Mechanics of Advanced Composite Structures

Journal homepage: https://macs.semnan.ac.ir/

Semnan University

ISSN: 2423-7043

*Research Article*

# Comparative Study on Impact Responses of Sandwich Composites with Stiff and Compliant Core Materials

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## ARTICLE INFO

***Article history:***

***Keywords:***

Finite element analysis;
B-stage natural-based prepreg;
sandwich composite;

## ABSTRACT

The current investigation focused on the Finite element analysis (FEA) study on the outcome of sandwich composite's low to high-velocity impact responses. The sandwich structure comprises jute, natural rubber as skin, and epoxy/ natural rubber as a core, mixed with sand as a filler (0%-40%) material for bonding skin, and core B-stage cured natural-based prepreg is employed. The structure is impacted with a low velocity of 10 m/sec, an Intermediate of 50 m/sec, a high-velocity impact of 100m/sec, and ballistic velocity impact of 350 m/sec. Based on the results in terms of energy absorption, filler plays a vital role in increasing energy absorption capabilities for all configurations. The sandwich structure with rubber as the core offers better energy absorption capability because of its flexible nature. For further study, sandwich structures with a 40% sand filler were examined, with a velocity limit of 350 m/s. Varying the core thickness from 5 to 20 mm revealed that increasing the core thickness and filler composition in both configurations results in 0.37% for FR40F and 1.70% for FE40F higher energy absorption. Rubber core sandwiches outperformed epoxy core, suggesting the potential utility of rubber and sand-filled cores in ballistic-loaded sandwich structures.

## 1. Introduction

Composite materials are employed in almost all engineering applications; in recent years, composites have been chosen over traditional alloys and metals for aerospace and structural applications because of the benefits like less weight, improved toughness, a higher strength-weight ratio, and better corrosion and heat resistance [1]. Composite failure is due to different failure mechanisms like matrix splitting, fiber splitting, delamination at the interface between fiber and matrix, etc. Precise planning and analysis should be done for composites, especially while selecting sandwich structures because these are significantly influenced by the material used, the shape of the material, stacking sequence, orientation, and material loading condition [2]. Sandwich composite structures are made by joining at least two stiff, thin skins to a strong, less-weighted core. The skin and core material are bonded with a matrix to improve loading mechanisms between the elements [3]. These structures gained popularity due to their improved bending stiffness and specific strength [4]. The lightweight nature of sandwich structures makes them suitable for various engineering applications, including aerospace, space, military, structural, and marine industries [5,6]. Various researchers have extensively examined the impact responses of sandwich composite for an extended period to verify the dependability and reliability of the structures. The study focuses on two main categories: the impact response of the core material with different filler percentages and the effect of core thickness [7]. Several approaches employed in multi-layer sandwich structures allow for the adaptation of mechanical properties based on factors such as the type and thickness of the core, skin, and interim layers. The sandwich structure's Ea (energy absorption) capability increases with the core thickness [8]. The impact experiment aims to differentiate between LVI (low-velocity impact), Intermediate, and HVI (high-velocity impact) scenarios to understand

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how various impact velocities affect a target material or structure. The study typically involves subjecting the target to implications of different velocities and observing the resulting damage, with LVI causing minor damage, intermediate-velocity impacts causing moderate damage, and HVI causing significant structural damage or failure [9]. Two covering skins are attached to less weight; the thicker core contributes to the sandwich structure and has excellent bending stiffness and specific strength. Due to their geometrical benefits, sandwiches are often used as energy-conserving structures exposed to impact loads [10].

Despite substantial research on sandwich structures, the impact behaviors of these structures are still unexplored in detail [11]. FRPs used as a face sheet and polymeric matrix used as a core are used for lightweight sandwich composites and employed in defense vehicles due to their high load-bearing capacity per unit weight and low maintenance requirements. Due to flying debris, sandwiches may be subjected to LVI load in rare circumstances. PMCs are often employed in sandwiches because they prolong the discharge, reducing kinetic energy [12]. Since it's related to BVID (Barely Visible Impact Damage), the impactor's contact on the PMCs surface primarily focuses on the LVI region [13]. According to bullet mass and velocity, they categorized projectile-produced impacts into low (1-10 m/sec), high velocities (100-1000 m/sec), and hypervelocity (more than 2000 m/sec). Several scholars claim that there is also an intermediate velocity (10 to 100 m/sec), and ballistic velocity ranges from (200- 1000 m/sec) [14].

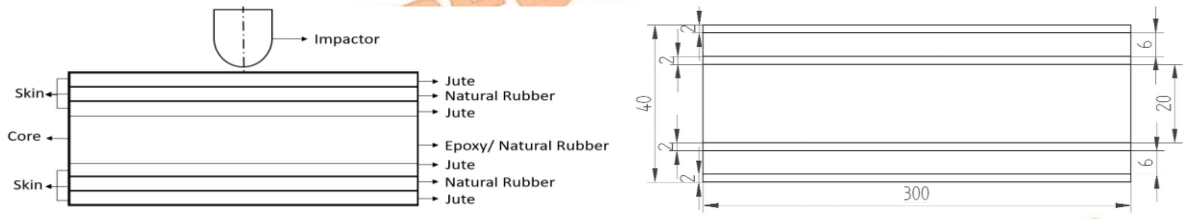
Sandwich structures might be exposed to HVI from low-weight debris that is extremely sensitive to such stresses during employment. This has led to considerable investigation, and the impact behavior of sandwich panels remains an unclear field for researchers [15,16]. In many circumstances, bullets and flying debris near the explosion may strike these structures at high velocities. These sandwich structures utilize a lot of polymer composites because they slow down the bullet by minimizing its KE (kinetic energy) at high velocity [17]. NR (Natural rubber) is one of the most commonly used materials for sandwich cores in various applications because of its higher EA properties, flexibility, low cost, environment friendly, tear resistant, and suitable fabric [18]. Many parameters for HVI have recently been investigated using NR-coated fabrics [19]. The rubber layer is blended into a composite; a study demonstrated that impact damage resistance could significantly improve when the load is applied from LVI to HVI [20]. Various failure modes of the sandwich structure were explored in a study that proposed that these structures may be updated using FG (functionally graded) materials because they reduce thermal and residual stresses created among the core and skin [21]. According to a study, a graded core could lower the interfacial shear stresses between the core and skin. Using various numerical models, other articles show the feasibility of decreasing impact damage in FGMs (functionally graded materials) [22]. Due to the high cost of several polymeric methods for generating FGMs, several fillers are used with matrices like fly ash, naturally available sand, alumina, silica, and cenosphere because they are less costly and have better mechanical properties. Numerical models for investigating ballistic impacts on composite structures are described in several studies. A 3-D FEM (finite element method) of the impactor and the composite is typically utilized to investigate the piercing of the composite by the impactor [23,24]. DYNA-3D, LS DYNA, PAM-CRASH, ABAQUS, ANSYS, and other well-known finite element codes [25]. Initially, damage to the sandwich structure starts from skin damage and core crushing, resulting in the crack growth into the core by reducing the strength on the other side; debonding of skin and core leads to a substantial loss in strength and toughness [26].

In the present study, Jute fiber is used for skin material instead of artificial fibers because it is biodegradable, less expensive, and has better mechanical characteristics [27]. With jute fiber, natural rubber is employed as a skin material, and rubber bonding gum is used as reinforcement. A thermosetting epoxy is used as a core because of its better mechanical properties [28]. Natural rubber is used since it is inexpensive and widely available, so it is chosen as a core material. Naturally available sand is used as a filler material with the core to improve the gradation and mechanical characteristics. Much research is done on the impact responses of composites and other materials; limited research has studied the potential of rubber as an energy absorption medium in high-velocity impacts. Overall, the comparative study provides a comprehensive understanding of the impact responses of sandwich composites with stiff and compliant core materials. It contributes to the broader knowledge base in the field of composite materials and assists in guiding the selection and design process for specific applications. This work aims to examine the impact responses of the sandwich structures at different velocities like low, intermediate, and high velocities impact with varying percentages of sand mixed with the epoxy/rubber and varying the core thickness of the optimized structure and HVI behavior of sandwich structure consisting of Jute-Rubber-Jute-Epoxy (40% of sand)-Jute -Rubber-Jute and

Jute-Rubber-Jute-Rubber (40% of sand)-Jute - Rubber-Jute at an impact velocity of 350 m/sec.

## 2. Finite Element Modelling

Figure 1 illustrates the sandwich structure used in the study. The face sheet on both sides of the core is modeled with dimensions (all dimensions are in (millimeter) mm) 300x300x10mm face sheet thickness. 20 mm thick core is used, which is two times the thickness of the skin for hybrid bio-composites (J-Jute, R-Rubber, J-Jute, E-Epoxy (with different percentages of sand) J-Jute, R-Rubber, J-Jute) JRJE(%S)JRJ, similarly for (J-Jute, R-Rubber, J-Jute, R-Rubber (with different percentage of sand) J-Jute, R-Rubber, J-Jute) JRJR(%S)JRJ also skin thickness is maintained at 10mm, Core thickness is of 20mm the configuration is as shown in table 1. For the optimized sandwich structure, the bullet's velocity of 350 m/sec and composition of 40% sand is kept constant, and the thickness of the core is varied for 5, 10, 15, and 20 mm; the configuration is as shown in Table 2.



a) b)

**Fig. 1.** Sandwich composite subjected to impact a) Sequencing of materials for sandwich structure, b) Dimensioning of sandwich structure (core and skin)

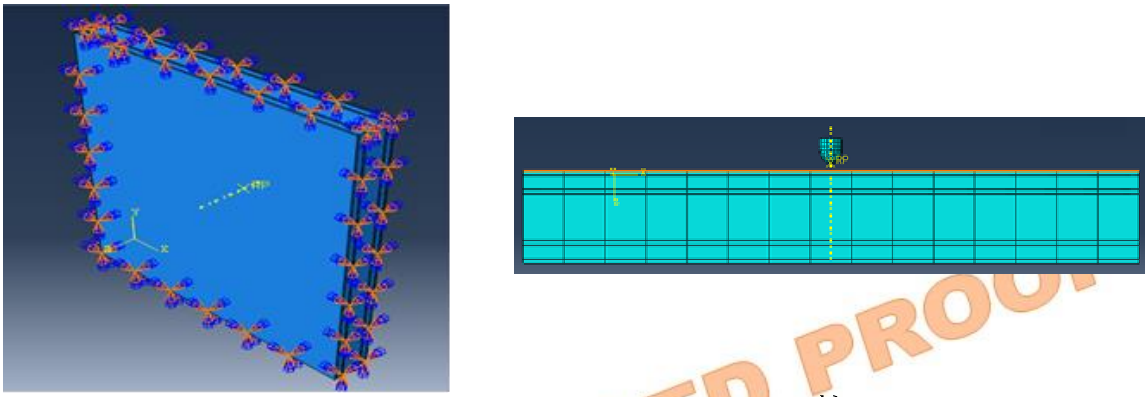
**Table 1.** Configuration of sandwich composites for the present study

| Sl. No. | Sandwich Structure | | The thickness of the core (mm) | Velocity (m/sec) |
|---|---|---|---|---|
| 1 | FESF | F-JRJ (J-Jute, R- Natural Rubber, J-Jute) | FE0F-0% Sand filler | • Low Velocity 10 m/sec<br>• Intermediate velocity 50m/sec.<br>• High Velocity: 100 and 350 m/sec |
| | | ES (core) - Epoxy and sand | FE10F-10% Sand | |
| | | F- JRJ (J-Jute, R- Natural Rubber, J-Jute) | FE20F-20% Sand | |
| | | 40- 40% sand with epoxy as a core material. | FE30F-30% Sand | |
| | | | FE40F-40% Sand | |
| 2 | FRSF | F-JRJ (J-Jute, R- Natural Rubber, J-Jute) | FR0F-0% Sand filler | |
| | | R (core) – Natural Rubber and sand | FR10F-10% Sand | |
| | | S-Sand (filler) percentage | FR20F-20% Sand | |
| | | F- JRJ (J-Jute, R- Natural Rubber, J-Jute) | FR30F-30% Sand | |
| | | | FR40F-40% Sand | |

The energy absorption ability is investigated using FE analysis for different configurations, as shown in Tables 1 and 2. The composite structures are modeled as a 3D deformable body using widely viable explicit (ABAQUS/CAE) software, while the projectile (hemispherical shaped) as a rigid body was modeled with inertia 2kgs. The right combination of the skin and core is modeled and assembled. The sandwich structure's four sides are constrained by the BC (boundary condition), and the projectile motion is limited to the Z-axis with different velocities. The boundary condition and assembly of structure for one combination are illustrated in Figure 2, which is replicated for all other combinations.

**Table 2.** Optimized sandwich composites.

| Sl No. | Sandwich Structure | The thickness of the core (mm) | Velocity (m/sec) |
|---|---|---|---|
| 1 | FE40F | 5,10,15,20 mm | 350 m/sec |
| 2 | FR40F | 5,10,15,20 | 350 m/sec |



a) b)

**Fig 2.** a) Boundary condition, b) Assembly view, and meshing of the sandwich structure

The structure and impactor auto-mesh for meshing is chosen with Quad-mesh; 1944 elements and 3939 nodes were used. A projectile (hemispherical-shaped) steel diameter of 16mm is taken [29]. Low, high, and Intermediate velocity impact tests on the sandwich structure using dynamic explicit analysis. The boundary conditions were applied to the structure, constraining four sides by varying velocity from low to high. The interaction properties for each layer are defined in the software's interaction module to ensure integrity between the layers. A penalty contact algorithm was utilized to establish contact between the projectile and the top surface of the laminate, which imposes hard contact and considers pressure over closure along with a friction coefficient of 0.3. In contrast, the contact between laminates was defined using a general contact algorithm, as per previous studies [30]. Table 3 presents the properties of the materials employed in this work [29].

**Table 3.** Material Properties: [14,19,20]

| **Sl No.** | **Used Materials** | **Density (Kg/m3)** | **Ultimate stress (GPa)** | **Young's Modulus (GPa)** | **Poisson's ratio** |
|---|---|---|---|---|---|
| 1 | Jute | 1450 | 0.35 | 20 | 0.38 |
| 2 | Natural Rubber | 987.18 | 0.00005 | 0.00045 | 0.49 |
| 3 | Epoxy | 1200 | 0.72 | 3.4 | 0.30 |
| 4 | Sand | 2410 | 0.1 | 70.6 | 0.17 |

## *2.1. The Governing and Constitutive Equations*

The governing and constitutive equations used to analyze LVI and HVI tests are typically based on the principles of mechanics, including the laws of motion and thermodynamics. The specific equations used will depend on the type of material being tested, the loading conditions, and the objective of the test. The governing equations for LVI tests are typically based on linear elasticity theory, which assumes that the material responds elastically to the applied loading, with the deformation proportional to the applied stress. These tests are typically used to determine the material's energy absorption capacity and dynamic stiffness.

The governing equations for high-velocity impact tests are typically based on nonlinear mechanics and may include plasticity, viscoelasticity, and fracture mechanics. These tests commonly evaluate the material's resistance to damage and ability to absorb energy in a highly dynamic loading environment. In addition to the governing equations, constitutive equations are often employed to explain how a material would behave under various loading scenarios. These equations may be based on empirical relationships, such as stress-strain relationships, or they may be derived from more fundamental physical models, such as the mechanical or

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thermal behavior of the material's microstructure. It is important to note that the accuracy and validity of the governing and constitutive equations used in impact testing will depend on the assumptions and quality of the input data. As such, it is essential to carefully consider these equations' limitations and validate the results through comparison with experimental data.

The Neo-Hookean material model can describe the nonlinear relationship between stress and strain for materials undergoing significant deformation [19,31–33]. In hyper-elastic material models, the governing equations for bending and stretching are determined using strain energy function W, as shown in Equation (1).

$$alpha - beta \tau^{\alpha\beta} = 2\frac{\partial \mathrm{W}}{\partial \mathrm{a}_{\alpha\beta}}, \mathrm{M}_0^{\alpha\beta} = \frac{\partial \mathrm{W}}{\partial \mathrm{b}_{\alpha\beta}} \qquad (1)$$

Cauchy-Green deformation tensor left invariants (I1, I2), defined by Equation (2).

$$\begin{aligned} I_1 &= \lambda_1^2 + \lambda_2^2 + \lambda_3^2 \\ I_2 &= \lambda_1^2\lambda_2^2 + \lambda_2^2\lambda_3^2 + \lambda_3^2\lambda_1^2 \end{aligned} \qquad (2)$$

Equation (3) describes the Cauchy stress tensor for incompressible materials.

$$\sigma = -\mathrm{PI} + 2\left[\left(\frac{\partial \mathrm{W}}{\partial \mathrm{I}_1} + \mathrm{I}_1\frac{\partial \mathrm{W}}{\partial \mathrm{I}_2}\right)\mathrm{B} - \frac{\partial \mathrm{W}}{\partial \mathrm{I}_2}\mathrm{BB}\right] \qquad (3)$$

Equation (4-7) gives fiber and matrix compression and tension failure modes in the material damage model.

$$F_{ft} = \left[\frac{\widehat{\sigma_{11}}}{X^t}\right]^2 + \alpha\left[\frac{\widehat{\sigma_{11}}}{S^l}\right]^2 \quad (\widehat{\sigma_{11}} \geq 0) \qquad (4)$$

$$F_{fc} = \left[\frac{\widehat{\sigma_{11}}}{X^c}\right]^2 \quad (\widehat{\sigma_{11}} \leq 0) \qquad (5)$$

$$F_{mt} = \left[\frac{\widehat{\sigma_{22}}}{Y^t}\right]^2 + \alpha\left[\frac{\widehat{\sigma_{12}}}{S^l}\right]^2 \quad (\widehat{\sigma_{22}} \geq 0) \qquad (6)$$

$$F_{mc} = \left[\frac{\widehat{\sigma_{22}}}{2S^t}\right]^2 + \left\{\left[\frac{Y^C}{2S^t}\right] - 1\right\} \times \left[\frac{\widehat{\sigma_{22}}}{Y^c}\right]^2 + \left[\frac{\widehat{\sigma_{12}}}{S^l}\right]^2 \quad (\widehat{\sigma_{22}} \leq 0) \qquad (7)$$

Constituents of the effective stress tensor represented by $\widehat{\sigma_{ab}}$ (a, b = 1, 2). Fiber and matrix tension ($F_{ft}$ , $F_{mt}$) and compression ($F_{fc}$ , $F_{mc}$) failure modes in the material damage model. Yt, Yc, and Xt, Xc give the compressive and tensile strength in transverse and longitudinal directions. Sl gives shear strength in-plane and out-plane, St. The material will exhibit linear elastic behavior before the onset of damage, and the relationship between stress and strain is expressed as $\sigma = \{C\} \times \{\varepsilon_0\}$ where, {C}= elasticity matrix and elasticity matrix damage {Cd}which is given by equation (8).

$$\{C_d\} = \begin{bmatrix} (1-d_f)E_1 & (1-d_f)(1-d_m)\gamma_{21}E_1 & 0 \\ (1-d_f)(1-d_m)\gamma_{12}E_2 & (1-d_m)E_2 & 0 \\ 0 & 0 & (1-d_s)G_{12}D \end{bmatrix} \qquad (8)$$

where df and dm are fiber/matrix shear damage, and D is given by equation (9)

$$D = 1 - (1-d_f)(1-d_m)\gamma_{12}\gamma_{21} \qquad (9)$$

## *2.2. Mesh Convergence Analysis*

In Finite Element Analysis (FEA), mesh convergence analysis is crucial in ensuring that the numerical results are independent of the discretization factors, including element size. To determine the ideal mesh size where the results stabilize and show convergence, analyze the ways in which the values of residual energy change with varying element sizes. Quad-mesh is chosen for meshing, and the element S4R, a 4-node double curved with thin or thick solids, hourglass control, finite membrane strains, and decreased integration, is used for meshing the plate, and R3D4, a 4-node 3-D bilinear rigid quadrilateral, is used for meshing the impactor. The total number of elements and nodes employed in this study is 3939 and 1944, respectively. A mesh convergence analysis was conducted using a range of mesh sizes from 3 mm to 10 mm with an increment rate of 1 mm to choose an optimal mesh size in terms of convergence and computing efficiency. The FE model simulates the sandwich composite structure's impact response under specified loading conditions. Boundary conditions and material properties are constant throughout all simulations. Once the simulation is complete, residual energy data are noted for every mesh configuration. The objective is to determine the element size at which the findings converge, meaning that increasing the mesh's fineness does not appreciably change the outcomes. In this analysis, we will assume that the findings have converged if the residual energy differs between consecutive element sizes of less than 1%. Initially, the percentage difference between successive element sizes for residual energy will be determined to perform mesh convergence analysis. The results show that residual energy begins to stabilize at about the element size of 5 mm based on the calculated percentage differences. The percentage disparities decline beyond this point, suggesting convergence, as shown in Figure 3. The element size of 5 mm appears to be the optimal choice for this mesh convergence analysis, as it shows a consistent trend toward convergence for both residual energies. By completing this mesh convergence investigation, we have determined the ideal mesh size (5 mm) that yields converged results for the specified simulation. This analysis helps determine the proper mesh density for upcoming simulations and ensures the accuracy and dependability of the Finite Element Analysis (FEA) model.

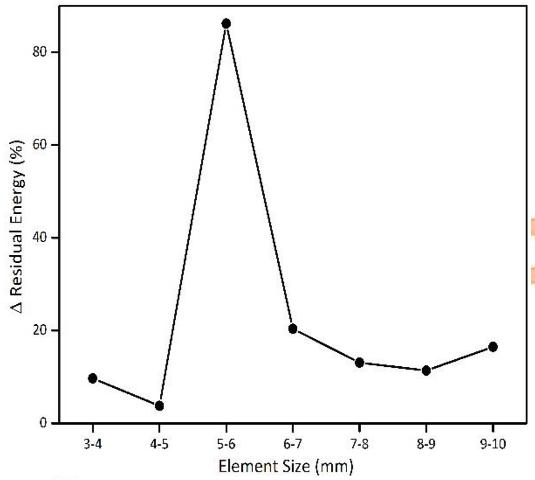


**Fig. 3.** Mesh convergence for the difference in residual energy % with Element size.

## 3. Result And Discussion

This comparative study investigates the impact response of sandwich composites with stiff and compliant core materials using FEM. The goal is to evaluate the performance of sandwich composites under impact loading and identify the impact response differences between stiff and compliant core materials.

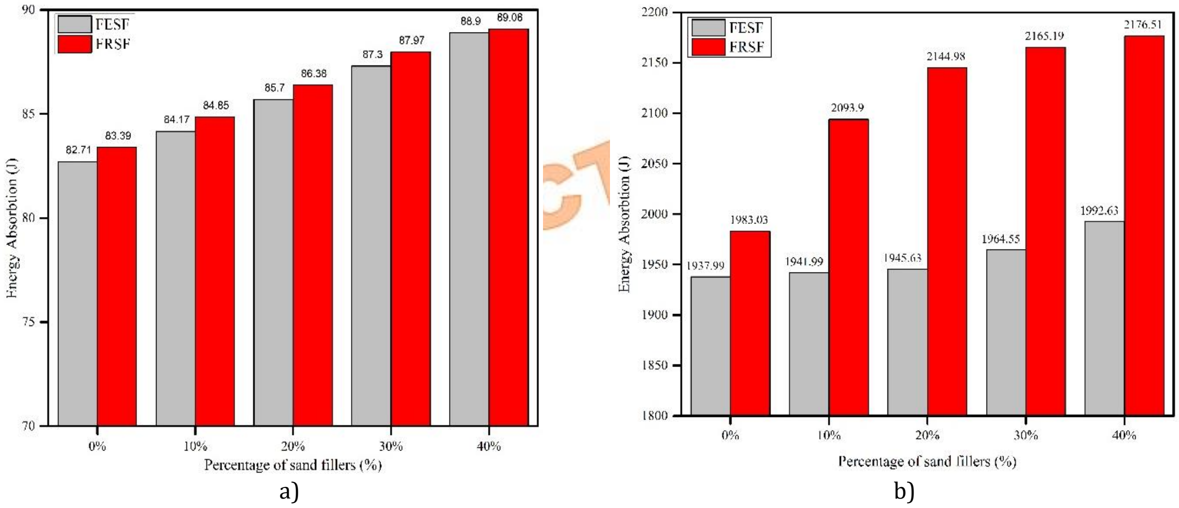
### *3.1. Influence of Composition of Filler on Sandwich Structure*

The kinetic energy (KE) for all the configurations was calculated based on the projectile's velocity. The initial KE, Emax (joules), is estimated using Equation 10.

$$E_{max} = \frac{1}{2}mv^2 \tag{10}$$

Upon contact with the composite, the projectile's KE progressively decreases, and its internal energy increases; the projectile's KE is at its lowest, and the composite's internal energy is at its highest. Projectile KE increases upon attaining a minimum because projectile rebounds from the composites eventually become constant. Projectile residual energy (ER) is determined using this constant energy. Equation 11 estimates the energy absorbed (EA) by the composite.

$$E_A = E_{max} - E_R \tag{11}$$



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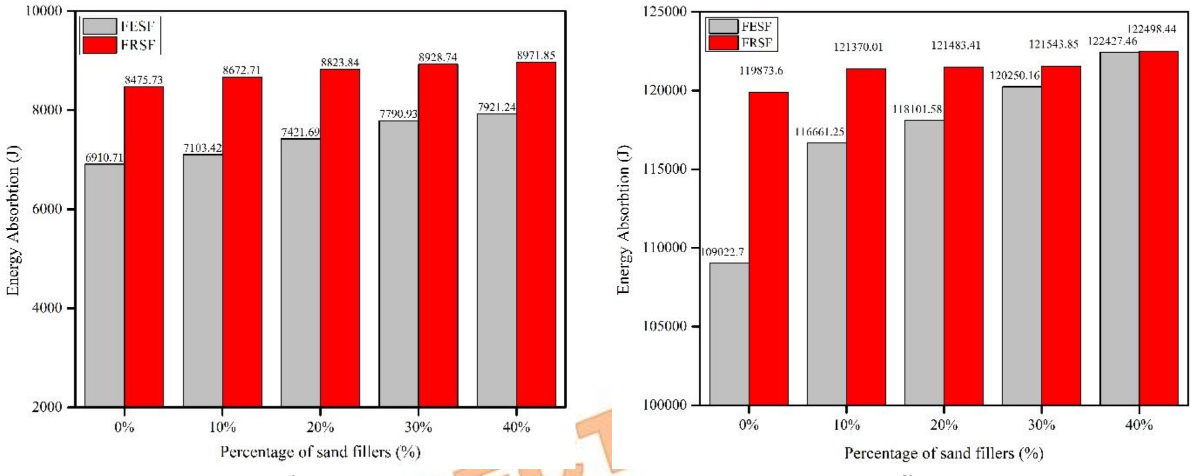


c) d)

**Fig. 4.** Energy absorption for FESF and FRSF for different Velocity a) Low (10 m/sec), b) Intermediate (50 m/sec), c) High (100 m/sec), and d) Ballistic (350 m/sec)

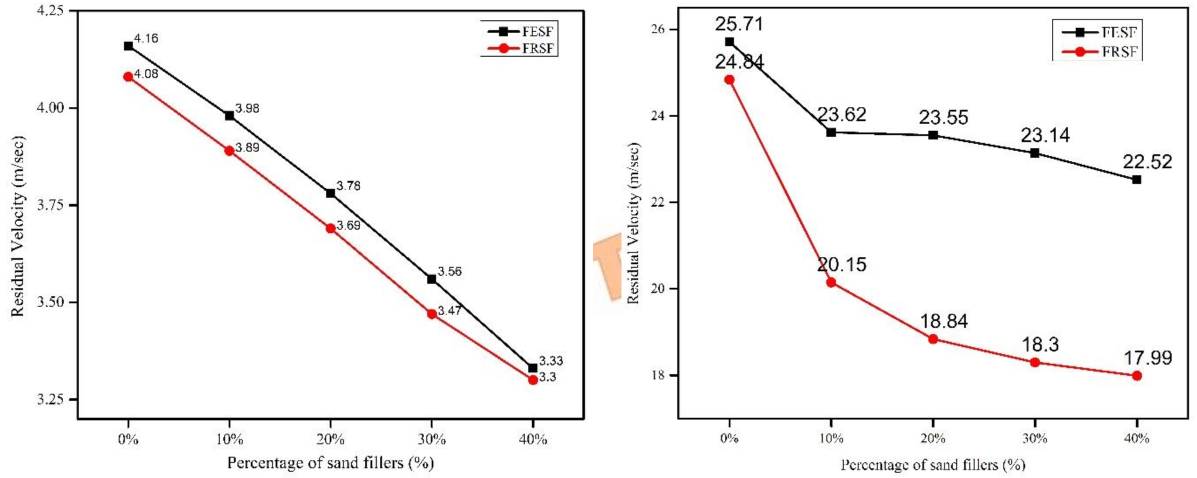
Figure 4 gives the energy absorbed for different percentages of sand (0%,10%,20%,30%,40%) with core materials Epoxy and Rubber for different velocities like 10m/sec, 50m/sec, 100m/sec, 350m/sec. The percentage increase of energy absorption from 0 to 40 percent is 7.48% for FESF and 6.81% for FRSF at a low velocity of 10 m/sec. Similarly, 2.81% for FESF and 9.75% for FRSF at an Intermediate velocity of 50 m/sec, 14.62% for FESF, and 5.85% for FRSF at a high velocity of 100m/sec and 12.29% for FESF and 2.18% for FRSF at high velocity 350 m/sec.

The bullet loses energy when it strikes the composite by decreasing its KE, dispersed in damages like matrix cracking, fiber breaking, etc. The projectile velocity is lowered, referred to as residual velocity (Vr).

After transferring the KE, the impactor may move inside and get stuck in the composite with less impact velocity or rebound at a lesser velocity. If the impactor struck inside the laminate, then Vr=0. Equation 12 is used to estimate the composite's residual velocity.

$$V_r = \frac{\sqrt{(2\times E_R)}}{m} \qquad (12)$$

where $V_r$= Residual velocity, $E_R$=Residual energy, m=mass of the impactor.



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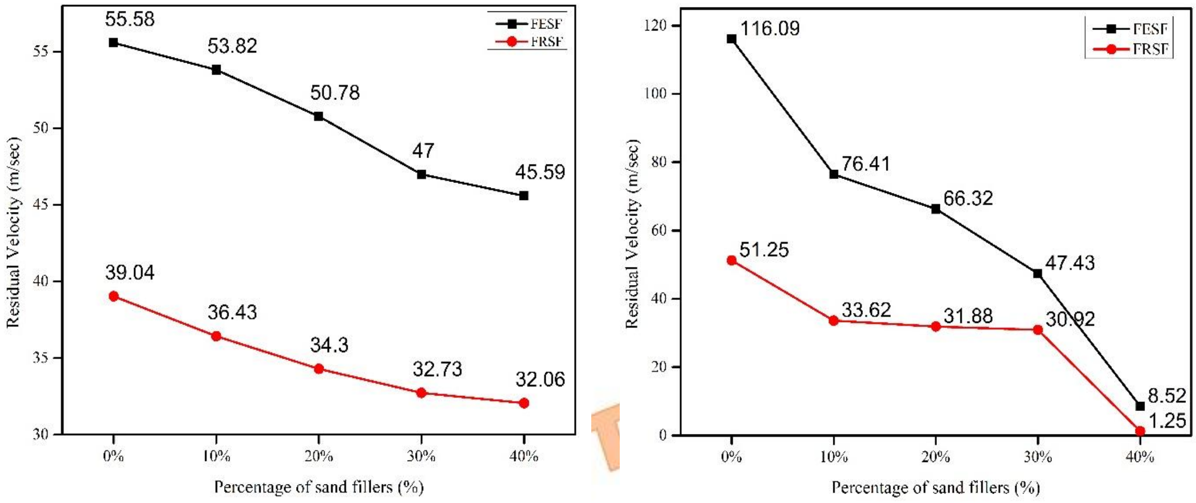

c) d)

**Fig. 5.** Residual Velocity for FESF and FRSF for different Velocity a) Low (10 m/sec), b) Intermediate (50 m/sec), c) High (100 m/sec), and d) Ballistic (350 m/sec)

Figure 5 shows the residual velocity for different percentages of sand (0%,10%,20%,30%,40%) with core materials Epoxy and Rubber for different velocities like 10m/sec, 50m/sec, 100m/sec, 350m/sec. The percentage decrease of residual energy from 0 to 40 percent is 24% for FESF and 23% for FRSF at a low velocity of 10 m/sec. Similarly, 5% for FESF and 26% for FRSF at an Intermediate velocity of 50 m/sec, 21.90% for FESF, and 21.75% for FRSF at a high velocity of 100m/sec and a ballistic velocity of 350 m/sec residual velocity shows the more significant value.

### *3.2. Influence of Core Thickness under High-velocity Behavior on Sandwich Structure*

Core thickness can significantly influence the impact behavior of a sandwich structure under ballistic impact. A thicker core provides excellent energy absorption and improved resistance to penetration. However, a thinner core can reduce weight and improve flexibility, making it better suited for specific applications. The choice of core thickness depends on the application's particular requirements and trade-offs, such as weight, stiffness, and resistance to impact damage. It is essential to consider the properties of the core material and its bonding ability with skins to optimize the sandwich structure's overall performance under ballistic impact. 40% of sand with the core material for different compositions shows better energy absorption capabilities.

The ability to absorb energy increases with an increase in filler composition. Studying the energy absorption capability for different core thicknesses of a material or structure is feasible. Varying the core thickness can alter how the material or structure responds to external forces and affect its ability to absorb and dissipate energy. By testing and analyzing the material or structure's behavior under different core thicknesses, researchers can gain insights into its energy absorption properties and optimize it for specific applications. However, it's important to note that studying the energy absorption capability of a material or structure typically involves a complex set of experiments and analyses and requires careful consideration of various factors, such as the loading conditions, material properties, and testing procedures.

The composition shows better energy absorption and the ballistic velocity of 350 m/s is limited and taken for further study; the high-velocity impact response of sandwich composites of different thicknesses at 350 m/sec impact velocity. Figures 6 and 7 indicate the effect of KE and deformation for various configurations for FE40F and FR40F, respectively. The initial velocity (350m/sec) is the same for all configurations. Equation (10) gives the energy Ei (Joules) at which the target gets hit by the impactor.

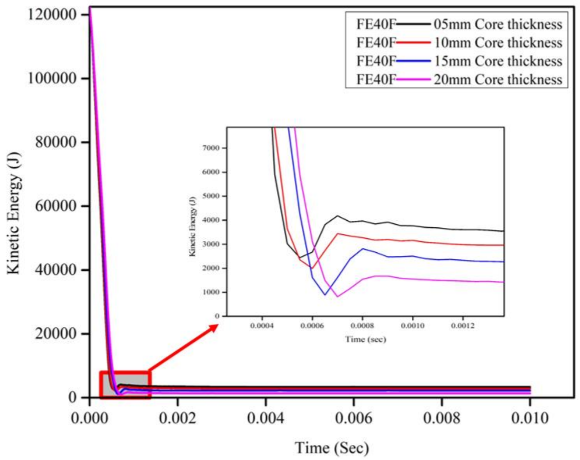

**Fig. 6.** Variation in Kinetic energy (J) for FE40F

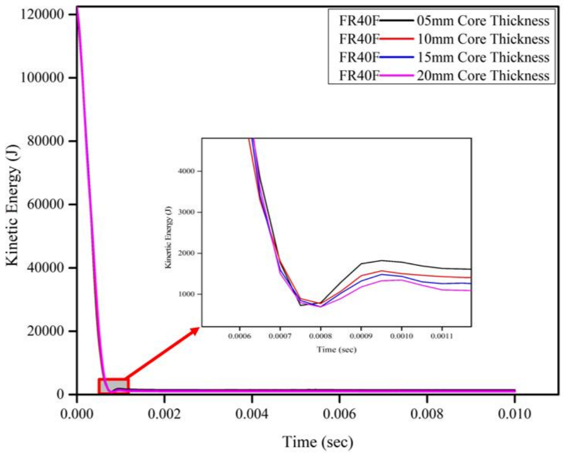

**Fig. 7.** Variation in Kinetic energy (J) for FR40F

The effect of core thickness on sandwich structure FE40F under ballistic-velocity impact loading (350 m/sec) can be analyzed using Figures 8 and 9. The main conclusion drawn from the graph is that as the core thickness increases, it is observed to increase energy absorption and decrease residual velocity. This could indicate that thicker cores are better able to absorb and dissipate energy, resulting in a lower residual velocity after impact. However, it's challenging to provide a definitive answer without seeing the graph and understanding the specifics of the experiment. It's important to carefully analyze and interpret data to draw accurate conclusions about the behavior of a material or structure under specific loading conditions.

The figure shows that as the laminate thickness improved, the Vr decreased, increasing EA. The trend in variance in residual energy and velocity for different thicknesses of the sandwich structure remains the same for all the configurations. In addition, it has been discovered that a sandwich structure with a core thickness of 20 mm has less residual velocity and absorbs more energy.

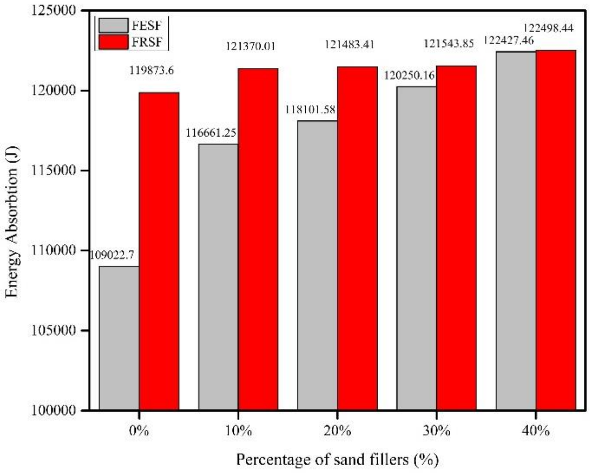

**Fig. 8.** Energy Absorption for different core thicknesses

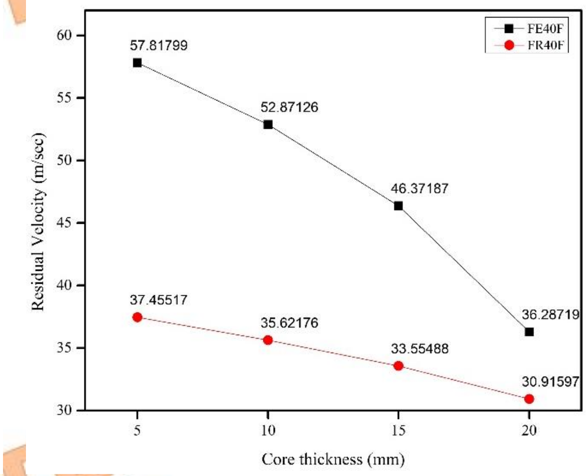

**Fig. 9.** Residual velocity of different core thicknesses

Figure 8 shows the percentage increase of energy absorption for different core thicknesses (5, 10, 15, 20mm) is 0.37% for FR40F and 1.70% for FE40F. Similarly, the percentage decrease in residual velocity is 21.15 % for FR40F and 59.33% for FE40F. Figures 7 and 8 show that an increase in core thickness Vr is decreased with improvement in Ea. However, for different thicknesses, the difference in Vr and Ea follows a similar pattern for all the configurations.

### *3.3 Damage Analysis*

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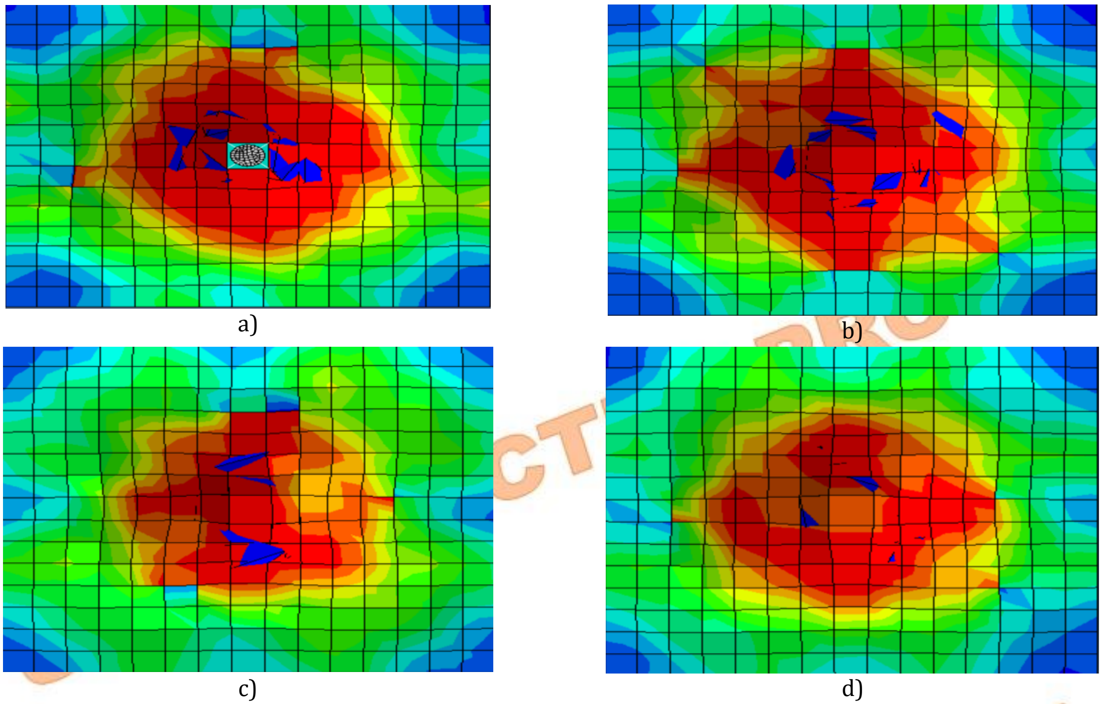
a)
b)
c)
d)

**Fig. 10.** Damage Behaviour for different core thicknesses in FESF40 a) 5, b) 10, c) 15, and d) 20mm.

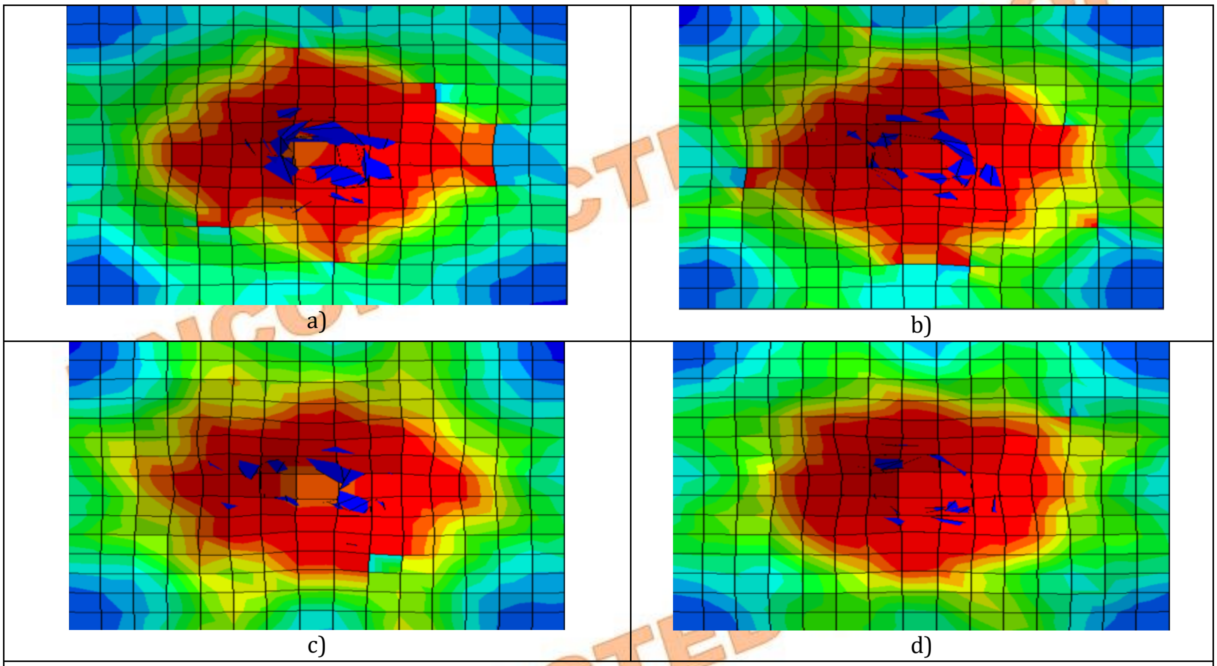
a)
b)
c)
d)

**Fig. 11.** Damage Behaviour for different core thicknesses in FRSF40 a) 5, b) 10, c) 15, and d) 20mm.

Figures 10 and 11 illustrate the damage caused by projectile striking sandwich structures FE40F and FR40F for different core thicknesses. Damage analysis was performed for this study's ballistic velocity of impact (350m/s). Results reveal that the sandwich structure impacted by the projectile causes an increase in the level of damage with decreased localized damage because the damage spreads widely from the area of impact. Increasing the core thickness reduces the extent of damage in both cases, but the extent of damage is more significant in FE40F compared to FR40F. This may be because rubber as a core material can help prevent further progression of damage in a composite structure. Rubber's elastic nature allows it to absorb and distribute stress and strain, reducing the likelihood of cracks or fractures propagating through the material. This is why rubber is often used as a shock-absorbing material in applications where impact or vibration is a concern [14].

Finally, the comparative analysis on the impact responses of sandwich composites with stiff and compliant core materials suggested that the core material used substantially impacts the

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composite's behavior. Sandwich composites with stiff cores demonstrated increased stiffness and resistance to deformation, making them appropriate for structural integrity and load-bearing capacity applications. Sandwich composites with compliant cores, on the other hand, demonstrated more excellent energy absorption characteristics, making them suitable for applications that prioritize impact mitigation and damage tolerance. When selecting between stiff and compliant core materials, the study stressed the need to consider weight, cost, and particular application requirements. Compliance core materials offer energy absorption, impact resistance, weight reduction, flexibility, and vibration-damping advantages. However, it is essential to consider the application's specific requirements, as compliant cores may have structural rigidity or load-bearing capacity limitations compared to stiff cores.

### *3.4 Comparative Analysis*

A comparative analysis was conducted between the proposed composite (FESF, FRSF) sandwich composite of 40% Sand composition, 350 m/sec input velocity, and thickness of core 5mm, 10mm, 15mm are taken, and an existing composite ( JE (Jute/epoxy), JRE (Jute/Rubber/ Epoxy), JE+Ru sandwich (Jute/Epoxy+ Rubber+ Jute/Epoxy)) that has been previously developed and documented in the literature [34]. For the second comparison, a low velocity of 10 m/sec was taken, and a composite with different sequences JRJ (Jute/Rubber/Jute), JRRJ (Jute/Rubber/Rubber/Jute), JRJRJ (Jute/Rubber/Jute/Rubber/Jute), that has been previously developed and documented in the literature [35]. To support the suitability of the suggested sandwich composite for engineering applications, the obtained comparison data are shown in Table 4.

**Table 4.** Comparative Analysis

| Properties | Input velocity (m/sec) | Thickness (mm) | Proposed Composite | | Referred work | | |
|---|---|---|---|---|---|---|---|
| | | | FESF | FRSF | JE | JRE | JE+Ru |
| Residual velocity (m/sec) | 350 | 5 | 57.81 | 37.45 | 342.90 | 234.35 | 58.34 |
| | | 10 | 52.87 | 35.62 | 339.83 | 155.88 | --- |
| | | 15 | 46.37 | 33.55 | 335.83 | 086.37 | --- |
| Energy Absorption (J) | 10 | --- | FESF | FRSF | JRJ | JRRJ | JRJRJ |
| | | | 87.3 | 87.97 | 51.55 | 52.26 | 53.69 |

During the comparative analysis of these composites, particular attention was given to identifying the composite with the residual velocity(m/sec). The data presented in Table 4 indicates that the proposed (FESF, FRSF) sandwich composite of 40% Sand composition, 350 m/sec input velocity, and thickness of core 5mm, 10mm, and 15mm outperforms the JE, JRE, JE+Ru sandwich for all the cases. The residual velocity decreases by 5.93, 6.43, and 7.24 times compared to JE with FESF. Similarly, it decreases by 9.16, 9.54, and 10.01 times compared to FRSF. Compared with JRE, with FESF, it decreases 4.05, 2.95, and 1.86 times. Similarly, it decreases by 6.26, 4.38, and 2.57 times compared to FRSF. When compared with JE+Ru and FESF, it decreases by 1.01 times. Similarly, it decreases by 1.56 times when compared with FRSF. In the second case, when compared with JRJ, JRRJ, and JRJRJ with FESF, the energy absorption increases by 1.69, 1.67, and 1.63 times, respectively. Compared with JRJ, JRRJ, and JRJRJ with FRSF, the energy absorption increases by 1.71, 1.68, and 1.64 times, respectively.

The comparative study of different composite materials reveals notable differences in their performance, especially regarding residual velocity and energy absorption capabilities. The most promising configuration among the tested ones is the proposed sandwich composites FESF and FRSF, which have 40% sand composition and vary in core thickness. Rubber is known for its excellent flexibility and damping properties. When subjected to impact loading, rubber cores can deform elastically, absorbing and dissipating energy through internal friction and viscoelastic behavior. This ability to deform and absorb energy can help mitigate the effects of impact forces, reducing the likelihood of structural failure and minimizing damage to the composite. The flexibility of natural rubber allows it to conform to the shape of the impacting projectile or force, distributing the load more evenly throughout the structure. This distributed loading helps prevent localized stress concentrations, which can lead to delamination, cracking, or perforation of the composite. As a result, sandwich composites with rubber cores often exhibit enhanced impact resistance compared to structures with rigid or less flexible core materials. Compared to other alternative configurations, these sandwich composite shows notable decreases in residual velocity and significant increases in energy absorption.

Factors such as material composition, core thickness, sand composition, input velocity, and material arrangement contribute to these observed differences. The superior performance of the sandwich composite can be attributed to a combination of these factors, resulting in enhanced mechanical properties conducive to effective energy dissipation upon impact. This analysis underscores the critical role of material selection and structural design in optimizing composite performance for impact resistance applications. This property is significant in defense applications where materials must endure dynamic and high-velocity impacts, such as ballistic events or explosive blasts. These properties make the sea sand-filled epoxy an excellent choice for core materials in sandwich structures, particularly in defense applications where high strength, impact resistance, and energy absorption are essential requirements. Using such composites can help develop structures for defense that are light but strong, providing better protection and durability.

## 4. Conclusions

The comparative study on the impact responses of sandwich composites with stiff and compliant core materials has provided valuable insights into the behavior and performance of these composite structures under impact loading. The investigation aimed to understand how the core material's stiffness affects the overall response of the sandwich composites. A sandwich composite consisting of jute/natural rubber as face sheet and epoxy and rubber as core material with different composition filler sand (0%, 10%,20%,30%, and 40%) are modeled under low (10m/sec), intermediate (50m/sec), and high (100 m/sec), and ballistic-velocity (350 m/sec) impact is optimized using FE modeling. The optimal configuration of 40% composition is taken for various core thicknesses (5, 10, 15, 20mm), and the velocity is limited to 350m/sec. The following are some of the conclusions drawn from this work.

- Numerical simulation determined different sandwich composites' energy absorption and residual velocity. The energy absorption increased, and residual velocity decreased with increasing initial velocity for all target materials with respect to increasing composition of filler and increasing thickness of core material. Notably, a 40% sand composition in the sandwich composite led to a considerable improvement in energy absorption.
- Increasing the core thickness from 5mm to 20mm in the FR40F sandwich composite under a ballistic velocity of 350 m/sec results in a 0.37% increase in energy absorption and a decrease in residual velocity to 21.15%. Similarly, in the case of the FE40F sandwich composite under the same conditions, there is a 1.70% increase in energy absorption and a reduction in residual velocity to 59.33%.
- Damage study results show that if the core thickness increases, the damage extent to the sandwich structure decreases, and it is observed that the damage in FESF40 is more than in FRSF40. This phenomenon is due to rubber being a core material that can help prevent further progression of damage in a composite structure. Its elastic nature allows it to absorb and distribute stress and strain.

Using a natural fiber-reinforced sandwich structure with natural rubber as a compliant core material increased Ea, damage reduction, uniform stress distribution, and strong interface bonding compared to the thermosetting matrix used as the stiff core material. It was also found that rubber is a reasonable energy observer due to its flexible nature.

## Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article. In addition, the authors have entirely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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