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Modelling and Dynamic Analysis of Auxetic Honeycomb Sandwich Structure using Finite Element Method

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Abstract - *Dynamic finite element analysis is concerned with converging transient dynamic forces analysis of various different core and face sheet material of re-entrant honeycomb auxetic structure which is designed in SOLIDWORKS software and assembled in Space claim software, both analysis and simulations is carried out in ANSYS Transient structural. Many analysis already done on honeycomb in-plane sandwich structure but in this report transient dynamic testing done by performing impactor compression test projecting on re-entrant honeycomb auxetic specimen. Modelling, meshing and Various simulations were performed on sandwich plate using different core material consecutively e.g. Polylactic Acid (PLA), Thermoplastic polyurethane (TPU), Polyether Ether ketone (PEEK) and Poly methyl methacrylate (PMMA) while keeping face sheets material same for all cases i.e. Acrylonitrile Butadiene styrene (ABS). Initial velocity 1 m/s is given to external load in all cases and force given from 2 kN to 10 kN step wise in particular time period. In the row of analysis, for each analysis results are shown in graph and tables with respective figures showing that core with TPU material shows maximum total deformation of beam and also maximum equivalent stress. In vibration analysis maximum deflection is seen in TPU core with 0.5mm face sheet thickness and 25 mm core thickness. Different mode shapes were captured and compared with natural frequency and highest frequency is observed in PEEK core due to its stiffness property. On comparing simulation results, there much effect in varying core thickness and face sheet thickness as well but not same in case of cell size variation. There is not much fluctuation in natural frequency in case of cell size varying from 0.5 mm to 2mm. This report provides various useful steps for design and virtual analysis of re-entrant honeycomb auxetic structure which helps in broader technical advancement applications due to its plastic deformation mechanical properties with energy absorption qualities which may be applied in windmill technology, aerospace, bio-medical and daily lifestyle in clothes, furniture etc.*

Keywords: Auxetic structure, multi-material core, Non-linear Dynamic analysis, Force convergence.

1. INTRODUCTION

Lightweight sandwich structures are extensively applied in aerospace, marine, automobile, windmill and building industrial sectors, mainly due to their excellent high flexural stiffness, thermal insulation and high energy absorption capabilities [1]. Sandwich Auxetic structure is could be single re-entrant geometry or structure such as core and face sheets attached and bonded to each other forms a sandwich that combines the features of single component to get together and shows compiled properties of which they could do alone. Auxetic structure exhibits negative Poisson's ratio (NPR) which means expansion or contraction happen in overall structure, irrespective in which direction force is applied. Composites with core (Example: Honeycomb) vital application in various real life and their fabrication, also areas consisting strength to weight along with high stiffness from weight ratio are important structures like sandwich panels. [2].

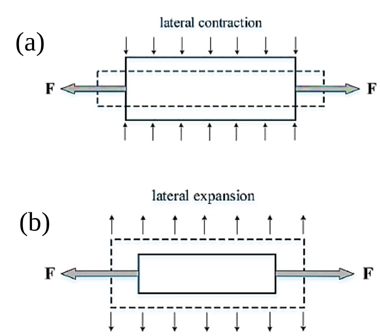

Fig-1. Schematic diagrams of (a) Regular non auxetic structure with positive Poisson's ratio (b) auxetic structure with NPR. [5]

Cores of sandwich structure can be made with suitable metastructures because these structures are metamaterial inspired concepts which are inducted in structural design [6]. Auxetic core structures deform when applied to load showing synclastic behavior which induces least stress to bonded surface until plastic deformation occurs. Auxetic honeycomb Structures are formed by linear pattern biaxial or triaxial of various form of auxetic unit cell either inplane or perpendicular to the plane but it is formed by face sheets and orientation of core, consideration of least density with required relative out of plane compression and shear properties [4]. Energy-absorption performance in auxetic mainly re-entrant structure consists important mechanical property for energy-absorbing materials and structures. In this process structure and material of structure plays a vital role in converting load dynamic potential energy or kinetic energy of impactor into another forms of energy usually in friction, heat through plasticity, viscosity or visco-elastic [10]. Fabrication material and various geometries of auxetic re-entrant structures like re-entrant angle, strut length, strut thickness and size of unit cell describes the strength and stiffness of honeycomb structure.

As these auxetic metastructure cores are having complex unit cell and full lattice as well, so additive manufacturing like 3D printing plays a robust manufacturing process for fabrication of auxetic core structure with least cost and time.

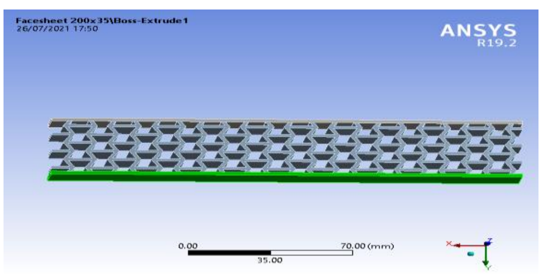

Fig- 2. Re-entrant honeycomb auxetic structure

Additive manufacturing also make possible of multimaterial fabrication of auxetic structures easily where a flexible and a stiffer material can be used in different regions of a sandwich structure which allows greater control over its mechanical properties [9].

2. METHODOLOGY

In this Non-linear Dynamics analysis is done on auxetic honeycomb sandwich structure with two face sheets made up of ABS on either side (top and bottom) is bonded and core of different materials – PLA, TPU, PMMA and PEEK.

2.1. Cell geometry of auxetic core

In this Dynamic finite element analysis, software Ansys used and in transient structural module is used for application of numerous loads and with various material input which needs much complicated engineering results which ae approximated. Solidworks for modelling of honeycomb re-entrant auxetic core and face sheets [3]. For conducting this dynamic FEM analysis, the core and the face sheets were modelled and improvised using Solidworks with thickness (2mm) of face sheets is taken for best results [7] and the meshing was done with tetragonal element using Ansys on the transient structure module.

Fig. 3 shows cell lattice geometry of re-entrant honeycomb core. The Finite Element dynamic analysis is performed on a auxetic sandwich structure which` has dimension of re-entrant honeycomb lattice core but material of the core is different as PLA, TPU, PMMA, ABS. All the tests are performed by switching the material of core one by one. Edge length = 5 mm, angle (θ) = 60°, h_c = 12.5 mm and t_c = 35 mm.

Sandwich structure is assembled in Ansys spaceclaim by aligning facesheet to auxetic core and inducted in mechanical model as bonded. Total elements formed are 31896 and nodes ass 98969 which are used for analysis purpose, with unit cell size 2 mm for honeycomb core and for face sheets thickness. Meshing is done with tetragonal element with Patch conforming method to contact surface of impactor and top facesheet. In meshing process, auxetic core with triangular element and face sizing to 5mm. Body sizing to whole impactor is given up to 2mm element size.

As this dynamic analysis is done for nonlinear material behavior when an impactor applied with some force and impacting on sandwich structure. So the connections with various parts in model analysis need some extra focus as compare to linear structural analysis. Contact regions for both face sheets with the auxetic core is made bonded but for making contact of impactor to the sandwich structure is made frictionless contact with asymmetric behavior and detection method is set to Nodal-Normal to target. Normal stiffness factor is set manually with value of 0.1. Interface treatment can be set if there is any offset in design model. One more option of contact tool is also set if any gap, penetration and status is happen in time of simulation of dynamic analysis.

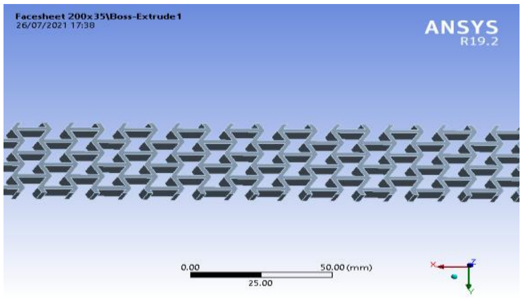

Fig- 3. Cell lattice geometry of re-entrant honeycomb core.

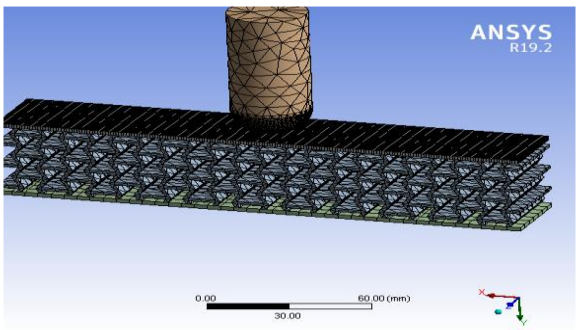

Fig-4. Mesh model of sandwich structure (90% tetrahedral)

2.2. Boundary conditions

Sandwich structure is modelled and analyzed for static structural testing in which bottom facesheet is fixed and an impactor is made to put load on load on the structure. Further under the static structural analysis [3], the von-Mises equivalent total stress, total deformation and try to solve force convergence at every core material using FEM [6]. Fig. 5 shows the boundary conditions for dynamic analysis where bottom facesheet is being fixed and forces are varying from 2kN to 10 kN are applied on top face sheet of sandwich structure for study the behavior of the auxetic sandwich structure.

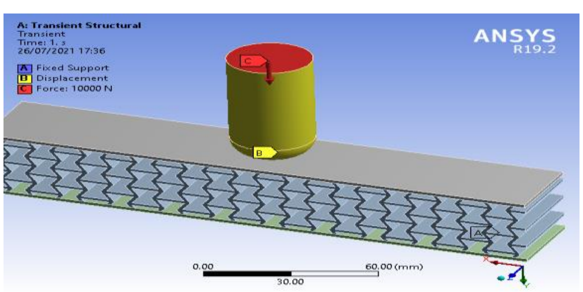

Fig- 5. Boundary conditions for fixed end beam.

Table- 1

Properties of materials used in analysis:

	Density (Kg/m³)	$E_{x,y,z}$ (MPa)	$\nu_{xy, yz, zx}$	$G_{x,y,z}$ (MPa)
PLA	1250	3450	0.39	1241
TPU	1300	1000	0.3	385
PMMA	1180	2690	0.395	965
PEEK	1310	3850	0.4	1375
ABS	1040	2390	0.399	855

Table 2

Max. Equivalent stress shown on sandwich structure when impact at 1 m/s.

	PLA	TPU	PMMA	PEEK	ABS
σ_{max} (MPa)	$1.5e^{-2}$	$2.4e^{-2}$	$1.2e^{-2}$	$1.1e^{-2}$	$2.4e^{-2}$
Total Deformation (mm)	$5.3e^{-5}$	$1.3e^{-4}$	$6.1e^{-5}$	$5.1e^{-5}$	$7.7e^{-5}$

3. RESULTS AND DISCUSSIONS

Under the non-linear dynamic analysis, the maximum equivalent stress which is developed during low velocity impact testing of auxetic sandwich structure at 100mm/s impact velocity. As the impact test shows not much variation in testing of sandwich structure. We can increase the impact velocity by 1000 times but it will take more time for computation because of so much nodes and elements generated to reach the accuracy of analysis. Table 2 determines maximum equivalent stress when bottom facesheet is fixed and with no pre stressed results. It can be observed that as the maximum deformation is happen in TPU core and also maximum equivalent stress is generated in it but there is no such major variation in stress in impact testing analysis. So, we switch to force dynamic analysis on the structure with varying material of the core and face sheets remain with ABS material which is made constant.

For TPU and ABS material, the corresponding stresses are similar. Highest Equivalent stress was captured with value of 0.024 MPa which is the stress value both TPU core and ABS face sheets.

Figs. 6.1, 8.1, 10.1 and 11.1 show the maximum total deformation on top face sheet along core with ABS face sheet thickness subjected to impact point force applied on top surface of sandwich structure and forces of magnitudes 2kN, 4kN, 6kN, 8kN and 10kN.

Similarly, Figs. 6.2, 8.2, 10.2 and 11.2 shows equivalent von-Mises stresses generated the specimen with ABS face sheet thickness subjected to impact point force applied on top surface of sandwich structure and forces of magnitudes 10kN.

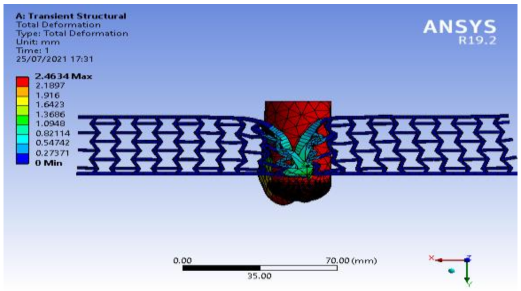

Fig- 6.1. Total deformation of PLA core at 10 kN.

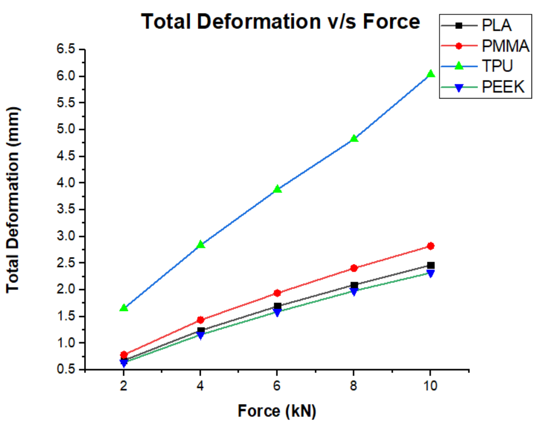

Fig- 7. Values of total deformation V/s forces on specimen for different core material.

Table 3: Values of total deformation under the various forces.

Force (kN)	Total Deformation			
	PLA	**PMMA**	**TPU**	**PEEK**
2	0.678	0.7827	1.6526	0.6376
4	1.2377	1.4359	2.8393	1.1607
6	1.6916	1.94	3.88	1.5881
8	2.0942	2.407	4.8272	1.98
10	2.4634	2.822	6.041	2.32

It is observed in the analysis that maximum deformation is occured in centre region which gradually decreases while moving in axial direction of auxetic structure because major deformation is handle by centre cells rather connecting to other cells. As per the auxecity of re-entrant honeycomb structure is haapen at centre with heavy compression. Initial stage of application of force on top ABS facesheet it resists in small deformation but as load and displacement of impactor increases gradually then the core structure distorts but not got delaminated the sandwich structure between the composite face sheet and auxetic honeycomb structure. It also shows material with higher Young's modulus.

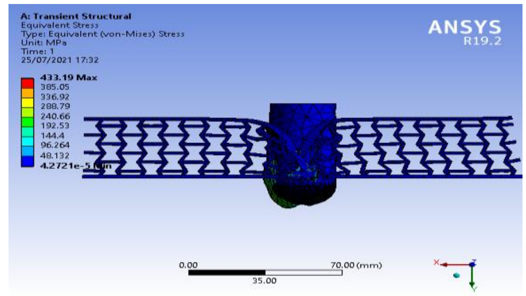

Fig- 6.2. Equivalent stress in PLA core at 10kN.

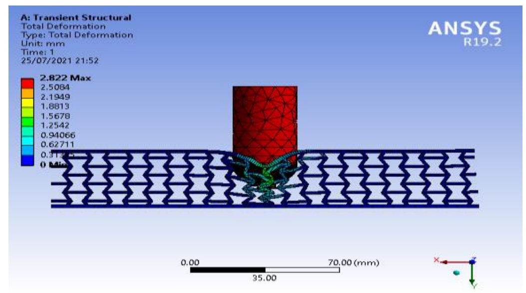

Fig-8.1. Total deformation of PMMA core at 10 kN.

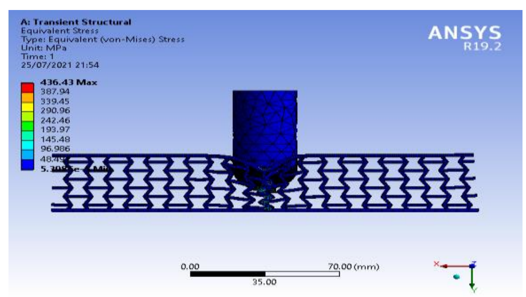

Fig- 8.2. Equivalent stress in PMMA core at 10kN.

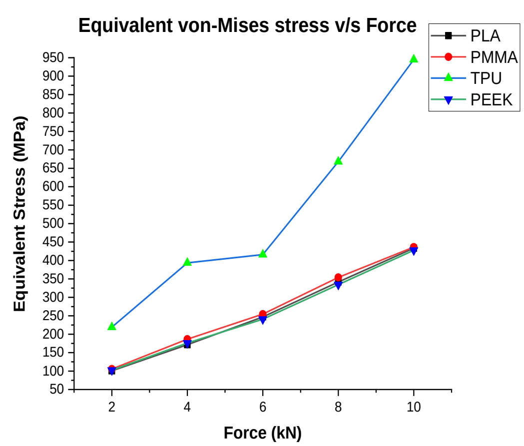

Fig- 9. Values of Equivalent stress V/s forces on specimen for different core material.

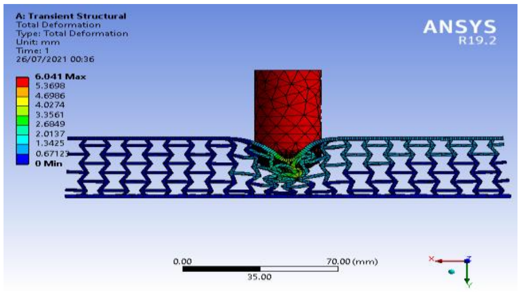

Fig- 10.1. Total deformation of TPU core at 10 kN.

composite face sheet and auxetic honeycomb structure. It also shows material with higher young's

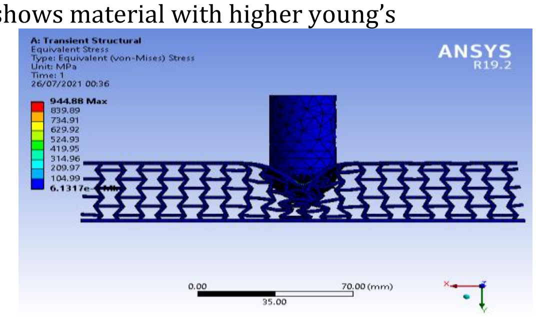

Fig- 10.2. Equivalent stress in TPU core at 10kN.

Table 4: Values of Equivalent von-Mises stress under the various forces.

Force (kN)	Equivalent von-Mises stress (MPa)			
	PLA	**PMMA**	**TPU**	**PEEK**
2	100.64	105.54	219.05	102.44
4	171.58	186.53	393.63	176.11
6	246.89	254.42	415.89	240.84
8	341.49	354.01	668.05	334.46
10	433.19	436.43	944.88	427.62

Young's modulus can resist large stress but flexible material TPU and higher shear strength cannot large force but in case of total deformation of TPU, it deforms major and retracts whenever the load removes. This is better advantage of using TPU in place of any other polymer. Maximum deformation of 6.041mm on application of10kN force with 100mm/s velocity is seen in TPU core sandwich structure and maximum stress is 944 MPa also seen in TPU core sandwich structure. Hence, varying material can give idea of which polymeric core sandwich structure could be useful for real life application. These clear results shows auxetic structures shows their properties of NPR while nullifying the back-stress created by different material which encounters the deformation locally

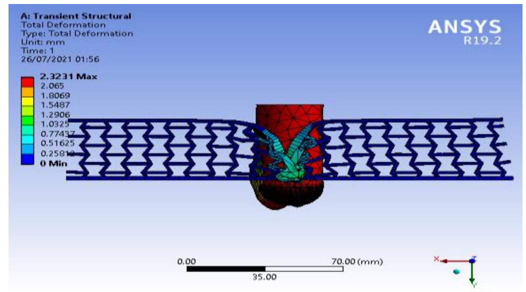

Fig-11.1. Total deformation of PEEK core at 10kN.

Without affecting whole structure and these various auxetic structures can be useful for multiple use of same sandwich structure without permanent deformation. These polymeric material used for core auxetic structures deform plastically on application of large force and fails the structure but some of polymers like TPU increases the resilience and flexibility of structure and prevent from deformation.

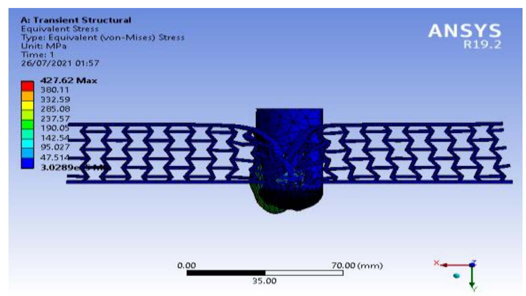

Fig- 11.2. Equivalent stress in PEEK core at 10 kN

4. CONCLUSIONS

The finite element method using the student version software ANSYS is performed on re-entrant auxetic honeycomb sandwich structure to determine total deformation and equivalent stress under different core material and loading conditions. In transient force converging dynamic analysis TPU material shows larger deformation under the same load and also highest equivalent stress. After the point of load when it retracts the as initially, the whole internal structure get regain its shape due to its flexible material property of core. We took auxetic structure in place of auxetic materials because elastic modulus (EI) of structure can be varied with large gap in different directions (x-axis and y-axis) rather than in material there elastic modulus converges to same value for large number of unit cells. Further the results improved by refining by mesh check of element size in meshing process of geometric design, connections and contact, meshing, element type, analysis settings, etc.

- Core cell size and thickness as well effects the deformation of sandwich panels.

- Total deformation is increased with decrease in thickness of face sheet, this may decrease in stiffness but may increase flexibility of specimen and more evenly distribution of forces on the core and the face sheet layers.
- Use of lower modulus material in place of hard material can absorb large dynamic energy.
- Increasing the core cell thickness causes increase in stress and create a spring back effect, which may decrease forces effect.
- Equivalent von-Mises stress is maximum at cell near to deformed core cells but far from deformed cells the stress goes decreasing and mitigates the stress effect at the side edges.

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