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Investigation of the effect of geometry ınner thickness on new designed auxetic structure

Geometri iç kalınlığının yeni tasarlanan ökzetik yapı üzerine etkisinin araştırılması

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Investigation of The Effect of Geometry Inner Thickness on New Designed Auxetic Structure

Highlights

- *All examined structures (new designed Auxetic structures) have negative Poisson's ratio.*
- *Inner lattice thickness increased, Poisson's values decreased in these examined lattice structures.*
- *4x2 lattice orientation has the lowest Poisson's Ratio than 4x4 Lattice structure Poisson's Ratio.*

Graphical Abstract

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

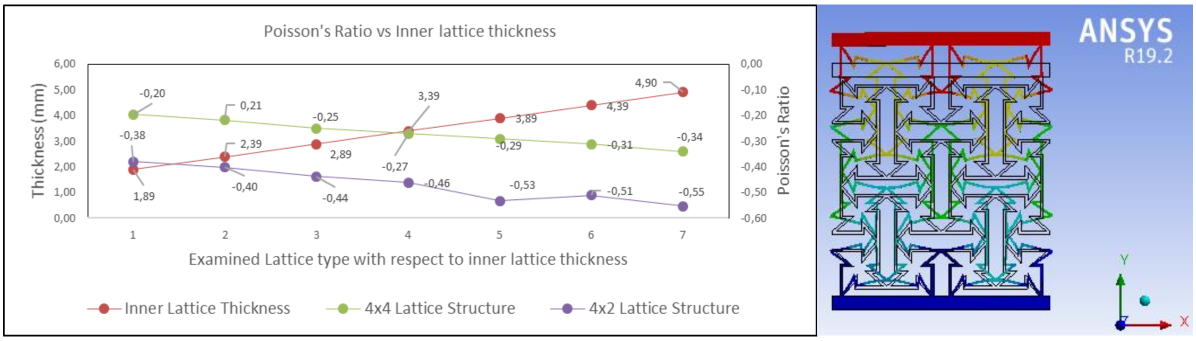

Figure. The result chart and new designed Auxetic structure

Aim

This study aims to design and analyze new Auxetic structure for literature and application area.

Design & Methodology

CAD Modeling and Finite element analysis were used and different new designed structure examined.

Originality

In this study, a newly designed Auxetic structure that is not in the literature was examined and brought into the literature.

Findings

The newly designed Auxetic structure was found to have a lower negative Poisson's ratio than similar shapes in the literature. 4,9 mm inner lattice thickness and 4x2 lattice matrix examined example has lowest Poisson ratio that is -0,55.

Conclusion

Lattice structures are lighter than other full structures. They are suitable for lightweight applications. The newly designed Auxetic geometry can be used with different structure orientations to investigate new structures. Maximum deformation and maximum equivalent stress were observed on the lowest inner lattice thickness of the 4x4 and 4x2 lattice matrix. In future work, new designed Auxetic structures can be examined in different application areas. Traditional designed systems can be changed with improved new lattice structures.

Declaration of Ethical Standards

The author(s) of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Geometri İç Kalınlığının Yeni Tasarlanan Ökzetik Yapı Üzerine Etkisinin Araştırılması

Araştırma Makalesi / Research Article

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ÖZ

Poisson oranı, malzemelerin ve yapının önemli mekanik özelliğidir. 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 4x4’lik düzendeki kafes yapısı ile 4x2’lik düzendeki kafes yapısının Poisson’s oranına bakıldığına en düşük Poisson’s oranı 4x2 ‘lik düzendeki kafes yapısına aittir. 4x2’lik düzendeki kafes yapısı daha Ökzetiktir. 4.9 mm geometri iç kalınlığı ve 4x2’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: Negatif poisson’s oranı, kafes yapı, yeni yapı.

Investigation of The Effect of Geometry Inner Thickness on New Designed Auxetic Structure

ABSTRACT

Poisson’s ratio is important mechanical property of materials and structure. Material and Structure showing negative Poisson’s ratios are called Auxetic. Properties of the Auxetic structures are very important to design the new structure, especially mechanical properties of the Auxetic materials that have structurally and functionally mission. Many researchers made experimental and theoretical works apropos this matter. In this study, the newly designed Auxetic lattice structure Poisson’s ratio was checked over via exploiting finite element analysis. 14 different lattice structures with respect to inner lattice thickness configurations are investigated. All examined structures have a negative Poisson’s ratio. Inner lattice thickness is increased; negative Poisson’s ratio values are decreased (closes to -1.) in these examined lattice structures. 4x2 lattice orientation has lowest Poisson’s ratio than 4x4 Lattice structure Poisson’s ratio, 4x2 is more Auxetic. 4.9 mm inner lattice thickness and 4x2 lattice matrix examined example has lowest Poisson’s ratio that is -0,55. Beneficial to indicate the purview of the structure on the applied force, the stiffness values and the stiffness/mass values were examined. Their energy dissipation capabilities were analyzed.

Keywords: Negative poisson’s ratio, lattice structure, novel structure.

1. INTRODUCTION

Poisson’s ratio, important mechanical property of materials and structure. Structures showing negative Poisson’s ratios are called auxetic. Properties of the auxetic structures are very important to examine new structure materials. Especially, the mechanically skillful peculiarities 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 Auxetic materials. 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 examined in works [1]. Many researchers made experimental and theoretical works. 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, artificial skin [2].

In this study, the newly designed lattice structure Poisson’s ratio was checked over via exploiting finite element analysis. 14 different lattice structures with respect to inner lattice thickness configurations are investigated. A variety of new 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"

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is a theme of this labor. To design lattice structure to use many applications is very important with respect to lightweight and mechanical properties that is negative Poisson's ratio.

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

N. Novak et al. [3] made experimental and computational studies Hexa and tetrarchical auxetic structures. Mechanical properties of examples were examined using Tensile Test. Results show that two different structures and materials have similar stiffness, stainless steel 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 datas and tentative values are allied to each alternative. S.Gohar et al. [4] accomplished an empirical and quantitative work about new Auxetic structures behaviors under some loads. Mechanical properties of the designed new auxetic structures analyzed. Some mechanical properties compared with known auxetic structure. Optimization was practiced 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. Kadir G. [5] made a computational and probatory work on properties of crushing additively manufactured auxetic lattice 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 passed down for this working. In this working, lattice thickness is the main parameter for matching the mechanical qualities of the construction. Conclusion of this study, Kadir G. reached that orientation of production geometry with a different angle. Anti-tetrarchical auxetic structures have good energy absorption than other examined structures. İbrahim K.T. [6] made a study about 3D-based manufactured thermoplastic auxetic structures mechanical behavior (especially energy absorption) below static and dynamic loads. 5 different auxetic structures were assessed in this empirical work. All examined auxetic structures have the same material. The only changing parameter is structure geometry. 5 different auxetic structures investigated. The weight and volume of structures are different inasmuch as the varied geometry. Results show that Auxetic structures with a double arrowhead and tetra chiral 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. The recurved structure has disadvantages than other auxetic structures in buckling loads effects more because of the geometry. Under dynamic loads, double arrowhead and tetra chiral core geometry are better properties than other structures. He reached most ideal structure is double arrowhead core geometry because of the mechanical properties especially energy absorption under more loads. Its high strength and deformation ability, have set that it is proper choice in areas of use where impact and collision energy absorption is required. Sercan G. [7] 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 structure in this study. He reached that, new designed Auxetic structure indicates NPR in itself and particular geometry diversty. Poisson's ratio closes to -1 for structure. This result can be utilized new design system with filling auxetic structure. These results show that when produced the new designed auxetic structure is for testing it gets through the identical data as FEM results. Kusum Meena and Sarat Singamneni [8] made an experimental and analytical analysis about 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. Finding express that the new designed auxetic structure has bettermost mechanical features than other auxetic structures. Poisson's ratio of the S-shaped structure is better up to -2,5 than re-entrant. The new designed auxetic structure has a low-stress area.

Chen L. et al. [9] performed a 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. They also reached the disadvantages and advantages of reviewing different tubular structures. Review results show that re-entrant auxetic structure, rotating unit, chiral structures can be utilized for future geometry, laser cutting and AM techniques can be engaged 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.

Milad N. et al. [10] accomplished an empirical analyse about the energy absorption of three auxetic structures. 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 drop impact test. Consequences indicate 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 superlative structure for this empirical work in both testing mechanisms.

Y. Shao [11] executed a job about experimental (Dynamic Compression) and FEM simulation study about two different auxetic honeycomb structures (Positive and Negative Gradient Honeycomb examined with the compression test. Implications infer that a new deformation mechanism was founded with different compressive velocities and properties. A negative Honeycomb displays decent mechanical demonstration and energy occlusion. R. Jafari Nedoushan et al. [12] actualized tentative finding about new designed Auxetic structure. Newly lay out and made auxetic structure anti tetra chiral types. Printed examined structure and FE analysis done finding mechanical properties as low stiffness, low strength on anisotropy of novel designed structure and basic structure using applicable case and devices. Novel auxetic structure and manufactured. Different structure thickness and different structure angle examined. Results show that New designed auxetic structure has good mechanical properties especially great stiffness particulars. The Poisson’s ratio ranges from -0,55 to +0,1. Reduced alpha angle and thickness has negative Poisson’s ratio.

S. Tabacu and N.D. Stanescu [13] made an tentative, quantitative study about the mechanically skillful conduct of anti-tetra chiral structure on tubes. An empirical work was wrought 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. J.Shen, K.Liu, Q.Zeng et al.[14] made an tentative and impractical work whereof re-entrant structure deformation properties. New designed re-entrant structure (4 new designs) examined. Titanium material and additive manufactured method (EBM) are used to manufacture experimental specimens. Results show that 2D structure introduces negative Poisson’s ratio, the 3D structure has good mechanical behavior compared with classical re-entrant auxetic structure. Energy absorption and design area are other better results.

Y. Gao et al. [15] fulfilled a computational, analytical and empirical study about an investigation of mechanical properties especially rotating features of the structure. They reached that, the new designed auxetic structure has an extensive scope of Poisson’s ratios. Using additive manufacturing methods provides good production.

Stefan B. [16] made an experimental study about optimization and mechanically skillful features of the designed structure. They achieve that energy absorption, mechanical lightweight design of auxetic structure crash box of cars. Different auxetic structures were enquired in their work. The additive manufactured method with polymer used to produce the experimental specimen. Also, the plating operation was made by nickel on the experimental specimen. Static (Quasistatic) and dynamic (Impact) evaluation were achived. Correspondingly, they reached that new designed auxetic structures have good energy-absorbing struts and mechanical properties.

A. R. Sangsefidi et. al [17] wrought a pore over 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. Software algorithms provide and generate different chiral, re-entrant auxetic. W. Wur et.al. [18] formed tentative and numerical work on new designed auxetic structure mechanical properties. The new designed auxetic structure contains two different structure geometry and combination shown Their new designed structure has different cases in different loads and directions. New designed auxetic structures were investigated and were reached some results. The new structure has good mechanical stiffness and mechanical properties especially energy absorbing. Xue Gang Zhang et. al [19] made tentative and quantitative examination of mechanically skillful settings about new designed chiral lattice structures. They examined two varied states in their studies. Two composites (filled with soft materials, foam) specimens and two lattice structures, a total of four specimens examined and mechanical properties viewed in this working. The result inferred that new designed and printed lattice structure has good mechanical features and good absorption peculiarities. New designed chiral lattice structure with filled foam has low auxetic properties but mechanical properties have increased. Energy absorption capacity has a maximum amount than traditional. Poisson's ratio of new designed chiral lattice structure is close to -0,38.

Matthew W. et. al. [20] impressed a look over study regarding the design procedure of auxetic lattice structures. They guide auxetic structure design in mechanical application. Workflow of designing of the auxetic lattice structure. Uğur K. [21] made an analysis about novel designed and traditional lattice structures. Traditional and newly designed structures have the same dimensional measurements and materials. Maximum stress and displacement of novel designed lattice structure higher than honeycomb structure. S. Wang et al. [22] executed a work on energy absorption of new designed and modeled 2D and 3D dimensional auxetic structure. Structures were deconstructing by handling a pressing test to exhibit the peculiarities of the design. They reached that, the new designed auxetic structure has good mechanical properties. Demetris P. et al. [23] made a quantitative and empirical work about new designed auxetic structure. AM techniques were utilized to generate test specimens. Results were verified by using tests and numerical analysis. The lowest Poisson’s ratio was reached -0,5.

Scores of works, the study of Ergene B. and Yalçın B. [26], their mechanical conduct has been enquired proving FEA various structures was investigated.

Ozkan M. T., Toktas I. and Doganay S. K. [28], and Toktas I., Ozkan M. T., Aldemir F., Yuksel N. [29] also examined their studies on different subjects and a concept study structure was created.

2.MATERIALS AND METHODS

2.1 Unit Geometry Design

The intention of this work is to think up a new structure module with a negative Poisson's ratio. Unit geometry was inspired by Islamic Geometric Patterns. Designed unit geometry and lattice structure are expensed in Figure 1.

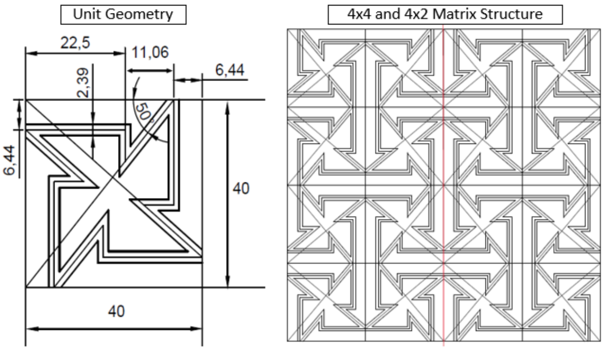
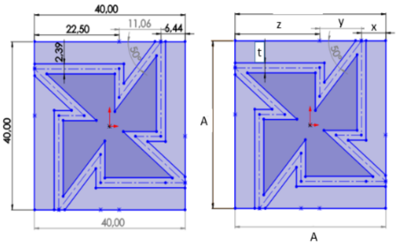


Figure 1. The order of formation of the unit geometry.

The geometry studied in this study was created with the polygonal technique used to create Islamic geometric patterns [24]. Similar shapes and new Auxetic structures can be created with other geometric pattern creation methods.New designed unit geometry was used for the structure module by taking its mirror image were given in Figure 1.

2.1.1 Mathematical Model of Novel Auxetic Structure

The mathematical representation of the unit geometry studied in this study is bestowed below. A value and Theta, θ, being fixed; The x, y, z and inner lattice thickness values are written in terms of A. Mathematical model of novel unit geometry is shown Figure 2.



$$A = x + y + z$$

$$x = A(0.161)$$

$$y = A(0.29)$$

$$z = A(0.5625)$$

$$t = \left((x + y + z)0.05975\right) + k$$

The k value is 0.5 each increase/decrease the geometry inner thickness.

A value, A=40 mm and Theta, θ=50° is constant.

Figure 2. Mathematical model of novel Auxetic structure.

In this study, only inner lattice thickness, t, changes were examined and all other values were kept constant.

2.1.2 Modelling and Design Parameters of Unit Geometry

In this survey, to find out a recent Auxetic structure with great mechanical properties. Figure 3 is showed a novel geometry unit in 2D and 3D Modelling, SolidWorks 2018. mm is used for dimensions.

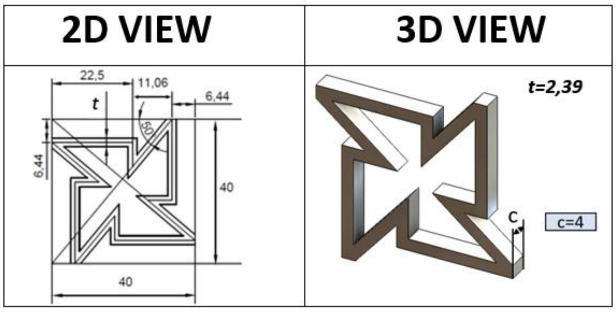


Figure 3. Novel unit geometry.

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 work, one variable parameter is the geometry inner thickness and the other is the structure matrix. Geometry inner thickness, (t), signified in Figure 3 is the variable parameter on other specimens. Geometry inner thickness of examined structures was shown in Table 1. Geometry or structure thickness, (c), and other basic measurements designated in Figure 3 are the identical and constant for other examined specimens.

Table 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 specimen modeled by changing geometry inner thickness, t.

2.2 Structure Modelling of New Designed Auxetic Geometry

The structure was modeled SolidWorks 2018 by using the extruded cut feature. Lattice structure modeling steps were given in Figure 4. Extruded Boss/Base feature were used structure with 4 mm lattice thickness. Unit geometry is used base feature for modelling process by mirroring image and cut feature.

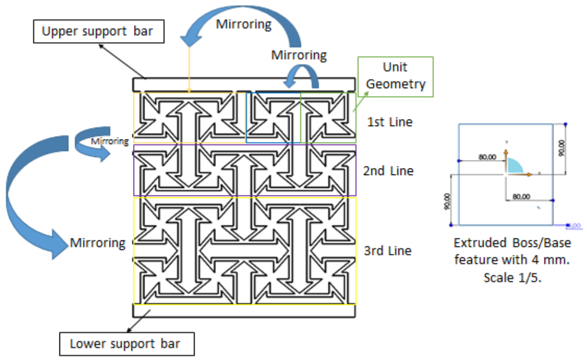


Figure 4. Lattice structure modelling process.

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

In this study, structure matrix is another variable parameter in the examined lattice structure. 2 different structure matrixes were examined with 7 different inner lattice thicknesses were shown in Figure 5 4x4 and 4x2 lattice structure matrix effects on negative Poisson's ratio on investigate.

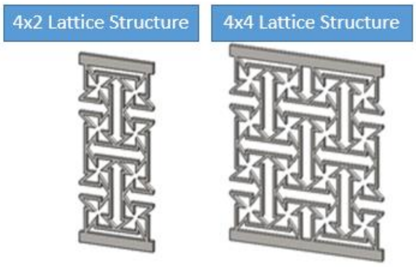


Figure 5. Lattice structure matrix types.

Lattice structures 4x4 and 4x2 matrix structure and 10 x 10 mm edge distance for analysis. 180 mm length, 160 mm width with 4 mm thickness (Structure thickness) for 4x4. 180 mm length, 80 mm width with 4 mm thickness (Structure thickness) for 4x2.

Detailed information of examined novel Auxetic structure dimensions and two variable parameters were given in Table 2.

Table 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)
4x2	14	4,900	160	80
4x2	13	4,390	160	80
4x2	12	3,890	160	80
4x2	11	3,390	160	80
4x2	10	2,890	160	80
4x2	9	2,390	160	80
4x2	8	1,890	160	80
4x4	7	4,900	160	160
4x4	6	4,390	160	160
4x4	5	3,890	160	160
4x4	4	3,390	160	160
4x4	3	2,890	160	160
4x4	2	2,390	160	160
4x4	1	1,890	160	160

In this study, besides the design, modeling and analysis, the structure with the lowest Poisson’s ratio of new designed auxetic structures. The 3D modeling of the examined lattice structures is expensed in Figure 6.

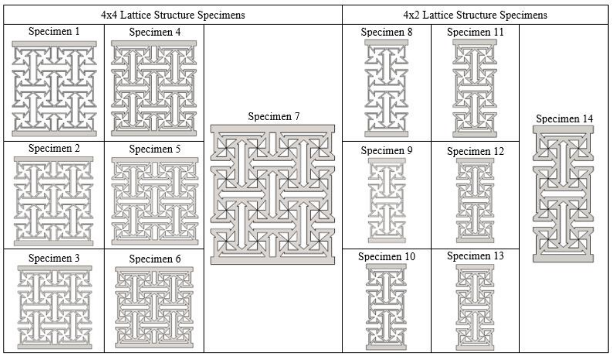


Figure 6. Examined specimen 3D models.

2.3 Poisson’s Ratio Analysis

Poisson’s ratio was calculated for all examined structures by using relations/equations (1), (2) and (3) given below.

$$\varepsilon_{\text{lateral}} = \frac{\Delta L_X}{L_{0X}} = \frac{L_{fX} - L_{0X}}{L_{0X}} \tag{1}$$

$$\varepsilon_{longitudinal} = \frac{\Delta L_Y}{L_{0Y}} = \frac{L_{fY} - L_{0Y}}{L_{0Y}} \tag{2}$$

$$\nu = -\frac{\varepsilon_{\text{lateral}}}{\varepsilon_{\text{longitudinal}}} \tag{3}$$

L_{0_X} is the original length of the specimen on the X-axis (Lateral Direction), L_{f_X} is the final length of the specimen on the X-axis (Lateral Direction), L_{0_Y} is the original length of the specimen on the Y-axis (Longitudinal Direction), L_{f_Y} is the final length of the specimen on the Y-axis (Longitudinal Direction), ν is Poisson's ratio and also ε is Strain. Poisson's ratio is unitless and scaler.

2.4 Finite Element Analysis

ANSYS R19.2 Analysis program has been used for finite element analysis. Material is selected Structural Steel given in Table 3 for analysis [25,27]. All element size dimensions used while creating the convergences mesh structure were determined as 0,5 mm for high accuracy. Nodes and elements are counted. Hex Dominant Method was used for good meshing results. Quad/Tri is Free Face Mesh Type.

2.4.1 Finite element analysis boundary conditions and tools

Static Structural parameters were designed to provide an analysis. Tensile test analogies were performed the software. Pressure and fixed support parameters are used for process. Flag Red, A (Pressure is -0,1563 MPa (100 N), Direction is parallel to the Y-axis, Tension) Flag Blue, B is denoted Fixed Support. All about information was delivered in Figure 7.

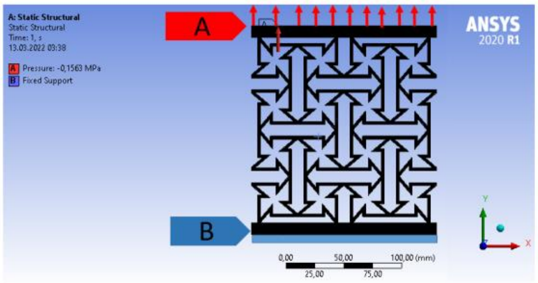


Figure 7. Limit terms and parameters.

Firstly, total deformations were get in the solving of the analysis. After that, Equivalent stress was found out in the solution of the analysis. Outcomes of these two parameters provides finding boundary values comparison of each structure during FEA. Examples of parameters for new designed lattice structure which default lattice structure, specimen number 2, created by Islamic geometric patterns, polygonal techniques were given in Figure 8.

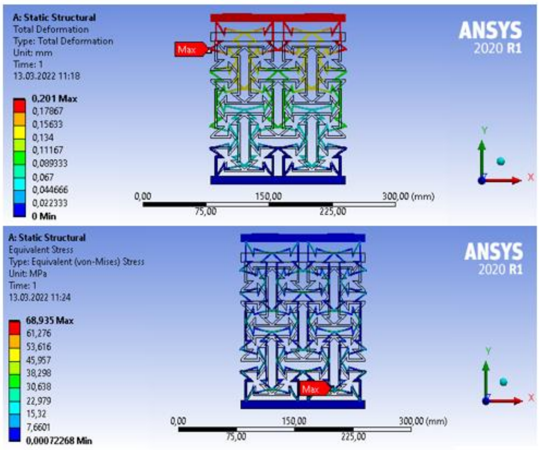


Figure 8. Analysis consequences for total deformation and equivalent stress.

The finding of Poisson's ratio of lattice structures needs directional deformation that is in the X-axis and Y-axis is necessary. For this reason, Lateral in the X-axis, Longitudinal in the Y-axis directional deformations were found using the software. Example of parameters for specimen number 2 (Default unit geometry, 2,39 mm, that created by using Islamic geometric patterns, polygonal technique). Directional deformation values were given in Figure 9. Four solution cases which are total deformation, Equivalent stress, directional deformation in the X axis and directional deformation in the Y-axis were examined for other lattice structures Poisson's ratio in the same manner.

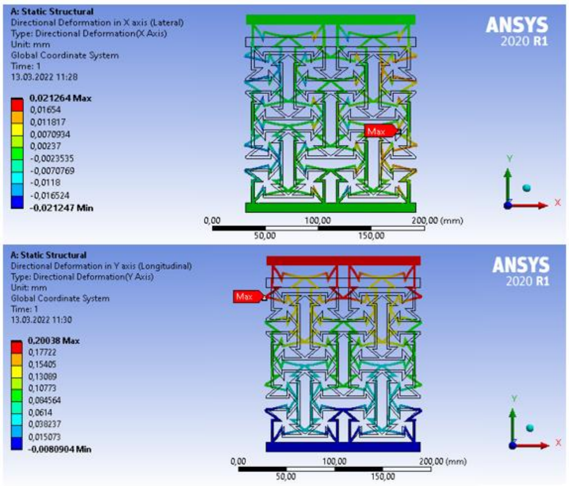


Figure 9. Directional deformation in X axis and Y axis.

Table 3. Structural steel properties [25].

Property	Density	Poisson's Ratio	Tensile Ultimate Strength	Tensile Yield Strength	Young's Modulus
Unit	kg m ^-3	Unitless	MPa	MPa	GPa
Value	7850	0,30	460	250	200

3. RESULTS AND DISCUSSION

In this work, latest designed lattice structure Poisson’s ratio was surveyed by adopting FEA. 14 different lattice structures for 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 were calculated given equations (1) and (2). Poisson’s ratio also calculated equation (3). A "static structural" system was utilised in all analyzes. Conducive to calculate Poisson’s Ratio, directional deformation in two axes was taken into account.

The Poisson’s ratio of the default structure, specimen number 2, that has inner lattice thickness is 2,39 mm 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 calculated given formula below;

$$\varepsilon_{\text{lateral}} = \frac{\Delta \mathbf{L}_{\boldsymbol{X}}}{\boldsymbol{L}_{\boldsymbol{0}\boldsymbol{X}}} = \frac{\boldsymbol{L}_{\boldsymbol{f}_{\boldsymbol{X}}} - \boldsymbol{L}_{\boldsymbol{0}_{\boldsymbol{X}}}}{\boldsymbol{L}_{\boldsymbol{0}\boldsymbol{X}}} = \frac{\mathbf{0,04253\ mm}}{\mathbf{160\ mm}} = \mathbf{0,00027}$$

$$\varepsilon_{longitudinal} = \frac{\Delta \boldsymbol{L}_{\boldsymbol{Y}}}{\boldsymbol{L}_{\boldsymbol{0}\boldsymbol{Y}}} = \frac{\boldsymbol{L}_{\boldsymbol{f}_{\boldsymbol{Y}}} - \boldsymbol{L}_{\boldsymbol{0}_{\boldsymbol{Y}}}}{\boldsymbol{L}_{\boldsymbol{0}_{\boldsymbol{Y}}}} = \frac{\mathbf{0,20038}\ \boldsymbol{mm}}{\mathbf{160}\ \boldsymbol{mm}} = \mathbf{0,00125}$$

$$\boldsymbol{\nu} = -\frac{\varepsilon_{\text{lateral}}}{\varepsilon_{\text{longitudinal}}} = -\frac{\mathbf{0,00027}\frac{\text{mm}}{\text{mm}}}{\mathbf{0,00125}\frac{\text{mm}}{\text{mm}}} = \mathbf{-0,21224}$$

First Lattice Structure Poisson's Ratio was calculated as -0,21224. In other structures, Poisson's ratio was

Table 4. Poisson’s ratio for examined structures.

Lattice Structure Matrix Type	Specimen Number	Inner lattice structure thickness (mm)	Strain-X Lateral	Strain-Y Longitudinal	Poisson’s Ratio
4x2	14	4,900	0,00013	0,00023	-0,55304
4x2	12	3,890	0,00028	0,00053	-0,53298
4x2	13	4,390	0,00018	0,00034	-0,51094
4x2	11	3,390	0,00038	0,00083	-0,46084
4x2	10	2,890	0,00061	0,00140	-0,43704
4x2	9	2,390	0,00105	0,00262	-0,40148
4x2	8	1,890	0,00218	0,00576	-0,37901
4x4	7	4,900	0,00004	0,00011	-0,34069
4x4	6	4,390	0,00005	0,00016	-0,31187
4x4	5	3,890	0,00007	0,00024	-0,29123
4x4	4	3,390	0,00010	0,00038	-0,27025
4x4	3	2,890	0,00016	0,00063	-0,25016
4x4	2	2,390	0,00026	0,00119	-0,21844
4x4	1	1,890	0,00049	0,00252	-0,19572

Table 5. Equivalent stress, total displacements and mass values with respect to inner lattice thickness.

Lattice Structure Matrix Type	Specimen Number	Inner lattice structure thickness (mm)	Poisson’s Ratio	Mass (gr)	Max Deformation (mm)	Equivalent Stress (MPa)
4x2	14	4,900	-0,55304	258,000	0,0375	24,138
4x2	13	4,390	-0,51094	238,000	0,0554	30,874
4x2	12	3,890	-0,53298	218,000	0,0848	38,342
4x2	11	3,390	-0,46084	198,000	0,133	56,847
4x2	10	2,890	-0,43704	177,000	0,225	77,455
4x2	9	2,390	-0,40148	156,000	0,420	111,370
4x2	8	1,890	-0,37901	134,000	0,924	216,340
4x4	7	4,900	-0,34069	516,230	0,017	12,304
4x4	6	4,390	-0,31187	476,000	0,025	17,948
4x4	5	3,890	-0,29123	436,000	0,039	19,994
4x4	4	3,390	-0,27025	396,000	0,061	24,580
4x4	3	2,890	-0,25016	354,000	0,101	35,110
4x4	2	2,390	-0,21224	312,000	0,201	68,935
4x4	1	1,890	-0,19572	270,000	0,404	96,613

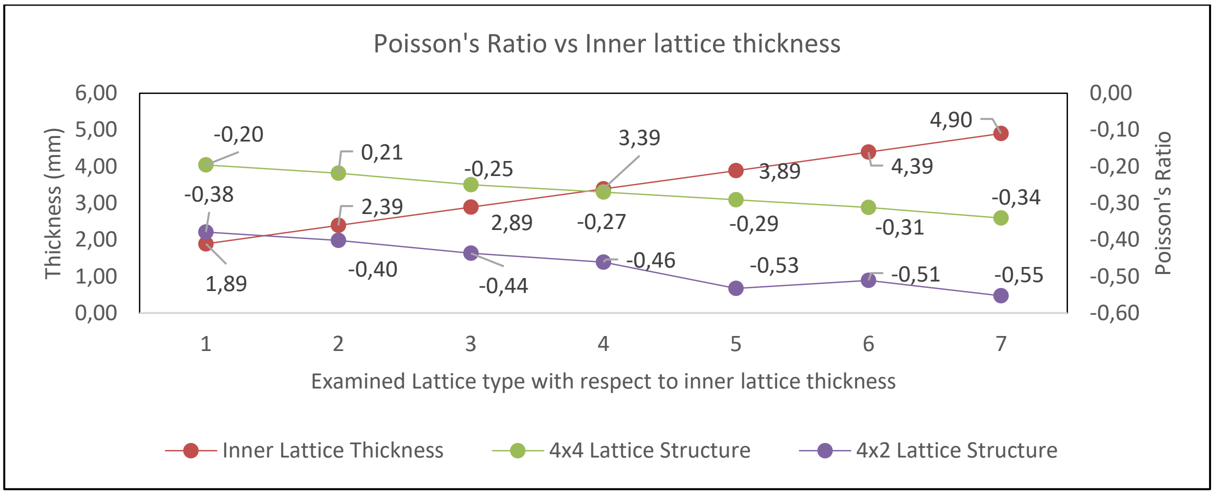


Figure 10. Poisson's ratio vs. inner lattice thickness.

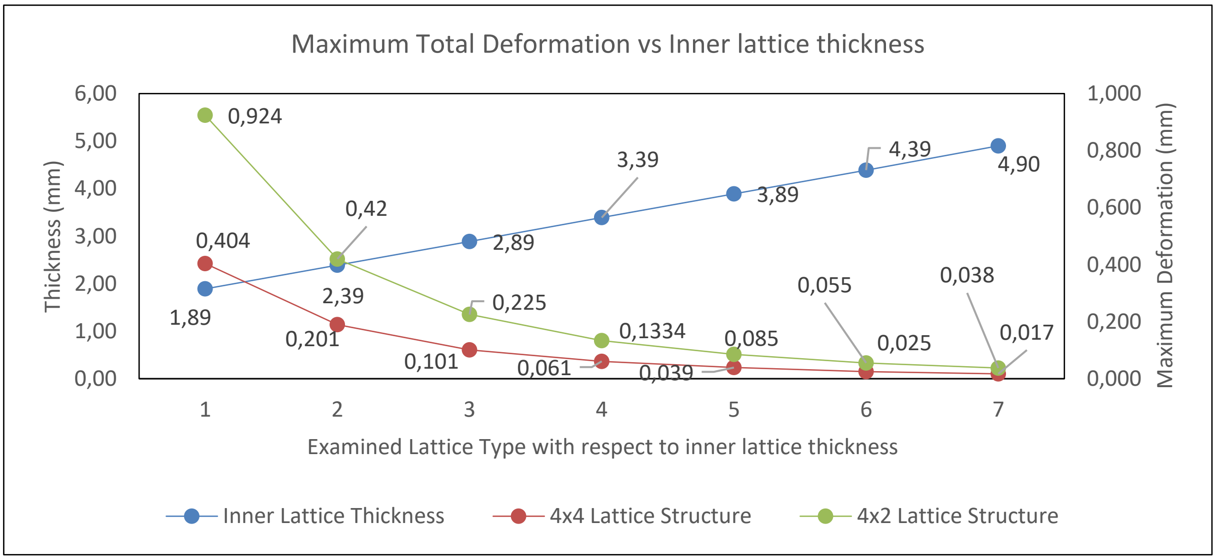


Figure 11. Maximum total deformation vs. inner lattice thickness.

calculated in the same way. Poisson's ratio of other structures was endued in Table 4.

Equivalent stress and total displacements related to the cross-sectional area of the lattice structures and effects of lattice and inner lattice thickness values. These values are given in Table 5.

Relation between inner lattice thickness and Poisson’s ratio were given in Figure 10 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 is increased, Poisson’s values are decreased in these examined lattice structures

In this figure understand 4x2 lattice orientation has the lowest Poisson's Ratio than 4x4 Lattice structure Poisson’s Ratio, 4x2 is more Auxetic. Maximum total deformations were investigated for inner lattice thickness in Figure 11. When inner lattice thickness is lowest maximum deformation occurs.1.89 mm inner lattice thickness specimen has maximum deformation.

Maximum equivalent stresses were investigated to inner lattice thickness in Figure 12. When inner lattice thickness is 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.

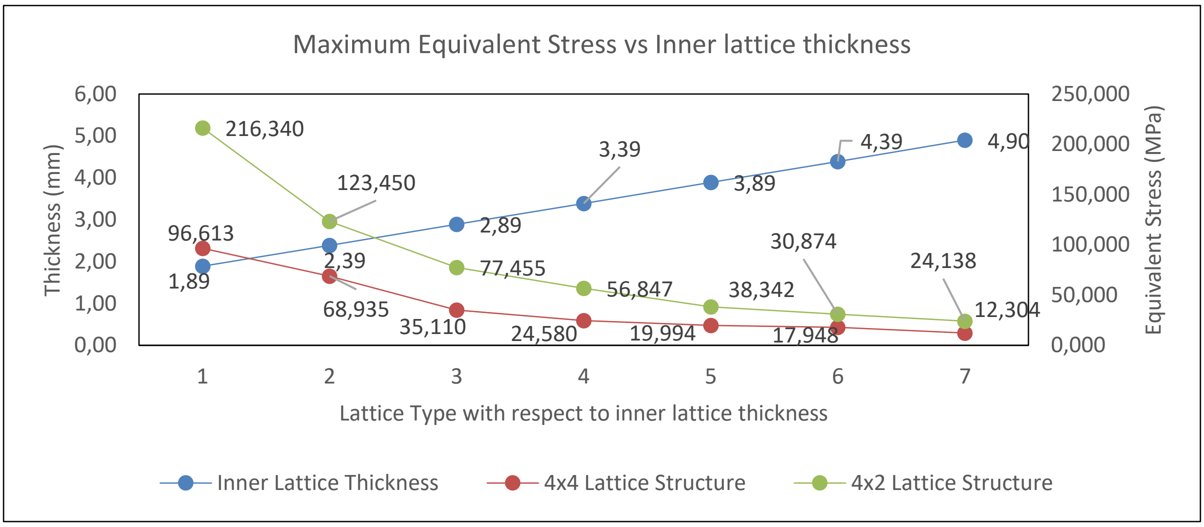


Figure 12. Maximum equivalent stress vs. inner lattice thickness.

Maximum total deformation and maximum equivalent region on examined structure are given in Figure 13. Maximum equivalent stress, Figure 13.B, occurs on the bottom middle of the structure owing to the geometry orientation. Maximum deformation, Figure 13.A, occurs on the end side of the structure by virtue of the pressure surface.

Stiffness /rigidity is declared as the speciality of maintaining its current state against a force. The stiffness and stiffness/mass ratio of the structures investigated in this working are screened in Figure 14 and Figure 15.

In the graphs showing the thickness and stiffness relations of the examined structures, it is seen that the stiffness of the structure raises when the interior geometry of the structure is increased.

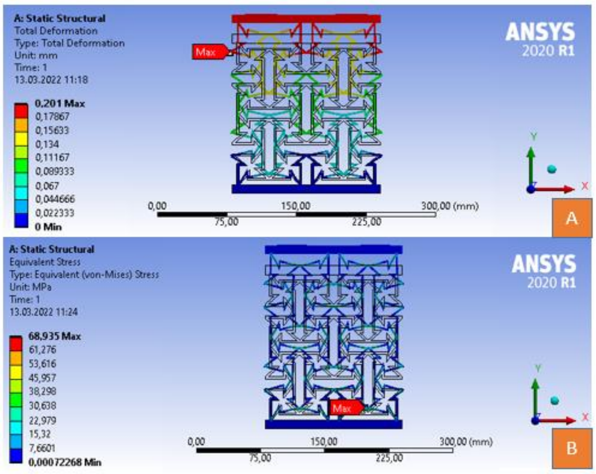


Figure 13. Maximum equivalent stress and total deformation regions.

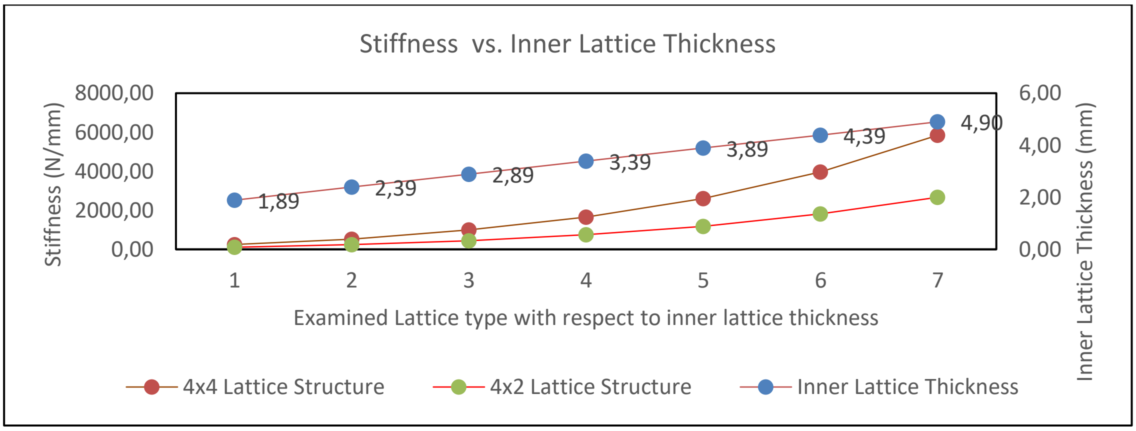


Figure 14. Stiffness values of examined structures.

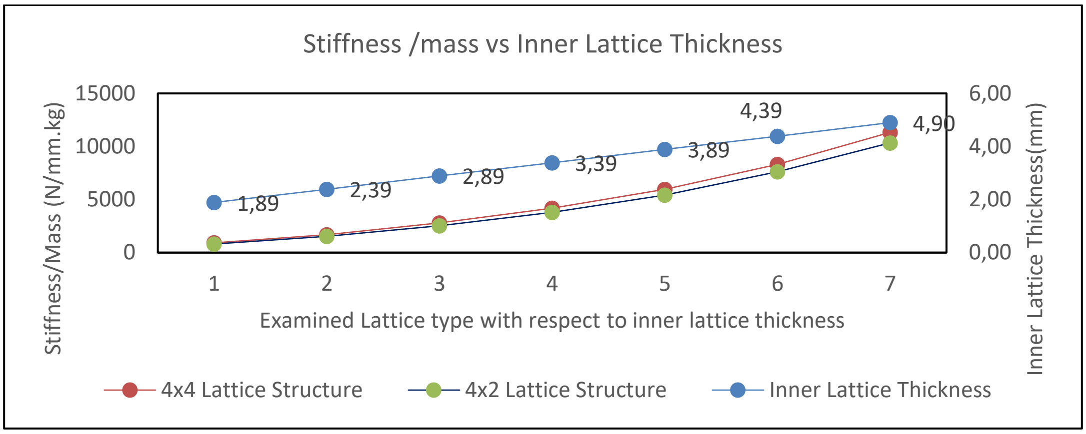


Figure 15. Stiffness/mass values of examined structures.

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, resistance to impact. Impact analysis of the newly created Auxetic structure in this study was performed with the impact test 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, 4x4 matrix structure that has the lowest Poisson's ratio on the piece from three different velocities, 3000 mm/s, 4000 mm/s, 5000 mm/s. The total deformation and total equivalent stresses were examined how this impact affects the structure formed.

As screened in Figures 16 and 17, 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.With this scrutiny, the energy immersion of the designed Auxetic Structure with the lowest negative Poisson's ratio was evaluated. When Figure 18 is examined, the increment in the proportion of impact on the main structure shows the energy absorption of the newly designed Auxetic structure against the impact.

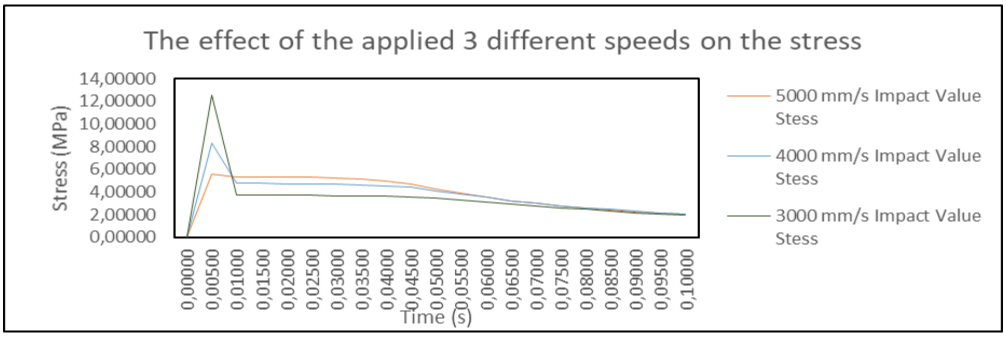


Figure 16. Impact analysis Stress values of novel Auxetic structure.

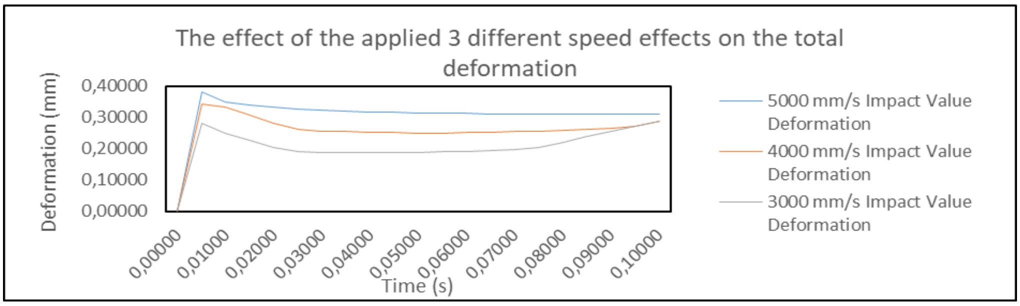


Figure 17. Impact analysis deformation values of novel Auxetic structure.

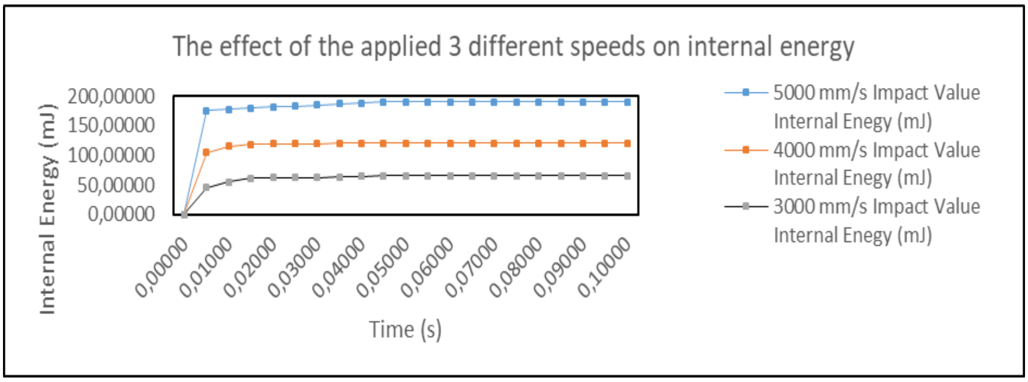


Figure 18. Impact analysis internal energy values of novel Auxetic structure.

4. CONCLUSION

In this study, newly contemplated lattice structure Poisson's ratio was examined by using FEA. 14 different lattice structures for inner lattice thickness configurations are investigated.

To sum up, Poisson's ratio of different Auxetic structures concerning inner lattice thickness was provided in the same condition. The conclusions in conducted study are given below;

- All examined structures (new designed Auxetic structures) have a negative Poisson's ratio.
- Inner lattice thickness is increased; Poisson's values are decreased in these examined lattice structures.
- 4x2 lattice orientation has the lowest Poisson's Ratio than 4x4 Lattice structure Poisson's Ratio, 4x2 is more Auxetic.
- 4.9 mm inner lattice thickness and 4x2 lattice matrix examined example has lowest Poisson's ratio that is -0,55.
- Lattice structures are lighter than other full structures. They are suitable for lightweight applications.
- Maximum deformation and maximum equivalent stress were observed on the lowest inner lattice thickness of the 4x4 and 4x2 lattice matrix.
- Maximum equivalent stress occurs in the middle of the structure because of the geometry orientation. Maximum deformation occurs on the end side of the structure because of the pressure surface.
- Stiffness and stiffness/ mass values were attached to see the effects of inner lattice thickness
- Energy absorption properties of novel Auxetic structure were observed with respect to time.

In future work, new designed Auxetic structures can be examined in different application areas. Traditionally designed systems can be changed with improved new lattice structures.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

İsmail ERDOĞAN: He has done modeling, analysis processes and article writing processes.

İhsan TOKTAŞ: He has contributed subject and article evaluation.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Mazaev A., Ajeneza O., Shitikova O. "Auxetics materials: classification, mechanical properties and applications," ***Materials Science and Engineering***, 747. (2020).

[2] Günel O. Ranjbar M. "Review on auxetic materials." ***ICAMMEN***, (1) 24, 8-19. (2018).

[3] Novak N., Biasetto L., Rebesan P., Zanini F., Carmignato S., et al. "Experimental and computational evaluation of tensile properties of additively manufactured hexa- and tetrachiral auxetic cellular structures." ***Additive Manufacturing***. 45-68. (2021).

[4] Gohar S., Hussain G., Ilyas M., Ali A. "Performance of 3D printed topologically optimized novel auxetic structures under compressive loading: experimental and FE analyses." ***Journal of materials research and technology*** 1(5), 394 -408. (2021).

[5] Günaydın K. "Numerical and experimental investigation on the crushing behaviour of auxetic lattice cell produced with additive manufacturing techniques." ***Published masters***, Istanbul Technical University. (April 2020).

[6] Türkoğlu İ. “Investigation of behavior of thermoplastic sandwich structures with auxetic core geometries produced by 3-dimensional additive manufacturing method under static and dynamic loads.” ***Published doctoral dissertation***, Bursa Uludağ University. (2020).

[7] Gök S. “Structural desıgn and analysıs of an ımpact resıstant auxetıc metamaterıal.” ***Published masters***, Istanbul Technical University. (February 2021).

[8] Meena K., Singamneni S. “A new auxetic structure with significanly reduced stress concetration effects.” ***Materials and Design***, (173), (2019).

[9] Luo C., Zhen C., Zhang X., Zhang G., Ren X., et al. “Design, manufacturing and applications of auxetic tubular structures: A review.” ***Thin-Walled Structures***, (163), (2021).

[10] Najafi M., Ahmadi H., Gholamhossein L. “Experimental investigation on energy absorption of auxetic structures.” ***Materials Today: Proceedings***, (2020).

[11] Shao Y. “Insight into the negative Poisson’s ratio effect of the gradient auxetic reentrant honeycombs.” ***Composite Structures***, (274), (2021).

[12] Nedoushan R., An Y., Yu W., Abghary M. “Novel triangular auxetic honeycombs with enhanced stiffness.” ***Composite Structures***, (277). (2021).

[13] Tabacu S., Stanescu N.D. “A theoretical model for the estimate of the reaction force for 3D auxetic anti-tetra chiral tubular structures under tensile loads.” ***Thin-Walled Structures***, (168). (2021).

[14] Shena J., Liua K., Zenga O., Gea,J., Donga Z., et al. “Design and mechanical property studies of 3D re-entrant lattice auxetic structure.” ***Aerospace Science and Technology***, (118). (2021).

[15] Gao Y., Wei X., Han X., Zhou Z., Xiong J.” Novel 3D auxetic lattice structures developed based on the rotating rigid mechanism.” ***International Journal of Solids and Structures***, (233). (2021).

[16] Bronder S., Adorna M., Fíla T., Koudelka P., Falta J., Jiroušek O. Et al. “Hybrid Auxetic Structures: Structural Optimization and Mechanical Characterization.” ***Adv. Eng. Mater***., (23). (2021).

[17] Sangsefidi A.R., Dibajian S. H., Kadkhodapour J., Anaraki A. P., Schmauder S., Schneider Y. “An Abaqus plugin for evaluation of the Auxetic structure performance.” ***Springer Nature***, (2021).

[18] Wu W., Liu P., Kang Z. “A novel mechanical metamaterial with simultaneous stretching-andcompression-expanding property”. ***Materials & Design***, (208). (2021).

[19] Zhanga G., Rena X., Jianga W., Zhanga X., Luoa C., Zhanga Y., Xieb M. “A novel auxetic chiral lattice composite: Experimental and numerical study.” ***Composite Structures***, (282). (2022).

[20] Wallbanks M., Khan M., Bodaghi M., Andrew Triantaphyllou A., Serjouei A. “On the design workflow of auxetic metamaterials for structural applications.” ***Smart Mater. Struct***. (31).(2022).

[21] Kemiklioglu U. “Novel Design and Comparision of Structural and Modal Analyses of Auxetic Geometry versus Honeycomb Geometry.” ***Journal of Applied Mechanical Engineering***, (2). (2021).

[22] Wang S., Deng C., Ojo O., Akinrinlola B., Kozub J. Wu L. “Design and modeling of a novel three dimensional auxetic reentrant honeycomb structure for energy absorption.” ***Composite Structures***, (280). (2022).

[23] Photiou D., Avraam S., Sillani F., Verga F, Jay O. Papadakis L. “Experimental and Numerical Analysis of 3D Printed Polymer Tetra-Petal Auxetic Structures under Compression.” ***Appl. Sci***. (11). (2021).

[24] Penrose R. “Islamic Geometric Patterns”, Springer Nature, ISBN 978-1-4419-0216-0, Pages 616, New York-USA 2017.

[25] Ansys Analysis Sofware Manual Book, ANSYS R19.2

[26] Ergene B. and Yalçın B., “Finite element analyzing of the effect of crack on mechanical behavior of honeycomb and re-entrant structures”, ***Journal of Polytechnic***, 23(4): 1015-1025, (2020).

[27] Özçatalbaş Y., “Machinability of steels: the relationship between machinability and chemical composition, microstructure and also mechanical properties”, ***Journal of Polytechnic***, 23(2): 457-482, (2020).

[28] Ozkan M.T., Toktas I. and Doganay S.K., “Estimations of stress concentration factors Cw/Kts for helical circular/square cross sectional tension-compression springs and artificial neural network modelling”, ***Journal of Polytechnic***, 23(3): 901-908, (2020).

[29] Toktas I., Ozkan M. T., Erdemir F. and Yuksel N., “Determination of stress concentration factor (Kt) for a crankshaft under bending loading: an artificial neural networks approach”, ***Journal of Polytechnic***, 23(3): 813-819, (2020).