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Impact Response and Efficiency Based Ranking of Auxetic - Conic Hybrid Sandwich Composites Under Normal Impact Loads

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Abstract

Composite materials continue to reshape modern engineering by enabling deliberate manipulation of impact response through their geometric and material tailoring. Sandwich composites particularly allows variations in core geometries for different deformation modes under dynamic loading. Presented here is the High Velocity Impact behaviour of a class of hybrid auxetic - conic sandwich cores. Re-entrant hexagonal topology is combined with parametric conic profiles for building cores in sandwich composites. Auxetics are known for their negative Poisson's ratio. They offer valuable deformation kinematics in impact processing. Combining auxetic core configuration with conic wall profiles, defined by a conic parameter ρ, induces graded stiffness and progressive damage patterns. These hybrid mechanisms, which are by virtue of core geometries, are useful for efficient conversion of impact energy to composite internal energy. This enables processing of the impact by the composites through absorption of the energy rather than transmission of it.

Four layered hexagonal re-entrant auxetic cores further modified to conic profiles ρ = 0.5 and ρ = 0.7 (HEX_0.5CON, HEX_0.7CON), are evaluated along with a bare hexagonal re-entrant auxetic core (HEX), a chiral featured hexagonal re-entrant auxetic core (HEX_CHIRAL) and a primitive vertical walled core (PRIMITIVE). All cores were subjected to normal impacts of 11.7 J, 26.47 J and 46.8 J. Impact responses are quantified through kinetic energy decay and internal energy build-up. A performance indicator by the term of Energy Absorption Efficiency at Stabilization is adopted to compare the ability of each core topology to convert incident kinetic energy into internal deformation energy. The HEX_0.7CON core achieves unity-level efficiency at all energy levels indicating complete conversion of impact energy through its multistage collapse sequence. The HEX_0.5CON core provides efficiencies between 0.957 and 0.978. These two results confirm that the conic architecture in cores along with hexagonal re-entrant overall core configuration offers better energy dissipation across varied impact energies. HEX_CHIRAL, which utilizes chiral element in the hexagonal re-entrant core configuration offers higher efficiency than HEX, which is a classic hexagonal re-entrant core. This proves the influence of its rotational mechanisms in core architecture for impact processing. However, conic profiles stands out with higher energy absorption efficiencies than chiral featured cores. Classical re-entrant auxetic, HEX, cores show moderate efficiencies at 0.82 to 0.94 , suggesting that re-entrant action alone is not sufficient for impact mitigation. Clearly auxetic geometries have to be supplemented with higher order geometric curves like conics. Primitive core configuration returns the lowest efficiencies (0.57 to 0.67), reinforcing its inherent limitation in processing impact energy. In essence, the study confirms that conic parameterization significantly advances the impact resilience of auxetic core systems.

Keywords: Auxetic cores, Conic profiling, Impact response, Energy absorption

1 Introduction

Composites have evolved from naturally reinforced materials used in early civilizations to the highly engineered systems that define modern structural designs. Over the centuries the concept of composite has evolved integrating ideas from multiple branches of science and technology. The definition of a composite has become increasingly inclusive to encompass engineered assemblies of any distinct phases that work in tandem to meet specific functional demands. Sandwich composites have emerged as a dominant structural form where strength to weight properties and energy absorption capabilities are important.

Performance of a sandwich composite under impact is predominantly governed by its deformation mechanisms by virtue of the geometric design of the core. The dominance of each of the damage mechanism like, indentation, bending, rotation, buckling and densification depends strongly on the geometry of the cell and the stiffness gradient along the core height [1]. Introducing curvature into the auxetic walls provide distributed failure pattern during High Velocity Impact [2].

Curved cell walls propagates stresses by suppressing shear localization and encouraging progressive folding modes [3]. Conic profiles in the present study is defined through a parameter that governs their curvature. This allows allow fine control over stiffness and deformation sequencing along the core. This is particularly relevant under high strain rate loading. In high strain rate loadings sudden collapse of the composite core can compromise the structural integrity of the sandwich composite [4]. Hybrids of auxetic and conic systems provide multiple deformation paths.

Chiral based auxetic cores exhibit rotational ligament motion thereby contributing to the distributed deformation. [5,6]. Present study shows that curvature tuned profiles can outperform purely rotational mechanisms because they engage a larger portion of the core during collapse. This results in reduced stress concentration and improved crushing stability.

The present study subjects cores of - conic profiled auxetic sandwich composites, bare hexagonal re-entrant auxetic, hexagonal re-entrant auxetic with chiral configuration and a vertical walled primitive to impact energies of 11.7 J, 26.47 J, and 46.8 J. Impact response is analysed using kinetic energy decay and internal energy accumulation [7]. Energy Absorption Efficiency at Stabilization is calculated to measure the incident kinetic energy retained as internal deformation energy once the impact process stabilizes. This approach provides a geometry sensitive indicator of energy management capability of architected cores.

2. Materials and model

2.1 Materials

Definition of material properties is significant in predicting the impact response of sandwich cored composites discussed in this paper. Here, both facesheets and core are of fused design and is fabricated using Aluminium alloy 2014-T6. Al2014-T6 is a heat treated high strength material extensively used in aerospace and defense structures [8, 9]. This alloy demonstrates superior performance in impact loading conditions due to its balanced combination of strength and ductility. The T6 temper of Al 2014 exhibits a density of approximately 2.8 g/cm³, an elastic modulus of 72 to 73 G Pa, a yield strength around 414 M Pa and an ultimate tensile strength near 483 M Pa accompanied by ~13% elongation [8, 11] to failure. These makes it an ideal candidate for impact resistant structures. The alloy demonstrates exceptional mechanical stability during impact loadings [10].

2.3 Numerical model

Nonlinear plastic deformation of the sandwich core structures in this study is modelled by a Power-Law Plasticity formulation defined by a strength coefficient (K) and a strain hardening exponent (n). K and n are critical in capturing the nonlinear material response under impact loading. Aluminium 2014 T6 alloy exhibits clear strain rate dependency [12, 13]. Recent findings on Al 2014-T6 highlight the occurrence of ductility, strain localisation and fracture behaviour at different strain rates [14]. A Poisson's ratio of 0.33 is employed for the elastic region in present simulations.

For modelling convenience and initial design fidelity both the auxetic core and the sandwich facesheets which are of fused design is assigned the same continuum material definition of Al 2014-T6. This treats the cellular core as a homogenised bulk solid and enables proper impact characterisation of different composite core variants. This assumption is beneficial for preliminary design studies of architected metallic core variants [15, 16]. Values of K and n are adopted from validated literature sources for Al 2014-T6 subjected to dynamic loading [17].

Elastic-plastic behaviour of the alloy is defined by Ramberg Osgood relation. It expresses total strain (ε) as the sum of elastic (σ/E) and plastic components governed by a power law in stress.

The form of the relationship is:

$$\varepsilon = \frac{\sigma}{E} + \alpha \left(\frac{\sigma}{\sigma_y} \right)^n$$

Where, σ is the applied stress, σ_y is the yield stress at 0.2% offset, E is the elastic modulus, α is a material constant (commonly 0.002 for 0.2% yield offset) and n is the strain-hardening exponent. Based on experimental characterisation in literature, typical values for Al 2014-T6 under dynamic conditions are adopted as K ≈ 560 MPa and n ≈ 0.55 [18].

2.4 Geometric model

Five distinct geometric variants of the conic profiled hexagonal re-entrant auxetic sandwich cores are designed, modelled and subjected to impact simulations. Each configuration represents a systematic variation in the core wall geometry. Cores are modelled as auxetic, auxetic chiral and auxetic chiral with conic profiling defined by the conic parameter (ρ). The baseline model, which is of straight re-entrant walls serves as a reference for evaluating the influence of conic curvature for impact response characteristics. The geometric details and nomenclature adopted for each model are presented in Table 1.

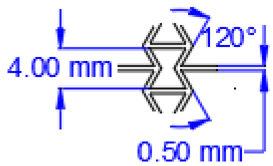
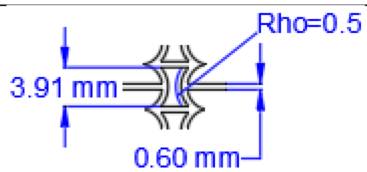
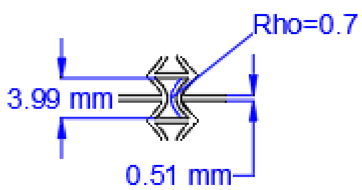
Sl	Description of core	Nomenclature	Unit cell configuration
1	**Hexagonal re-entrant sandwich structure with straight core walls**	**HEX**	 Fig. 1. Unit cell of HEX
2	**Hexagonal re-entrant sandwich structure with core walls at 0.5 conic parameter**	**HEX_0.5CON**	 Fig. 2. Unit cell of HEX_0.5CON
3	**Hexagonal re-entrant sandwich structure with core walls at 0.7 conic parameter**	**HEX_0.7CON**	

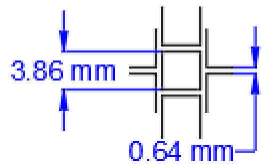
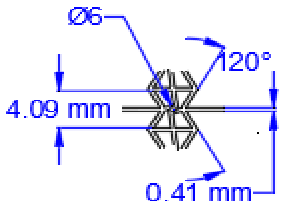
			Fig 3. Unit cell of HEX_0.7CON
4	**Primitive Geometry**	**PRIMITIVE**	 Fig 4 Unit cell of PRIMITIVE
5	**Hexagonal re-entrant sandwich structure with straight core walls and with Ø6 chiral configuration**	**HEX_CHIRAL**	 Fig 5. Unit cell of HEX_CHIRAL

Table 1. Description of geometric particulars of the core

The design philosophy adopted in present study ensures that all composite variants maintain a constant total weight of 60 grams and an identical overall size of 100 × 30 × 20 mm, thereby enabling direct comparison of their mechanical performance under different impact loads. Variations in geometry is compensated by proportional redistribution of material to ensue mass and volume conservation across all models. Each sandwich composite is designed into four core layers for examination of inter layer coupling effects and progression of damage mechanisms during impact events.

2.3 Results

Numerical simulations are conducted using explicit dynamic platform in LS Dyna conducted to evaluate the transient impact response of the five designed sandwich composite variants. Each CORE configuration is studied at impact energies of 11.7 J, 26.49 J and 46.8 J. Figures 6 to 10 presents the Von Mises stress contours and corresponding deformation images for each geometric variant - HEX, HEX_CHIRAL, PRIMITIVE, HEX_0.5CON and HEX_0.7CON subject to the three different impact states. The colour in the figures represent the spatial distribution of equivalent stress. Each subfigure (a to d) shows the structural response of sandwich composites at the initial state and three different impact energy levels.

2.3.1 Impact response of Hexagonal re-entrant sandwich structure with straight core walls (HEX)

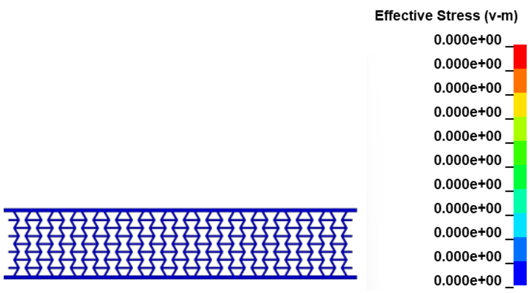


Fig.6.a Initial state of HEX

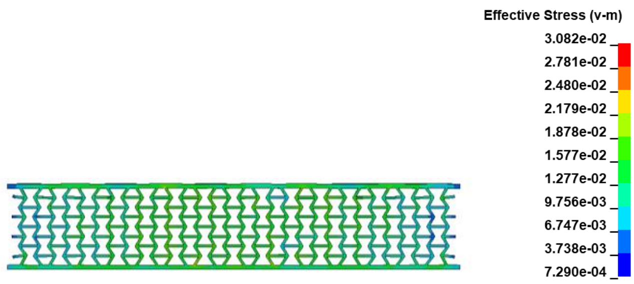


Fig.6.b 11.7 J Impact Response of HEX

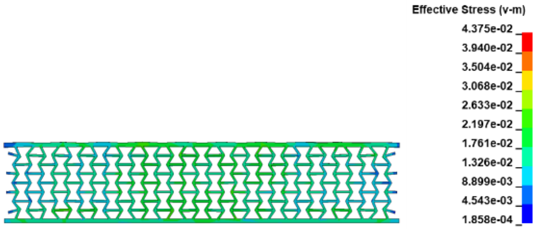


Fig.6.c 26.49 J Impact Response of HEX

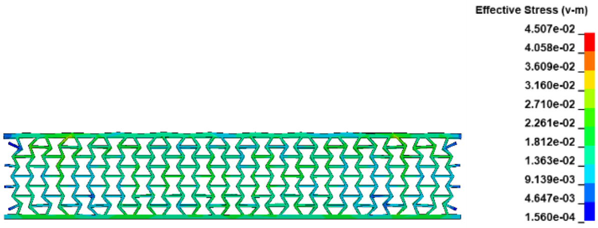


Fig.6.d 46.8 J Impact Response of HEX

2.3.2 Impact response of Hexagonal chiral sandwich structure (HEX_CHIRAL)

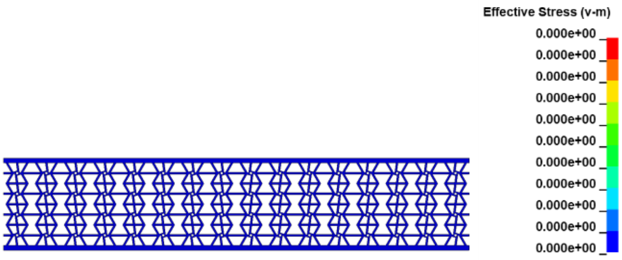


Fig.7.a. Initial state of HEX_CHIRAL

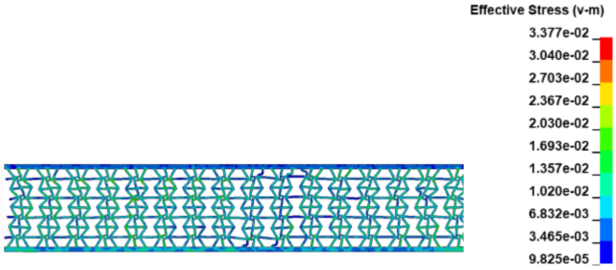


Fig.7.b. 11.7 J Impact Response of HEX_CHIRAL

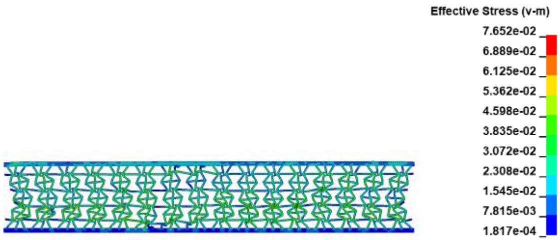


Fig.7.c. 26.49 J Impact Response of HEX_CHIRAL

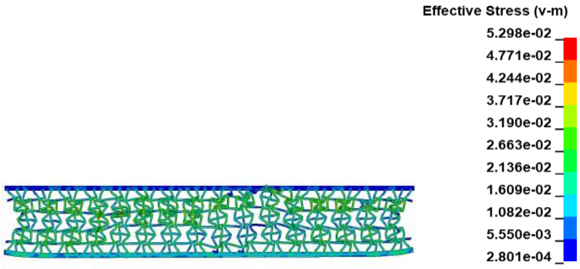


Fig.7.d. 46.8 J Impact Response of HEX_CHIRAL

2.3.3 Hexagonal re-entrant sandwich structure with a primitive core design (PRIMITIVE)

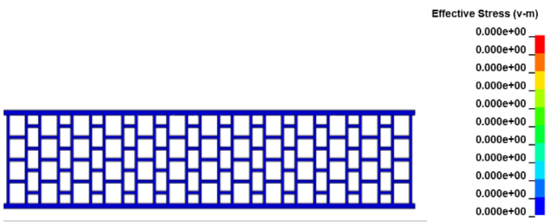


Fig.8.a. Initial state of PRIMITIVE

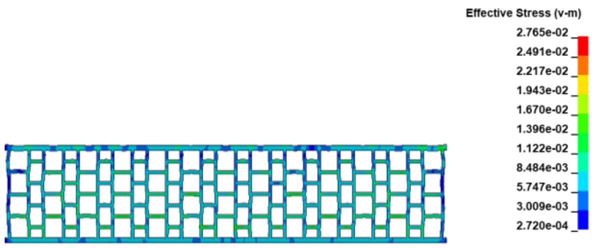


Fig.8.b. 11.7 J Impact Response of PRIMITIVE

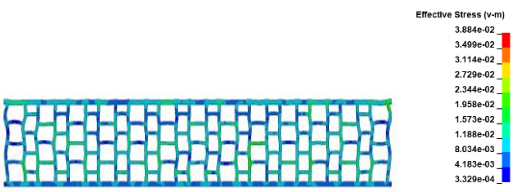


Fig.8.c. 26.49 J Impact Response of PRIMITIVE

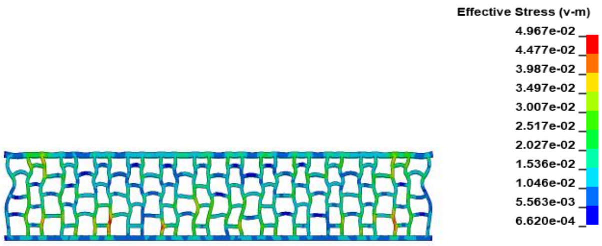
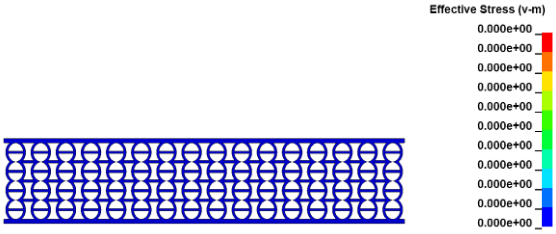


Fig.8.d. 46.8 J Impact Response of PRIMITIVE

2.3.4 Hexagonal re-entrant sandwich structure with core Walls at 0.5 conic parameter (HEX_0.5CON)



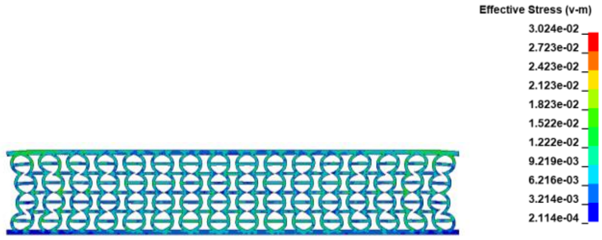
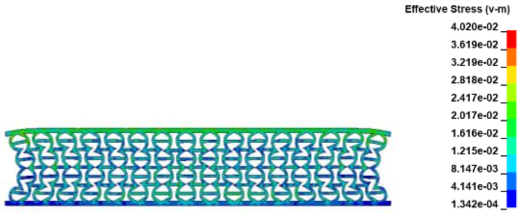


Fig.9.a. Initial state of HEX_0.5CON Fig.9.b. 11.7 J Impact Response of HEX_0.5CON



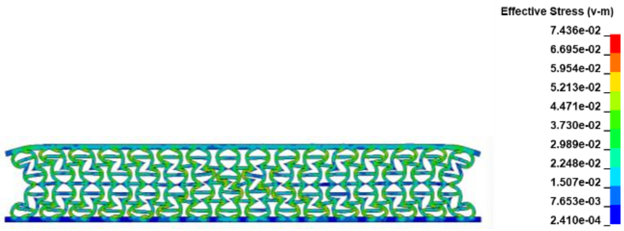
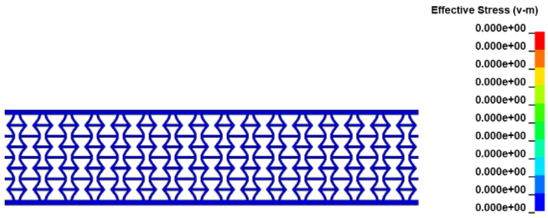


Fig.9.c. 26.49 J Impact Response of HEX_0.5CON Fig.9.d. 46.8 J Impact Response of HEX_0.5CON

2.3.5 Hexagonal re-entrant sandwich structure with core Walls at 0.7 conic parameter (HEX_0.7 CON)



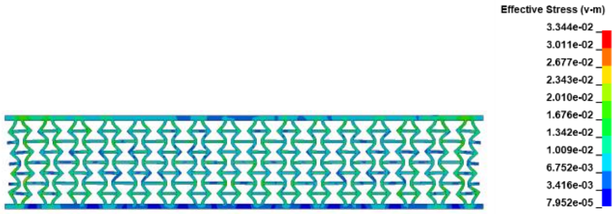
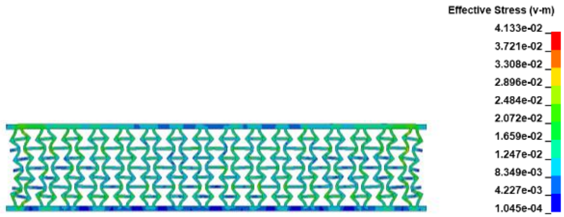


Fig.10.a. Initial state of HEX_0.7CON Fig.10.b. 11.7 J Impact Response of HEX_0.7CON



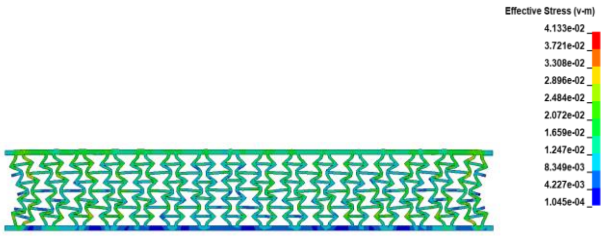


Fig.10.c. 26.49J Impact Response of HEX_0.7CON Fig.10.d. 46.8 J Impact Response of HEX_0.7CON

2.3.6 Comparative Performance

Combined plots of Kinetic Energy decay and Internal Energy build up in HEX, HEX_CHIRAL, PRIMITIVE, HEX_0.5CON and HEX_0.7 subject to impact loads of 11.7 J, 26.49 J and 46.8 J is presented in Fig. 11 to 13.

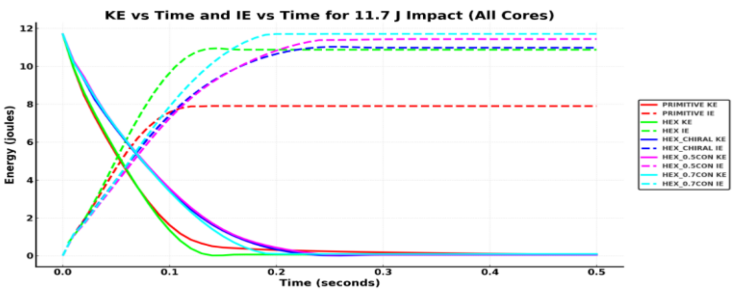


Fig. 11 Kinetic Energy vs. Impact Energy at 11.7 J impact

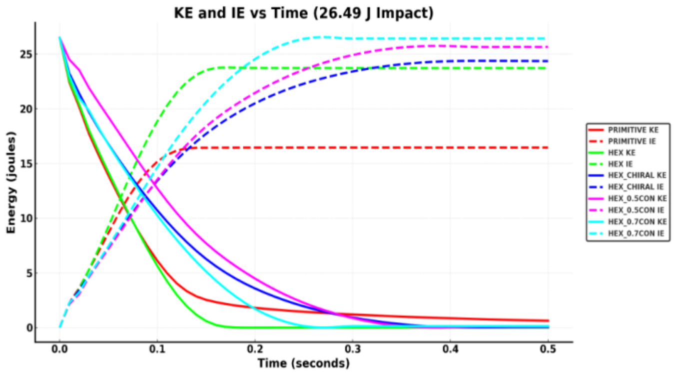


Fig. 12 Kinetic Energy vs. Impact Energy at 26.49 J impact

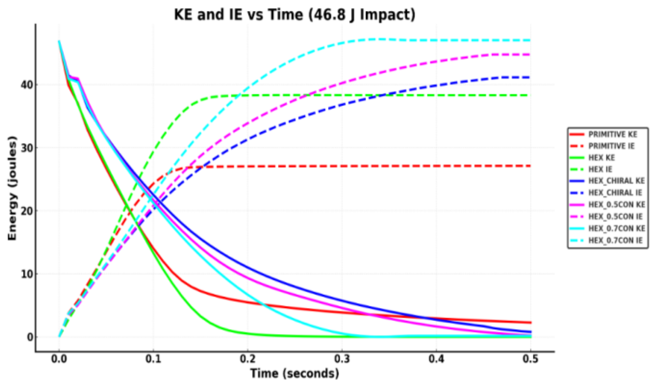


Fig. 13 Kinetic Energy vs. Impact Energy at 46.8 J impact

Kinetic Energy (KE) decay and Internal Energy (IE) accumulation plots across the three impact energy levels 11.7 J, 26.47 J and 46.8 J provide a quantitative understanding of how geometric variations in auxetic and conic-profiled cores influence impact absorption behaviour of sandwich composite variants.

In all plots KE invariably decreases with IE increases during the progresses of impact, but the rate of variations of KE and IE are peculiar for each core geometry. This highlights the dominant role of cell geometry in governing energy dissipation mechanisms.

At 11.7 J, the HEX_0.7CON rteaches an IE stabilization value of 11.72 J providing an efficiency of 1.00. HEX_0.5CON also performs exceptionally good with an IE stabilizing at 11.45 J, imparting efficiency of 0.98. The HEX and HEX_CHIRAL cores display moderately strong responses, each absorbing above 94% of the incident energy. IE of PRIMITIVE stabilizes at only 7.91 J thereby indicating an efficiency of 68% only. Fig. 10.

At 26.47 J, geometric effects become more pronounced. HEX_0.7CON once again exhibits complete conversion of KE to IE reaching 26.56 J (100% efficiency) and HEX_0.5CON reaches 25.75 J (97% efficiency). They outperform HEX_CHIRAL and HEX. The IE PRIMITIVE absorbs only 16.46 J (62% efficiency), showing a large proportion of energy transmitted through the composite. Fig. 11.

At 46.8 J, superiority of the conic-profiled cores in impact processing becomes conclusive. HEX_0.7CON again achieves full absorption (47.20 J), while HEX_0.5CON maintains near-complete conversion (44.77 J, 96% efficiency). This is undoubtedly the contribution of the conic geometry of the core walls. The HEX_CHIRAL core absorbs 41.14 J (88% efficiency) thereby reflecting the contribution of rotational ligaments. The lack of conics based stiffness grading limits its capacity relative to conic variants. HEX absorbs 38.34 J (efficiency at 82%) marking a clear drop in performance at higher load levels. The PRIMITIVE geometry performs poorest, stabilizing at 27.11 J (58% efficiency).

The comparative efficiency plot (Fig. 14) consolidates these observations by showing a distinct and consistent performance hierarchy across all impact energies:

HEX_0.7CON > HEX_0.5CON > HEX_CHIRAL > HEX > PRIMITIVE.

CORE TYPE	INTERNAL ENERGY AT STABILIZATION (Joules)			ENERGY ABSORPTION EFFICIENCY AT STABILIZATION		
	at 11.7 J	at 26.47 J	at 46.8 J	at 11.7 J	at 26.47 J	at 46.8 J
HEX	10.95	23.78	38.34	0.94	0.90	0.82
HEX_0.3CON	11.45	25.75	44.77	0.98	0.97	0.96
HEX_0.7CON	11.72	26.56	47.20	1.00	1.00	1.00
PRIMITIVE	7.91	16.46	27.11	0.68	0.62	0.58
HEX_CHIRAL	11.03	24.39	41.14	0.94	0.92	0.88

Table. 2 Internal Energy stabilization values and corresponding Energy Absorption Efficiencies.

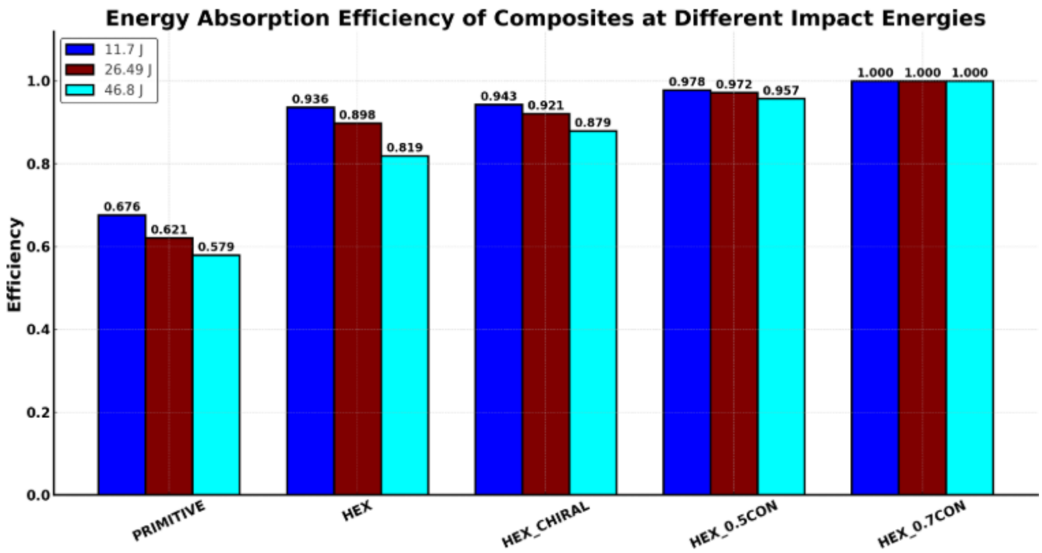


Fig. 14 Comparative plots of Energy Absorption Efficiency of composite variantsfor three different energy levels

2.4 Conclusion

The study reveals that geometric tailoring through conic profiling is the most influential factor governing impact resilience in sandwich composites. HEX_0.7CON core consistently demonstrates the highest performance, achieving 100% energy absorption efficiency across all impact energies. This is by virtue of its core topology characterized by conic profiling of hexagonal auxetic re-entrant geometry. The HEX_0.5CON variant follows closely with efficiencies of 0.96–0.98 confirming the role of conic profiling in Internal Energy accumulation. Chiral augmented auxetic cores exhibit improved absorption over classical re-entrant geometries. HEX core shows only moderate IMPACT handling capability especially at higher impact loads where its efficiency drops to **0.82**. The PRIMITIVE core performs the poorest, absorbing only 58–68% of incident impact energy. This highlights the inability of vertical walled cores to engage in progressive crushing while handling impact scenarios. The results establish the clear performance hierarchy HEX_0.7CON > HEX_0.5CON > HEX_CHIRAL > HEX > PRIMITIVE. This confirms that conic auxetic hybrids offer the most robust impact-mitigation behaviour among all tested core architectures.

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