

# Velocity Impact Performance of Hybrid Composite Structures

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**Abstract:** A numerical investigation of the low-velocity impact (LVI) behavior of carbon, flax and hybrid flax-carbon composite laminates (CFC, FCF) to find a compromise between sustainability and mechanical performance. Woven carbon and flax fabrics embedded in a toughened epoxy resin were used to create laminates. Carbon composites exhibited the highest strength and specific energy absorption, whereas flax exhibited better ductility but low load-bearing ability. MAT54/55 carbon plies, MAT58 flax plies and cohesive elements (MAT138) for interlaminar damage were used to create numerical finite element (FE) models in LS-DYNA that faithfully replicated the tensile, compressive, and impact behaviors. Load-displacement curves with energies ranging from 10-55 J were considered. The findings highlight that although flax and hybrid laminates cannot be expected to compete with carbon composites in terms of pure energy absorption, hybridization significantly improves the mechanical response of natural fibre-reinforced laminates, thus supporting them as eco-friendly energy-absorbing structures within the transportation and structural industries. The stacking techniques, both quasi-isotropic and all layers aligned at 0°, alternate C-F fibre arrangement and comparison between the CZM and Tie-break contact along with strain rate sensitivity were carried out. Carbon laminates exhibited the highest specific energy absorption and load capacity, flax laminates with larger displacements but lower energy absorption, while hybrid provided a compromise between the two. This proves that although carbon laminates are the most efficient in strength and energy absorption, flax and hybrid laminates can still offer satisfactory impact resistance and sustainability; therefore, they are appealing alternatives for lightweight and environmentally sustainable structural and automotive components.

**Keywords:** Carbon, Flax, Hybrid Composites, LS DYNA, Low Velocity Impact, Non-Destructive Evaluation, Structural, Strength

## I. INTRODUCTION

The improvement of structural materials has always been motivated by the necessity to enhance performance while reducing weight. This is also known as the “strength-to-

weight” or “stiffness-to-weight” optimization. Metals such as steel, aluminium, and titanium have traditionally been used in structural applications owing to their properties, processing routes, and performance. However, in the latter part of the last century, this position of metals was threatened by composites. Initially, CFRP were targeted, with their unparalleled stiffness and strength-to-weight characteristics. Hybrid composites were brought in as a tool to combine the beneficial characteristics of several fiber systems in one laminate. This concept of “tailoring material at the structural level” represented a paradigm shift, allowing engineers to tailor mechanical performance according to application-defined requirements [1,2,7,26]. When analyzing hybrid composites under velocity impact conditions, the situation is far more complex than in static or fatigue cases. As opposed to static loading in which stress is transferred progressively and damage is propagated in a well-controlled manner, impact loading involves localized and transient loads that tend to transcend the inherent strain-rate accommodation ability of the composite[18,19,20]. In addition, as opposed to metals that tend to deform plastically in order to absorb energy, fiber-reinforced composites depend largely on damage tolerance mechanisms, including matrix cracking, fiber pull-out, and delamination, to absorb impact energy[31]. In hybrid composites, such mechanisms are further amplified by the heterogeneity provided by multiple fibers, so their response is highly sensitive to stacking sequence, hybridization scheme, and fiber-matrix adhesion. The velocity regimes, each linked to various failure mechanisms. Under low velocity impacts e.g., tool falls or runway debris, the damage might not necessarily be seen on the surface but may cause widespread internal delamination—usually referred to as BVID[15,16]. This decreases residual stiffness and strength, and may cause sudden in-service failure under future loads[5,8,9]. At intermediate, the impact energy is adequate to create local fiber breakage, matrix cracking, and global laminate deformation. Lastly, at high impacts like ballistic penetration, failure modes such as perforation, fragmentation, and laminate disintegration are seen[11,14]. Hybrid composites are usually developed to seek the balance of performance across these regimes such that not only is damage tolerance retained in low-velocity impacts but also resilience and survivability for extreme high-velocity impacts[27,30].

One of the reasons why hybrid composites are of special interest in impact-critical applications is that they have a potential to balance stiffness, strength, toughness, and cost. Carbon fiber composites, for example, though possessing high modulus and strength, are brittle and costly[22,23]. Likewise, natural fibers like flax, when hybridized with man-made fibers, provide enhanced damping, energy absorption, and sustainability advantage without substantially detracting from mechanical strength the elasticity in property tailoring thus renders hybrid composite material choice for industries that need to optimize concurrently performance, safety, and cost-effectiveness[28]. The increasing need for sustainable and recyclable hybrid composites also adds further impetus to the research in this area, since engineers aim to minimize environmental footprint while not compromising structural dependability. The velocity impact of hybrid composite structures helps to advance how materials respond under dynamic high strain-rate conditions. Composites manifest nonlinear, anisotropic, and heterogeneously behaving material characteristics that cannot be treated by simple analytical solutions[24]. Fiber–matrix interface, vital for load transfer under quasi-static loading, plays an important role under impact since it determines if energy is dissipated due to debonding or transferred into the fiber network. Furthermore, it shows that there is interaction between materials, for instance, stress concentrations that occur in hybrid fibers, where different fibers are used, thus creating complexity in their behavior. Hybrid fiber-reinforced composites are increasingly being used in bridge decks, column reinforcement, and barriers due to their light weight and resistance to corrosion. In all these applications, the function of velocity impact studies is not abstract but has practical consequences for safety, durability, and performance[17]. Their behavior is very much a function of design decisions like fiber volume fraction, stacking sequence, and hybridization technique (intra-ply vs inter-ply). Inadequate design can be worse than single-fiber laminates as they can suffer from premature delamination or poor interfacial bonding between unlike fibers. The importance of investigating the velocity effect of hybrid composite structures is therefore doubly-named: it responds to current engineering requirements for more reliable, safer structures, and it further develops the general field of materials science by revealing the intricate interaction among constituents of the material under severe loading. With continuous progress in manufacturing technologies—like (AFP), 3D weaving, and additive manufacturing—the hybrids could be designed with unrestrained precision, which unlocks new domains for impact-resistant structural systems[21]. Combined with computational simulations like finite element analysis, cohesive zone modeling, and artificial intelligence-assisted material optimization, the domain of velocity impact studies is leading the pack of composite research in the 21st century[10,25].

## II. AIM, OBJECTIVE AND SCOPE

The aim of this project is to model and analysis hybrid composite structure. The primary objectives are as follows:

To study velocity impact in hybrid composite structures -LS DYNA. Assess the energy absorption and failure modes under various impact conditions. Compare natural, synthetic, and hybrid composites for designing lightweight, safe, and sustainable products. Use various stacking sequences and fiber ratios of carbon and flax. Use various ply orientations such as  $0^\circ$ ,  $\pm 45^\circ$ , and  $90^\circ$ . Damage Analysis: Analyze delamination, matrix cracks, and energy absorption. Cohesive sensitivity: Comparison of the hybrid composite with cohesive zone modelling and Tie break contact. Strain-rate sensitivity. Inter-laminar and intra-laminar behaviour of plies -Ply by ply behaviour. The requirement to investigate the same is increasing need for materials with lightweight, safety, and sustainability. Hybrid composites that integrate synthetic fibers with natural fibers to provide a specific combination of high stiffness, strength, and enhanced energy absorption. It prevents structural integrity and service life from being affected in safety-critical situations.

Yet another critical need is generated because of the world's shift towards sustainability. Hybridization of natural and man-made fibers meets the critical need for sustainable high-performance composites that match global climate objectives such as Agenda 2030 and 2050 sustainability objectives. The current scope of velocity impact studies on hybrid composite structures is broad and multi-dimensional, ranging from basic scientific investigation to industrial applicability. Hybrid laminates are also being considered for blast-resistant facades and protection structures as a sustainable alternative to conventional impact-resistant materials. In conclusion, the field has moved beyond conventional material testing to include considerations of sustainability-driven innovation, industrial applications, and modeling techniques, so it stands to reason that hybrid composites must be at the center of impact-resistant design in the future. Experimental testing is not sufficient to capture the enormous design space.

## III. METHODOLOGY

Material properties such as Young's Modulus, Poisson's ratio, density, tensile and compressive, shear strength, fracture toughness ( $G_{IC}$ ,  $G_{IIC}$ ) will be assigned to capture the behaviour under different velocities. Use of load-displacement curves for estimation of impact performance in hybrid composite from 10-55J. Carbon- Flax composite structure is the one preferred and the comparison of the individual versus combination is getting assessed. Carbon - MAT54, Flax-MAT58 and cohesive mixed mode MAT138.

### *Procedure:*

Initially, a carbon only model with boundary condition of 76 mm diameter circular clamping outward, provided with the material and section properties which later incorporated to parts. The surface to surface contact between the plate and impactor also gets defined. Control the timestep, termination and database for plots are run the model. Flax only model with 4 shell layers and 3 cohesive solid layers and spherical impactor with structured. An initial velocity of 1.13m/s is provided and repeated for 1.38, 1.53, 1.97, 2.28, 2.54, 2.67m/s. For the plate -cohesive layers, single surface contact and plate – impactor layers surface to surface contact. The CFC, FCF hybrid model are also considered as shown in Fig.1. The study involving the orientations and various

layups such as single -double stacking sequence and alternating with 0, 45 and ISO are also considered. This is followed by the comparison between the CZM and Tie break contact. Models are repeated for a regime of 10-55J.

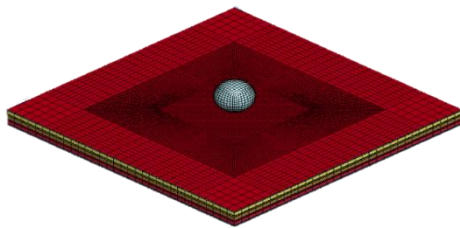


Fig.1 Impact model

The load vs displacement curve of the model are considered for the same. Pure carbon model with energies 20, 30, 40, 50 and 55J shows the corresponding displacement of 7.76, 7.54, 9.96, 10 and 7.9 mm respectively. Pure flax model with energies 10, 15, 20, 30 and 40J shows 2.72, 3.20, 4.24, 3.16 and 4.27 mm respectively. For CFC  $[0]_8$  20, 30, 40 and 50 J has 5.65, 5.1, 6.45 and 6.87 mm while  $[0_3/45/-45/90/0_2]$  5.84 and 5.87mm displacement for 20 and 50J. Hybrid FCF model with energies 20, 30, 40, 50 and 55J has 6.8, 7.69, 8.36, 6.94 and 6.9 mm respectively. Layup variations in the hybrid model including the single – double and alternating stacking and the comparison for this at lower energy of 20J and critical energy of 50J. For carbon, flax only and hybrid model orientations of 0, 45, -45 and 90 are taken into account. The comparison of cohesive zone model and tie break contact for the CFC hybrid model for showcasing the better performance aspect of CZM. For the layup variations CFC, FCF and alternate CF and FC are considered and Fig.2 and 3 shows the obtained plot. From the above, it is clear that CFC in comparison with FCF shows a difference of 20.3 % for 20J and 1.01% in 50J. Initially, orientations are  $[45]_8$  where carbon only shows 7.36 and 9.35mm for 20 and 50J with a difference of 5.15, 5.65% from  $[0]_8$ . Flax only shows 2.60 and 3.97mm for 20 and 50J with a difference of 4.41, 7.02 %. CFC hybrid only shows 5.57 and 6.22 mm with a difference of 1.41, 9.4 % and FCF 5.5 and 6.51mm with 19.8, 6.19 % from  $[0]_8$ . CFC ISO shown from Fig. 4 -11.

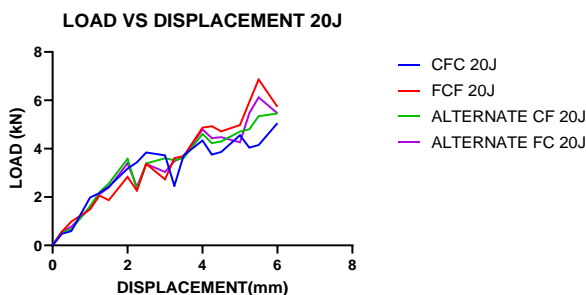


Fig. 2 Load vs Displacement 20 J- Layup

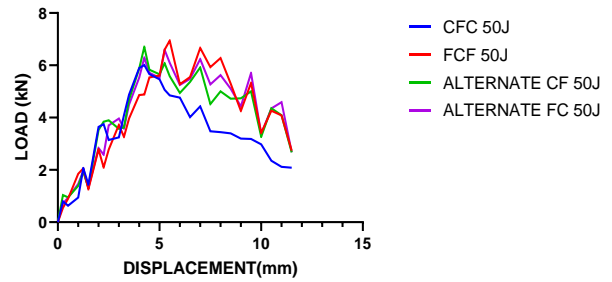


Fig. 3 Load vs Displacement 50 J- Layup

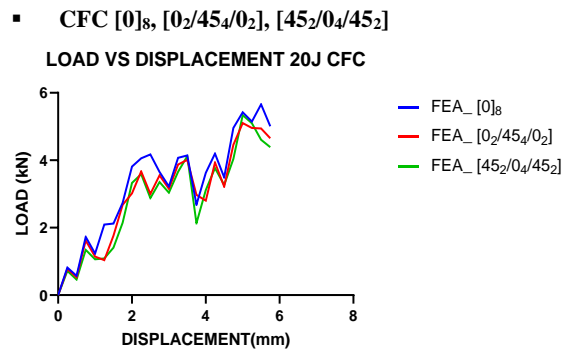


Fig. 4 Load vs Displacement CFC - 20J

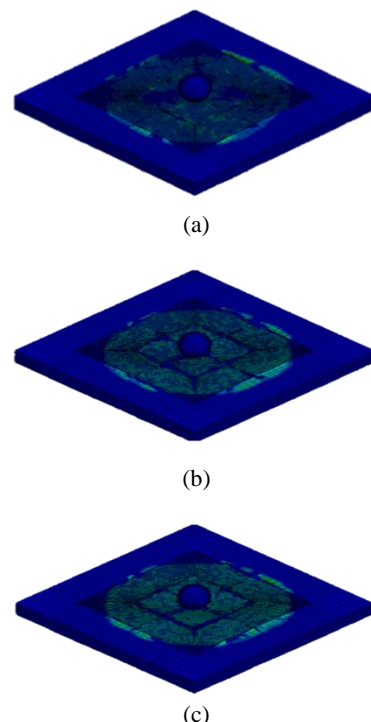
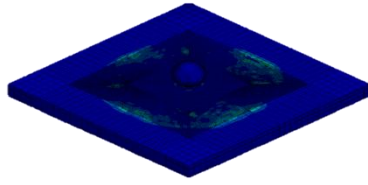
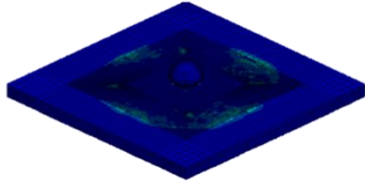


Fig. 5 (a) CFC  $[0_2/45_4/0_2]$  (b) CFC  $[45_2/0_4/45_2]$  (c) CFC  $[0]_8$   
 $CFC [0_2/45_4/0_2] > CFC [45_2/0_4/45_2] > CFC [0]_8$



(a)



(b)

Fig. 6 (a) CFC  $[0_2/-45_4/0_2]$  (b) CFC  $[-45_2/0_4/-45_2]$   
 $CFC [0_2/-45_4/0_2] > CFC [-45_2/0_4/-45_2] > CFC [0]_8$   
 • CFC  $[0]_8, [0_2/-45_4/0_2], [-45_2/0_4/-45_2]$

LOAD VS DISPLACEMENT 20J CFC

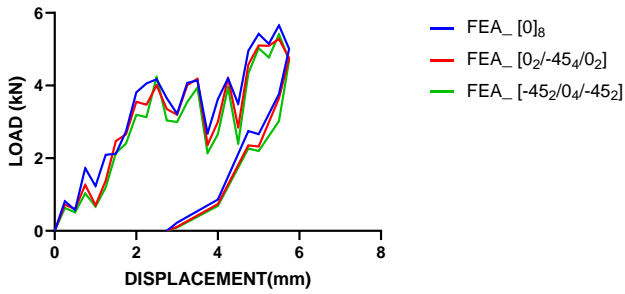


Fig. 7 Load vs Displacement 20 J- Layup  
 • CFC  $[0]_8, [0_2/45_4], [45_4/0_2]$

LOAD VS DISPLACEMENT 20J CFC

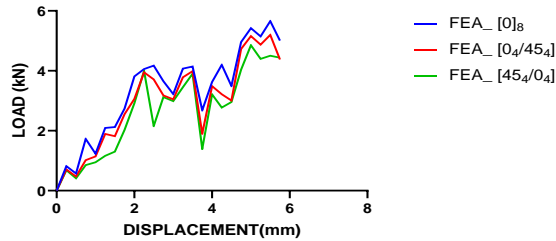
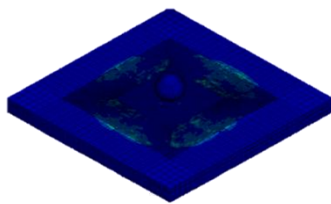
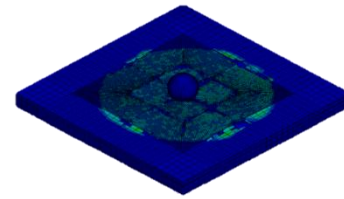


Fig. 8 Load vs Displacement 20 J- Layup



(a)



(b)

Fig.9 (a) CFC  $[45_4/0_4]$  (b) CFC  $[0_4/45_4]$   
 $CFC [45_4/0_4] > CFC [0_4/45_4] > CFC [0]_8$   
 • CFC  $[0]_8, [0_4/-45_4], [-45_4/0_4]$

LOAD VS DISPLACEMENT 20J CFC

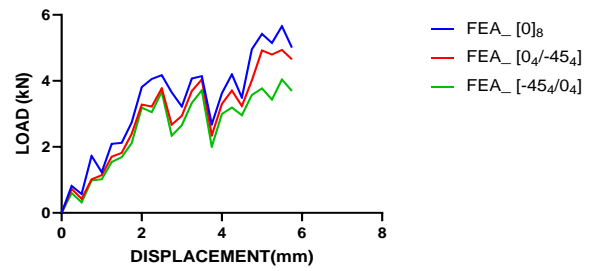
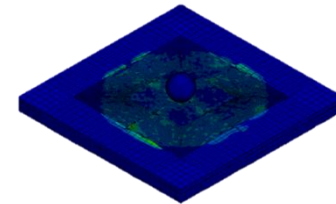
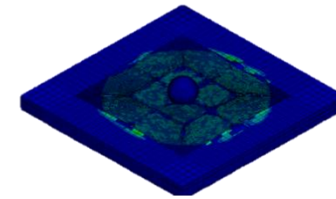


Fig. 10 Load vs Displacement 20 J- Layup



(a)



(b)

Fig.11 (a) CFC  $[-45_4/0_4]$  (b) CFC  $[0_4/-45_4]$   
 $CFC [-45_4/0_4] > CFC [0_4/-45_4] > CFC [0]_8$

LOAD VS DISPLACEMENT 20J

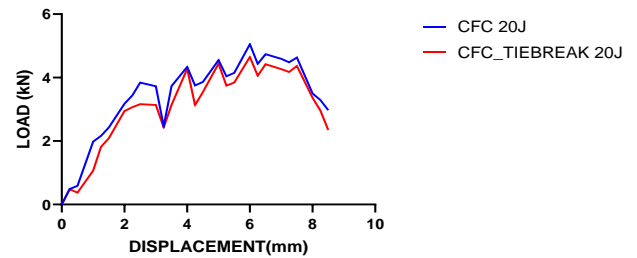


Fig. 12 Load vs Displacement 20 J- Layup  
 CFC -CZM and Tie Break comparison for 20 and 50J are shown in Fig. 12 and 13 where 4.65 and 5.78 mm indicating 7.92, 3.82% difference in between.

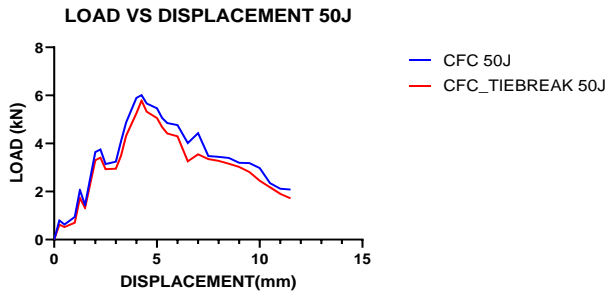


Fig. 13 Load vs Displacement 50 J- Layup

- **Specific Energy Absorption**

- i. CARBON

- For 20 J - Baseline (Elastic-Dominated Response)**

- Energy absorption is purely elastic with negligible damage. Dominated by bending strain energy, with almost no delamination or failure progression.

- For 30J - Onset of Damage Initiation**

- Transition from elastic to damage initiation. First appearance of matrix cracking and interlaminar (Mode II) delamination, though still controlled and stable.

- For 40 J - Critical Energy Threshold**

- Peak energy absorption with instability onset. Marks the transition from stable to unstable damage, with maximum load and significant delamination growth.

- For 50 J - Damage-Dominated Absorption**

- Shift from stiffness-controlled to fracture-controlled behavior. Energy absorbed mainly through extensive delamination and fibre failure, not elastic deformation.

- For 55 J - Collapse / Pseudo-Ductile Regime**

- Energy absorption governed by global structural collapse mechanisms. Dominated by membrane action, fibre pull-out, and progressive collapse, with plateau-type response.

- ii. FLAX

- For 10J- Elastic-Damping Dominated Response**

- Energy absorption is elastic with high damping and negligible damage. Behaviour governed by viscoelastic bending, not fracture.

- For 15J- Damage Initiation with Interface Weakening**

- First activation of interfacial damage (delamination + matrix cracking). Transition from pure elastic damping → elastic-damage interaction.

- For 20J- Peak Load Mobilization**

- Maximum load-carrying capacity reached. Energy absorption shifts to combined fibre mobilization + delamination propagation.

- For 30 J- Fibre Pull-Out Dominated Absorption**

- Transition to pull-out and friction-based energy absorption. Less brittle failure, more softening due to damping.

- For 40 J- Membrane + Plateau (Ductile Collapse Behavior)**

- Energy absorption governed by membrane action and long plateau response. Fully damage-dominated with frictional sliding and ductile fibre failure.

- iii. CFC

- For 20J- Carbon-Dominated Elastic Control**

- Energy absorption is governed almost entirely by carbon skins (elastic bending). Hybrid effect is minimal; flax core is largely inactive.

- For 30J- Interface-Controlled Transition**

- Interfacial mismatch becomes dominant, triggering early delamination. Shift from pure carbon control → interface-driven damage response.

- For 40 J- Optimal Hybrid Interaction**

- Maximum synergy between carbon skins and flax core. Energy absorption is most efficient due to combined stiffness (carbon) + ductility (flax).

- For 50J- Hybrid Fracture + Membrane Mechanism**

- Energy absorption governed by hybrid fracture mechanisms and membrane action. Carbon undergoes brittle failure, while flax enables pull-out and bridging, preventing sudden collapse.

- iv. FCF

- For 20J- Flax Surface-Controlled Elastic Response**

- Energy absorption is controlled by flax outer layers, reducing stiffness. Carbon core remains inactive and intact

- For 30J- Carbon Core Activation Begins**

- Carbon core starts contributing to load resistance (tensile role). Transition from flax-dominated → hybrid participation begins

- For 40J- Peak Hybrid Synergy (Maximum Load)**

- Full mobilization of carbon core + flax layers. Achieves maximum load capacity with combined hybrid action

- For 50 J- Surface Failure Governs Response**

- Early crushing of flax outer layers limits peak performance. Energy absorption shifts to pull-out and delamination, reducing structural efficiency.

- For 55J- Membrane + Progressive Collapse**

- Energy absorption governed by membrane action and progressive failure. Flax crushing + carbon membrane stiffness prevents sudden collapse

- v. CFC ISO

- For 20J- Brittle Peak with Sudden Collapse**

- Energy absorption is stiffness-driven with abrupt post-peak failure. Dominated by carbon limit failure with immediate stiffness collapse, minimal hybrid contribution.

- For 50J- Progressive, Membrane-Dominated Absorption**

- Energy absorption shifts to progressive mechanisms with extended tail response. Governed by delamination, fibre pull-out, and membrane action, with flax core becoming dominant.

- **Strain rate sensitivity**

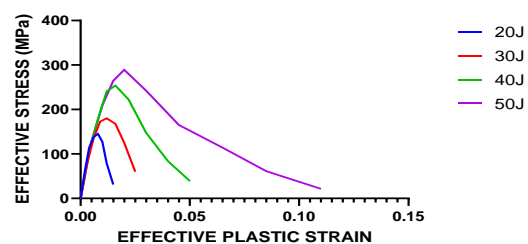


Fig. 14 Stress vs Strain  
 For 20J- No Effective Damage Activation

Response remains stiffness-controlled with negligible strain-rate-driven damage. Only matrix microcracking, no progressive mechanisms; laminate behaves almost elastically ( $D \approx D_0$ )

#### For 30J- Damage Initiation Threshold

Strain rate becomes sufficient to trigger first interlaminar delamination. Transition from elastic response  $\rightarrow$  interface-controlled damage initiation ( $D < D_0$ )

#### For 40J- Stable Progressive Damage Propagation

Strain rate drives continuous energy absorption via multiple mechanisms. Delamination + fibre pull-out + friction dominate, with clear stiffness degradation and controlled softening

#### For 50J- Failure-Dominated, Maximum Strain Accumulation

Strain rate leads to structural breakdown and longest plastic deformation regime. Fibre fracture + ply fragmentation + large-scale delamination, with membrane-like load transfer replacing bending

20 J < 30 J < 40 J < 50 J in peak stress. 50 J shows longest plastic strain region. Smooth softening. Peak 250- 300 MPa as shown in Fig.14. Hybrid strength is lower than pure carbon. Flax core reduces global stiffness. Damage initiates earlier. Stress magnitudes 200-300 MPa for hybrid impact response. Shear deformation increases. Delamination reduces effective load transfer. Flax core experiences compressive deformation. CZM layers undergo delamination.

Stress increases with impact energy due to higher contact force, larger bending deformation, greater interlaminar shear, more matrix plasticity. At 50J: Laminate stiffness degrades, System takes longer to recover. Higher energy- higher velocity- higher contact force. Contact force increases with energy. Plastic strain region becomes larger at 50 J. Matrix cracking starts first. Then delamination initiates. Flax core yields earlier. Progressive stiffness degradation occurs. Damage spreads over a large area. Plastic deformation accumulates. Stress softening tail becomes longer. Impact loading is bending- dominated, not pure tension. Laminate never reaches fiber tensile failure. Matrix cracking, shear damage, delamination, local indentation. Reduced rebound energy confirms greater internal damage. Carbon – slight strain rate sensitivity, Flax- moderate strain rate sensitivity. Rebound energy = initial kinetic energy – absorbed energy. For CFC hybrid: 20J –high rebound (minor damage), 30J – moderate rebound, 40J – reduced rebound, 50J – lowest rebound (maximum damage). Plastic strain tail is longest.

- *Inter and intralaminar behavior: Kinking failure*

#### CFC

For 20J, elastic-dominated, matrix cracking failure mode with very small delamination and fibre kinking initiation as shown in Fig.15. Here, the interlaminar shear is low. Localized stress trend with maximum  $\sigma_x$  329, Von Mises 352, maximum principal  $\sigma_1$ 344, minimum principal  $\sigma_3$ -250 MPa. Circular damage radius of 10-12mm. Moderate central deformation and small bending zone. Intact carbon plies, active flax core. Matrix cracking with high energy dissipation. Preserved stiffness, high load capacity and resilience. Failure initiation and plate bending. The structure is stable with moderate shear trend.

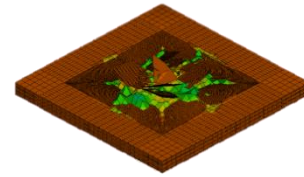


Fig. 15 CFC 20J

For 30J, fibre instability onset, fibre kinking failure mode with moderate delamination and fibre kinking propagation as shown in Fig.16. Here, the interlaminar shear is increasing. Expanding stress trend with maximum  $\sigma_x$  445, Von Mises 484, maximum principal  $\sigma_1$ 469, minimum principal  $\sigma_3$ -170 MPa. Circular damage radius of 18-22mm. Significant central deformation and expanded bending zone. Unstable carbon plies, active flax core. Matrix and fibre cracking with mixed energy dissipation. Reduced stiffness, load capacity and resilience. Failure transition and stiffness mismatch. The structure starts instability with high shear trend.



Fig. 16 CFC 30J

For 40J, compression-dominated critical, fibre crushing failure mode with large delamination and strong fibre kinking as shown in Fig.17. Here, the interlaminar shear is very high. Concentrated core stress trend with maximum  $\sigma_x$  746, Von Mises 719, maximum principal  $\sigma_1$ 420, minimum principal  $\sigma_3$ -205 MPa. Circular damage radius of 25-30mm. Severe central deformation and distorted bending zone. Crushing carbon plies, crushed flax core. Fibre crushing with fragmentation energy dissipation. Degraded stiffness, critical drop load capacity and low resilience. Failure propagation and interlaminar shear. The structure reduces capacity with peak shear trend.

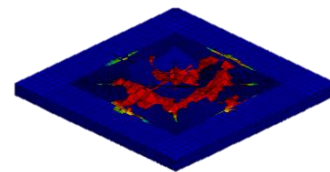


Fig. 17 CFC 40J

For 50J, post-failure degradation, matrix cracking failure mode with very small delamination and fibre collapse shown in Fig.18. Here, the interlaminar shear governs failure. Redistributed stress trend with maximum  $\sigma_x$  611, Von Mises 686, maximum principal  $\sigma_1$ 529, minimum principal  $\sigma_3$ -217 MPa. Circular damage radius of 30-40mm. Very large central deformation and fully developed bending zone. Fragmented carbon plies, ineffective flax core. Fracture with failure-driven energy dissipation. Collapse stiffness, lost load capacity and zero resilience. Catastrophic and global failure. Failure dominates the structure with redistributed shear trend.

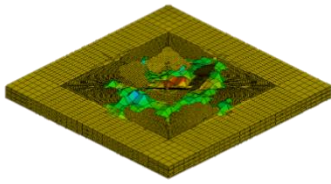


Fig. 18 CFC 50J

#### **Progressive Damage Evolution**

From 20-50J, moves from safe to failure. Matrix cracking, kinking of fibres, crushing of fibres, delamination, and catastrophic failure.

### **IV. RESULTS AND DISCUSSION**

FCF has the highest peak. CFC has difference of 26.3%, alternate CF with 20.5% and FC 10.7% of % for 20J. CFC 13.4%, alternate CF with 3.4% and FC of 5.1% for 50J. Contact oriented, Carbon has greater stiffness while flax show more displacement.  $CFC > Alternate\ CF > Alternate\ FC > FCF$ . Alternate design strategy improves impact tolerance and delamination resistance. CFC shows lowest peak in both 20 and 50J. Plateau behavior is smooth for CFC which makes the sequence with highest preference. CFC  $[0]_8$  has the highest peak, principal bending stress. CFC  $[0_2/45_4/0_2]$  has difference of 9.73%, CFC  $[45_2/0_4/45_2]$  of 5.66 % for 20J. CFC  $[0_2/45_4/0_2]$  of 12.95%, CFC  $[45_2/0_4/45_2]$  of 17.03 % for 50J. Lamina oriented,  $[0]_8$  has greater stiffness while  $[45]$  and  $[-45]$  show more displacement.  $CFC\ [0_2/45_4/0_2] > CFC\ [45_2/0_4/45_2] > CFC\ [0]_8$ . Angle plies arrest crack propagation – stresses to shear. CFC  $[0_2/45_4/0_2]$  which makes the sequence with highest preference. CFC  $[0_2/-45_4/0_2]$  has difference of 6.54 % and CFC  $[-45_2/0_4/-45_2]$  of 4.24 % for 20J. CFC  $[0_2/-45_4/0_2]$  of 10.18 % and CFC  $[-45_2/0_4/-45_2]$  of 14.11 % for 50J. CFC  $[0_2/-45_4/0_2] > CFC\ [-45_2/0_4/-45_2] > CFC\ [0]_8$ . CFC  $[0_2/-45_4/0_2]$  which makes the sequence with highest preference. CFC  $[0_4/45_4]$  has difference of 8.14% and CFC  $[45_4/0_4]$  of 14.15 % for 20J. CFC  $[0_4/45_4]$  of 6.25%, CFC  $[45_4/0_4]$  of 13.97 % for 50J. CFC  $[45_4/0_4] > CFC\ [0_4/45_4] > CFC\ [0]_8$ . CFC  $[45_4/0_4]$  which makes the sequence with highest preference. CFC  $[0_4/-45_4]$  has difference of 12.74 % and CFC  $[-45_4/0_4]$  of 28.4 % for 20J. CFC  $[0_4/-45_4]$  of 8.15 %, CFC  $[-45_4/0_4]$  of 12.22 % for 50J. CFC  $[-45_4/0_4] > CFC\ [0_4/-45_4] > CFC\ [0]_8$ . CFC  $[-45_4/0_4]$  which makes the sequence with highest preference. SEA, at (20–30 J) carbon laminates exhibit high initial stiffness, efficient energy storage through elastic bending, low damage and minimal interlaminar activity. 40 J, a critical transition is observed, characterized by significant delamination growth, fibre–matrix debonding, and progressive stiffness degradation. 50–55 J, the response becomes dominated by fracture mechanisms including fibre breakage, kinking, and pull-out, extensive delamination and membrane action, indicating a loss of structural integrity. In contrast, flax laminates exhibit a more ductile energy absorption mechanism. At 30–40 J, flax laminates show stable load–displacement plateaus, indicating progressive damage evolution and high damping characteristics. This behavior highlights their superior ability to absorb impact energy without catastrophic failure.

Hybrid laminates (CFC and FCF) shows improved SEA performance. The carbon layers provide stiffness and load-bearing capacity, while the flax layers contribute to energy dissipation through ductile failure mechanisms. 40–50 J, hybrid laminates exhibit optimal energy absorption due to the coexistence of delamination, fibre bridging, and frictional sliding. Consequently, hybrid configurations demonstrate superior impact resistance and delayed failure compared to pure laminates.

The strain rate sensitivity of 20 J, the response is primarily elastic, with negligible plastic deformation and limited to matrix micro-cracking. As 30 J, interlaminar shear stresses exceed the interface strength, initiating delamination and introducing mild nonlinearity in the response. 40 J, the laminates exhibit pronounced strain rate sensitivity, characterized by significant softening behavior, extensive delamination, and fibre pull-out. The neutral axis shifts due to the accumulation of damage, which in turn affects the amount of deformation. The mechanism of energy absorption in this phase is based on the combination of debonding, friction, and progressive cracks. In the 50 J phase, the response is nonlinear, with a significant amount of plastic strain and a long softening tail. Carbon fibres begin to fail in tension at the bottom surface, whereas compressive failure occurs at the top surface, resulting in a fragmented laminate. Hybrid laminates show controlled strain rate sensitivity, which in turn helps in the progression of damage evolution. Overall, hybridization reduces peak stress levels but enhances damage tolerance and impact resistance.

The interlaminar and intralaminar behavior at 20 J, intralaminar matrix cracking, with minimal delamination and only the initiation of fibre kinking. The structure remains stable. Localized damage is also observed. However, stiffness is maintained. When the energy input is 30 J, kinking of the fibre is more pronounced. This indicates that intralaminar instability is occurring. This is where stability is changed to damage growth. 40 J, failure mechanisms intensify, with fibre crushing and strong kinking dominating the response. Extensive delamination and high interlaminar shear stresses result in significant damage propagation and severe stiffness degradation. The critical transition point, beyond which structural integrity is compromised. At 50 J, the laminates exhibit post-failure behavior characterized by extensive interlaminar damage, fibre collapse, and matrix cracking. The carbon plies fragment, and the flax core becomes ineffective, resulting in a fully developed damage state. The structure loses its load-bearing capacity and behaves as a fragmented layered system. The progression of failure mechanisms follows a sequence from matrix cracking to fibre kinking, fibre crushing, and ultimately laminate collapse.

### **V. CONCLUSION**

Velocity impact plays a vital role in hybrid composite performance. Higher strength and energy absorption it also predicts impact behavior. Unified velocity-impact models are still lacking in research. The study focuses on strain-rate sensitivity, CZM in a way that it aims to enhance durable and lightweight structural designs. Carbon laminates possess the

highest stiffness and peak load capacity but fail in a brittle manner with limited deformation.

Among the hybrids CFC shows the best performance and the stacking sequences along with the alternate design strategy which is followed by the orientations and layups shows  $[0_2/45_4/0_2]$ ,  $[45_4/0_4]$  the impact behaviour are contact oriented rather than core and peak do not ensure strength gain. Specific energy absorption increases with impact energy but critical threshold of 40 J. Hybrid laminates achieve the best performance by resulting in enhanced energy absorption and improved damage tolerance.

Strain rate sensitivity increases with impact energy. Hybrid laminates prevent catastrophic failure and promoting gradual energy dissipation. The critical instability that causes failure is a result of interlaminar shear being the governing factor in damage evolution, and fibre kinking is a critical instability mechanism. Therefore, the optimal design of impact-resistant composite structures should be aimed at balancing stiffness and ductility through hybridization of materials to achieve maximum energy absorption.

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