can be designed with auxetic properties and printed using various 3D printing methods.
Chiral structures: Chiral structures, which exhibit a non-symmetrical design, can also be 3D printed to achieve auxetic.
Materials: Flexible polymers like TPU or even PLA can be used for printing auxetic structures.

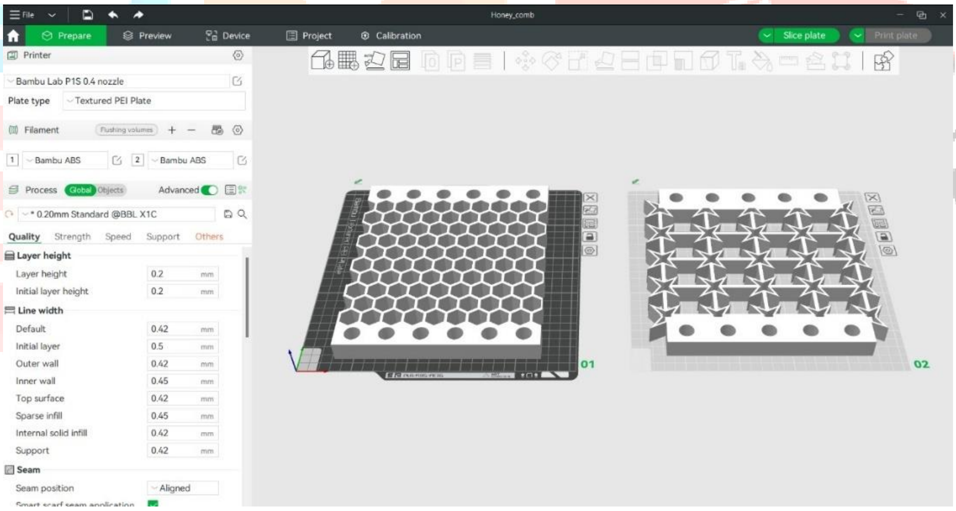


Fig-5.1- FABRICATION OF HONEY COMB STRUCTURE

5.2.MATERIAL SELECTION

Metamaterials: These are engineered materials made from a periodic arrangement of basic elements that interact in such a way as to produce properties not found in natural materials. For example, a network of cells or fibres arranged in a specific way can result in auxetic behaviour.
Polymeric Materials: Some polymers and rubber-like materials can be fabricated into auxetic structures through processing techniques that create microstructures with negative Poisson's ratio.
Composite Materials: By combining different materials (e.g., fibres embedded in a matrix), it’s possible to design composites that exhibit auxetic properties. The fibres might be aligned in specific patterns to achieve the desired expansion under stress.

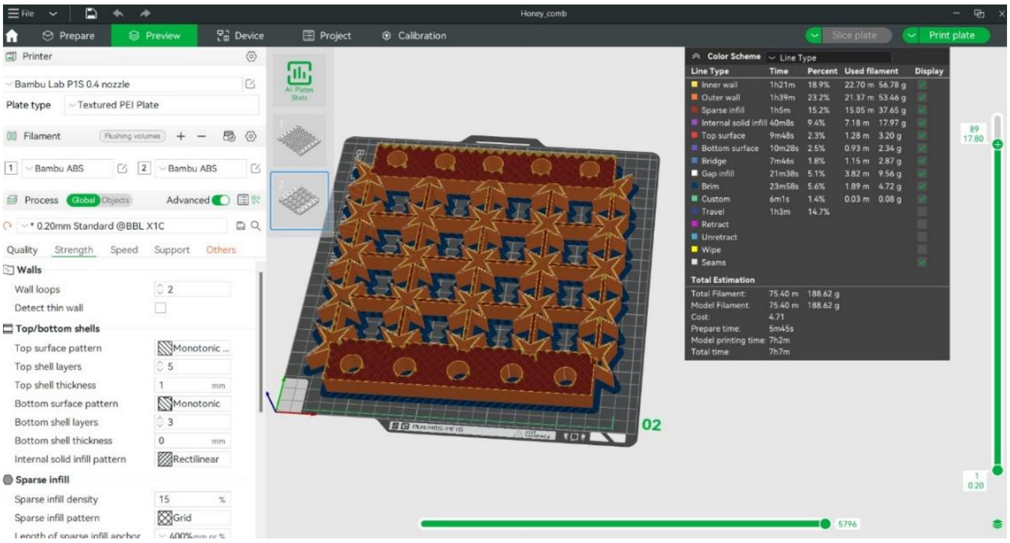


FIGURE 5.2 FABRICATION OF RE-ENTRANT

5.3 ADDITIVE MANUFACTURING

3D Printing: One of the most promising techniques for fabricating auxetic structures is additive manufacturing, or 3D printing. This allows for the creation of complex geometries with high precision. Using 3D printing, it's possible to directly print structures with auxetic patterns that would be difficult or impossible to create using traditional manufacturing methods.

Materials: Additive manufacturing can use a wide range of materials such as thermoplastics, metals, and even bio-based materials. The auxetic structure is printed layer by layer, and each layer's design contributes to the overall negative Poisson’s ratio of the final product.

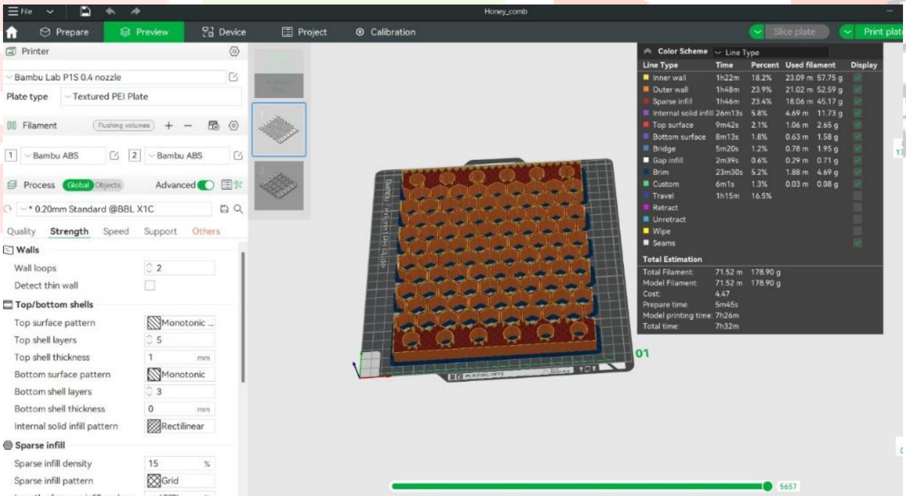


FIGURE 5.3 FABRICATION OF S-STAR STRUCTURE

6. RESULT AND DISCUSSION

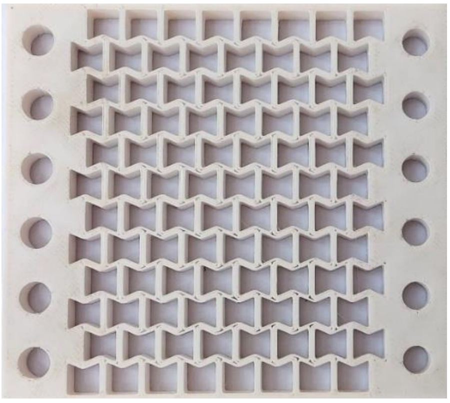


FIGURE 6.1 S-STAR STRUCTURE

The S-Star Auxetic structure is a type of auxetic material designed with a specific geometric arrangement that exhibits the unique property of a negative Poisson's ratio, meaning it expands laterally when stretched. This structure is particularly interesting due to its efficient mechanical properties, such as improved energy absorption and enhanced flexibility. S-star auxetic structures, characterized by their negative Poisson's ratio, expand laterally when stretched and contract laterally when compressed, a behaviour opposite to conventional materials. These structures, often designed with intricate star-shaped unit cells, exhibit unique mechanical properties and are used for applications like energy absorption and enhanced material performance. The S-Star unit cell is designed with a series of arms or points extending out from a central hub, creating a star-like shape. The geometry of the cell is such that when force is applied, the arms rotate and deform in a way that causes the overall structure to expand in directions perpendicular to the applied stress. This deformation results in the material exhibiting a negative Poisson's ratio, where the material becomes wider.

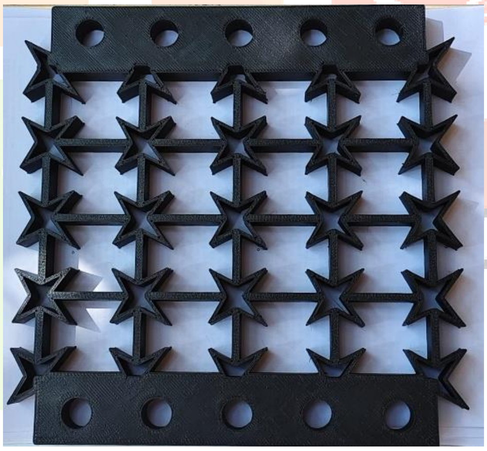


FIGURE 6.2 RE-ENTRANT AUXETIC STRUCTURES

A Re-entrant Auxetic Structure is a type of auxetic material where the unit cells have a "reentrant" or inward-bending geometry that gives the material its unique negative Poisson's ratio. In simpler terms, when this material is stretched in one direction, it expands laterally (perpendicular to the applied force), which is the defining characteristic of auxetic materials. This re-entrant design makes these structures particularly useful for applications that require flexibility, shock absorption, and increased energy dissipation. Re-entrant auxetic structures exhibit a negative Poisson's ratio. This means when the material is stretched in one direction, it becomes thicker in the perpendicular direction, as opposed to the typical materials that contract laterally when stretched. Re-entrant auxetic structures are a class of materials that exhibit negative Poisson's ratio, which means they expand laterally when stretched, as opposed to conventional materials that contract. These structures are a key example of auxetic materials, which have unique deformation properties due to their specific geometric configurations.

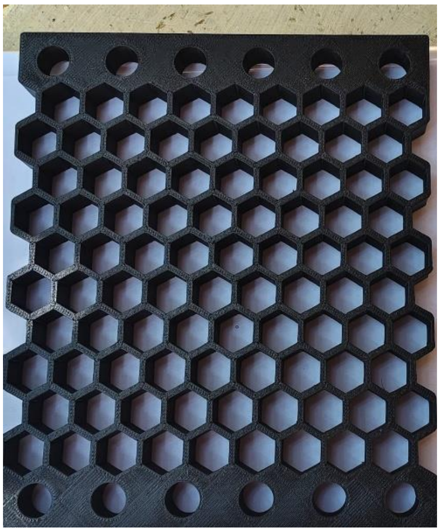


FIGURE 6.3 HONEY COMB AUXETIC STRUCTURES

A honeycomb structure is a widely used, highly efficient design that mimics the hexagonal pattern of a beehive. This type of structure is renowned for its lightweight yet strong properties, making it useful in various industries, including aerospace, automotive, construction, and packaging. Honeycomb structures can be designed with different materials, including metals, polymers, ceramics, and composites, and are often optimized to provide a balance between strength, weight, and energy absorption. Honeycomb auxetic structures are a class of cellular materials that exhibit negative Poisson's ratio, meaning they expand laterally when stretched rather than contracting like most materials. The honeycomb pattern, inspired by natural structures such as bee hives, is well-known for its efficiency in terms of weight distribution and structural integrity.

7. CONCLUSION

The auxetic structures are known for its unique properties like stiffness and superior strength. In this project

- Selection of auxetic structures were done based on auxetic geometry and pattern type like honeycomb, re-entrant, s-star auxetic structure.
- These structures were modeled by solid works software.
- Auxetic structures were fabricated by additive manufacturing technique , 3D printing and selected materials are PLA&ABS as they have properties like high strength, density, rigidity, toughness.

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