Determination of Energy Absorption Capacity of Auxetic Hexagon Structure with Different Geometrical Parameters by Simulation and Experimentation

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Abstract - *Day by day there is extensive research for advancement in technology. One of the main sections under technology advancement is material and structures. Nowadays, there is a lot of research on alternatives to conventional materials and structures to meet present and future needs. One of the researches is on Auxetic structures and materials. The auxetic structure and materials, originally found in nature, have been observed to separate from traditional materials because of their various mechanical properties, mainly deformation mechanisms. The main objective of this study is to check the energy absorption capacity of the Auxetic re-entrant Hexagon structure by varying its geometrical parameters such as thickness, angle, aspect ratios, and the number of layers. Different samples with varying topologies were 3D printed using TPU material which later was checked for their energy absorption capacity with simulation in Ansys and experimental testing for compression on Universal testing machines. Uniaxial tensile test was done on standard 3D printed TPU samples to get the stress-strain data which was used as input for simulation. From uniaxial testing, it was found that TPU material has a very long elongation of more than 380% and it has a nonlinear stress-strain relationship. Since TPU has a long elongation it was found that it is a Hyper-elastic material. The results obtained from Ansys simulations agreed well with the data from the experimental compression tests for energy absorption.*

***Key Words*: Auxetic re-entrant, energy absorption, TPU, tensile test, compression test, Ansys**

1. INTRODUCTION

Auxetics are materials or structures that have a negative Poisson ratio. When stretched, they expand perpendicular to the applied force and when compressed, they shrink perpendicular to the applied force. This occurs due to their particular internal structure.

Knowledge about auxetic structures can be traced as far back as in the 1800s where Voigt et.al had already discovered the NPR in some materials but didn't draw much attention to it. Later in 1987, Lakes studied an auxetic foam structure that could be produced easily by tri-compression and heating which were considered to be a man-made process. Developments on auxetic materials thereafter have never ceased. [1]

Auxetic materials have various characteristics such as Negative Poisson Ratio, High energy absorption, High fracture resistance, low density, High indentation resistance, thermal insulation, high shear modulus, acoustic absorption, variable permeability, synclastic curvature, buoyancy. [2] Because of such characteristics, they are widely used in applications such as protecting equipment, packaging, shock absorbers, air filters, gaskets, seat belts, fasteners, automobiles, reinforced composites, textile, and biomedical applications. [3, 4]

Shokri Rad [5] studied the effect of unit cell configuration on the energy absorption response of different cellular auxetic structures subjected to quasi-static and dynamic loadings through experimental and numerical methods. He used ABAQUS software for validating the experimental test result. He discovered that the auxetic structures are superior to non-auxetic structures in terms of all studied impact resistance and energy absorption indicators due to their ability to withstand quasi-static axial impact loads.

Dipen Kumar [6] in his paper studied the energy absorption behaviour of aluminium foam-filled structures and compared it with the empty mild steel samples. He found that the energy absorption of Al foam-filled mild steel sample is increased by 1.56 times as compared to empty mild steel samples at a strain rate of 0.1

Wenzheng Liu [7] studied negative Poisson Ratio and Energy Absorption Characteristics of modified Arrow Honeycomb Structure with added embedded straight and curved ribs. He used ANSYS/LS-DYNA to analyze the energy absorption of the proposed cellular structures at different impact velocities. Numerical simulation results show that the modified structures have greater stress platform value, specific energy absorption, and impact force efficiency than symmetric concave honeycomb structures, indicating that the new structures exhibited better energy absorption efficiency and impact resistance performance.

1.1 Energy Absorption Theory

During the deformation of the energy-absorbing structure, the reaction force which the structure generates must remain constant for longer deformation zones. An in-plane compressive test is performed for Load-Displacement behaviour of the structures, for which the area under the curve will be the energy absorbed by the structures.

Energy absorbed = Force*displacement

According to the equation, in order to keep the reaction force to a minimum constant value, the deformation zone of the Auxetic honeycomb structure must be as large as possible.

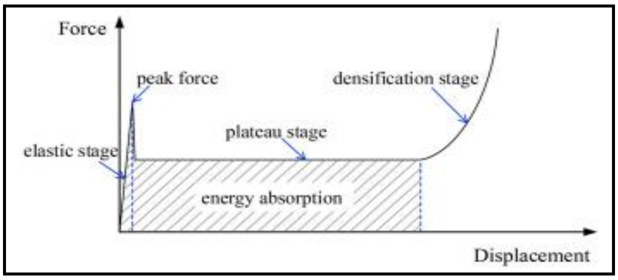


Fig - 1: Schematic diagram of a typical force-displacement curve of energy-absorbing materials [8]

The curve includes three stages; first elastic stage, in which the deformation of the material is elastic and reversible; second is the plateau stage, in which the reactive force is almost constant for a long stroke because of irreversible plastic deformation; and the final stage, in which the crushing force rises steeply. The shaded area enclosed under the curve characterizes total energy absorption, which is expected to be as large as possible. [8]

Work done by a constant force, W = F.s

Work done by a variable force, $W = \sum F.\Delta s$

$= \oint F.ds$

The nominal strain and nominal stress are defined as:

$$\sigma = \frac{F}{A}$$

$$\varepsilon = \frac{\delta}{H}$$

Where, δ and H are the compressive displacement in the y-direction and height of the model, respectively, F is the compressive reaction force of rigid plate and model; A is the cross-sectional area of contact between rigid plate and model.

2. CAD MODELLING AND 3D PRINTING:

The overall size of the samples is considering a number of cells fitting the 3X3 pattern. The geometrical parameters varied are thickness (t), angle (θ), aspect ratio (h/l), and the number of layers. The samples were cad modelled in Creo. Fused Deposition Modelling (FDM), a 3D Printing technique was implemented in the fabrication of the TPU Auxetic honeycomb structure samples.

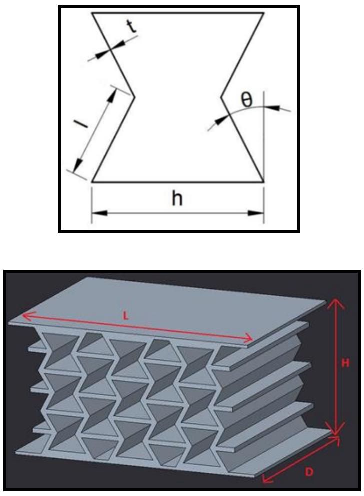
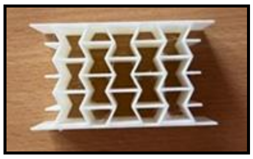
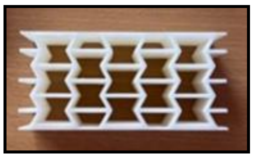
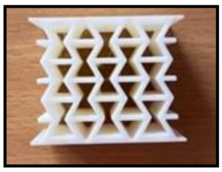


Fig - 2: Auxetic hexagon unit cell and Auxetic hexagon multi-cell structure

Table - 1: 3D printed Samples with their dimensions

Sample No.	Dimensions	3D printed Sample
1	h=15mm, l=7.5mm, **t=1.5mm**, θ=30deg, layers=3, L=80mm, H=40mm D=50mm	
2	h=15mm, l=7.5mm, **t=1mm**, θ=30deg, layers=3, L=80mm, H=40mm, D=50mm	
3	h=15mm, l=7.5mm, t=1mm, **θ=15deg**, layers=3, L=80mm, H=40mm, D=50mm	
4	h=18.75mm, l=7.5mm, **h/l=2.5** t=1mm, θ=30deg, layers=3, L=90mm, H=40mm, D=50mm	
5	h=11.25mm, l=7.5mm, **h/l=1.5**, t=1mm, θ=30deg, layers=3, L=50mm, H=40mm, D=50mm	
6	h=15mm, l=7.5mm, t=1mm, θ=30deg, **layers=2**, L=80mm, H=40mm, D=50mm	

3. SIMULATION

Computer simulations were carried out in Ansys software under static structural and hyper elastic models since TPU is a flexible material. As TPU is a non-linear material, a tensile test was needed to be done to find its stress-strain non-linear behaviour. TPU Tensile test samples were 3D printed with dimensions as per D638 specification and tested on a Universal testing machine. The most accurate test result was considered as input for simulation in Ansys. Mooney Rivlin parameter approach was considered. The mesh element size was considered as 1.5 mm with Tetrahedron meshing. The lower surface was given rigid support and displacement was applied on the upper surface with Auto time-stepping till the opposite walls interfered. Large deformation was kept on. Further, Reaction forces, displacement, and stresses were obtained as results.

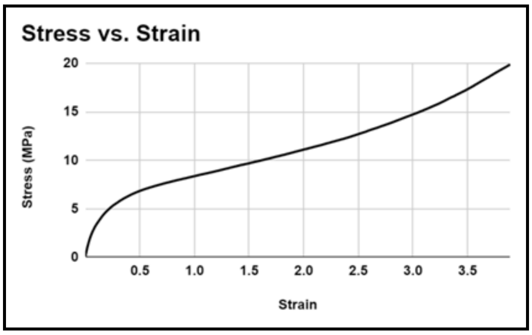


Fig – 3: TPU stress-strain curve

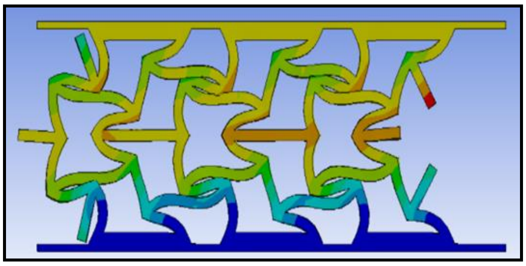


Fig – 4: Deformation of Sample No. 1 in Ansys

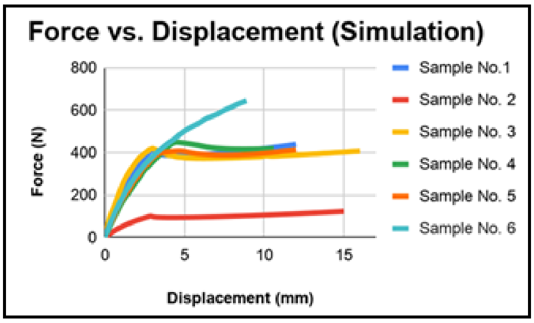


Fig – 5: F-d curves for all samples (Simulation)

4. EXPERIMENTATION

Compression tests were carried out on all 3D printed samples. Test Conditions: Load Cell 1000 kg, Temperature 25 deg C, Speed 5 mm/min, Pretension Load 0 N. The force-displacement values for different time-stepping were obtained and the graphs were plotted. Later, the energy absorption capacities were calculated from the area under the graphs till the plateau region.

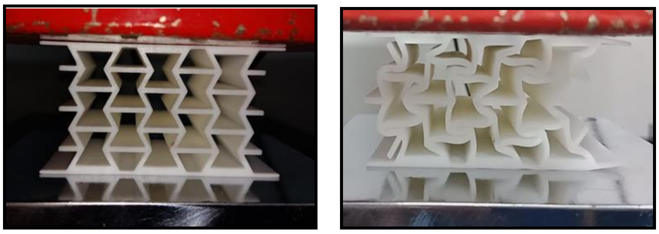


Fig – 6: Deformation of Sample No.1 for displacement = 0, 15 mm

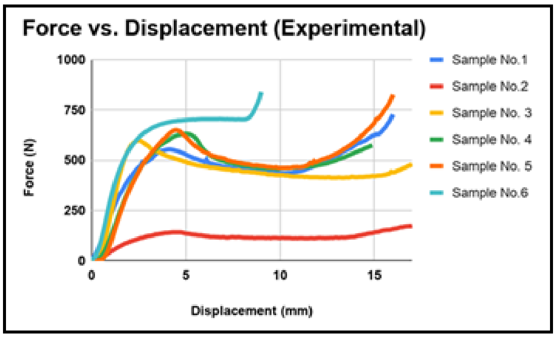


Fig – 7: F-d curves for all samples (Experimental)

5. RESULTS

Table - 2: Experimental and Simulation results

Sample No.	d (mm)	F (N) (Experimental)	F (N) (Simulation)	σ (MPa) (Experimental)	σ (MPa) (Simulation)
1	12	479.2	438.848	0.120	0.109
2	15	140.1	123.596	0.035	0.030
3	16	442	407.609	0.110	0.101
4	10	455.7	418.428	0.101	0.092
5	12	490	414.528	0.196	0.165
6	8.5	715.4	644.754	0.204	0.184

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Table - 3: Experimental and Simulation results

Sample No.	E (N-mm) (Experimental)	E (N-mm) (Simulation)	Percent error (%)
1	5250.90	4466.53	14.94
2	1657.02	1464.12	11.64
3	6889.34	5849.65	15.09
4	4423.64	3825.23	13.53
5	5366.83	4401.94	17.98
6	5007.63	4021.65	19.69

Here,
d = maximum displacement for energy absorption (till the end of the plateau region)
F = maximum constant force for energy absorption (till the end of the plateau region)
σ = Stress generated by a maximum constant force (till the end of plateau region)
E = Energy absorbed (area under the F-d curve till the end of plateau region)

6. CONCLUSIONS

In this paper, energy absorption of Auxetic re-entrant hexagonal structures with different geometrical parameters was studied by simulation and experimentation. The comparison between results obtained revealed the following:

1. Thickness variation: The thickness parameter was varied for samples 1 and 2 (t = 1.5mm, 1mm) keeping other parameters constant. It showed that the larger the thickness, greater is the energy absorption. Along with this, it was found that the thickness parameter is of great importance as the energy absorbed by sample 1 was 3.5 times more than that of sample 2.
2. Angle variation: The angle parameter was varied for samples 1 and 3 (θ = 30º, 15º) keeping other parameters constant. It showed that the smaller the angle higher is the energy absorption.
3. Aspect ratio variation: The aspect ratio (h/l) was varied for samples 1, 4 and 5 (h/l = 2, 2.5 and 1.5) keeping other parameters constant. It showed that as the aspect ratio increases the energy absorption decreases.
4. No. of layers variation: The number of layers was varied for samples 1 and 6 (layers = 3 and 2) keeping other parameters constant. It showed that as the number of layers is increased the energy absorption also increases.

Maximum stresses were observed in samples 5 and 6 with h/l = 1.5 and 2 layers. The percent error was below 20% for energy absorption capacities calculated from simulation and experimentation which shows that there is a good agreement between simulation and experimentation results.

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BIOGRAPHIES

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