Journal of Mines, Metals and Fuels, *71(12B): 167-171; 2023. DOI: 10.18311/jmmf/2023/45545*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Deformation Behaviour Analysis of Structures for Impact Loading

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Abstract

Materials used structures that undergo impact in various applications such as helmets that are used in sports and mining applications, bumpers in cars and space vehicles, play a major role in protecting human life and structures. In this paper, we present the design of auxetic structure, which can sustain more impact when compared to conventional structures. Auxetic structures have negative Poisson's ratio which aids them to behave in a different way. These structures contract (expand) transversely under uniaxial compression (tension). Auxetics is a term used to describe materials and structures that have this property. A comprehensive review of previous auxetics research is presented, covering diverse auxetic cellular models, naturally observed auxetic behaviour, various desirable auxetic features, and potential applications. In this study, the deformation behaviour of auxetic re-entrant structure is compared with conventional structures to know the behaviour of auxetic structures. Various structures are analysed using FEA software such as Ansys and Abaqus Explicit for different application purposes. This paper proposes the possibilities of developing new sustainable structures for use in absorbing impact structures in mining and automobile, among other possible applications.

Keywords: *Abaqus Explicit, Ansys, Auxetics, FEA, Poisson's Ratio*

1.0 Introduction

Auxetics are structures with negative Poisson's ratio that are most created by the structural geometry of their cells and can range in size from nano to macro depending on the material. Increased energy absorption, improved indentation resistance, high fracture toughness, and synclastic curvature in bending are all mechanical features of auxetics. Auxetic materials have the potential to offer various benefits and find applications in the aerospace, automobile, maritime and mining industries, due to their unique mechanical properties. The potential applications of auxetic materials in the mining industry are vast and diverse, ranging from protective gear and sealing systems to support structures and drilling tools. By exploiting the unique mechanical properties of auxetic materials, one can enhance safety, efficiency, and sustainability in operations. Synthetic or man-made auxetic materials under mechanical strain can be used as replacement for existing structures in these applications.

Auxeic structure is made up of unit cells and when a tensile or compressive load is applied to the connected nodes, auxetic behaviour occurs. The unit cell then spins in a specific direction, pulling or pushing neighbouring units through ribs that run in the opposite direction of the load. The Poisson's ratio could approach values close to -1 in this scenario. This sort of mechanism has a three-dimensional configuration made up of joints and flexible ribs. The Poisson's ratio decreases from a positive to a negative value as the number of unit cells rises, and the structure itself becomes prone to the size effect.

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A computer-aided design and engineering tool-based comparison of two-dimensional and three-dimensional auxetic geometries was presented[1]. The first phase of the research was devoted to the creation of an auxetics CAD library. They simulated the behaviour of the different auxetic geometries and established a systematic comparison, considering significant aspects of these geometries such as Poisson ratio(s), maximum volume or area reductions feasible, and comparable Young's modulus after the library was developed. Khan *et al.,*[2] presented research on the mechanical behaviour of a laser-assisted Direct Metal Deposition (DMD) auxetic structure. In tensile loading, the auxetic structure's effective modulus wascalculated. Experimentation was used to validate the results of Finite Element Analysis (FEA). The work by Liu *et al.,*[3] explored FE methods to simulate the impact response of the re-entrant auxetic honeycomb in-plane dynamic crushing. The unusual crushing patterns and modes in the re-entrant honeycomb are discussed in detail. The honeycomb of re-entrant auxetic and the hexagonal are contrasted in terms of energy absorption. The research by Habib *et al.,*[4] forecasts the global behaviour of honeycomb structures and their energy absorption characteristics by looking at their micro-topology. The impact of cell shape and arrangement on honeycomb selection for energy absorption is explored, and a methodology for balancing energy absorption with maximum transmitted stress is proposed, which is critical for energy-absorbing structure design. Imbalzano *et al.,*[5] investigated and compared similar sandwich panels with auxetic and conventional honeycomb cores and metal facets for impulsive loading resistance. The dynamic behaviour of these structures is numerically explored, with rate-dependent effects considered. Li *et al.,*[6] presented two novel auxetic cellular structures with dramatically increased Young's modulus and yield strength while maintaining a negative Poisson's ratio in the corresponding perpendicular direction.

The mechanical characteristics of a Three-Dimensional (3D) re-entrant structure subjected to dynamic compression using a high-speed Instron machine was presented by Logakannan *et al.,*[7] For comparison, quasi-static tests were performed. Multi-jet fusion technology was used to fabricate all of the samples. Using ABAQUS/Explicit, an FE model was created and validated against dynamic test findings in terms of deformation mode, plateau stress, and Poisson's ratio. To improve energy absorption, Jiang *et al.,*[8] developed a bio-inspired self-similar "concentric auxetic re-entrant honeycomb (CARH)". For quasi-static, low, medium, and high-velocity compression, a finite element model is built and confirmed using existing reference results. CARH-I and CARH-II are two varieties of CARHs that are used to investigate crashworthiness in a systematic manner. Different structures' quasi-static and dynamic compression behaviours, as well as EA properties, are compared. Shah *et al.,*[9] used finite element analysis to investigate the ballistic impact behaviour of auxetic sandwich composite human body armour. The armor's auxetic core was made up of separate re-entrantunit cells. The Explicit Dynamics/Autodyne 3-D code was used to execute numerical simulations. The auxetic armour reaction was predicted using a variety of bullet velocities and identical boundary circumstances. These findings were compared to the results of monolithic body armour. The auxetic armour improved indentation resistance, according to the findings. Al-Rifaie *et al.,*[10] set out to build the UGAD in a cost-effective manner, experimentally and computationally establishing its load–deformation parameters and energy absorption potential. The UGAD's geometry, fabrication method, experimental setup, and computational model are all discussed**.** By referring to these papers, we have carried out our study to understand the behaviour of auxetics and utilized for various applications.

The key insight that led to the work reported here is the fact that human safety is one of the important aspects in an industrial environment. In this paper, an effort has been made to demonstrate how auxetic materials properties can be exploited in designing a better structure to sustain impacts. In many challenging situations, Auxetic materials could be used in the design of protective gear, such as helmets, vests, and knee pads, to provide better shock absorption and protection against impacts. The auxetic behavior could help dissipate and spread the force of impacts more effectively, reducing the risk of injury.

The paper is structured as follows: Section 2. Describes the numerical model of auxetic structure. Section 3 presents the finite elements simulations of the proposed structure and results and discussion, followed by the conclusion of the current research.

2.0 Materials and Methods

2.1 Numerical Model of Auxetic Structure

A Concentric Auxetic Re-entrant Honeycomb (CARH) is modelled using SolidWorks software. It consists of vertical, horizontal and inclined struts. The main parameters considered while designing auxetic structure are thickness of struts, orientation of struts, H/L ratio, angle between inclined strutsand type of loading.

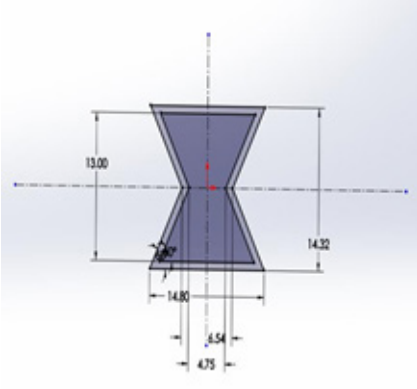


Figure 1. CARH unit cell.

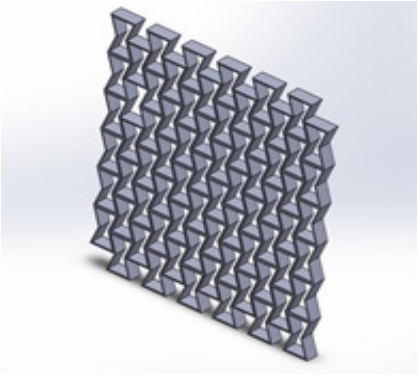


Figure 2. CARH assembly.

By adjusting the vertical and inclined strut's angle, a unit cell of a 2D re-entrant structure and its assembly (depicted in Figure 1 and Figure 2 respectively) was formed from a hexagonal unit cell of a typical honeycomb. A negative Poisson's ratio results from this change in geometry. Four dimensions H, L, θ, and t regulate the overall size and mechanical reaction of the unit cell and the entire structure, which is built up of 6X6 unit cells. The vertical and inclined struts' lengths are H and L, respectively, and the angle between the vertical and inclined struts is θ. The strut thickness is t. In this study, all of the struts had a square cross-section and a t-length edge.

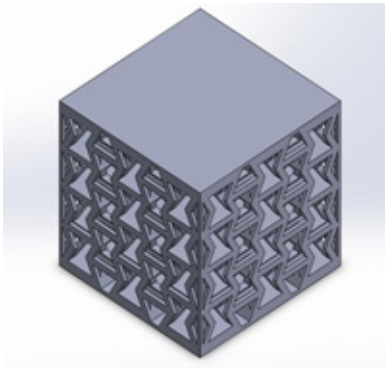


Figure 3. 3D re-entrant auxetic cube.

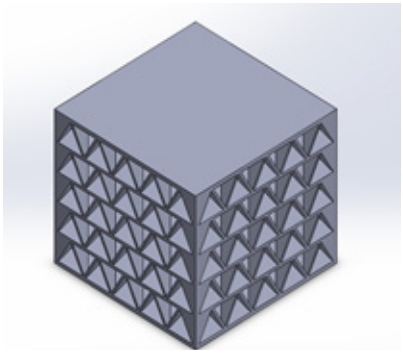


Figure 4. 3D triangular auxetic cube.

The unit cell of structure in Figure 3 is re-entrant where in Figure 4 is triangular. These models are modelled to similar overall dimensions and their deformation patterns are observed.

3.0 Finite Element Analysis

To systematically obtain more details about mechanical behaviours of CARH, a finite element model is built using Ansys. A static compressive load of 981N is applied and von-misses stress and deformation is noted. The stress distribution shows that, for the applied load the stress distribution is very less among overall structure. The capacity to withhold load is more. Only few of the unit cells have experienced the stress. The maximum stress for applied load is 139.8 MPa and the least is 4. -5 MPa.

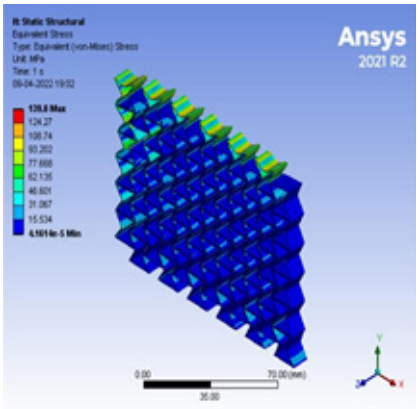


Figure 5. Stress distribution.

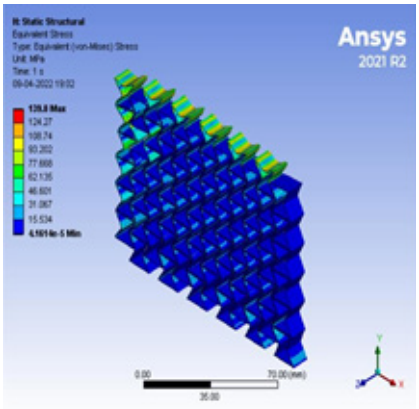


Figure 6. Deformation.

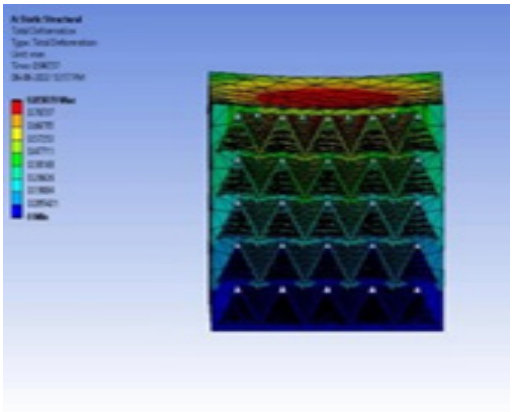


Figure 7. Deformation of re-rentrant unit cell cube.

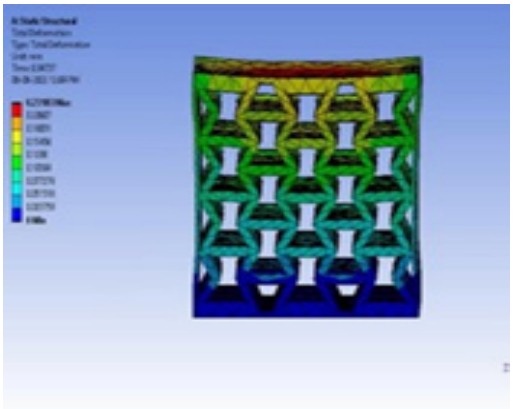


Figure 8. Deformation of triangular unit cell cube.

The stress distribution and the deformation of the assembly is as shown in Figure 5 and Figure 6 respectively. For the applied load, only first layer of unit cells has deformed to a maximum of 0.136 mm. The minimum deformation is 0 mm that means the bottom layer unit cells has not undergone any deformation under applied load. It also verifies us that the load bearing capacity of this structure is more.

A comparative study is conducted between re-entrant and triangular cube structure to understand their deformation pattern under compressive load. A compressive load of 1000N is applied on both the structures. The boundary conditions are defined as $UX = UZ = URX = URY = URZ = 0$.

The re-entrant cube showed its auxeticity by compressing along both directions while conventional structure like triangle compressed only in the direction of applied load. The Figures 6-8 above illustrate the deformation behaviour of re-entrant and triangular structures.

4.0 Conclusion

Regardless of loading direction, the analysis findings of our auxetic structures revealed that θ has a more substantial effect on SEA, Von-misses stress, and Poisson's ratio than H/L ratio. As the H/L ratio rises, the specific energy absorption falls. CARH crashworthiness is influenced by several factors, including wall thickness, distances, and the number of concentric walls. The physical qualities of a material, such as density, stiffness, toughness, energy absorption capacity, and damping ability, are altered by auxetic structures rather than material features. The proposed auxetic structure is suitable in all applications where energy absorption and greater impact resistance is of much interest, such as in various components of sports, mining, manufacturing, space, and aerial

engineering components. Such structures will enhance safety, efficiency, and sustainability in various challenging environments as mentioned.

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