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Modified Lattice Structure with Close-To-Zero Poisson's Ratio for Enhanced Energy Absorption: A Numerical Study

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Abstract: Lattice structures have garnered significant interest across various sectors due to their unique characteristics, such as a high strength-to-weight ratio and a high damping coefficient. In addition, honeycomb structures necessitate a zero Poisson's ratio to prevent unnecessary stress and strain. To address this issue, a cellular honeycomb core that incorporates in-plane corrugated U-shaped beams with close-to-zero Poisson's ratio was proposed. This research assesses a method to increase the capacity of structure to absorb energy. To achieve this goal, a circular cylinder was utilized to improve the mechanical properties. The compressive characteristics of the modified structure were analyzed and compared to the conventional structure. The objective of this study was to boost the energy absorption capabilities of the conventional structure while maintaining the Poisson's ratio.

Keywords: Energy Absorption, Finite Element Analysis, Lattice Structure, Poisson's Ratio

Biographical notes: Abolfazl Sharifi received his BSc degree in mechanical engineering from Shahid Bahonar University of Technology, Kerman, Iran, in 2018. He is currently a member of the research group at the Panganco, Kerman, Iran. His current research interest includes lattice structure and Finite element analysis.

Research paper

1 INTRODUCTION

Researchers have extensively attempted to modify the current existing structures' geometric parameters or introduce new structures in the hope of enhancing mechanical performance [1-2]. The cellular metastructure stands out for its ability to achieve a range of exceptional characteristics such as being lightweight and high strength, exhibiting negative expansion [3], negative stiffness, zero Poisson's ratio [4], compression-torsion coupling, and multi-stability [5]. These features are crucial in military, aerospace, medical, and other industries. The traditional hexagonal and re-entrant honeycombs, known for their positive and negative Poisson's ratio, have been commonly utilized in various industries. Many studies have been carried out to examine their elastic and nonlinear mechanical characteristics using theoretical approaches, finite element methods, and experimental studies [6-11]. Dong et al. [12] Combined 2D similar re-entrant with conventional re-entrant structure (CRS) to create a new self-similar re-entrant auxetic metamaterial(SREAM) and studied the mechanical characteristics of SREAM and CRS under quasi-stratic compression test. The experimental and finite element results show that SREAM achieves better mechanical stability than CRS because of increased stiffness while maintaining the comparatively good negative Poisson's ratio. Choudhry et al. [13] demonstrated the in-plane energy absorption characteristics of a modified re-entrant auxetic honeycomb. According to their analysis, adding more nodes with low rotational stiffness increased the modified re-entrant structure's failure strain and enhanced its capacity to absorb energy. Chen et al. [14] proposed a novel auxetic honeycomb structure by incorporating self-similar inclusion into the conventional re-entrant structure. In comparison to the original construction, the new re-entrant honeycomb shows improved auxeticity and stiffness. The new auxetic structure has a specific energy absorption that is approximately ten times greater than the previous structure. Materials with Zero Poisson's ratio (ZPR) maintain constant transverse width under longitudinal strain. Instead of changing the chemical composition of materials, a lot of engineering effort is concentrated on creating micro-structural architectures to change the mechanical properties of those materials. As a result, meta-material is created, which can have characteristics not present in natural material. However, while some materials, like glasses and corks, exhibit a Poisson's ratio of near zero [15], none of these materials can be used to create lattice structures. Various cellular structures have been developed to meet diverse performance criteria, exhibiting positive, negative, and zero Poisson's ratios. Zero Poisson's ratio(ZPR) structure has not been studied as much as the negative and positive Poisson's ratio (NPR) structure [16]. Chen et al. [17] suggested a new honeycomb by incorporating a rib into each cell of the existing zero Poisson's ratio configuration, semi re-entrant honeycomb. It is demonstrated theoretically, numerically, and experimentally that the new honeycomb has zero Poisson's ratio (ZPR) characteristic. Liu et al. [18] proposed a novel honeycomb structure with zero Poisson's ratio. The findings indicated that by adjusting the geometric parameters, the honeycomb structure's mechanical characteristics can be customized. From the review above, It is evident that researchers have proposed new lattice designs that can enhance the energy absorption of lattice structures. however, few research studies have been done on improving the energy absorption of close-to-zero Poisson's ratio structures while maintaining the Poisson's ratio. This study's main objective is to numerically investigate the in-plane mechanical characteristics of the close-to-zero Poisson's ratio structure. Two lattice structures were designed to examine the correlations between their Load-Displacement curve and Poisson's ratio value. The principal objective of this research is to investigate numerically the in-plane mechanical characteristics of the close-to-zero Poisson's ratio structure. Two lattice structures were designed to examine the correlations between their Load-Displacement curve and Poisson's ratio values.

2 LATTICE STRUCTURE

2.1. The Unit Cell's Geometric Configuration

Regarding structural design, a lattice structure can be formed through the repetition of a unit cell following a specific pattern. Consequently, the design of a lattice structure involves the design of unit cells and patterns. Two lattice structures were selected for this investigation: the U-type structure and the U-type structure with circular cylinder (modified), as displayed in "Fig. 1". These cellular structures comprise a regular pattern of unit cells, as shown in "Fig. 1".

a **b**

Fig. 1 Unit cells: (a): U-type, and (b): U-type with circular cylinder.

2.2. Energy Absorption

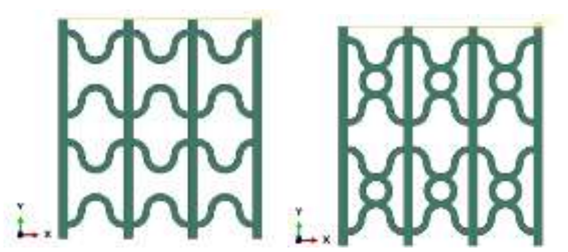
Specimen Energy absorption is the amount of external energy absorbed, which is determined by the force-displacement curve integral:

$$EA = \int_0^d F(x)\,dx \tag{1}$$

Where, d stands for the maximum displacement under compression and F for the compression load, the term "specific energy absorption" describes the amount of absorbed energy per mass, which is determined by dividing the total amount of absorbed energy by the structure's weight.

3 FINITE ELEMENT ANALYSIS

ABAQUS/Standard was employed to simulate the uni-axial compression of the conventional and modified structures. A 2D lattice structure was designed in Abaqus ("Fig. 2"). The global mesh size was set at 0.3 mm and to verify the effect of mesh size, a mesh convergence study was conducted. To apply vertical displacement load, the upper reference point was used. Table 1 presents the geometric parameters of both the conventional and modified lattice structures.
The lattice structure is 50 mm × 47 mm × 20 mm.



a b

Fig. 2 lattice structures :(a): U-type, and (b): U-type with circular cylinder.

Table 1 Geometrical parameters of the Aluminum structures

structures	Volume	FE.Mass
conventional	15479 mm^3	41.8 g
Modified	17854 mm^3	48.2 g

4 RESULTS

This section compares Poisson's ratio, Load-Displacement curve, and energy absorption of the conventional and modified structures.

4.1. Poisson's Ratio

Zero Poisson's ratio honeycomb structures are the structures that show zero or negligible deformation in the lateral direction when stretched or compressed in the longitudinal direction. The modified structure has a close-to-zero Poisson's ratio and is not sensitive to different displacements. The Poisson ratio of the modified structure is determined through numerical analysis using the displacements of two specific nodes, as shown in "Fig. 3".

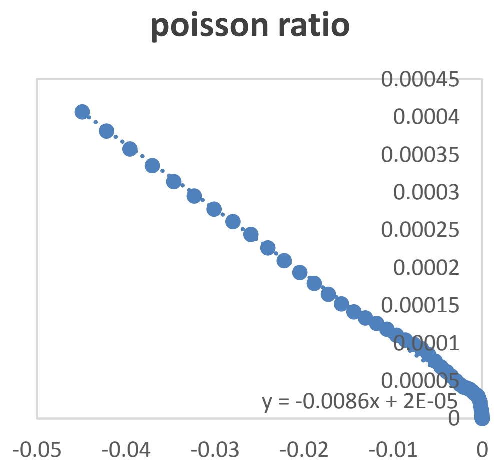


Fig. 3 The Poisson ratio of the modified structure.

4.2. Load-Displacement Curve

The lattice structure is designed to increase energy absorption. In addition, the mechanical characteristics of the lattice structure such as Young's modulus must be at an acceptable level. Figure 4 shows the numerical Load-Displacement curves of the lattice structures. Figure 6 shows Insignificant lateral deformation in the x direction.

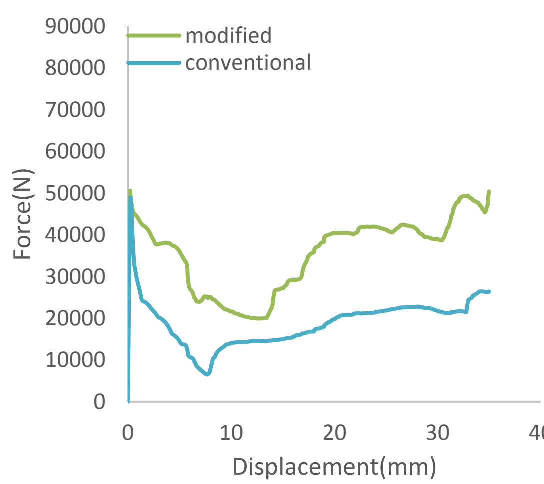
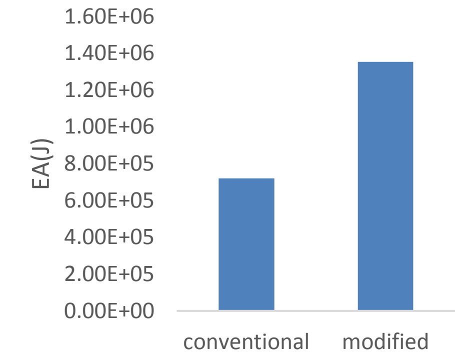


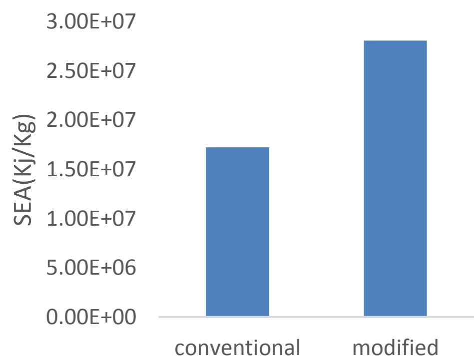
Fig. 4 Comparison of the numerical force–displacement curves of the conventional and modified lattice structures.

4.3. Energy Absorption

In the in-plane compressive analysis, the capacity of structures to absorb energy is a key performance indicator of structure. For this reason, a comparison of energy absorption of two lattice structures is shown in "Fig. 5".

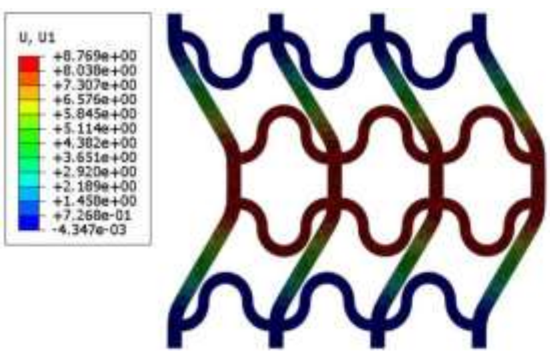


a



b

Fig. 5 (a): energy absorption of the two structures, and (b): specific energy absorption of the two structures.



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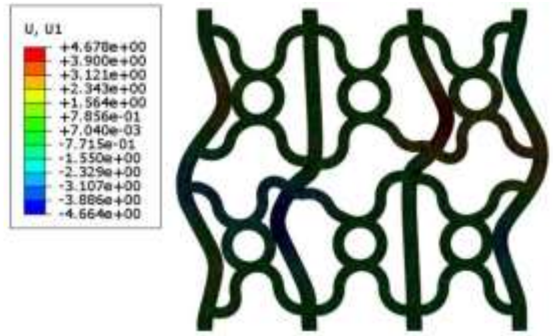

b

Fig. 6 FEA results of two selected configurations: (a): U-type, and (b): U-type with circular cylinder.

Energy absorption (EA) and specific energy absorption (SEA) of the modified structure are 87% and 63% better than the conventional structure, respectively, ("Fig. 6").

7 CONCLUSIONS

This study focused on analyzing the mechanical characteristics of U-type and U-type with circular cylinder (modified) structures through simulation. Aluminum was the chosen material for this investigation. The assessment included the estimation of mechanical properties like energy absorption and Poisson's ratio, revealing that both U-type and modified structures exhibit a Poisson's ratio close to zero. Furthermore, the findings indicated that the structure with a circular cylinder demonstrates higher energy absorption compared to the simple U-type.

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