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INVESTIGATION OF THE EFFECT OF GEOMETRY INNER THICKNESS ON NEW DESIGNED AUXETIC STRUCTURE

M.Sc. Thesis by

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INVESTIGATION OF THE EFFECT OF GEOMETRY INNER THICKNESS ON NEW DESIGNED AUXETIC STRUCTURE

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M.Sc. THESIS EXAMINATION RESULT FORM

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2022 June **İsmail ERDOĞAN**

INVESTIGATION OF THE EFFECT OF GEOMETRY INNER THICKNESS ON NEW DESIGNED AUXETIC STRUCTURE

ABSTRACT

Poisson's ratio, one of the important mechanical properties of materials and structure, is positive for almost all of the known materials and structures. Material and structure showing negative Poisson's ratios are called Auxetic. Properties of the auxetic structures are very important to design a new structure, especially mechanical properties of the auxetic materials that have structurally and functionally mission. Many researchers made experimental and theoretical work on this topic. In this study, the newly designed auxetic lattice structure Poisson's ratio was examined by using finite element analysis. 14 different lattice structures concerning inner lattice thickness configurations are investigated. All examined structures have a negative Poisson's ratio. Inner lattice thickness increased, and negative Poisson's ratio values decreased (closes to -1.) in these examined lattice structures. 4×2 lattice orientation has the lowest Poisson's ratio than 4×4 Lattice structure Poisson's ratio, 4×2 is more Auxetic. 4.9 mm inner lattice thickness and 4×2 lattice matrix examined example has lowest Poisson's ratio that is -0.55. To show the effect of the structure on the applied force, the stiffness values and the stiffness/mass values were examined. Their energy dissipation capabilities were analyzed.

Keywords: Auxetic, Negative Poisson's ratio, lattice structure, novel auxetic structure.

GEOMETRI İÇ KALINLIĞININ YENI TASARLANAN ÖKZETIK YAPI ÜZERINE ETKISININ ARAŞTIRILMASI

ÖZ

Önemli mekanik özelliklerinden biri olan Poisson's oranı bilinen malzeme ve yapıların büyük çoğunluğunda pozitiftir. Yapı ve malzemeler negatif Poisson's oranına sahip olduklarında Ökzetik olarak adlandırılırlar. Yeni yapıların tasarlanmasında ökzetik yapıların özellikleri önemlidir, özellikle yapısal ve işlevsel olarak görevi olan mekanik özellikleri. Bu konu ile ilgili birçok araştırmacı deneysel ve teorik çalışma yapmıştır. Bu çalışmada, sonlu elemanlar analizi ile yeni tasarlanmış ökzetik yapının Poisson's oranı incelenmiştir. Geometri iç kalınlık yapılandırmalarına göre 14 farklı kafes yapısı incelenmiştir. Bütün incelenen yapılar negatif Poisson's oranına sahiptir. Geometri iç kalınlığı arttıkça negatif Poisson's oranı -1'e yaklaşmaktadır. En düşük Poisson's oranı 4×4'lik düzendeki kafes yapısı ile 4×2'lik düzendeki kafes yapısının Poisson's oranına bakıldığına en düşük Poisson's oranı 4×2'lik düzendeki kafes yapısına aittir. 4×2'lik düzendeki kafes yapısı daha ökzetiktir. 4.9 mm geometri iç kalınlığı ve 4×2'lik düzende incelenen örnek yapı -0.55 ile en düşük Poisson's oranına sahiptir. Uygulanan kuvvete yapının göstermiş olduğu etkiyi göstermek için sertlik değerleri ile sertlik/kütle değerleri incelenmiştir. Enerji sönümleme kabiliyetleri analiz edilmiştir.

Anahtar Kelimeler: Ökzetik, negatif Poisson's oranı, kafes yapı, yeni ökzetik yapı.

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NOMENCLATURE

Roman Letter Symbols

G	Shear modulus, Pa
K	Bulk modulus, N/ m^2
E	Young's modulus, N/ m^2
H	Hardness property, N/ mm^2
L_{0_X}	The original length of the specimen on the X-axis, mm
L_{f_X}	The final length of the specimen on the X-axis, mm
L_{0_Y}	The original length of the specimen on the Y-axis, mm
L_{f_Y}	The final length of the specimen on the Y-axis, mm
F	The Force in Y-axis
S_y	The stiffness in Y-axis.
S_{ym}	The stiffness/mass ratio on Y-axis.

Greek Letter Symbols

ν	Poisson's ratio
δ	The displacement produced by the force along the same direction of Force in Y axis.
γ	Constant, uniform pressure distribution
ε	Strain, mm/mm

Subscripts

ym	Y axis stiffness / mass
y	Y axis stiffness
f	Final status
o	Original status

Acronyms

FEA	Finite element analysis
NPR	Negative Poisson's ratio

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CHAPTER 1

INTRODUCTION

1.1 Materials and History of Materials

A material is generally defined as any state ingredient that composes any devices or objects. Material science examines materials applications and works of the materials. Materials can be naive and impure they have classified their properties as mechanical, physical, thermal, vs. Materials are natural and synthetic [1]. The history of materials is given in Figure 1.1 [2].

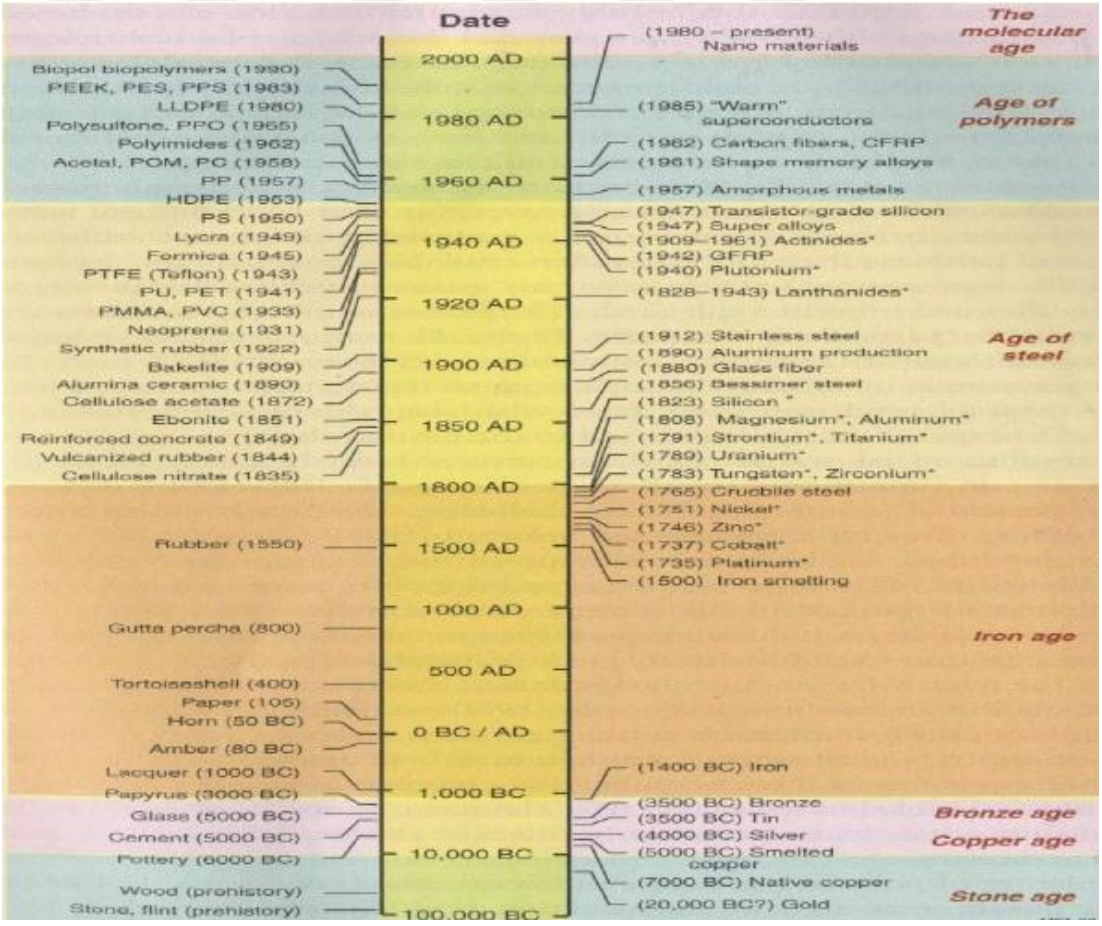


Figure 1.1 The materials timeline [2]

1.2 Classification of Materials

Materials generally, systemically and engineering divided into classification as below,

- Metals
- Polymers
- Semi-conductors
- Ceramics
- Composite
- Biomaterials

1. 2.1 Metals

Metals are solid in room conditions. Having good heat and electricity and they cannot compound among themselves. They are generally used in daily life because of their strong structure. Machinability and melting-boiling point are high are other properties of metals [3].

Metals are divided into groups based on usage. These are,

Pure Metals	Pure Aluminium - 99.99%
Alloyed Metals	Duraluminum - Durable and Aluminium
Ferrous Metals	High Carbon Steels, Cast Irons
Non–Ferrous Metals	Chromium, Mercury, Cobalt, Tungsten, Vanadium, Molybdenum
Sintered Metals	Nickel, Brass, Steel, Stainless steel, Titanium.

1.2.2 Ceramics

Two or more materials are combined without changing physical and chemical properties. New materials are created with good mechanical properties.

1.2.3 Polymers

Polymers are macromolecules composed of many repeating monomer units.

1.2.4 Semi-Conductors

Materials that have electrical properties with a plate between conductors and insulators.

1.2.5 Biomaterials

These kinds of materials used for humans damaged structures and other relevant structures. Biomaterials do not cause negative effects on other structures in the human.

Table 1.1 Examples of materials properties [3]

Property	**Metals**	**Ceramics**	**Polymer**	**Composite**
1.Tensile strength (N/mm^2)	200 - 2000	10-400	30-100	20-110
3. Hardness	Medium	High	Low	Low
5. Melting point (℃)	200-3500	200-4000	70-200	-
6. Thermal Expansion	Medium	Low	High	Low

1.3 Properties of Materials

Materials have lots of properties that compound systems. Some properties are given in Table 1.2 [4, 5, 6, 7, 8].

Table 1.2 Properties of materials [4, 5, 6, 7, 8]

Structural properties	- Composition - Crystal structure	Microstructure
Physical properties	- State - Density - Solubility	Magnetism -Viscosity
Mechanical properties	- Malleability - Ductility - Strength - Hardness - Toughness	- Stiffness - Plastic deformation - Elasticity - Brittleness

1.3.1 Mechanical Properties of materials

Materials have lots of Mechanical properties that define the behavior of systems. Compression, plastic deformation, and fracture vs. are related to these properties of the material. Some mechanical properties are given as a summary in Table 1.3. Especially, the Strength concept plays an important role to design systems [4].

Table 1.3 Definition of mechanical properties of materials

Malleability:	Workability
Ductility:	The capability to change shape
Hardness:	The reluctance become perennially deformed
Toughness:	Rigidity
Brittleness:	Friability
Elasticity:	Flexibility
Plastic deformation:	Permanently change shape
Strength:	Resistance, durability

1.3.1.1 Poisson's Ratio

Poisson's ratio is a ratio of lateral compression and longitudinal extension on one axis stress with a negative sign. When the force is applied (extension) on rod-shaped material, the rod will extend (length) at the same time diameter of the rod will decrease the effects of the longitudinal extension. Vise, versa when the force is applied (compression) length will be decreased but diameter will be increased. Figure 1.2 is about the concept of Poisson's ratio [9].

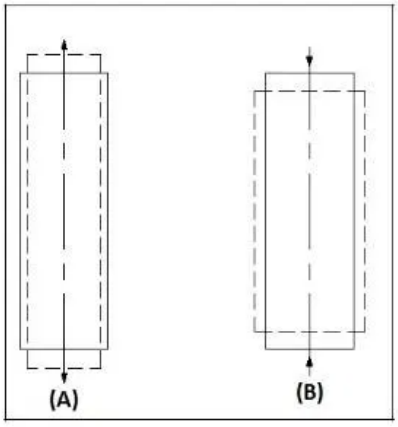


Figure 1.2 Concept of the Poisson's ratio [9]

Poisson's ratios understand that if the volume is constant extension and compression should be in constant relation. This ratio given in Eq.1.1 was found by French mathematician and physicist Siméon Poisson.

Poisson's ratio formulation is given below,

$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{longitudinal}} \quad \textbf{(1.1)}$$

ν: Poisson's ratio

ε*:* Strain

Poisson's ratio is unitless and scaler.

Poisson's ratios of known structures and materials range from 0.3 to 0.5. With engineering equations, the Poisson's ratio of materials at the atomic level ranges from -1 to 0.5. Poisson's ratios of some materials are shown in Table 1.4. [9].

Table 1.4 Some materials Poisson's ratio [9]

Materials	**Poisson's Ratio**
Aluminum	0.33
Cupper	0.36
Concrete	0.1 – 0.2
Cast Steel	0.27
Cork	0.00
Monel Metal	0.32
Rubber	0.48-0.50

The relations between shear modulus, young modulus, bulk modulus, and Poisson's ratio are given in Eq.1.2 and Eq.1.3.

$$G=\frac{E}{2(1+\nu)} \quad \textbf{(1.2)}$$

$$K=\frac{E}{3(1-2\nu)} \quad \textbf{(1.3)}$$

On the other hand, some materials have negative signs of Poisson's ratio named auxetics materials in engineering.

1.4 Aim of the Study

In this study, the newly designed lattice structure of Poisson's ratio was examined by using finite element analysis. This newly designed auxetic unit geometry is not found in the literature. It is designed within the structural and geometric boundaries that are not in the literature. First, it was investigated whether the designed shape was Auxetic or not, and then the relationship between thickness and matrix structure was examined. In this study, 14 different lattice structures concerning inner lattice thickness configurations and lattice matrix are investigated. A variety of newly designed auxetic lattice structures were examined to provide better mechanical properties and negative Poisson's ratio. "Basic Investigation of the effect of geometry on Poisson's ratio" is the concept of this study. To design lattice structure to use many applications is very important concerning lightweight and mechanical properties that are negative Poisson's ratio.

1.5 Review of Related Works

Lots of different new designed and traditional auxetic structures have been investigated experimental, numerical, and analytical by investigators. Mechanical properties of the auxetic structure were examined in their studies.

Novak N. et al. [10] made an experimental and computational study that was approved on 20 April 2021 about the mechanical properties of laser powder bed fusion manufactured Hexa and tetrachiral (Two different chiral structure) auxetic structure that shown in Figure1.3 and materials (AlSi10Mg Aluminum alloy and AISI 316L Stainless steel). Mechanical properties of examples were examined using a tensile test. Results show that two different structures and materials have similar stiffness, stainless steel is more ductile than aluminum alloys. Examination of examples done with digital image correlations. The lowest Poisson's ratio detected at the first structure which is named hexachiral is -0.74. Simulation values and experimental values are similar to each other.

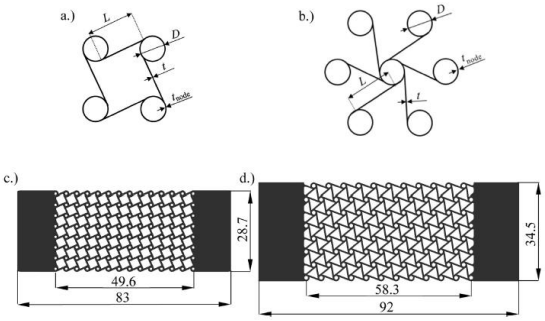


Figure 1.3 First auxetic structure tetra- (a,c) and second auxetic structure hexachiral (b,d) [10]

Gohar S. et al. [11] made an experimental and computational study that was approved on 28 July 2021 about new auxetic structure behaviors under some loads. In this study, three new auxetic structures were examined shown in Figure 1.4. Mechanical properties of the designed new auxetic structures were analyzed. Some mechanical properties compared with known auxetic structure. Geometry optimization was applied to the new structure and conventional structure to reach better mechanical properties like the highest Young's modulus %40 higher and energy absorption capacity %200 higher. They show that optimized structures have good mechanical properties and performance.

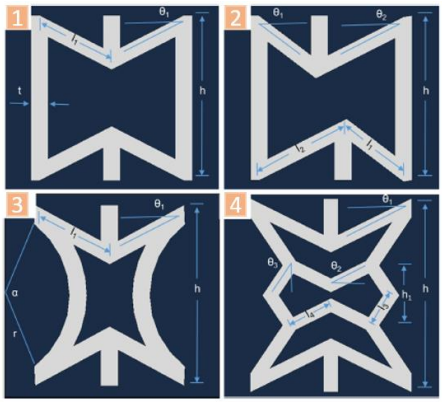


Figure 1.4 Four novel structures were examined in S.Gohar et al.' study [11]

Tiritoğlu M. et al. [12] made a study about measurements of Poisson's ratio using a universal tensile test and other experimental devices shown in Figure1.5. In this study Knitted manufacturers (zigzag and foldable patterns) were tested to provide Poisson's ratio with UTT and extensometer. Two Poisson's ratio measurement systems are

compared with each other according to the "Standard Test Method for Poisson's ratio at room temperature." Finally, extensometer experimental setup and devices can be utilized as an alternative to the UTT for measurements of Poisson's ratio of the structures.

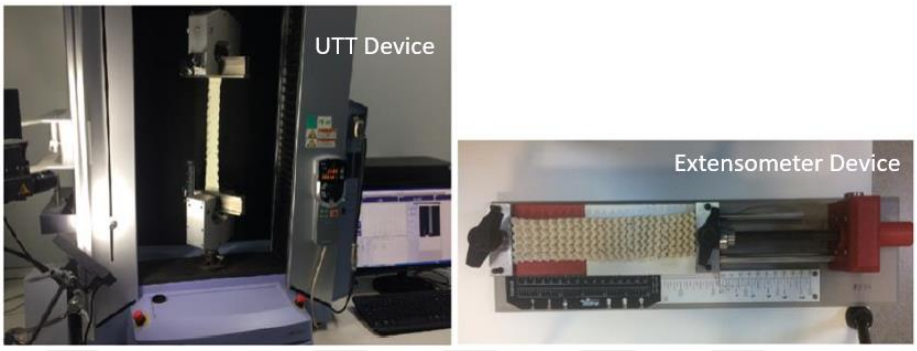


Figure 1.5 Poisson's ratio measurements devices [12]

Günaydın K. [13] made a numerical and experimental study (Ph.D. Thesis) on the properties of crushing additively manufactured auxetic lattice shown in Figure 1.6. Firstly, general information was given about auxetic structure history, properties, and usage area. After that, suitable additive manufacturing methods were selected to produce an auxetic structure as Electron Beam Melting (EBM). Different layer thicknesses were produced using the ARCAM EBM A2 3D printing machine. Titanium Alloy (Ti6Al4V) material was used for this study. In this study, lattice thickness is the main parameter for comparing the mechanical properties of the structure.

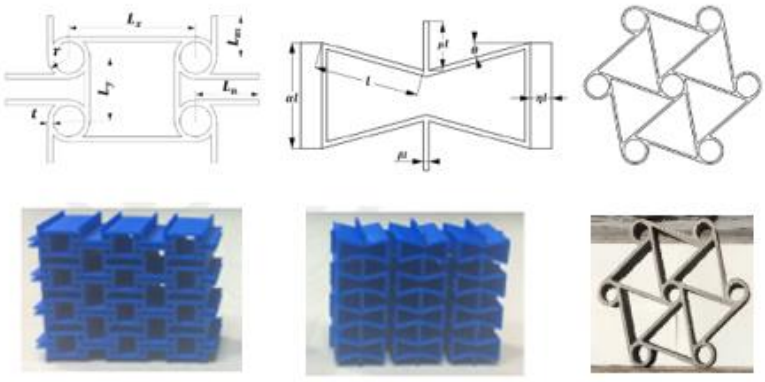


Figure 1.6 Examined auxetic structure [13]

In conclusion of this study, Günaydın reached that orientation of production geometry with a different angle is the main effective parameter for mechanical properties of the auxetic structure. Anti-tetrachiral auxetic structures have good energy absorption than other examined structures.

Türkoğlu İ. [14] made a study about 3D-based manufactured thermoplastic auxetic structure's mechanical behavior (especially energy absorption) below static and dynamic loads. 5 different auxetic structures shown in Figure 1.7 are examined in this experimental study. All examined auxetic structures have the same material PLA and same production process (3D Printing Machine). The only changing parameter is structure geometry. Structure thickness is approximately the same with a small difference between 5 different auxetic structures because of the core geometry. The weight and volume of structures are different because of the different geometry.

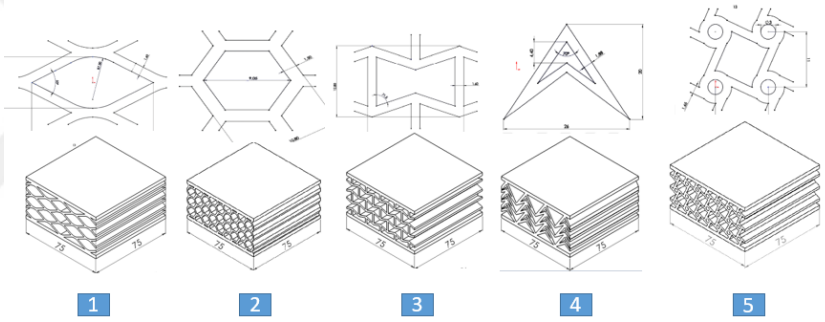


Figure 1.7 Examined auxetic structures 1; sinusoidal groove, 2; hexagonal honeycomb, 3; recurved, 4; double arrowhead, 5; Tetrachiral [14]

Results show that auxetic structures with double arrowhead (Figure 1.7.4) and tetrachiral (Figure 1.7.5) core geometry display a very superior strength below compression load and when this strength is compared to their weight, the specific compressive strength found is far superior to other structures. Recurved structures (Figure 1.7.3) have disadvantages over other auxetic structures in buckling loads effects more because of the geometry. Under dynamic loads, double arrowhead (Figure 1.7.4) and tetrachiral (Figure 1.7.5) core geometry are better properties than other structures. He reached the most ideal structure in double arrowhead core geometry because of the mechanical properties especially energy absorption under more loads.

Its high strength and deformation ability, have shown that it is the most ideal choice in areas of use where impact and collision energy absorption is required.

Gök S. [15] made a study using FEM about novel designed auxetic structure and its mechanical properties. He offered some information about auxetic structures, materials, mechanical properties, production method, design, and analysis of new auxetic structures in this study. Figure 1.8 shows new designed auxetic structure by his study.

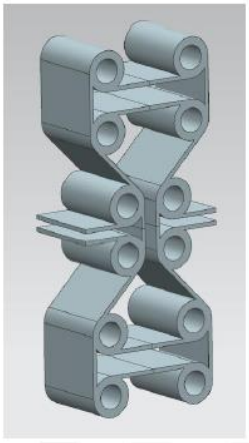


Figure 1.8 New designed auxetic structure [15]

He reached that, the newly designed auxetic structure shows NPR in itself and each geometry change. Poisson's ratio closes to -1 for structure. This result can be used new design system with a filling auxetic structure to see effects on impact and energy absorption properties. These results show that when produced the newly designed auxetic structure for testing it reaches the same values as FEM results.

Meena and Singamneni [16] made an experimental and analytical analysis of a novel designed auxetic structure. They designed and produced new auxetic geometry and structure. Two auxetic structures (1; Re-entrant and 2; S-Shape (new designed)) compared mechanical properties using tensile test systems. Figure 1.9 shows examined the auxetic structure and test stage.

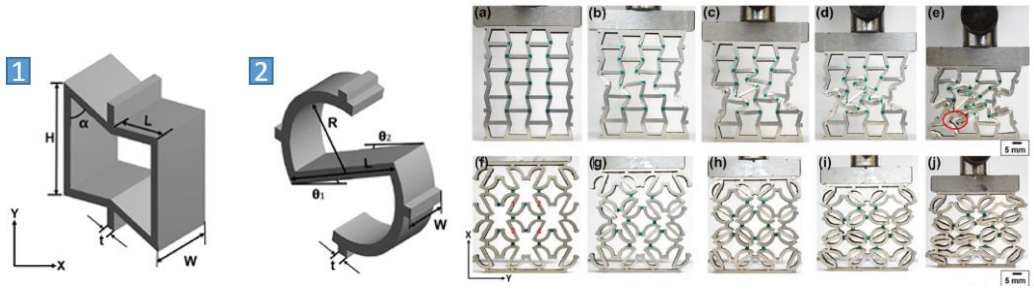


Figure 1.9 Examined auxetic structure and test stage [16]

Results show that the newly designed auxetic structure has better mechanical properties than other auxetic structures. There observed no deformation during the test shown in Figure 1.9. Poisson's ratio of the S-shaped structure is better up to -2.5 than re-entrant. The newly designed auxetic structure has a low-stress area.

Chen L. et al. [17] made a review study about tubular auxetic structure's design, production, and practices. They reached that different types of manufactured tubular auxetic structures and designs, mechanical properties, and application areas are shown in Figure 1.10. They also reached the disadvantages and advantages of reviewing different tubular structures. Review results show that re-entrant auxetic structure, rotating unit, and chiral auxetic structures can be used for design, and laser cutting and additive manufacturing methods can be used for production. Energy absorption, bending performance, and deformation response properties for mechanical properties can be reached. Potential applications are absorption systems, surgical devices, stents, rivets, crash boxes, and nosecones.

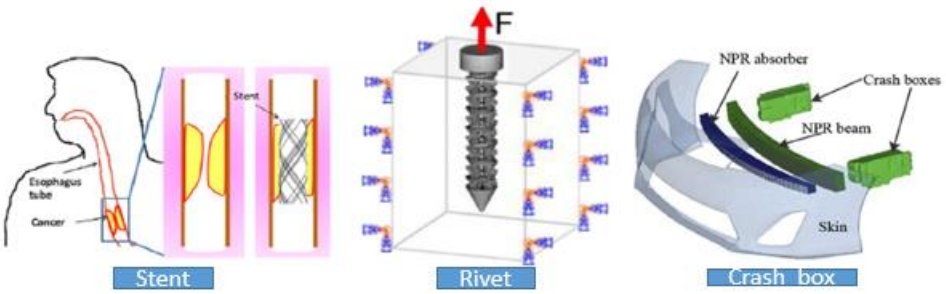


Figure 1.10 Reviewed some auxetic applications [17]

Milad N. et al. [18] made an experimental study about energy absorption of three auxetic structure dimensions are shown in Figure 1.11 and Figure 1.12. These three auxetic structures are produced using 3D printing within the same thickness and ABS material. They made two tests for the selected auxetic structure which are the compression test and the drop impact test.

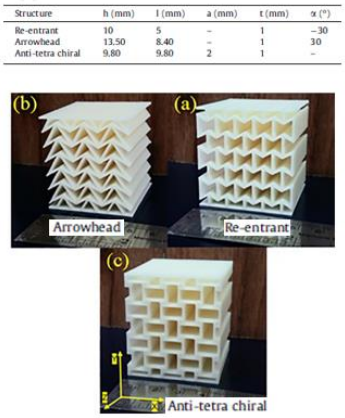


Figure 1.11 Examined auxetic structures in ref [18]

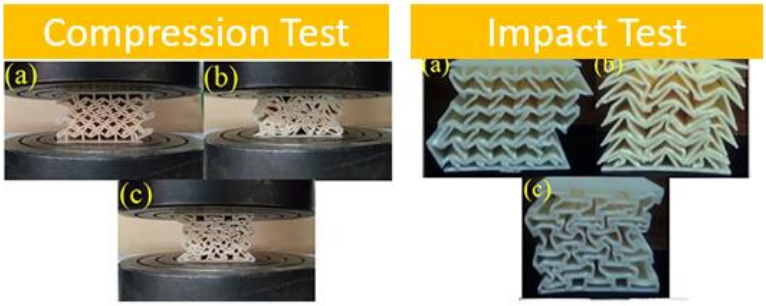


Figure 1.12 Tested structures [18]

Results show that; in the compression test, arrowed and chiral auxetic structures have good energy absorption values than re-entrant structures. In the impact test, the re-entrant structure has great properties than others. The chiral structure is the best structure for this experimental study in both testing mechanisms.

Shao Y. et al. [19] made a study about experimental (Dynamic Compression) and FEM simulation study about two different auxetic honeycomb structures (Positive and negative gradient honeycomb shown in Figure 1.13) and examined with compression

test its mechanical performance. In this study, results show that a new deformation mechanism was founded with different compressive velocities and properties. A negative honeycomb displays better mechanical performance and energy absorption.

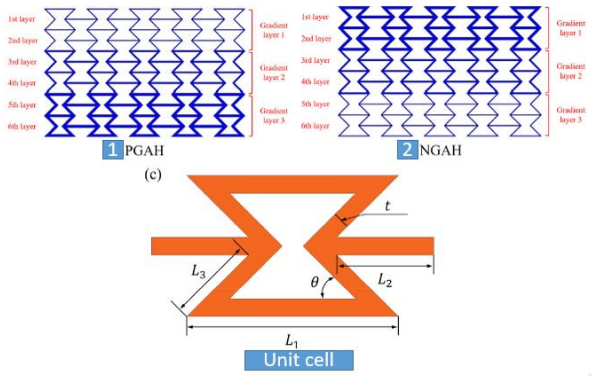


Figure 1.13 Positive and negative gradient honeycomb auxetic structure [19]

Nedoushan R. et al. [20] made an experimental analysis about new designed auxetic structure. New designed and manufactured (3D Printing) auxetic structure anti tetra chiral types. Printed examined the structure and FE analysis done finding mechanical properties as low stiffness, low strength on the anisotropy of novel designed structure and basic structure using applicable case and devices. Novel auxetic structure and manufacture are shown in Figure 1.14. Different structure thicknesses and different structure angles are examined shown in Figure 1.15.

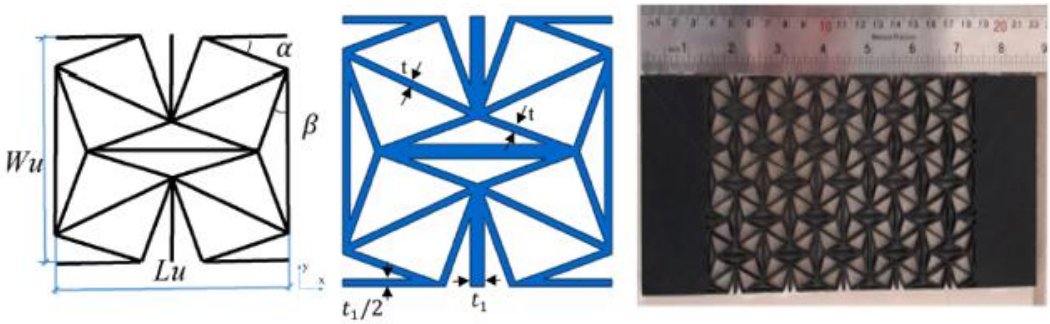


Figure 1.14 Designed anti tetra chiral auxetic structure [20]

Results show that new designed auxetic structure has good mechanical properties, especially great stiffness properties. Poisson's ratio of this structure range from -0.55 to +0.1. Reduced alpha angle and thickness have a negative Poisson's ratio.

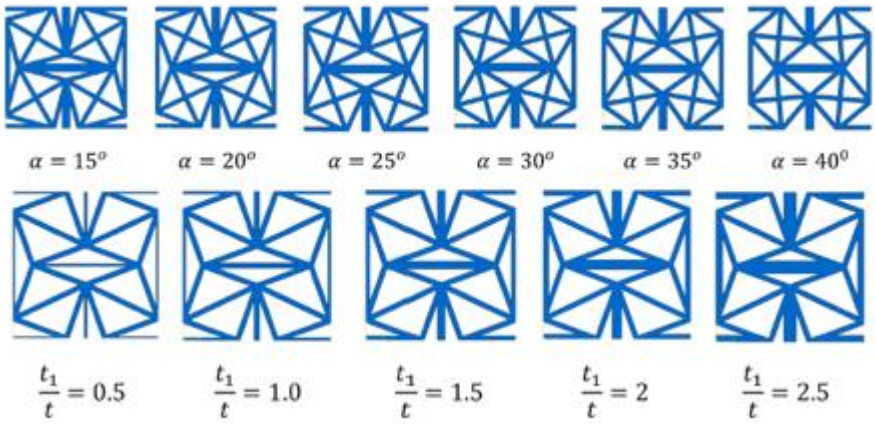
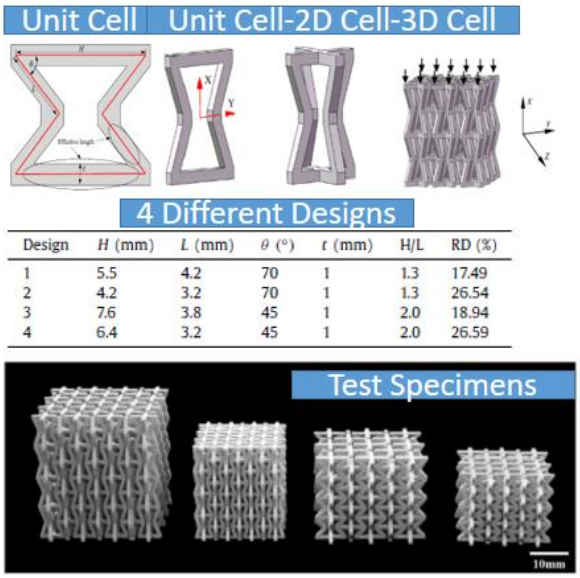


Figure 1.15 Designed anti tetra chiral auxetic structure [20]

Tabacu and Stanescu [21] made an experimental, numerical and theoretical study about the mechanical behavior of anti-tetra chiral structure on tubes. An experimental study was done by using quasi-static loads on manufactured laser cutting specimens. Numerical analysis was provided of the structure numerical model. They showed that, reaction behavior of the auxetic structure under loads. Zeng et al. [22] made an experimental and theoretical study about re-entrant structure deformation properties. A newly designed re-entrant structure (4 new designs) is examined shown in Figure 1.16 in this study. Titanium material and additive manufactured method (EBM) are used to manufacture experimental specimens in Figure 1.16. Results show that 2D structure shows a negative Poisson's ratio, and 3D structure has good mechanical behavior compared with classical re-entrant auxetic structure. Energy absorption and design area are other better results.



Design	H (mm)	L (mm)	θ (°)	t (mm)	H/L	RD (%)
1	5.5	4.2	70	1	1.3	17.49
2	4.2	3.2	70	1	1.3	26.54
3	7.6	3.8	45	1	2.0	18.94
4	6.4	3.2	45	1	2.0	26.59

Figure 1.16 New designed and examined auxetic structures [22]

Gao Y. et al. [23] made a numerical, analytical, and experimental study to investigate mechanical properties especially rotating properties of the newly designed 3D auxetic structure shown in Figure 1.17. They reached that, a newly designed auxetic structure has a wide range of negative and positive Poisson's ratios. The use of additive manufacturing methods provides good production.

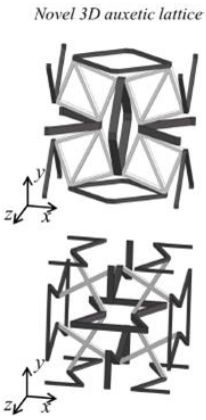


Figure 1.17 New designed and examined auxetic structures [23]

Stefan B. [24] made an experimental study about optimization (energy and weight) and mechanical behavior of the auxetic structure. They achieve that energy absorption, mechanical lightweight design of auxetic structure crash box of cars. Different auxetic

structures were investigated in their study. An additive manufactured method with polymer material was used to produce an experimental specimen. Also, the coating process was done by using nickel on the experimental specimen. Static (Quasistatic) and dynamic (Impact) tests were performed. As a result, they reached that newly designed auxetic structures have good energy-absorbing struts and mechanical properties.

Sangsefidi A. R. et al. [25] made a research study about auxetic structure performance by using Abaqus plugin software. Their research contains a parametric study on some different auxetic structures by using the software. The software algorithm shown in Figure 1.18 provides and generates different chiral, re-entrant auxetic.

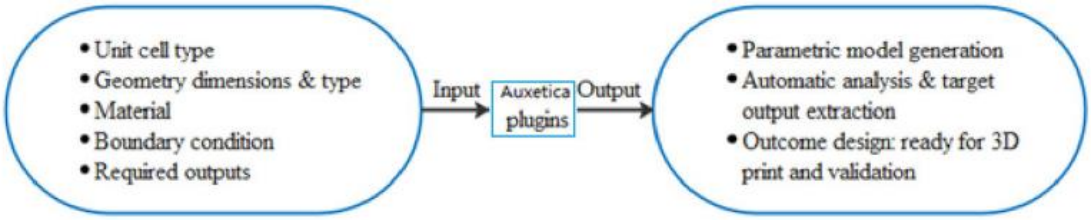


Figure 1.18 Algorithm [25]

Kang Z. et al. [26] made an experimental and numerical study about newly designed auxetic structure mechanical properties. The newly designed auxetic structure contains two different structure geometry and combination shown in Figure 1.19 Their newly designed structure has a different case in different loads and directions.

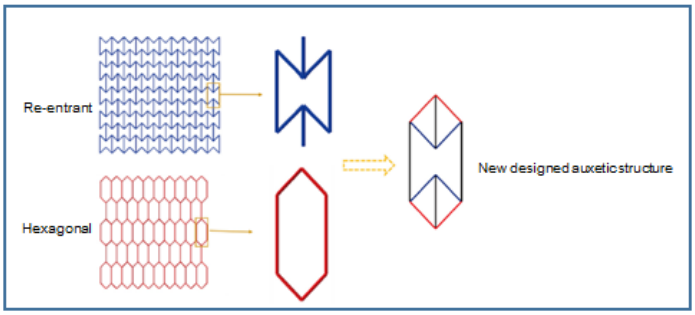


Figure 1.19 Novel designed auxetic structure [26]

New designed auxetic structures were investigated and were reached some results. The new structure has good mechanical stiffness and mechanical properties especially energy absorbing.

Zhang X. G. et al. [27] made an experimental and numerical investigation of the mechanical properties of the newly designed chiral lattice structure. They examined two different cases in their studies. Two composites (filled with soft materials, foam) specimen and two lattice structures, a total of four specimens examined and mechanical properties investigated in the study and shown in Figure 1.20

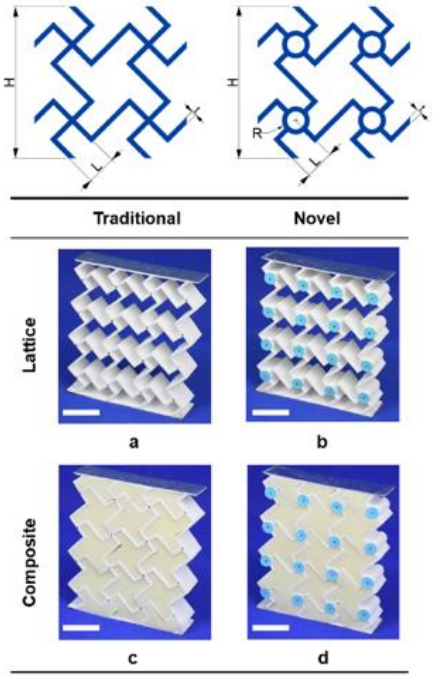


Figure 1.20 Novel designed auxetic structure with composite and lattice [27]

Results showed that the newly designed and printed lattice structure has good mechanical properties and good energy absorption properties. New designed chiral lattice structure with filled foam has low auxeticity properties but mechanical properties have increased. Energy absorption capacity has a maximum amount than traditional. Poisson's ratio of the newly designed chiral lattice structure is close to -0.38.

Matthew W. et. al [28] made a review study about the design procedure of auxetic lattice structures. They guide auxetic structure design in mechanical applications. The workflow of designing of auxetic lattice structure is shown in Figure 1.21.

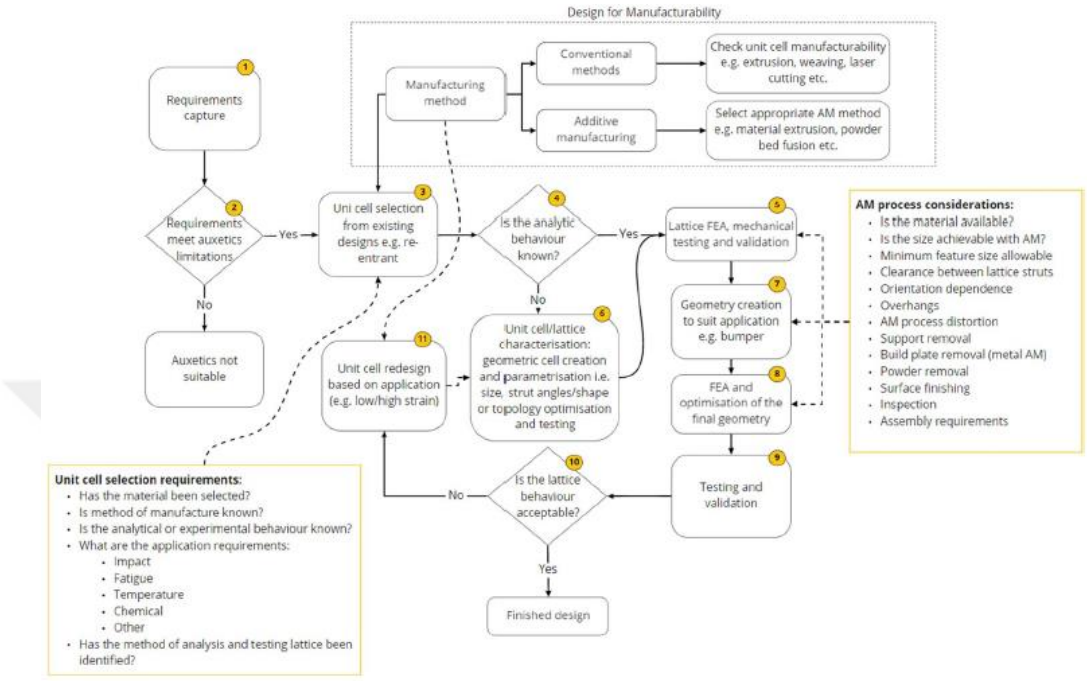


Figure 1.21 Workflow of designing auxetic lattice structure [28]

Uğur K. [29] made a structural and modal analysis in Ansys about novel designed and traditional lattice structures are shown in Figure 1.22. The traditional and newly designed structure has the same dimensional measurements and materials. Maximum stress and maximum displacement of novel designed lattice structure higher than honeycomb structure.

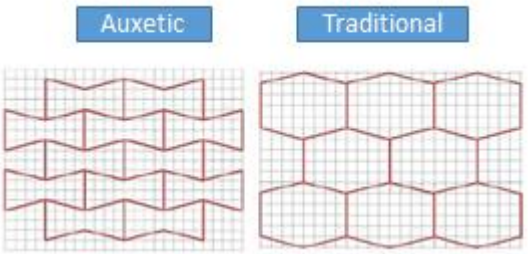


Figure 1.22 Examined auxetic lattice structure [29]

Wang S. et al. [30] made a study about energy absorption of newly designed and modeled 2D and 3D dimensional auxetic structures. Specimens were tested by using a compression test to see the properties of the newly designed. They reached that, a newly designed auxetic structure has good mechanical properties.

Demetris P. et al. [31] made a numerical and experimental analysis about new designed auxetic structure shown in Figure 1.23. 3D printing methods were used to produce test specimens. Results were verified by using tests and numerical analysis. The lowest Poisson's ratio was reached -0.6.

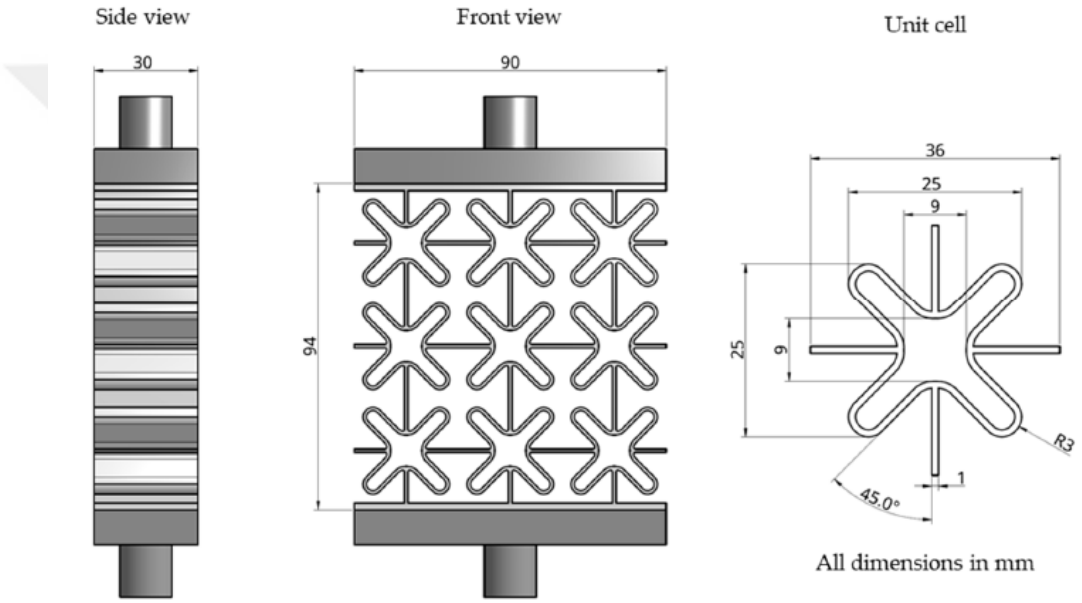


Figure 1.23 Examined auxetic lattice structure [31]

CHAPTER 2

BASICS OF AUXETIC STRUCTURE

2.1 What Is Negative Poisson's Ratio (Auxetic)? and History of Negative Poisson's Ratio Materials/Structure

Poisson's ratio is a ratio of lateral compression and longitudinal extension on one axis stress with a negative sign. When the force is applied (extension) on rod-shaped material, the rod will extend (length) at the same time diameter of the rod will decrease the effects of the longitudinal extension. Vise, versa when the force is applied (compression) length will be decreased but diameter will be increased. In the early year, isotropic materials accepted Poisson's ratio as positive. But some materials inversed this concept. Negative Poisson's ratio is defined as that materials expand transverse dimension when subjected to an axial tensile strength or reduction when compressed. "Auxetics" name is derived from the Greek word (Auxetikos) which means "tends to increase" found by Ken Evans. In engineering and theory, Poisson's ratio is assumed that -1 and 0.5 (3D structures and -1 and 1 (2D structures) for isotropic materials/structures [10].

In the history of the Auxetic materials/structures in the early year, natural auxetic materials were found as an example. Iron pyrite monocrystals were examined first materials by using an experimental study twisted and bent. They reached Poisson's ratio is - 0.1428 in 1882. Polymorphic silicones, zeolites, and silicates were examined with the same concept. RFS structures (diamond-fold structures) were examined artificially structures by K. Pietsch in 1978. Biological research was done by using the first auxetic structures as cat skin, cow skin, and cancellous bone in 1980. Different applications and structures were made with basic auxetic structures and synthesized like biological fibrous materials. R.S. Lakes manufactured the first auxetic foam structure to show properties and character in 1987 [10].

2.2 Classification of Auxetic Materials/Structure

When classifying auxetic structures/materials, they are divided into two natural structures and unnatural structures. Natural and unnatural structures are also examined in two classes themselves. When natural auxetic structures are examined, we come across minerals and biological structures. In the formation of minerals, biological structures appear as the basic building blocks of cellular systems. The structures that are created by gaining superior properties from materials that are not natural, that is, known by man, are divided into two classes 2-dimensional and 3-dimensional structure formation. In this study, a newly designed auxetic structure created in 2D structure was examined and a different geometry structure was presented to the literature. Summary information is given in Table 2.1 [32].

Table 2.1 Auxetic materials/structures classification [32]

AUXETIC MATERIALS			
Natural materials		Synthetic materials	
Mineral	Biological	Two Dimensional	Three Dimensional

The auxetic structure is a basic concept of the structured methodology to type, shape orientation, different interaction, thickness vs. affected mechanical properties as well as Poisson's ratio.

2.3 Structure Cases

The theory of elasticity says that isotropic materials describe one elastic constant and Poisson's ratio is about 0.20-0.30. Poisson's ratio can be changed with some deviations to a reached the best structure. Three cases here for structure;

- Non-central forces between particles in the structure
- Forces that do not depend on distance alone
- Anisotropy

For the above parameters, a lot of structures as micro and macro are described. In engineering and theory, Poisson's ratio is assumed that -1 and 0.5 (3D structures and -1 and 1 (2D structures) for isotropic materials/structures [7,10].

2.3.1 Non-affine Deformation

Deformation is a basic case for structure and understanding positive or negative Poisson's ratio. Non-affine deformation is properties of the auxetic structure. Figure 2.1 shows the working principles of affine structure, non-affine structure, and non-affine (negative Poisson's ratio) structure sample [32].

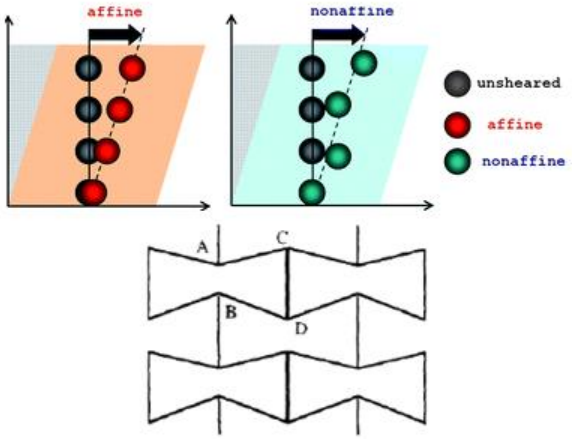


Figure 2.1 Affine, non-affine deformation [32]

The re-entrant honeycomb structure showed in Figure 2.1 This structure produces a negative Poisson's ratio. In detail, when they were subjected to force on structure, A and B changed by the effect of the force, however, C and D maintain status. In addition, if one structure has a positive Poisson's ratio, adding soft materials or changing rotation points can be structure change negative Poisson's ratio parameter.

2.3.2 Non-central Forces

Structures affected some forces central and non-central. Their parameter behavior is negative or positive Poisson's ratio. Changing structure by force affects the mechanical properties of examined samples.

2.3.3 Noncentrosymmetry

The chiral structure is a type of anisotropy hexagonal structure shown in Figure 2.2 This structure has a negative Poisson's ratio. These kinds of structures are defined as Noncentrosymmetry. Based on geometry they are not central symmetry because in this case when compressed or stretched whole structure is affected [33].

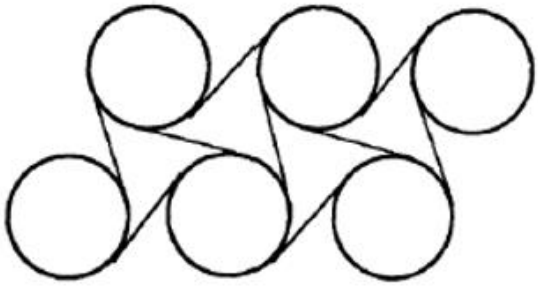


Figure 2.2 Chiral structure [33]

2.4 Properties of NPR-Auxetics Structures

Properties of the auxetics materials are very important to examining new structure materials. Especially, the mechanical properties of the auxetic materials shown in Table 2.2 have structurally and functionally mission. Auxetic materials have good damping cases and absorption for the usage of life. Enhanced indentation resistance, high shear stiffness, high fracture toughness, bending, and reduce abrasive wear in auxetic material/structure.

Table 2.2 Auxetic properties [33]

Auxetic Properties	
Primary Properties	Secondary Properties
Negative Poisson's Ratio	Shear Resistance
Synclastic Behaviour	Indentation Resistance
Variable Permeability	Fracture Resistance
	Energy Absorption
	Impact Resistance

2.4.1 Shear Modulus and Resistance

Shear resistance of the negative Poison's ratio structure ıs greater than other known structures. Theory of the elasticity for isotropic materials. the bulk modulus and the shear modulus can be determined by two equations (Eq.2.1 and Eq.2.2) involving the four constants:

$$G=\frac{E}{2(1+\nu)} \quad \textbf{(2.1)}$$

$$K=\frac{E}{3(1-2\nu)} \quad \textbf{(2.2)}$$

Two equations clearly understand Poisson's ratio relationship with other mechanical parameters. In first equations at the increase of negative Poisson's ratio the shear modulus increases and therefore the shear resistance increases too. If the Poisson's ratio is negative for any structure or materials shear modulus would be greater than the bulk modulus of structure or materials [33, 34].

2.4.2 Resistance to Indentation

The mechanical indention parameter is a method that measures structure properties as deformation or contraction. When subjected to a load applied on any structure/materials by an indenter a deformation occurs on location. Pressed location open out for poor resistance to indentation. However, when a force is applied to an auxetic structure or material location the force is seen as a local resistance. This property is very important for auxetic structure and their defense and aerospace engineering [35]. Figure 2.3 shows the concept of the non-auxetic (A) and auxetic (B) structure resistance to indentation [36,37].

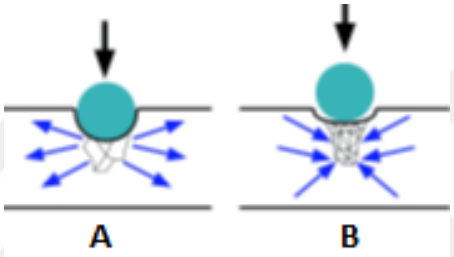


Figure 2.3 Concept of the resistance indentation [36, 37]

To explain the relationship between the theory of elasticity and material hardness property is given below in Eq.2.3.

$$H \alpha \left[\frac{E}{(1-v^2)}\right]^{\gamma} \quad \textbf{(2.3)}$$

When the formula is examined, and Poisson's ratio value near the lower limit -1 hardness of the materials goes to infinity and the upper limit 0.5 hardness of the materials is lower for 3D isotropic materials [38]. On the other hand, Poisson's ratio near 1 hardness of the materials goes to infinity too for 2D isotropic material/structure [38].

2.4.3 Fracture Resistance

Auxetic and convention foams were examined as materials that possess a negative Poisson's ratio to have a good fracture resistance than known materials/structures the auxetics have a smaller Young's modulus [34]. Lower crack propagation occurs on auxetic materials [39]. This case is explained by the basic principle of the auxetic structure. When a load is submitted to auxetic structure its dimension increases. These expanding cells close the fractures that will occur.

2.4.4 Acoustic Absorption

Acoustic absorption of the auxetic structure is a good comparison to known structures especially polyurethane foams that were used in the study [40,41]. Auxetic structure acoustic performance is cover 100-1600 Hz frequencies.

2.4.5 Synclastic Behavior

Synclastic behavior is a body's ability to deform into a shape of a dome when it is bent [42]. The basic principle of the mechanics of materials, when submitted to tensile and compression stresses on any materials, or body, is bent. Bending deformation cause concavity and dome shape structure on the auxetic structure and known structure. Figure 2.4 shows the synclastic and anticlastic behavior of the auxetic structure and known structure.

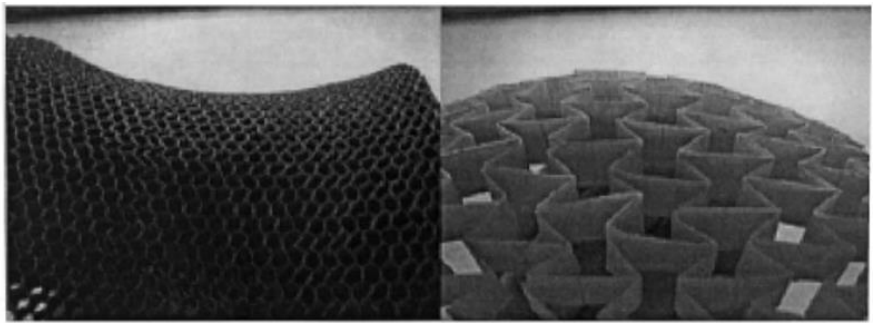


Figure 2.4 Synclastic and anticlastic behavior [42]

These types of structures are used in many application areas and concepts because of their physical properties and structural properties. Re-entrant unit cell structures were especially used for medicine, defense, aerospace, and sports activities.

2.4.6 Variable Permeability

Changing shape and dimensions provides a good variation of permeability on auxetic structure [34]. When the applied load on structure unit cells opens and closes this case provides good porous variability. Property can be seen in Figure 2.5.

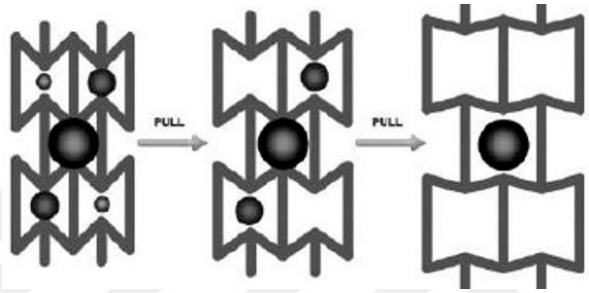


Figure 2.5 Variable permeability [34]

2.4.7 Shape Memory Auxetic

The memory of the shape is very important for the engineering World because of the application capabilities. The memory of the shape is the capability of materials submitted to any deformation and to remember and go back to the initial position (shape and size) [43,44]. On the other hand, the temperature profile affects the memory shape of the structure.

2.5 Fabrication of Auxetic Structure

Auxetic structures can be produced in many ways. In this context, many production methods have been examined and summary information has been presented. First of all, the production of the materials that make up a structure is made with traditional or non-traditional production methods. The methods used in the production of the main components of the auxetic structures are sometimes not used in the formation of the structure. For example, a detailed part can be produced by extrusion, but this production method cannot be used when one or more structures are to be produced. Many production methods have been considered for auxetic structures and experimental studies have been carried out. Auxetic materials can be made synthetically to provide high properties to humanity using laser cutting machines, open-cell foams, and 3D printing. Auxetic structures can be created especially from solid structures by cutting methods, additive manufacturing methods, and various foam and form processes. The popular production methods are cutting and additive manufacturing. Additive manufacturing methods have started to take an important place in today's production. It is widely preferred in the production of such difficult-to-manufacture structures, in the production process, in the processes of production processes, in dimensional quality and accuracy, and in minimizing material waste. In production, fused deposition modeling, which is one of the additive manufacturing methods, is mostly preferred. It is a preferred structure when the parameters of ease of production and efficiency, speed, time, and accuracy are examined. Reentrant and chiral structures, which are known especially in auxetic structures, are easily made by cutting methods and additive manufacturing methods. In Table 2.3, the structures and the methods generally used in the production of these structures are given [7-9].

Table 2.3 Fabrication of auxetic structure [7-9]

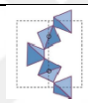
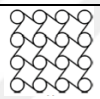
Fabrication of auxetic structure	
Fabrication Methods	**Structure**
Cutting Machine	- Perforated sheets - Missing rib type cell - Re-entrant unit cell - Rotating unit cell - Chiral units
3D Printing	- Perforated sheets - Missing rib type cell - Re-entrant unit cell - Rotating unit cell - Chiral units - Open-cell foams
Foam	- Open-cell foams
Folding/Spinning Method	- Crumpled sheets - Miura-ori folded structures - Entangled single-wire models
Combination Methods	- Composite

2.6 Auxetic Structures

Auxetic structures differ in structure orientation. Re-entrant, chiral, rotating units, and similar structures are structurally different from each other. Reentrant structures are the auxetic features of concave or convex structures. Examples of reentrant structures can be seen in many auxetic structures. Another structure is the chiral structure. these structures are structures that cannot be created as mirror images. It differs from reentrant and other structures with its different mechanical properties. While reentrant and chiral structures are mostly used in the formation of synthetic auxetic structures, newly designed auxetic structures appear as structures designed as a result of the combination. In particular, designs with superior features are created from the existing shapes that are not in the literature, finite element analysis, and the shapes that are

examined experimentally and brought to the literature are seen a lot. In this study, the new geometry and assembly structure, which was created using old motifs and the principles of ornamentation, was examined and brought to the literature. Some auxetic structures were given below providing samples in Table 2.4.

Table 2.4 Some structures of NPR [9]

Structure	Description
	Synthetic auxetic structure Re-entrant unit structure
	Synthetic auxetic structure 3D Re-entrant unit structure
	Synthetic auxetic structure Structure with rotating units
	Synthetic auxetic structure 3D structure with rotating units
	Synthetic auxetic structure Chiral unit structure
	Synthetic auxetic structure Perforated plates structure
	Synthetic auxetic structure Missing-rib type model structure

2.7 Application of Auxetic Structures

Auxetic structures are newly developing engineering structures. Due to their superior features to known structures, their use in many areas is becoming widespread. It offers options in many areas, especially due to its innovative design and different mechanical properties. In this context, it is used in various sectors and fields. These fields and application types are given below. Auxetic materials are used in aerospace, military, automotive, biomedical, structure, sensors, and textile areas.

2.7.1 Application of Auxetic Structure in Aerospace and Military Industry

In the Aerospace and defense industry, many structures and systems in the aviation industry consist of more than one part. The most important example of this situation is honeycomb structures. Honeycomb structures are the best example of the use of composite structures in the aviation industry. It is a system based on the mentality of creating a whole by using two different structures for support purposes. Another area of use is that the mechanical properties of auxetic structures are different from other conventional structures, and they will be used in connectors and aircraft structures. Some examples of auxetic structures used in aviation are given below. Engine parts, aircraft protection cases, aircraft panels like a pylon, fuselage, and wing, aircraft cones, fasteners, energy absorbers, and acoustic vibrations are examples of the application of auxetic structure in the Aerospace industry. Protective cases, explosion-proof structures, and body protective equipment are an example of the application of auxetic structure in the Defense Industry.

2.7.2 Application of Auxetic Structure in the Automotive and Construction Industry

The automotive and construction industry are application areas that have common aspects. Due to their energy-absorbing properties, auxetic structures in automotive are seen in crash boxes, protective skeleton structures, and similar structures used in the connector and structural systems used in aviation. In the construction industry, the light and durable structure and the high mechanical properties given by the negative Poisson’s ratio are seen in the filling materials and applications.

2.7.3 Application of Auxetic Structure in Biomedical, Sensor, and textile Industry

In the biomedical industry, euthanasia is a favorite field of interest. The use and development of auxetic structures, which can do efficient work with different designs and features, are rapidly taking place in the biomedical field. It continues to develop with a stent, medical structures, implants, and much protective equipment, supporting apparatus, prostheses, bandages, scaffolds, and artificial skin. The sensor industry is also developing using eutectic structures and the properties of these structures. The

effects of auxetic structures are seen in piezoelectric and hydrophone structures. In the textile sector, on the other hand, it continues to develop and is applied with clothing and protection equipment created by using the negative Poisson's ratio of auxetic structures.

2.8 Advantages and Disadvantages of Auxetic Structures

According to the mechanical properties and manufacturing process, auxetic structures have advantages and disadvantages status were given in Table 2.5. Günel and Ranjbar [9] made a review study about the better the mechanical properties of a structure, the more its use and preference. In this context, the advantages and disadvantages of auxetic structures are important in the selection and construction of the structure.

Table 2.5 Advantages and disadvantages of auxetic structures [9]

Advantages of auxetic structures	Disadvantages of auxetic structures
• High stiffness • High strength • Lightweight • High shear modulus • High indentation resistance • High synclastic behavior • Good crack resistance • High strength-to-weight ratio • Energy consumption • Changing properties by changing material or structure proportions	• Difficult to manufacture • Complex structure

CHAPTER 3

DESIGN AND ANALYSIS OF NOVEL AUXETIC STRUCTURE

3.1 A Unit Geometry Design

The first aim of this study is to design a new structure module with a negative Poisson's ratio. Unit geometry was inspired by Islamic Geometric Patterns. The geometry studied in this study was created with the polygonal technique used to create Islamic geometric patterns [45]. This newly designed unit geometry is not found in the literature. It is designed within the structural and geometric boundaries that are not in the literature. Many different unit cells were examined and preliminary analyzes were made to determine whether they were Auxetic or not. Until the structure examined in this study was designed, many unit cells were created and examined. Some designed unit geometries are shown in Figure 3.1.

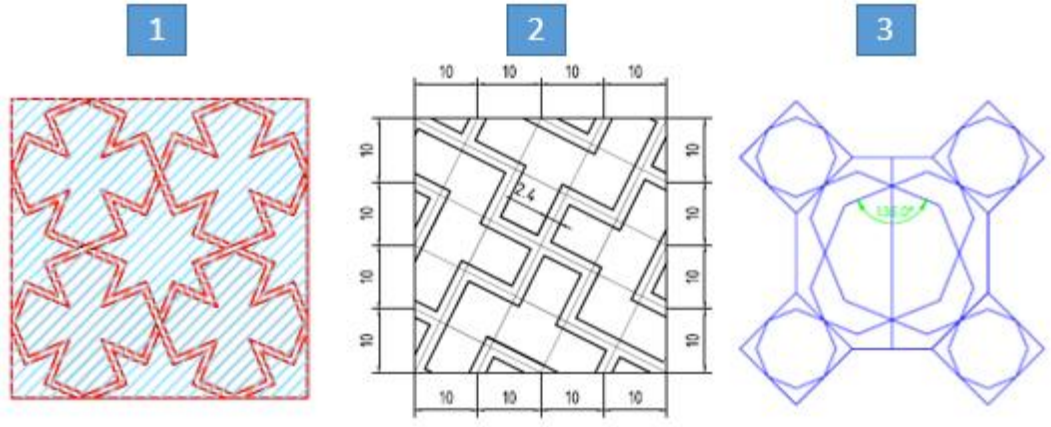


Figure 3.1 Preliminary designed unit geometry

First, it was investigated whether the designed unit geometry was auxetic or not, and then the relationship between thickness and matrix structure was examined. The design stages of the newly designed unit geometry to be examined in this study are shown

below. New designed unit geometry was used for the structure module by taking its mirror image were given in Figure 3.2.

The first stage is creating a 40 mm – 40 mm square for a unit geometry. In the second stage, the square with a side length of 40 mm is divided into 8 equal coins with equal lines, each of which is 5 mm. In the third stage, it is obtained with the lines drawn from the corner point of the square 5 mm to the other corner. In the fourth stage, the principal axes of geometry were formed by drawing lines from the midpoint of the square structure 5 mm away from the lines drawn to the corner points to the edges. In the 5th and 6th stages, other lines and areas in the geometry and square structure were deleted. The sixth stage creates the basic shape of the unit cell, in which the principal axes of the geometry are shown. In the seventh stage, the geometry inner thickness of 2.39 mm was shown. Similar shapes and new auxetic structures can be created with other geometric pattern creation methods. The designed unit geometry and lattice structure are given in Figure 3.2. In the preliminary study, it was determined that the designed structure showed auxetic properties. Then, its relations with the thickness and matrix structure were mentioned in the following sections.

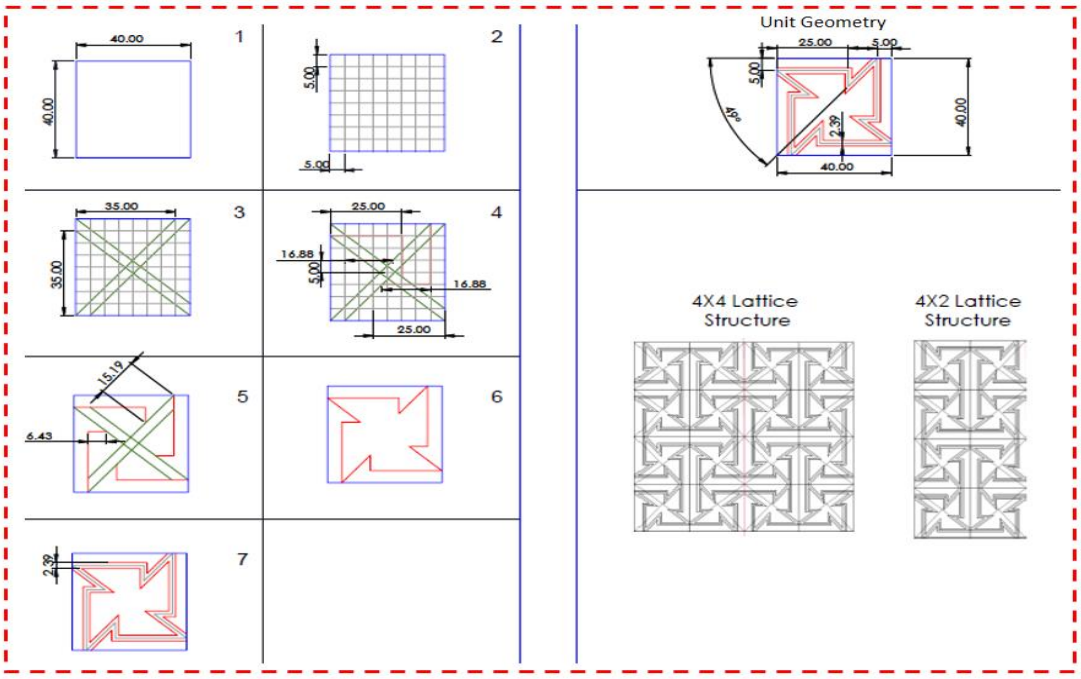


Figure 3.2 Design stages of the unit geometry

3.1.2 Modelling and Design Parameters of Unit Geometry

This study is to find a new auxetic structure with great mechanical properties. Figure 3.3 is showed a novel geometry unit in 2D and 3D Modelling, SolidWorks 2018. Dimensions are in mm.

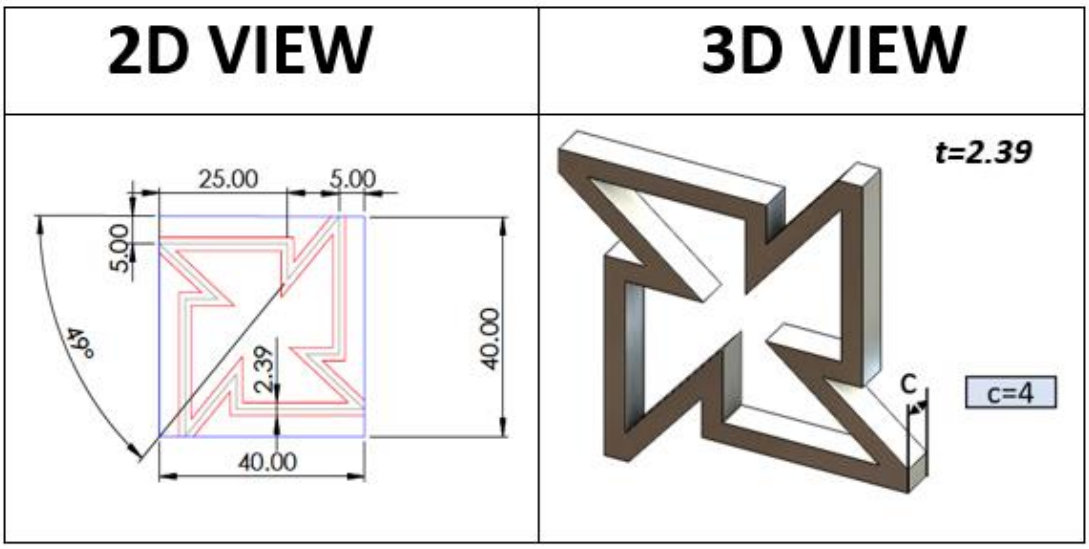


Figure 3.3 Novel unit geometry

In a novel designed and modeled unit, geometry has four edges to build a structure by using mirror image connection. Geometry was arranged by rounding sharp corners and edges for good production properties.

In this study, one of the variable parameters is the geometry inner thickness and the other is the structure matrix. Geometry inner thickness, *(t)*, shown in Figure 3.3 is the variable parameter on other specimens. The geometry inner thickness of examined structures was shown in Table 3.1.

Geometry or structure thickness, *(c)*, and other basic measurements shown in Figure 3.3 is the same and constant for other examined specimens.

Table 3.1 Geometry inner thickness and examined specimen type

Specimen type	Inner lattice structure thickness *t*, (mm)
7	4.900
6	4.390
5	3.890
4	3.390
3	2.890
2	2.390
1	1.890

There are 7 different specimens modeled by changing geometry inner thickness, t. Inner lattice structure thickness was created as 4.9 mm at most. The thickness increases to be made after this thickness have not been examined since they will disrupt the structure of the geometry. In Figure 3.4, it is seen that the structure of the shape will deteriorate after the inner lattice structure thickness is 4.9mm

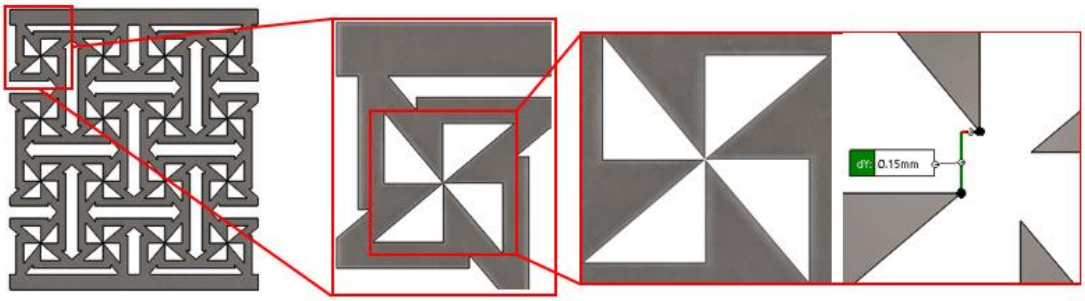


Figure 3.4 Limitation of geometry inner thickness

The reason why the inner lattice structure thickness value is not less than 1.89 mm was not examined because the equivalent stress exceeds the safety stress and the strength of the structure decreases.

3.1.3 Structure Modelling of New Designed Auxetic Geometry

In this study, the unit cell layout of the 4×4 and 4×2 matrix structure was examined as a preliminary study. Since the negative Poisson's ratio of the structure in the orientation examined as a preliminary study was lower in the orientation used in this study, the whole study was continued from this orientation as shown in Figure 3.6. Poisson's ratio of preliminary orientation is -0.33. As a result of the fact that the Poisson's ratio was not lower than the other, the new unit cell orientation was tried and it was observed that it was lower than the investigated antecedent structure. Subsequent studies were carried out and examined in this orientation. Preliminary orientation is shown in Figure 3.5.

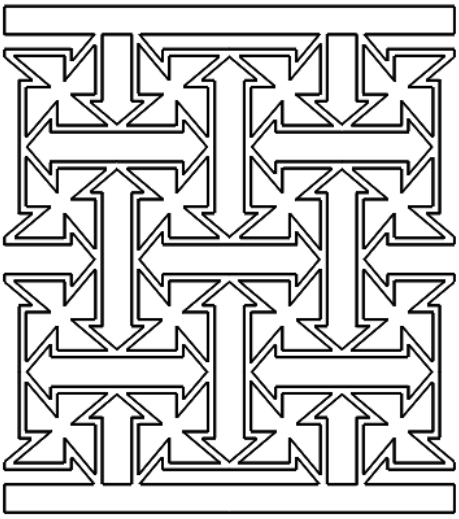


Figure 3.5 Newly designed unit geometry preliminary orientation study

The examined structure was modeled in SolidWorks 2018 by using the extruded cut feature. Lattice structure modeling steps were given in Figure 3.6. Extruded Boss/Base features were used in structures with 4 mm lattice thickness. A unit geometry is used base feature for the modeling process by mirroring images and cut features.

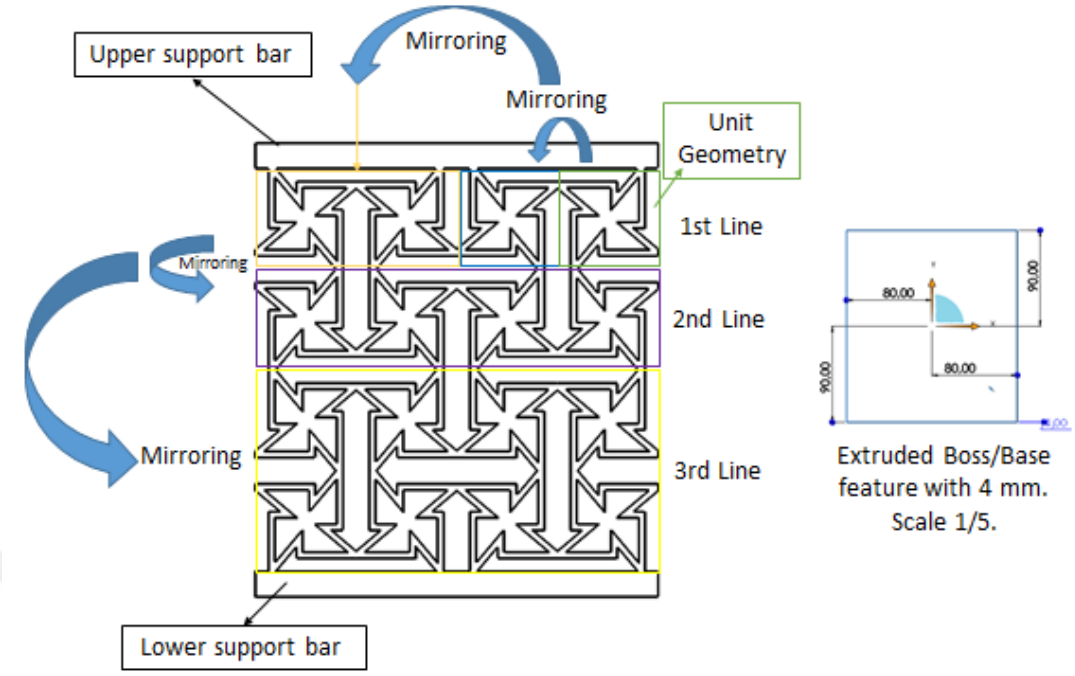


Figure 3.6 Lattice structure modeling process

Extruded features with 4 mm lattice thickness were created first. After that, the unit geometry located in the green box was attached and cut into the extruded feature. Mirroring the image of unit geometry is the next step which is located in the blue box. Then, the mirror image of these two modeled geometry was taken which was displayed in the orange box. The first line of the model to be surveyed is thus completed. The second line which is located in the purple box is created by using mirroring of the first line. The first and second lines were created with operations. Finally, the third line which is located in the yellow box of the model was created by mirroring an image of the affiliation of first and second-line geometry. Upper and Lower support bars were created in all models for analysis.

In this study, structure matrix is another variable parameter in the examined lattice structure. 2 different structure matrix were examined with 7 different inner lattice thicknesses shown in Figure 3.7 4×4 and 4×2 lattice structure matrix effects on negative Poisson's ratio on the investigation.

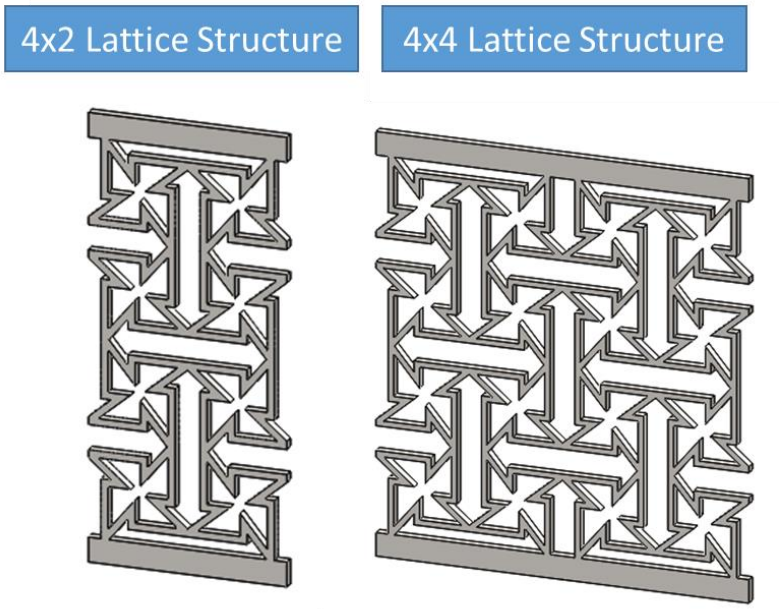


Figure 3.7 Lattice structure matrix types

Lattice structures 4×4 and 4×2 matrix structure and 10×10 mm edge distance for analysis. 180 mm length, 160 mm width with 4 mm thickness (Structure thickness) for 4×4. 180 mm length, 80 mm width with 4 mm thickness (Structure thickness) for 4×2. Detailed information on examined novel Auxetic structure dimensions and two variable parameters were given in Table 3.2.

In the preliminary study, different values were observed when the 4×1 and 4×3 matrix structures were analyzed because they were not in the proper orientation to the geometry and structure shape. Especially when the analysis in which the 4×1 matrix structure is examined, the structure exhibited anisotropic behavior. It has been observed that the 4×3 matrix structure has anisotropic properties too. Two preliminary matrix structures were given in Figure 3.8. In this study, 4×2, and 4×4, matrix structures were examined in terms of the application area and material structure properties, and the results were interpreted.

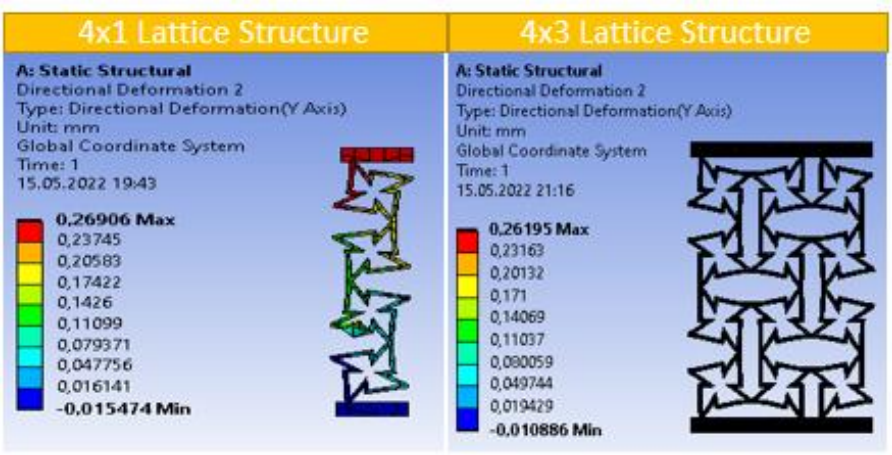


Figure 3.8 4 × 1 and **4 × 3** Matrix structure structural analysis cases

Table 3.2 Detail information about examined lattice structures

Lattice structure matrix type	Specimen number	Inner lattice structure thickness (mm)	Original dimensions (y Axis) (mm)	Original dimensions (x Axis) (mm)
4 × 2	14	4.900	160	80
4 × 2	13	4.390	160	80
4 × 2	12	3.890	160	80
4 × 2	11	3.390	160	80
4 × 2	10	2.890	160	80
4 × 2	9	2.390	160	80
4 × 2	8	1.890	160	80
4 × 4	7	4.900	160	160
4 × 4	6	4.390	160	160
4 × 4	5	3.890	160	160
4 × 4	4	3.390	160	160
4 × 4	3	2.890	160	160
4 × 4	2	2.390	160	160
4 × 4	1	1.890	160	160

Table 3.3 Examined specimen 3D models

4 × 4 Lattice structure specimens			4 × 2 Lattice structure specimens		
Specimen 1	Specimen 4	Specimen 7	Specimen 8	Specimen 11	Specimen 14
Specimen 2	Specimen 5		Specimen 9	Specimen 12	
Specimen 3	Specimen 6		Specimen 10	Specimen 13	

The 3D modeling of the examined lattice structures is given in Table 3.3. In this thesis, besides the design, modeling, and analysis, the structure with the lowest Poisson's ratio of the study was analyzed with a 3D printing machine. As an example, a sample of PLA-type polymer material was produced with a 100% filling rate. This sample, shown in Figure 3.9, has a 4 × 2 matrix structure and its geometry inner thickness is 4.9 mm. The length of the produced sample is 180 mm and its width is 80 mm.

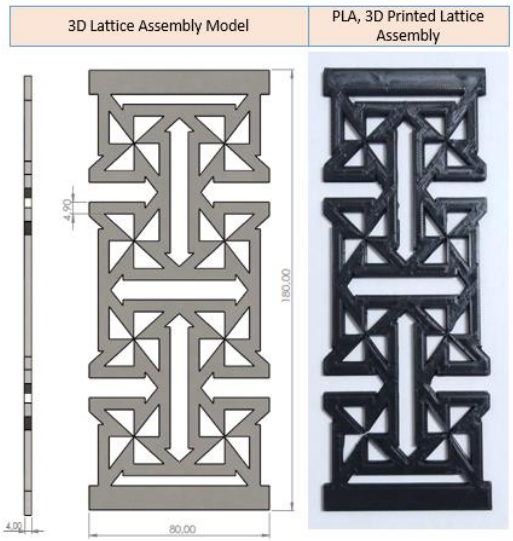


Figure 3.9 3D manufactured 4×2 matrix type novel auxetic structure

3.2 Analysis of Poisson's Ratio

Poisson's ratio is a ratio of lateral compression and longitudinal extension on one axis stress with a negative sign. When the force is applied (extension) on rod-shaped material, the rod will extend (length) at the same time diameter of the rod will decrease the effects of the longitudinal extension. Vise, versa when the force is applied (compression) length will be decreased but diameter will be increased. Figure 3.10 is about the concept of Poisson's ratio.

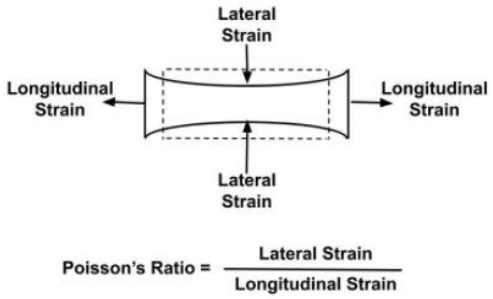


Figure 3.10 Concept of the Poisson's ratio [9]

Poisson's ratios understand that if the volume is constant extension and compression should be in constant relation. This ratio was found by French mathematician and physicist Siméon Poisson. Poisson's ratio was calculated for all examined structures by using relations/equations (3.1), (3.2), and (3.2) given below.

$$\varepsilon_{lateral} = \frac{\Delta L_X}{L_{O_X}} = \frac{L_{f_X} - L_{0_X}}{L_{0_X}} \quad \textbf{(3.1)}$$

$$\varepsilon_{longitudinal} = \frac{\Delta L_Y}{L_{O_Y}} = \frac{L_{f_Y} - L_{0_Y}}{L_{0_Y}} \quad \textbf{(3.2)}$$

$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{longitudinal}} \quad \textbf{(3.3)}$$

L_{0X}: is the original length of the specimen on the X-axis. (Lateral Direction)

L_{fX}: is the final length of the specimen on the X-axis. (Lateral Direction)

L_{0Y}: is the original length of the specimen on the Y-axis. (Longitudinal Direction)

L_{fY}: is the final length of the specimen on the Y-axis. (Longitudinal Direction)

ν: Poisson's ratio

ε: Strain

Poisson's ratio is unitless and scaler.

3.3 Analysis of Stiffness and Stiffness/mass

Stiffness /rigidity is defined as the property of maintaining its current state against a force. The stiffness and stiffness/mass values are calculated with the following equations [47].

$$S_y = \frac{F}{\delta} \tag{3.4}$$

F: is the force on the Y-axis

δ: is the displacement produced by the force along the same direction as a force on the Y-axis.

S_y: is the stiffness on Y-axis.

In addition, the stiffness/mass value was calculated using the equation below.

$$S_{ym} = \frac{S_y}{m} \tag{3.5}$$

S_{ym}: is the stiffness/mass ratio on the Y-axis.

In this study, stiffness and stiffness/mass ratio were calculated using equations (3.4) and (3.5) in the Y-axis direction since the pressure was applied along with the Y force in the analysis operating setup.

3.4 Finite Element Analysis

Analysis of novel auxetic structure mechanical properties was made by using Finite elements analysis. Effects of 2 variable parameters were investigated on negative Poisson's ratio by using Static structural analysis. Poisson's ratios of the newly designed auxetic structure were compared concerning variable parameters.

3.4.1 Static Structural Analysis Setup

ANSYS 20 R1 Analysis program has been used for FEA. The instance structure 4 × 4 matrix is given in Figure 3.11.

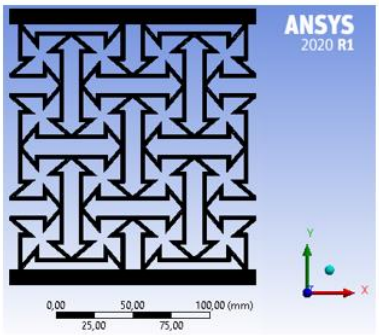


Figure 3.11 Instance structure

Although structural steel is frequently used in the construction sector, it is preferred in many structural parts in the automotive industry and aviation sectors due to its mechanical properties. Structural steel is used in many fields. Steel was preferred in structural analysis by taking this usage area and studies as a reference. Structural Steel was selected as a material for all analyses because of to negate the effect of the material parameter. Properties of the material are given in Table 3.4 taken from ANSYS engineering data [46].

Table 3.4 Properties of the material in ANSYS engineering data [46]

Property	Value	Unit
Density	7850	$\frac{kg}{m^3}$
Poisson's Ratio	0.30	Unitless
Tensile Ultimate Strength	460	MPa
Tensile Yield Strength	250	MPa
Young's Modulus	200	GPa

All element size dimensions used while creating the mesh structure were determined as 0.5 mm for good mesh convergence in Table 3.5. The average number of nodes is 1692740 and elements are 351312. Hex Dominant Method, Quad/Tri is Free Face Mesh Type was used for good meshing results. The average aspect ratio is 1.178., the average skewness value is 0.090, and the Jacobian ratio is 1.1798. Increasing node number and element number provide good accuracy in results. Increasing the number of nodes and the number of elements increases the accuracy of the results. In this study, the error in the results was accepted as less than 1%, and mesh selection was made.

Table 3.5 Optimum mesh selection

Element size (mm)	Node number	Element number	Equivalent (von Mises) stress (MPa)	Change %
12.00	4987	536	47.28	-
6.00	7854	747	51.09	8.05
3.00	24174	2984	55.33	8.30
1.50	105591	16659	60.15	8.70
1.00	536986	67789	64.59	7.38
0.55	1429051	293976	68.36	5.84
0.50	1692740	351312	68.94	0.85

The meshed structure is given in Figure 3.12. Detailed sections/views were given right side of the Figure.

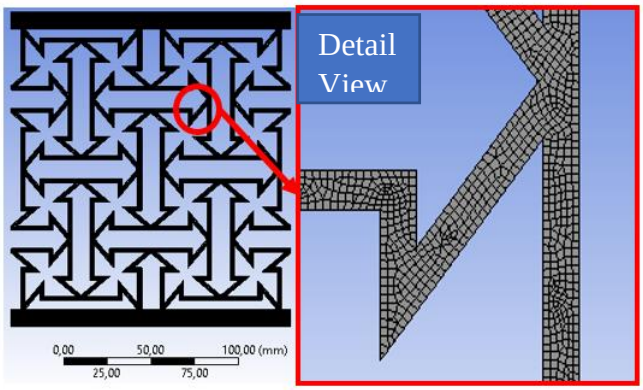


Figure 3.12 Meshed structure

3.4.1.1 Static Structural Analysis Boundary Conditions and Tools

Static structural parameters were designed to provide an analysis. Flag Red, A is denoted Pressure contact area or surface, direction, and magnitude. (Pressure is -0.1563 MPa (100 N), Direction is parallel to the Y-axis, Tension) and Flag Blue, B is denoted Fixed support contact area were shown in Figure 3.13.

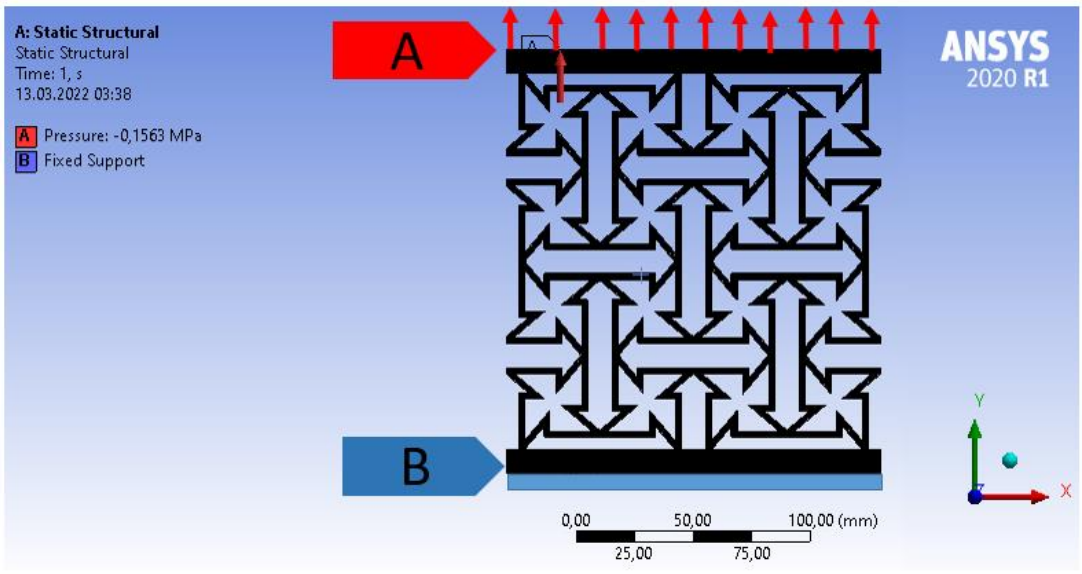


Figure 3.13 Boundary conditions and parameters

The solution to the analysis parameters is given in Figure 3.14.

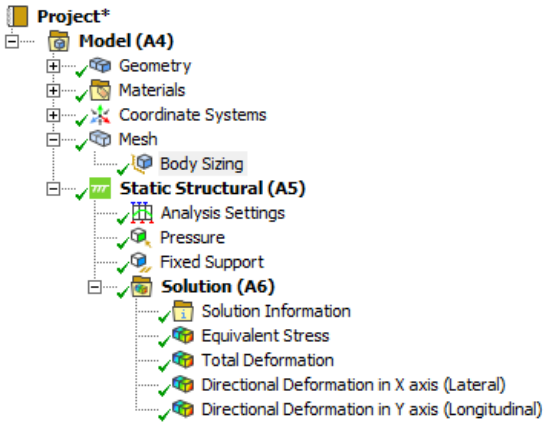


Figure 3.14 Analysis solutions

Firstly, total deformations were found in the solution of the analysis. After that, equivalent stress was found in the solution of the analysis. The finding of these two parameters provides finding boundary values comparison of each structure during FEA. Examples of parameters for newly designed lattice structures were given in Figure 3.15.

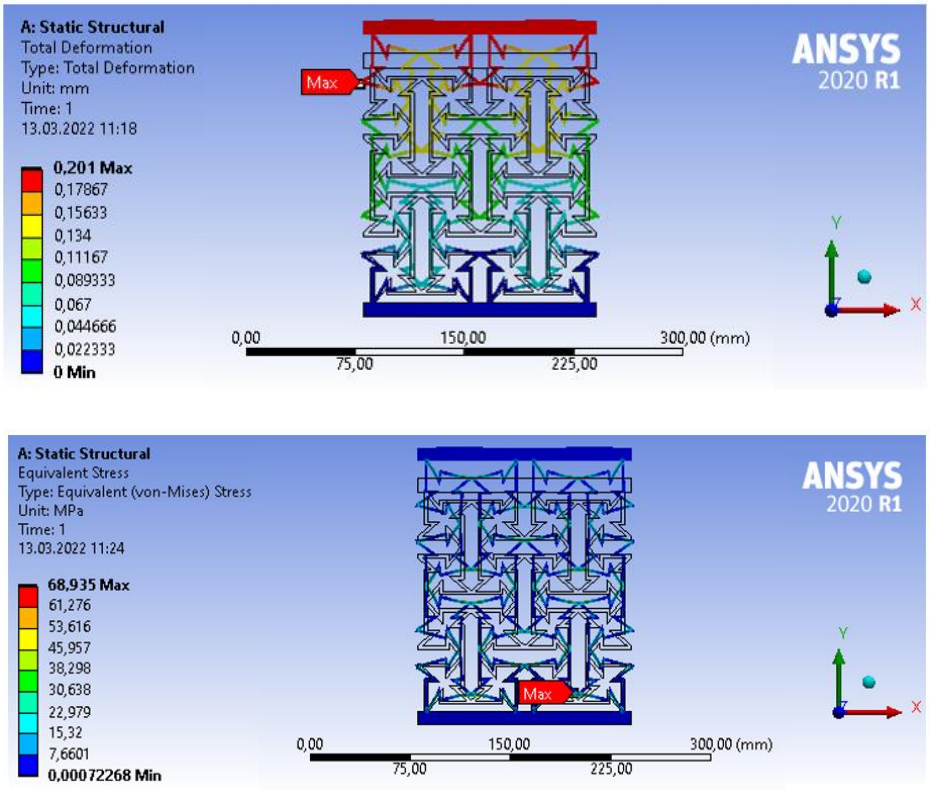


Figure 3.15 Analysis results for total deformation and equivalent stress

The finding Poisson's ratio of lattice structures needs directional deformation that is on the X-axis and Y-axis is necessary. For this reason, lateral in X-axis, and longitudinal in Y-axis directional deformations were found using the software. Example of parameters for specimen number 2 (Default unit geometry, 2.39 mm, that was created by using Islamic geometric patterns, polygonal technique). Directional deformation values were given in Figure 3.16. Four solution cases which are total deformation, equivalent stress, directional deformation on the X-axis, and directional deformation on Y-axis were examined for other lattice structures Poisson's ratio in the same manner.

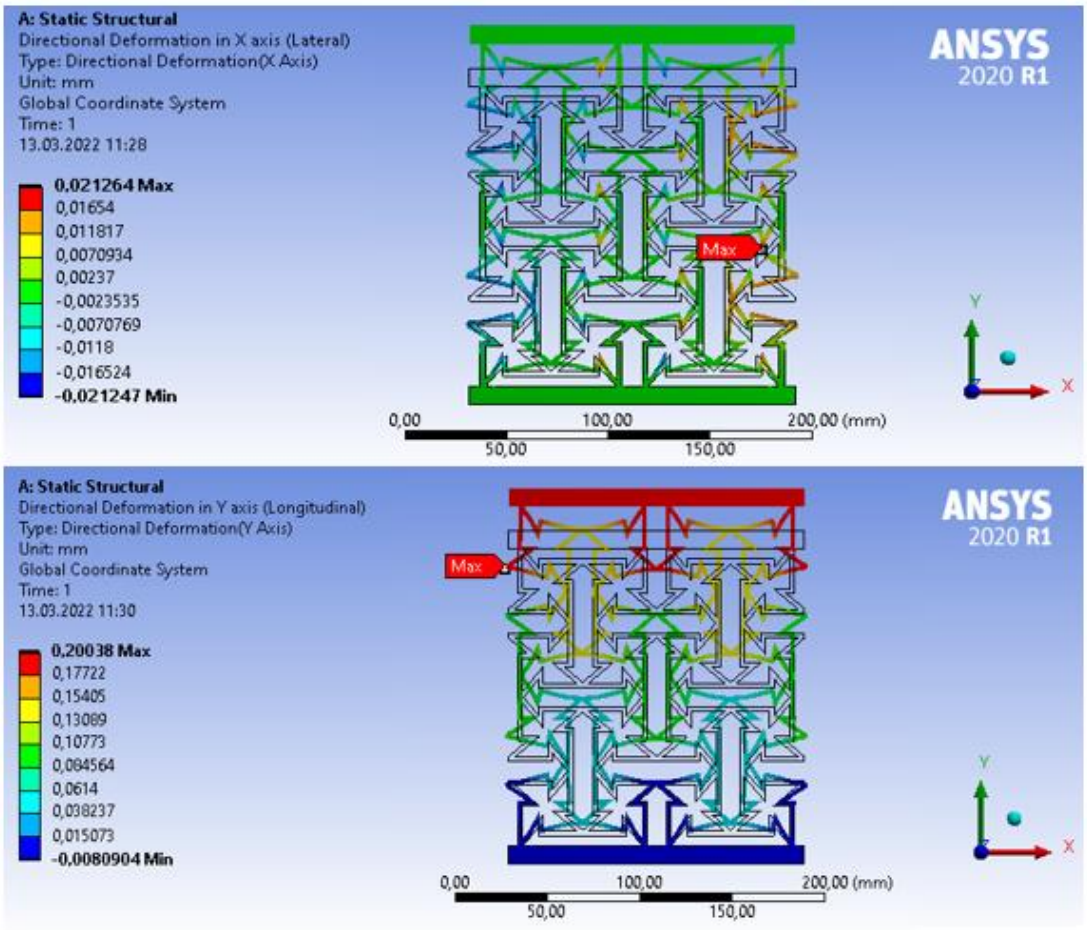


Figure 3.16 Directional deformation in X-axis and Y-axis

3.4.2 Explicit Dynamics Analysis Setup

Impact analysis of the newly created auxetic structure in this study was performed with the impact test by using the explicit dynamics mode of ANSYS. The effect of the object hitting the main structure at certain speeds over 10 mm of the lattice structure was investigated. The geometries used in this analysis are shown in Figure 3.17. Impact structure materials were chosen as AL-6061-T6; lattice structure material is structural steel. Mesh size and mesh properties were selected the same as static structural analysis.

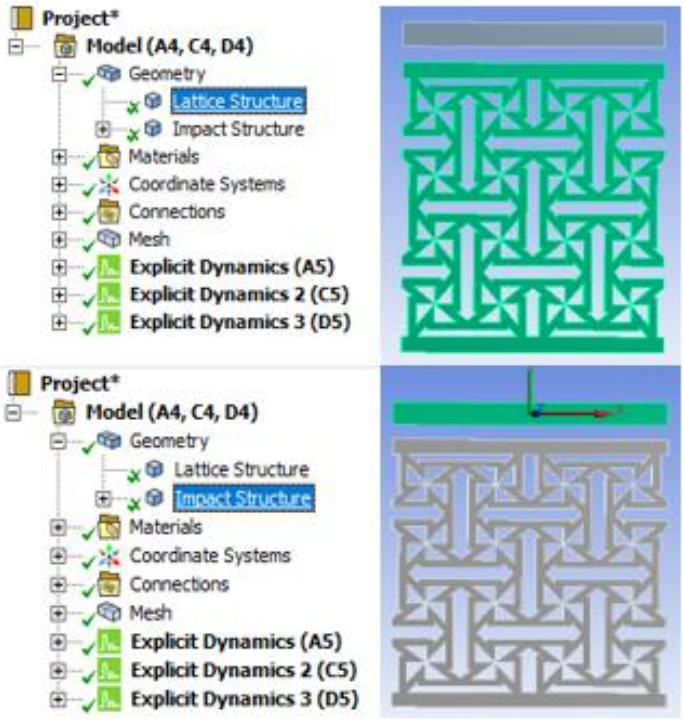


Figure 3.17 Impact analysis geometry definitions

Below is the analysis structure in the explicit module for one analysis. In the setup given in Figure 3.18, the impact of the Impact structure against the part at a speed of 3000 mm/s from a height of 10 mm and fixed support are shown.

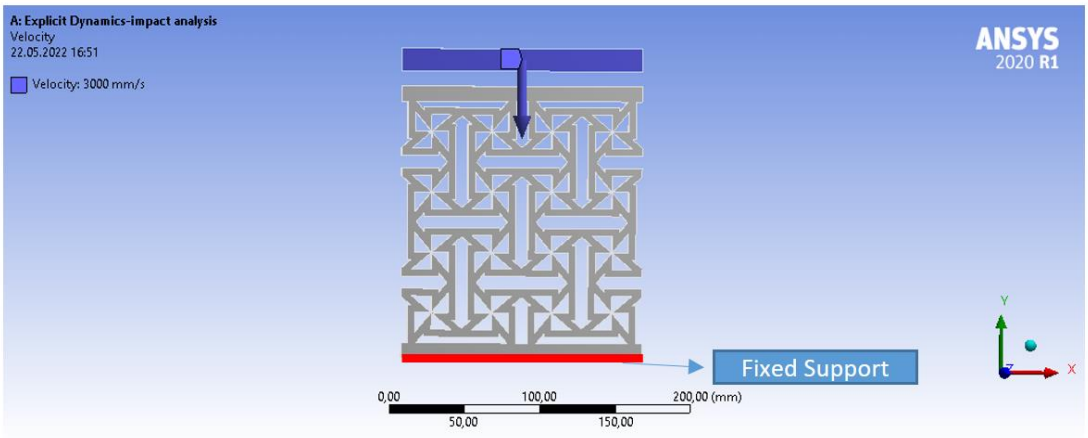


Figure 3.18 Impact analysis setup

The analysis setup is completed by adding the equivalent stress and deformation values to the results section. Equivalent stress and deformation value for the reference analysis setup are shown in Figure 3.19.

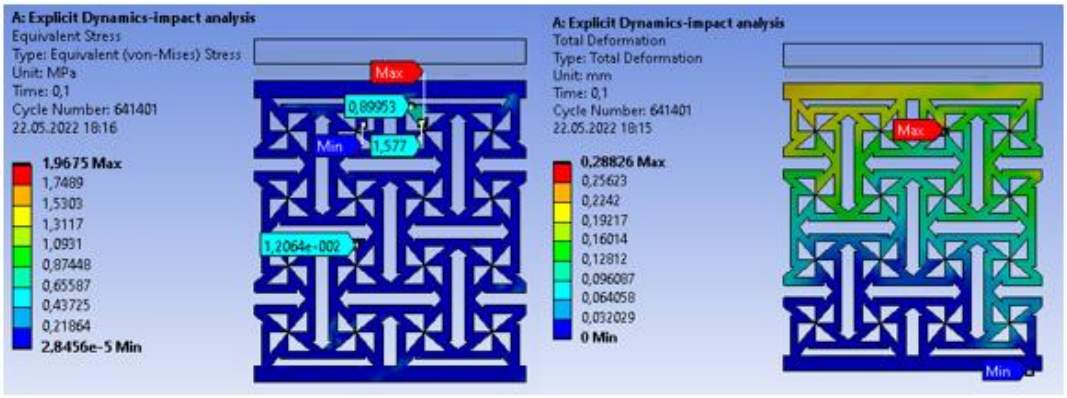


Figure 3.19 Equivalent stress and deformation reference analysis setup

CHAPTER 4

RESULTS

4.1 New Designed Structure Study Results

In this study, the newly designed lattice structure of Poisson's ratio was examined by using finite element analysis. 14 different lattice structures concerning inner lattice thickness configurations are investigated. During finite element analysis, examined structures were subjected to tensile with the same load in all structures. Total deformation and equivalent stress values and behaviors of the structure were examined. Directional deformations in two axes were taken and investigated. Lateral strain and longitudinal strain are calculated given equations (3.1) and (3.2). Poisson's ratio also calculated equation (3.3). A "static structural" system was used in all analyzes. In order to calculate Poisson's Ratio, directional deformation in two axes was taken into account.

4.1.1 Tensile Analysis Results

4.1.1.1 Total Deformation

New designed lattice structure Poisson's Ratio and geometry orientations were examined in this section. Lots of lattice structures will be possessed different basic measurements. This basic value is the original inner lattice structure thickness. Inner lattice structure thickness is 2.39 mm given in Figure 4.1.

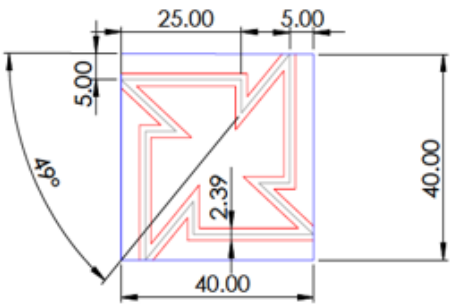


Figure 4.1 Inner lattice structure thickness

All settings and parameters are the same as narratives up to this point unless otherwise stated.

In this section, the basic lattice structure and default structure shown in Figure 4.2 is examined. Figure 4.2 shows that the inner lattice structure thickness is 2.39 mm.

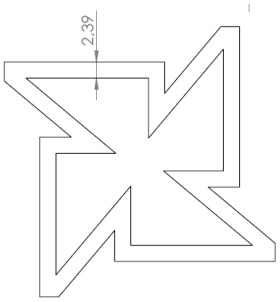


Figure 4.2 Inner lattice structure thickness is 2.39 mm

Total deformation was calculated by using ANSYS. Maximum deformation detected region of force. The maximum deformation is 0.201 mm. The total deformation region and values are given in Figure 4.3.

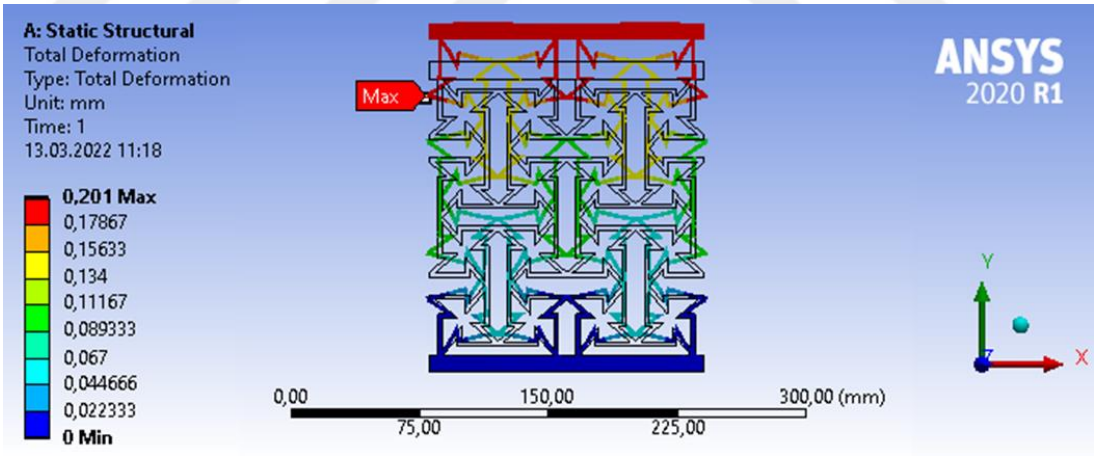


Figure 4.3 Total deformation of the original lattice structure

Following the figure selected by default, 13 other samples were also examined using the same solutions. The results are shown in Table 4.1.

Table 4.1 Total deformation of examined novel structure

Lattice structure matrix type	Specimen number	Inner lattice structure thickness (mm)	Poisson's ratio	Max deformation (mm)
4 × 2	**14**	**4.900**	**-0.55304**	**0.037**
4 × 2	13	4.390	-0.53298	0.084
4 × 2	12	3.890	-0.51094	0.055
4 × 2	11	3.390	-0.46084	0.133
4 × 2	10	2.890	-0.43704	0.225
4 × 2	9	2.390	-0.40148	0.420
4 × 2	8	1.890	-0.37901	0.924
4 × 4	7	4.900	-0.34069	0.017
4 × 4	6	4.390	-0.31187	0.025
4 × 4	5	3.890	-0.29123	0.039
4 × 4	4	3.390	-0.27025	0.061
4 × 4	3	2.890	-0.25016	0.101
4 × 4	2	2.390	-0.21224	0.201
4 × 4	1	1.890	-0.19572	0.404

The maximum total deformation region on the examined structure is given in Figure 4.4. Maximum deformation occurs on the end side of the structure because of the pressure surface.

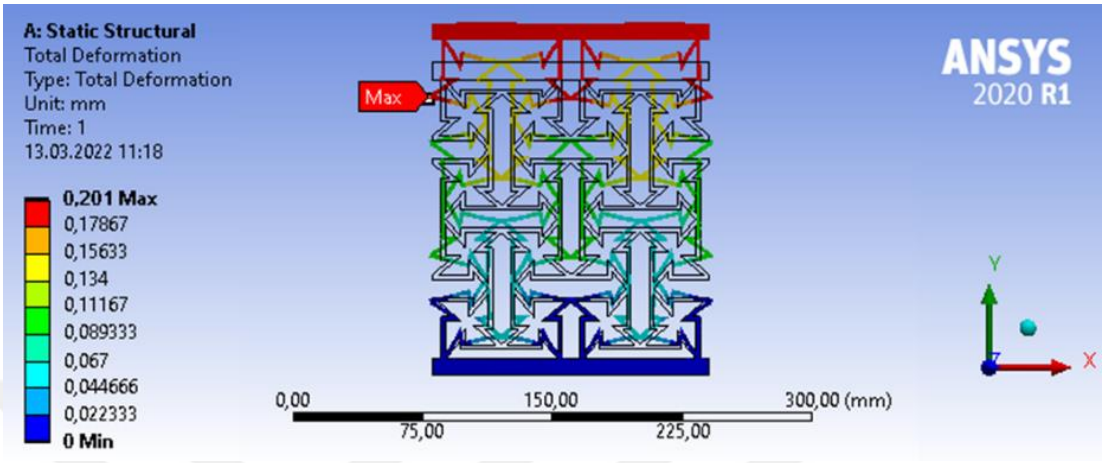


Figure 4.4 Maximum total deformation regions on the examined structure

Maximum total deformations were investigated with respect to inner lattice thickness in Figure 4.5. When inner lattice thickness is lowest maximum deformation occurs.1.89 mm inner lattice thickness specimen has maximum deformation.

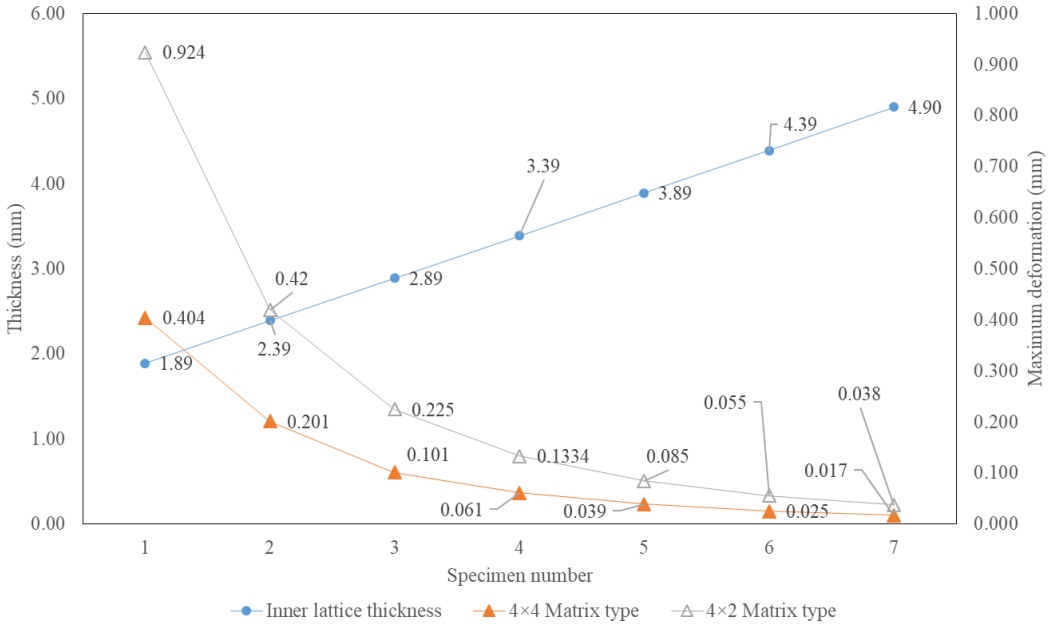


Figure 4.5 Variation of maximum total deformations with inner lattice thickness in **4 × 4** and **4 × 2** matrix types

4.1.1.2 Equivalent Stress

Maximum equivalent stress was calculated by using ANSYS for the original lattice structure. Maximum equivalent stress (based on von Mises) is 68.935 MPa. This value is smaller than Tensile ultimate strength. Equivalent stress of original lattice structure values and regions is given in Figure 4.6.

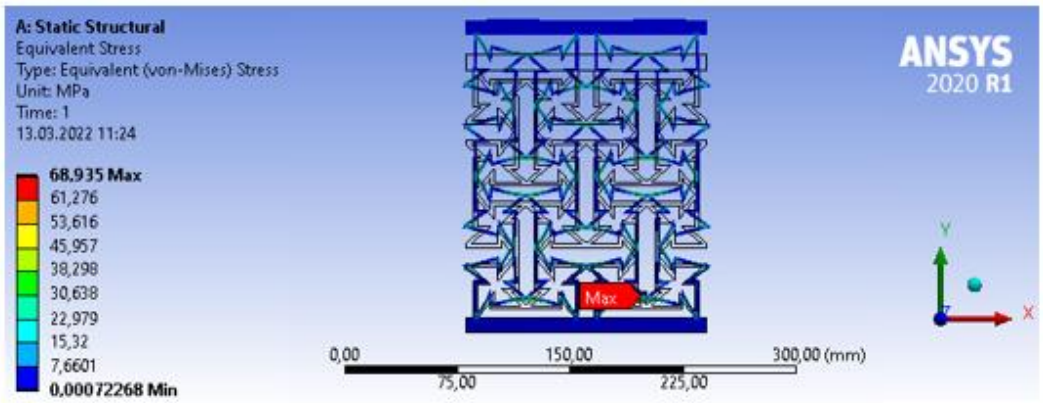


Figure 4.6 Equivalent stress of first lattice structure

Following the figure selected by default, 13 other samples were also examined using the same solutions. The results are shown in Table 4.2.

Maximum equivalent regions on examined structure were given in Figure 4.7. Maximum equivalent stress occurs bottom of the structure because of the geometrical orientation and forces subjected to direction.

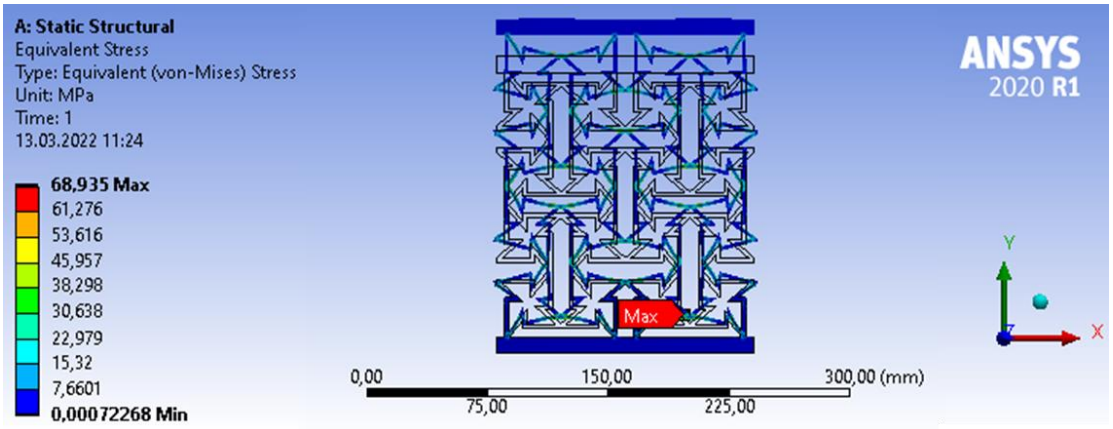


Figure 4.7 Maximum equivalent stress regions on the examined structure

Maximum equivalent stresses were investigated with respect to inner lattice thickness in Figure 4.8. When inner lattice thickness is the lowest maximum equivalent stress occurs.1.89 mm inner lattice thickness specimen has maximum equivalent stress. The test on all examined structures was completed in the elastic region.

Table 4.2 Equivalent stress of examined novel structure

Lattice structure matrix type	Specimen number	Inner lattice structure thickness (mm)	Poisson's ratio	Equivalent stress (MPa)
4 × 2	**14**	**4.900**	**-0.55304**	**24.138**
4 × 2	13	4.390	-0.53298	38.342
4 × 2	12	3.890	-0.51094	30.874
4 × 2	11	3.390	-0.46084	56.847
4 × 2	10	2.890	-0.43704	77.455
4 × 2	9	2.390	-0.40148	123.45
4 × 2	8	1.890	-0.37901	216.340
4 × 4	7	4.900	-0.34069	12.304
4 × 4	6	4.390	-0.31187	17.948
4 × 4	5	3.890	-0.29123	19.994
4 × 4	4	3.390	-0.27025	24.580
4 × 4	3	2.890	-0.25016	35.110
4 × 4	2	2.390	-0.21224	68.935
4 × 4	1	1.890	-0.19572	96.613

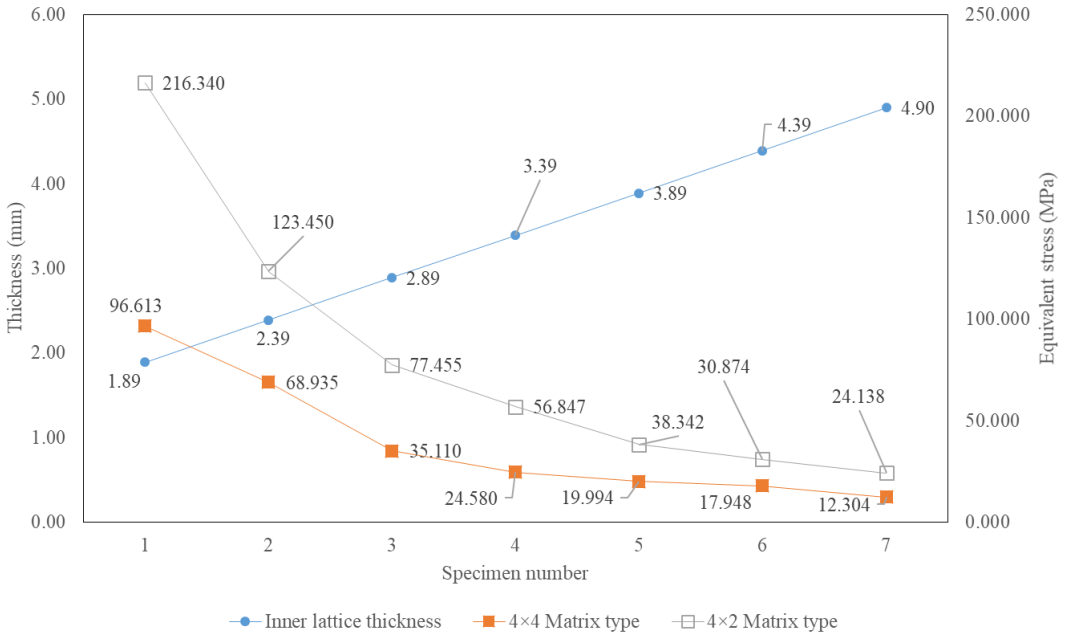


Figure 4.8 Variation of maximum equivalent stress with inner lattice thickness in **4 × 4** and **4 × 2** matrix types

4.1.1.3 Poisson's Ratio

While calculating the Poisson's Ratio of the first lattice structure, the directional deformation tool in the software was used. With this tool, the deformation values of the X and Y axis will be compared. Figure 4.9 shows the value of deformation on the X-axis (Lateral deformation).

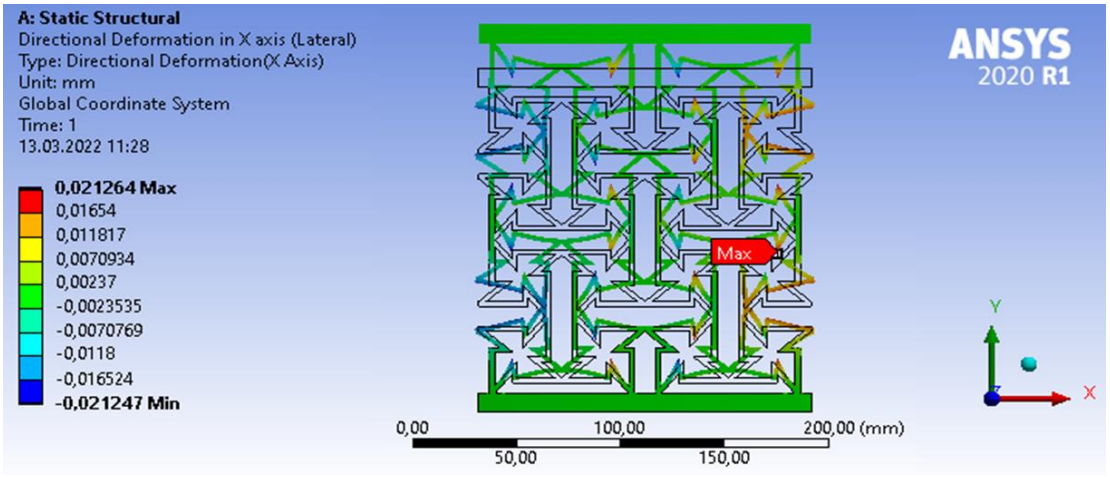


Figure 4.9 Lateral directional deformation of the first lattice structure

Figure 4.10 shows the value of deformation on the Y-axis (Longitudinal deformation).

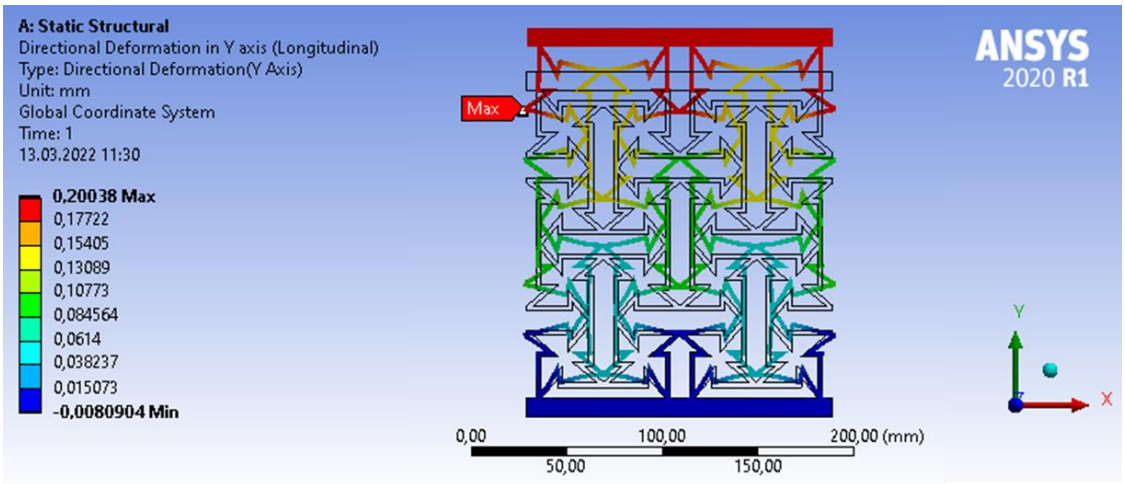


Figure 4.10 Longitudinal directional deformation of the first lattice structure

A "static structural" system was used in all analyzes. In order to calculate Poisson's Ratio, directional deformation in two axes was taken into account. Poisson's ratio of this first structure was calculated using the directional deformation tool. X-Axis, deformation tool value is 0.021264, Y-Axis, deformation probe tool value is 0.20038. Poisson's ratio is calculated given the formula below;

$$\varepsilon_{lateral}=\frac{\Delta L_X}{L_{OX}}=\frac{L_{fX}-L_{0X}}{L_{0X}}=\frac{0.04253\ mm}{160\ mm}=0.00027$$

$$\varepsilon_{longitudinal}=\frac{\Delta L_Y}{L_{OY}}=\frac{L_{fY}-L_{0Y}}{L_{0Y}}=\frac{0.20038\ mm}{160\ mm}=0.00125$$

$$\nu=-\frac{\varepsilon_{lateral}}{\varepsilon_{longitudinal}}\rightarrow-\frac{0.00027\frac{mm}{mm}}{0.00125\frac{mm}{mm}}=-0.21224$$

First Lattice Structure Poison's Ratio calculated as -0.21224. In other structures, Poisson's ratio was calculated in the same way. Poisson's ratio of other structures were given in Table 4.3.

Table 4.3 Poisson's ratio of examined novel structure

Lattice structure matrix type	Specimen number	Inner lattice structure thickness (mm)	Strain-X lateral	Strain-Y longitudinal	Poisson's ratio
4 × 2	**14**	**4.900**	**0.00013**	**0.00023**	**-0.55304**
4 × 2	13	4.390	0.00028	0.00053	-0.53298
4 × 2	12	3.890	0.00018	0.00034	-0.51094
4 × 2	11	3.390	0.00038	0.00083	-0.46084
4 × 2	10	2.890	0.00061	0.00140	-0.43704
4 × 2	9	2.390	0.00105	0.00262	-0.40148
4 × 2	8	1.890	0.00218	0.00576	-0.37901
4 × 4	7	4.900	0.00004	0.00011	-0.34069
4 × 4	6	4.390	0.00005	0.00016	-0.31187
4 × 4	5	3.890	0.00007	0.00024	-0.29123
4 × 4	4	3.390	0.00010	0.00038	-0.27025
4 × 4	3	2.890	0.00016	0.00063	-0.25016
4 × 4	2	2.390	0.00027	0.00125	-0.21224
4 × 4	1	1.890	0.00049	0.00252	-0.19572

In this section, the information obtained from the analysis will be compared. 7 different lattice structures were examined and analyzed. One parameter (Inner lattice structure thickness) only changed in seven lattice structures. Poisson's ratio values were performed by examining the effects of inner lattice structure thickness. The pressure acting on the analysis model in all structures, and free body diagrams, completely is the same. Relations between inner lattice thickness and Poisson's ratio were given in Figure 4.11 shows the effects of inner lattice thickness on lattice Poisson's ratio. The effect of the inner lattice thickness on the Poisson's ratio was observed. So, if inner lattice thickness increased, Poisson's values decreased in these examined lattice structures. In this figure understand that 4 × 2 lattice orientation has the lowest Poisson's Ratio than 4 × 4 Lattice structure Poisson's Ratio, 4 × 2 is more auxetic.

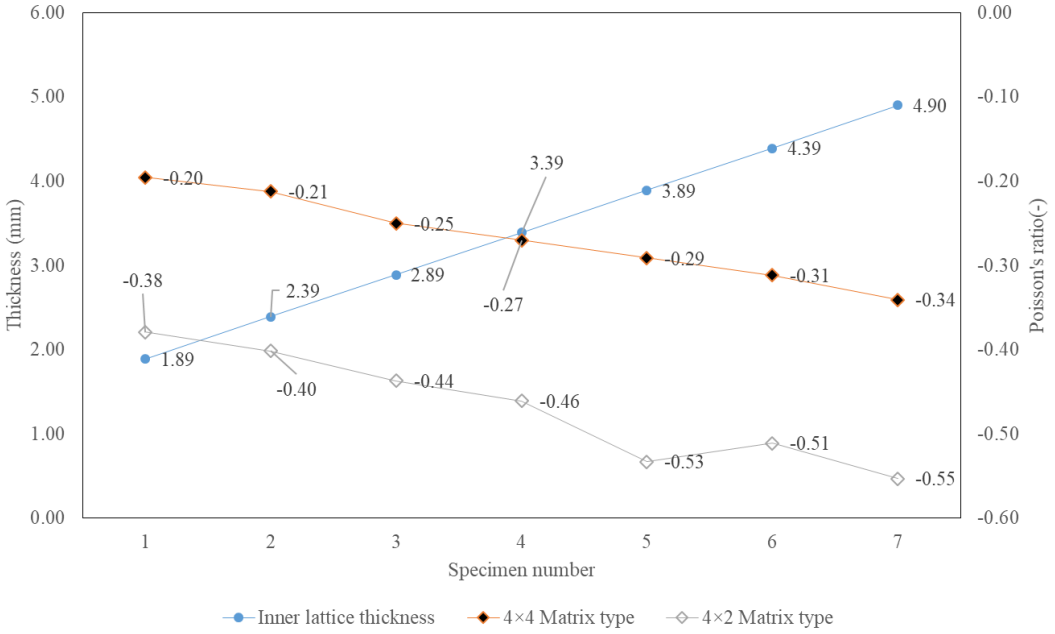


Figure 4.11 Variation of Poisson's ratio with inner lattice thickness in **4 × 4** and **4 × 2** matrix types

4.1.1.4 Stiffness

The stiffness and stiffness/mass ratio values of the structures were calculated using equations (3.4) and (3.5) and given in Table 4.4 and relations between inner lattice thickness in this study are shown in Figure 4.12 and Figure 4.13.

Table 4.4 Stiffness and stiffness/mass of the examined novel structure

Lattice structure matrix type	Specimen number	Inner lattice structure thickness (mm)	Poisson's ratio	Mass (kg)	Stiffness (N/mm)	Stiffness /mass (N/mm.kg)
4 × 2	**14**	**4.900**	**-0.55304**	**0.258**	**643.680000**	**2494.883721**
4 × 2	13	4.390	-0.53298	0.218	451.901091	2072.940786
4 × 2	12	3.890	-0.51094	0.238	557.292419	2341.564785
4 × 2	11	3.390	-0.46084	0.198	426.011691	2151.574195
4 × 2	10	2.890	-0.43704	0.177	344.658034	1947.220532
4 × 2	9	2.390	-0.40148	0.156	264.933273	1698.290212
4 × 2	8	1.890	-0.37901	0.134	234.225456	1747.951163
4 × 4	7	4.900	-0.34069	0.516	712.862109	1381.515715
4 × 4	6	4.390	-0.31187	0.476	705.974905	1483.140556
4 × 4	5	3.890	-0.29123	0.436	517.617211	1187.195438
4 × 4	4	3.390	-0.27025	0.396	405.042432	1022.834425
4 × 4	3	2.890	-0.25016	0.354	347.554940	981.7936147
4 × 4	2	2.390	-0.21224	0.312	277.592816	889.7205649
4 × 4	1	1.890	-0.19572	0.270	239.164769	885.79544

Figure 4.12 shows the relations between inner lattice thickness and stiffness in 4×4 and 4×2 matrix types on novel auxetic structures. When inner lattice thickness increases stiffness values are increased, because that structure is more resistant to subjected forces.

In Figure 4.13 showing the thickness and stiffness/mass relations in 4 × 4 and 4 × 2 matrix types of the examined structures, it is seen that the stiffness/mass of the structure increases when the geometry inner thickness of the structure is increased.

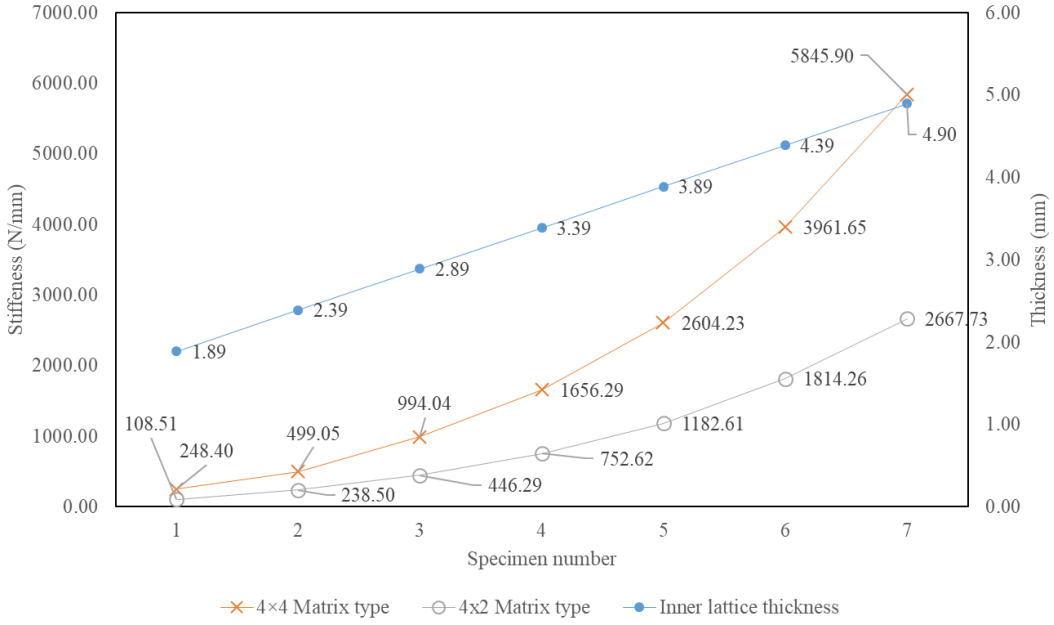


Figure 4.12 Variation of stiffness with inner lattice thickness in **4 × 4** and **4 × 2** matrix types

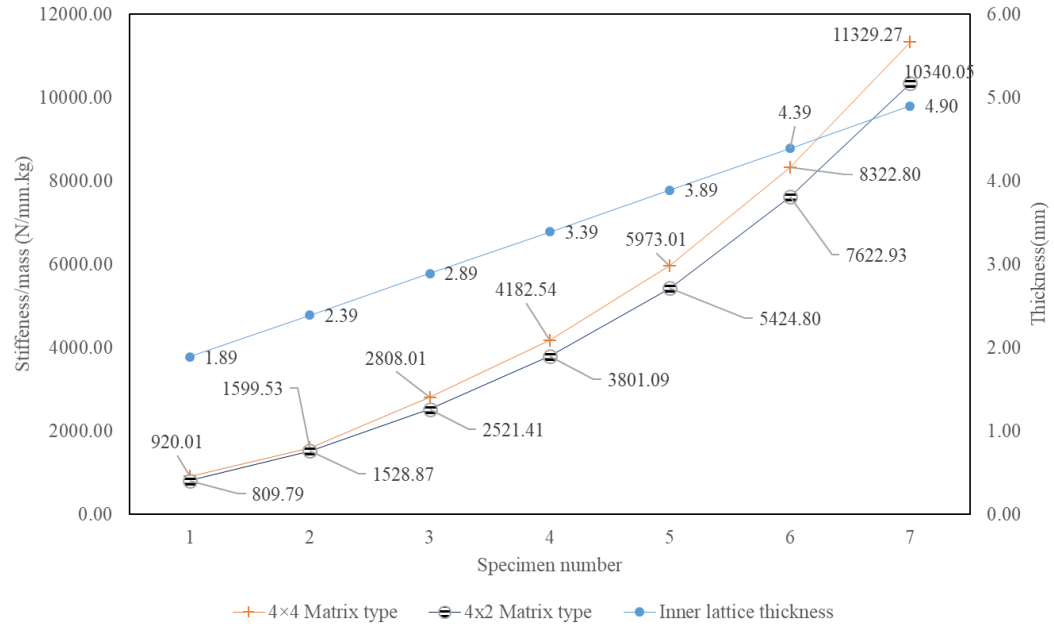


Figure 4.13 Variation of stiffness/mass ratio with inner lattice thickness in **4 × 4** and **4 × 2** matrix types

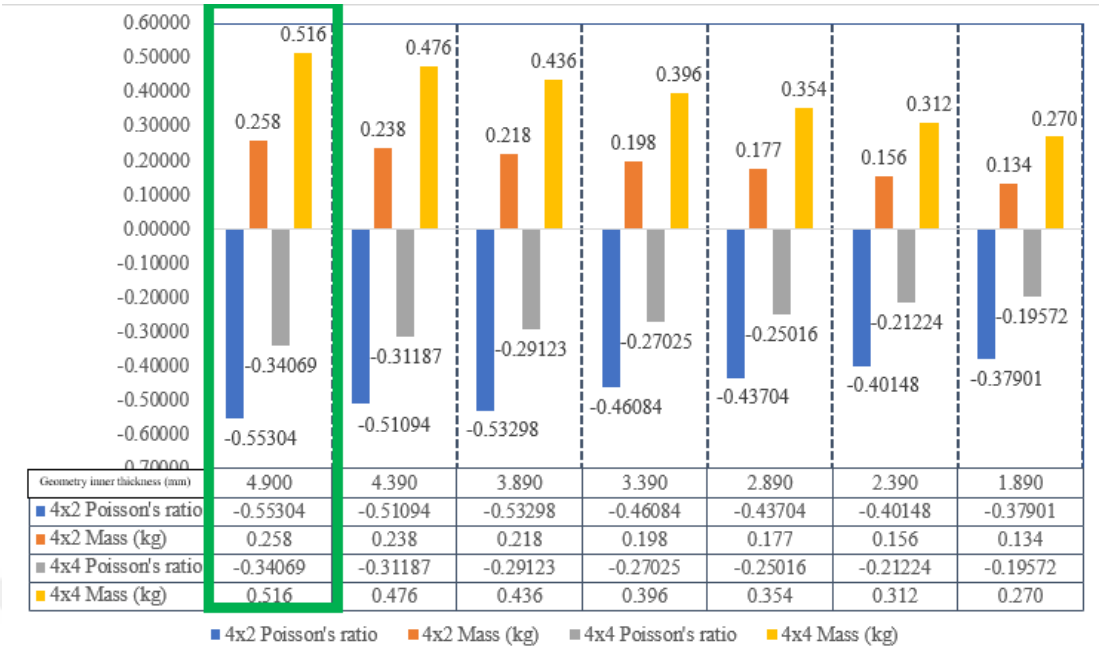
The masses of the solid-state of all the structures examined and the masses of the newly designed auxetic lattice structures are given in Table 4.5. When the masses are

compared, it is seen that the newly designed structures have 42% to 70% less mass. Since the weight of the auxetic structure is less than that of the filled structures, its usability in applications requiring lightness and strength has been observed.

Table 4.5 Mass of auxetic structure and full structure of the examined novel structure

Matrix type	Specimen number	Inner lattice structure thickness (mm)	Poisson's ratio	Mass (kg)	Full structure mass (kg)	Difference between full and auxetic structure mass (kg)	%
4 × 2	**14**	**4.900**	**-0.55304**	**0.258**	**0.449**	**0.191**	**42.54%**
4 × 2	13	4.390	-0.53298	0.218	0.449	0.231	51.45%
4 × 2	12	3.890	-0.51094	0.238	0.449	0.211	46.99%
4 × 2	11	3.390	-0.46084	0.198	0.449	0.251	55.90%
4 × 2	10	2.890	-0.43704	0.177	0.449	0.272	60.58%
4 × 2	9	2.390	-0.40148	0.156	0.449	0.293	65.26%
4 × 2	8	1.890	-0.37901	0.134	0.449	0.315	70.16%
4 × 4	7	4.900	-0.34069	0.516	0.898	0.382	42.54%
4 × 4	6	4.390	-0.31187	0.476	0.898	0.422	46.99%
4 × 4	5	3.890	-0.29123	0.436	0.898	0.462	51.45%
4 × 4	4	3.390	-0.27025	0.396	0.898	0.502	55.90%
4 × 4	3	2.890	-0.25016	0.354	0.898	0.544	60.58%
4 × 4	2	2.390	-0.21224	0.312	0.898	0.586	65.26%
4 × 4	1	1.890	-0.19572	0.270	0.898	0.628	69.93%

Below in Figure 4.14 is Poisson's ratio graph of the examined inner lattice thickness, mass, and matrix structures.



Geometry inner thickness (mm)	4.900	4.390	3.890	3.390	2.890	2.390	1.890
4x2 Poisson's ratio	-0.55304	-0.51094	-0.53298	-0.46084	-0.43704	-0.40148	-0.37901
4x2 Mass (kg)	0.258	0.238	0.218	0.198	0.177	0.156	0.134
4x4 Poisson's ratio	-0.34069	-0.31187	-0.29123	-0.27025	-0.25016	-0.21224	-0.19572
4x4 Mass (kg)	0.516	0.476	0.436	0.396	0.354	0.312	0.270

Figure 4.14 Variation of Poisson's ratio, mass, and geometry inner thickness in **4 × 4** and **4 × 2** matrix types

4.1.2 Energy Absorbing (Tensile Impact Test) Analysis Results

The impact test is a mechanical test for many structures. The purpose of this is to determine the ability of the structure to absorb the effect in the event of an impact. It is mostly used to show toughness behavior, and resistance to impact. Impact analysis of the newly created auxetic structure in this study was performed with the impact test by using the explicit dynamics mode of ANSYS and the results are given below. The effect of the object hitting the main structure at certain speeds over 10 mm of the main structure was investigated.

While performing an impact analysis, the 4 × 4 matrix structure that has the lowest Poisson's ratio on the piece from three different velocities, 3000 mm/s, 4000 mm/s, and 5000 mm/s. The total deformation and total equivalent stresses were examined how this impact affects the structure formed. All parameters and values were given in Table A.1, appendices.

As shown in Figures 4.15 and 4.16, the deformation and stress graphs of the effect of three different impact velocities on the structure are given. When these graphs are

examined, the deformation and the stress on the main structure increase as the attachment speed increases.

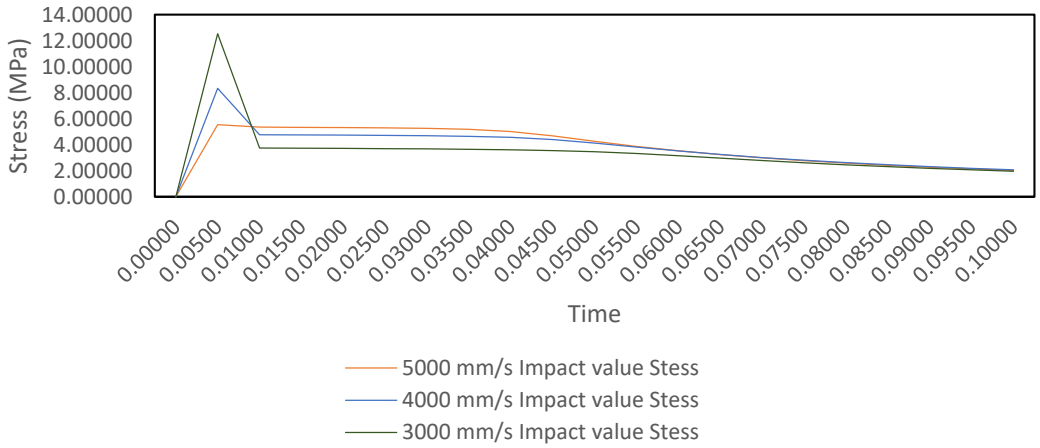


Figure 4.15 Variation of stress with time during impact analysis in lowest Poisson's ratio

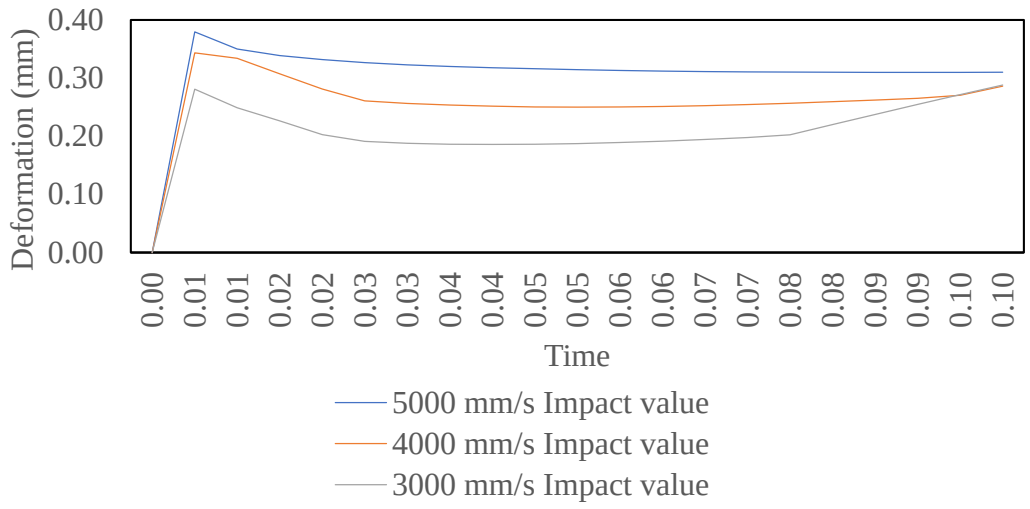


Figure 4.16 Variation of deformation with time during impact analysis in lowest Poisson's ratio

With this analysis, the energy absorption of the newly designed auxetic structure with the lowest negative Poisson's ratio was evaluated.

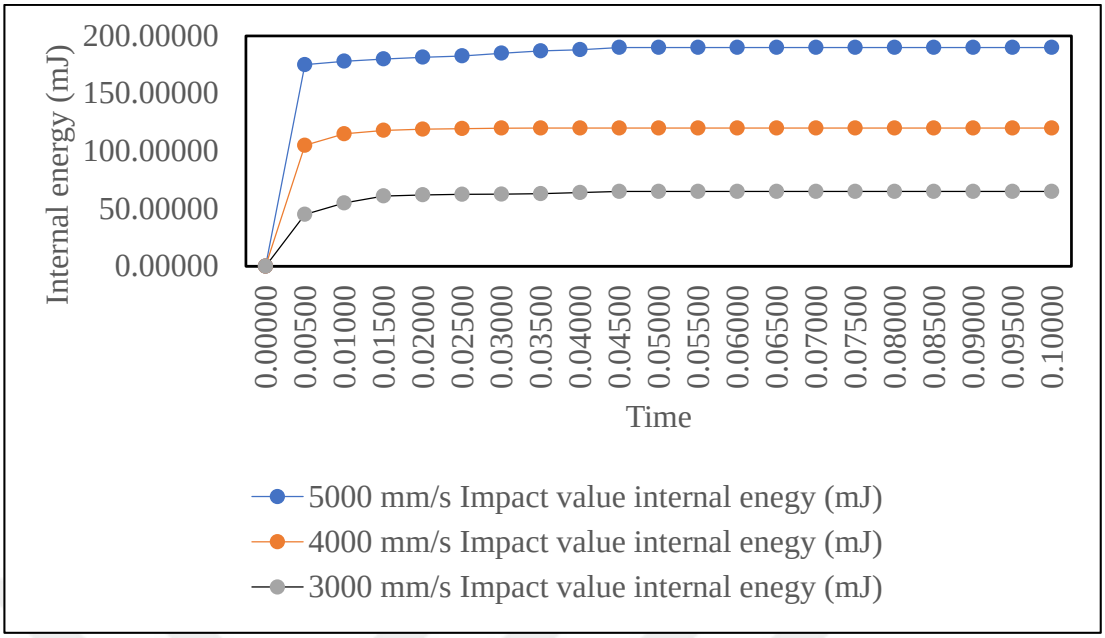


Figure 4.17 Variation of internal energy with time during impact analysis in lowest Poisson's ratio

When Figure 4.17 is examined, the increase in the rate of impact on the main structure shows the energy absorption of the newly designed auxetic structure against the impact.

4.2 Comparison with Auxetic Structures Found in the Literature

There are studies on different auxetic structures in the literature. In this section, the newly designed auxetic structure in this study is compared with the structures found in other literature Some unit cell and auxetic structure pictures in the literature are shown in Figure 4.18. In the literature, many researchers have examined 2D and 3D structures and investigated the effect of geometry on the negative Poison's ratio. While some researchers have created new geometry, some have designed new shapes by developing the shapes in the literature.

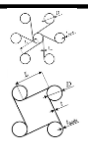
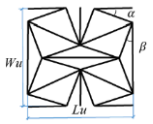
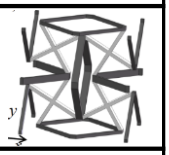
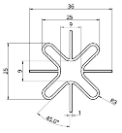
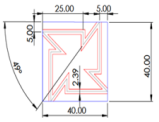
Reference	Unit geometry	Reference	Unit geometry
[10]		[20]	
[15]		[27]	
[31]		This Study	

Figure 4.18 Comparison of auxetic unit geometry of this study and other studies

Figure 4.19 shows the comparison of the Poisson's ratios of the auxetic structures in the literature with the auxetic structures examined in this study. It is seen in Figure 4.19 that the newly designed geometry in this study provides a better Negative Poisson's ratio feature than the geometries in the literature. in terms of Poisson's ratio.

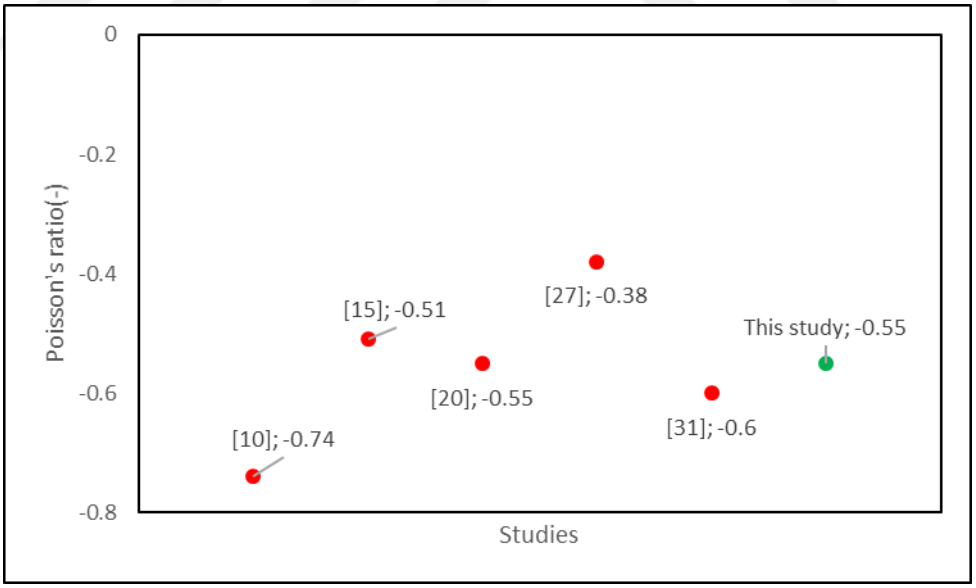


Figure 4.19 Comparison of Poisson's ratio of this study and other studies

CHAPTER 5

DISCUSSION AND CONCLUSION

Poisson's ratio, one of the important mechanical properties of materials, is positive for almost all of the well-known materials Material showing negative Poisson's ratios are called auxetics. Properties of the auxetics structures are very important to examining new structure materials. Especially, the mechanical properties of the auxetic materials that have structurally and functionally mission. Auxetic materials have good damping cases and absorption for the usage of life. Enhanced indentation resistance, high shear stiffness, high fracture toughness, and bending. Foams, cells, and sandwich panels are a sample of the auxetics materials. Auxetic materials can be made synthetically to provide high properties to humanity using laser cutting machines, open-cell foams, and 3D printing. Many researchers made experimental and theoretical work. Auxetic materials are used in aerospace, military, automotive, biomedical, structure, sensor, and textile areas. For example, In aerospace, aircraft parts, panels. In automotive, energy absorption devices, fasteners. In biomedical, stents, implants, prostheses, bandages, scaffolds, and artificial skin.

In this study, the newly designed lattice structure of Poisson's ratio was examined by using finite element analysis. 14 different lattice structures with respect to inner lattice thickness configurations are investigated.

Firstly, materials and properties of materials were investigated. The aim of the study and related literature work was done. Lots of researchers and students made an experimental and numerical studies about the newly designed auxetic structure and its mechanical properties.

Secondly, Basics of auxetic structure and general information were given. Classification of auxetic structure, properties of auxetic structures, fabrication of auxetic structure, types of design structures, application of auxetic structure, and advantages and disadvantages of auxetic structures respectively.

In the third chapter, analysis of newly designed auxetic structure geometry, Poisson's ratio, and finite element analysis.

During finite element analysis, examined structures were subjected to tensile with the same load in all structures. Total deformation and equivalent stress values and behaviors of the structure were examined. Directional deformations in two axes were taken and investigated. Lateral strain and longitudinal strain were calculated given engineering relations. Poisson's ratio is also calculated in engineering equations. The relationship between the stiffness value and the geometry inner thickness on a novel designed auxetic structure was examined.

In order to examine the energy absorption capabilities, a particle was thrown on the selected part with three different velocities. Deformations, equivalent stress, and internal energy were examined.

To sum up, Poisson's ratio of different auxetic structures with respect to inner lattice thickness was provided in the same condition. The results of the conducted study are given below;

- All examined structures (newly designed auxetic structures) have a negative Poisson's ratio.
- Inner lattice thickness increased, and Poisson's ratio values decreased in these examined lattice structures.
- 4×2 lattice orientation has the lowest Poisson's Ratio than 4x4 lattice structure Poisson's Ratio, 4×2 is more auxetic.
- 4.9 mm inner lattice thickness and 4×2 lattice matrix examined example has lowest Poisson's ratio that is -0.55.
- Maximum deformation and maximum equivalent stress were observed on the lowest inner lattice thickness of 4×4 and 4×2 lattice matrix.
- Stiffness and stiffness/ mass values were attached to see the effects of inner lattice thickness.
- A 4×4 matrix structures have high stiffness than the 4×2 matrix structures.
- Energy absorption properties of the novel auxetic structure were observed with respect to time.

- Lattice structures are lighter than other full structures. They are suitable for lightweight applications.
- In this study, the auxetic behavior of a unit cell was examined and its situations in 4×4 and 4×2 matrix structures were evaluated. The results obtained are the data of these two matrix structures. Other matrix structures and settlements in other directions should be analyzed and examined in the application and study area.

In future work, newly designed auxetic structures can be examined in different application areas. Although auxetic structures were created and used in the past, their use today stands out in terms of meeting our needs. In this context, there are many areas of use for the coming years. At the forefront of these are design and modeling, together with large sectors such as the health, defense industry, and automotive. The figure revealed in this study was created from the art of Islamic ornamentation and is a source of inspiration for many subjects in the literature and application field. In future studies, the mechanical properties of the samples made with two different additive manufacturing methods can be examined within the experimental analysis of the same shape. In the same way, new auxetic structures can be created by using Islamic palace motifs and new structures can be brought to the literature and application area. Traditionally designed systems can be changed with improved new lattice structures.

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APPENDICES

Appendix A: Impact Analysis parameters and results.

Appendix A: Impact Analysis Parameters and Results

Table A.1 Impact Analysis Parameters and Results.

Impact Analysis Parameter, Time (s)	5000 mm/s Impact Value	4000 mm/s Impact Value	3000 mm/s Impact Value	5000 mm/s Impact Value	4000 mm/s Impact Value	3000 mm/s Impact Value	5000 mm/s Impact Value	4000 mm/s Impact Value	3000 mm/s Impact Value
	Deformation Values, mm			Stress Values, MPa			Internal Energy, mJ		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.005	0.379	0.343	0.281	5.55	8.33	12.53	175.00	105.00	45.00
0.01	0.350	0.334	0.249	5.35	4.77	3.75	178.00	115.00	55.00
0.015	0.338	0.307	0.226	5.34	4.76	3.74	180.00	118.00	61.00
0.02	0.331	0.281	0.202	5.32	4.74	3.72	181.50	119.00	62.00
0.025	0.326	0.260	0.191	5.29	4.72	3.70	182.60	119.50	62.50
0.03	0.322	0.256	0.187	5.26	4.69	3.68	185.00	119.90	62.60
0.035	0.320	0.253	0.186	5.18	4.65	3.65	187.00	120.00	63.00
0.04	0.318	0.251	0.185	5.01	4.57	3.61	188.00	120.00	64.00
0.045	0.316	0.250	0.186	4.68	4.40	3.55	190.00	120.00	65.00
0.05	0.314	0.250	0.187	4.27	4.13	3.46	190.00	120.00	65.00
0.055	0.313	0.250	0.189	3.87	3.82	3.33	190.00	120.00	65.00
0.06	0.312	0.251	0.191	3.54	3.52	3.16	190.00	120.00	65.00
0.065	0.311	0.252	0.194	3.24	3.25	2.97	190.00	120.00	65.00
0.07	0.310	0.254	0.197	2.99	3.01	2.79	190.00	120.00	65.00
0.075	0.310	0.256	0.202	2.78	2.81	2.62	190.00	120.00	65.00
0.08	0.310	0.259	0.220	2.59	2.63	2,46	190.00	120.00	65.00
0.085	0.310	0.262	0.237	2.42	2.46	2.32	190.00	120.00	65.00
0.09	0.310	0.265	0.254	2.28	2.32	2.18	190.00	120.00	65.00
0.095	0.310	0.270	0.271	2.15	2.19	2.07	190.00	120.00	65.00
0.1	0.310	0.286	0.288	2.03	2.07	1.97	190.00	120.00	65.00

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I. Erdoğan, İ. & Toktaş, İ., "Investigation of The Effect of Geometry Inner Thickness on New Designed Auxetic Structure" 7th International Congress on Engineering and Technology Management, İstanbul. E-ISBN: 978-625-7367-49-3, 588-594, 2022.

II. Erdoğan, İ. & Toktaş, İ., "Investigation of The Effect of Geometry Inner Thickness on New Designed Auxetic Structure" Journal of Polytechnic, Early view, 2022.