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Original Article

Impact Strength Analysis of Glass-Jute Hybrid Composites: Experimental and FEA Investigation

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Abstract - *This study investigates the impact strength of jute-glass hybrid composites. Composite laminates were prepared using the hand-layup method with varying jute layer positions, and Impact testing was carried out in compliance with standard ASTM D256. The results demonstrated that the placement of jute fiber significantly influences impact strength, with the highest performance observed when jute is positioned in the eighth layer. Finite Element Analysis using ANSYS Workbench validated the experimental findings, showing good agreement between simulated and tested results. This research highlights the potential of glass-jute hybrid composites for structural applications, optimizing strength while reducing synthetic fiber content.*

Keywords - *Glass-jute hybrid composite, Impact strength, ASTM-D256, Hand layup, Ansys Workbench.*

1. Introduction

Axial Flow Fan Blades (AFFB) made of glass fiber reinforced polymers are problematic for the environment because of their low biodegradability and difficulty in recycling. Jute and other natural fibers provide environmentally friendly alternatives. Scientists are looking at ways to hybridize glass fiber reinforced plastics with natural fibres to make the composites more environmentally friendly and less harmful to the environment once they have served their purpose without compromising mechanical characteristics. Hybrid composites have garnered significant attention due to their ability to combine the advantages of both synthetic and natural fibres, making them suitable for various structural applications while ensuring both eco-friendliness and cost-effectiveness. Natural fibers such as jute, flax, sisal, and hemp have been increasingly used in composite materials for their lower weight, cost-effectiveness, renewability, and biodegradability. Hybrid composites with partial synthetic fiber reinforcement improve mechanical characteristics, balance cost and performance, and offer sustainable alternatives for various engineering applications [1].

2. Literature Review

Several studies have explored the mechanical performance of hybrid composites. Rafiquzzaman et al. [2] demonstrated that jute-glass fiber composites exhibited superior tensile, flexural, and impact properties compared to a composite with individual constituents. Assis et al. [3] investigated the performance of jute non-woven mat-reinforced polyester composites under impact loading, revealing improved energy absorption. El-baky et al. [4] investigated flax, basalt, and glass fiber hybrids, noting significant enhancements in impact properties due to fiber hybridization. Subagia et al. [5] examined carbon-basalt hybrid composites, emphasizing the role of stacking sequences in enhancing impact resistance. Sanjay et al. [6] compared jute/kenaf/glass hybrids, revealing that glass fiber layers improved impact performance. Das et al. [7] studied glass/flax and glass/jute hybrids, concluding that fiber volume fraction and stacking order were crucial for optimizing impact strength. Margabandu et al. [8] examined the composite featuring jute layers at the core and carbon layers on the surface, revealing a 7.8% increase in impact strength compared to the one with jute layers on the surface and carbon layers at the core. The impact behavior of jute/glass hybrid composites has been studied by varying stacking sequences, and the results have been published [9-11]. Synthetic fibres positioned in the laminate's skin resulted in better impact strength than those positioned in the laminate's core. Although numerous studies have explored jute-glass composites broadly, there has yet to be a focused investigation on the impact strength analysis of AFFB materials with jute reinforcements. This study addresses these gaps by systematically varying the jute layer positions in glass-jute hybrid laminates and evaluating their impact performance through both experimental methods and FEA. The innovation lies in identifying the optimal stacking sequence that maximizes impact strength while maintaining cost-effectiveness and sustainability, contributing valuable insights into the design of hybrid composites for high-impact applications.

3. Materials and Methods

The material for the AFFB is evaluated in terms of its suitability for jute fibre reinforcements.

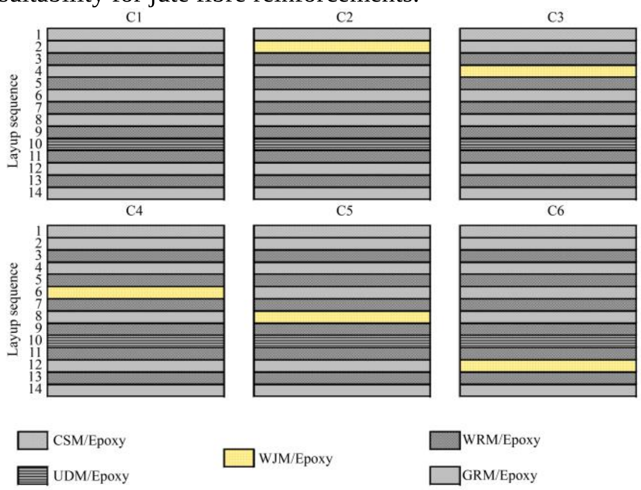

Fig. 1 Layup sequence of AFFB with woven jute reinforcements [CSM/ (GRM/WRM)$_4$/UDM/(WRM/GRM)$_2$]

The 18' fan blade (GFRC) layup sequence, represented by C1 and shown in Figure 1, consists of 6 layers of WRM, 1 layer of CSM, 1 layer of UDM and 6 layers of GRM. The GRM, a type of glass fibre utilized in the GFRC blade, exhibits a weight equivalent to that of a woven jute mat (WJM). Consequently, it was proposed to substitute GRM with WJM at 2, 4, 6, 8, and 12 locations in the GFRC structure considered as C2 to C6, respectively [12]. It is important to note that the 14th layer, which functions as the external layer susceptible to moisture absorption, must not be substituted with WJM.

Fig. 2 Impact test machine

4. Izod Impact Test

ASTM D-256 [13] standard is used to determine the Izod impact strength. The impact testing machine is shown in Figure 2. With a gravitational distance of 0.916m and an angle of fall of 90°, a hammer with a mass of 18.7kg was implemented. The specimen dimensions are taken as 65 mm, and the height of the specimen is 12.7mm. The 'v' notch height is taken as 2.5 mm.

The specimens shown in Figure 3 were examined for impact strength, and an average result was produced.

Fig. 3 Specimens for impact test

5. Results and Discussion

5.1. Results from Experiment

The impact resistance of the materials C1 – C6 found during the experiment is illustrated in Figure 4. The fan blade material C1 exhibited greater resistance to failure under impact loads. The energy absorbed by C1 is found to be 26J. C5 outperformed other single-layer woven jute reinforced composites in terms of impact load resistance. The energy absorbed by C5 is found to be 25.2J. So, by placing woven jute in the 8th position of the blade material, it has 96.9% impact resistance of C1. By changing the position of WJM, the energy absorbed increases from C2 to C5 and decreases to C6.

5.2. Results from FEA

In the Finite element analysis software Ansys Workbench R22.1, the explicit dynamics module was used to validate the impact test results. Figure 5 shows a meshed model. The converged model has 60828 elements and 70512 nodes. The striker is modelled as a rigid body, and its mass is set as 18.7 kg to represent exactly the pendulum mass. Then, under initial conditions, a velocity of 4.24 m/s is assigned to the striker. Due to the fact that it is susceptible to slippage, the boundary that separates the striker and the Izod specimen was modeled as a contact boundary.

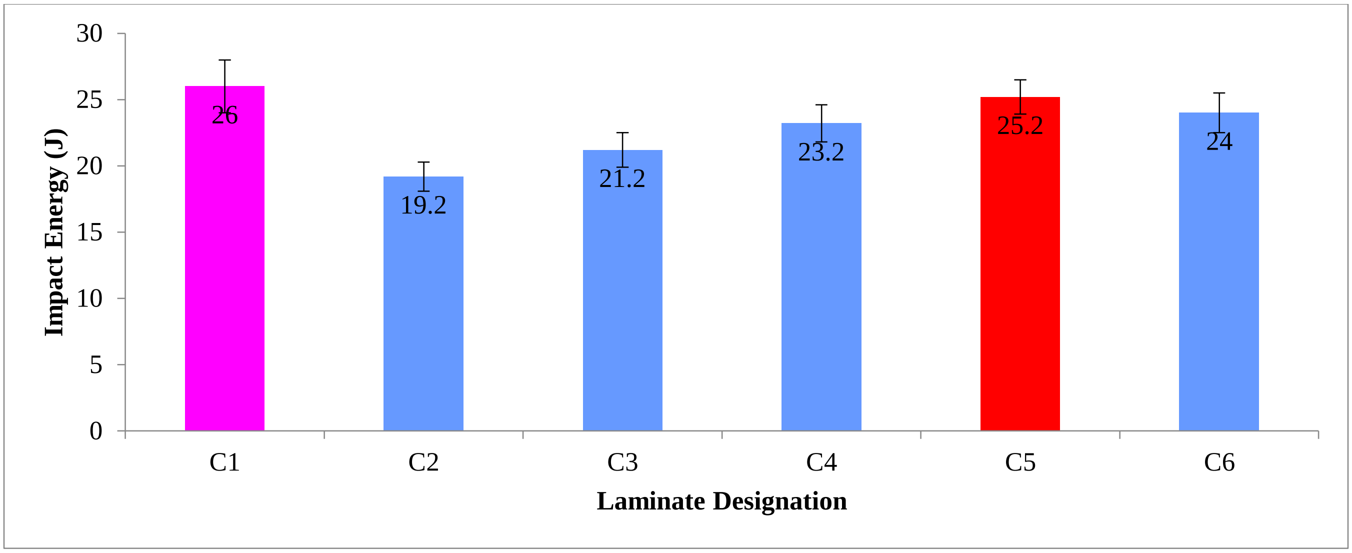

Fig. 4 Energy absorbed by the specimens

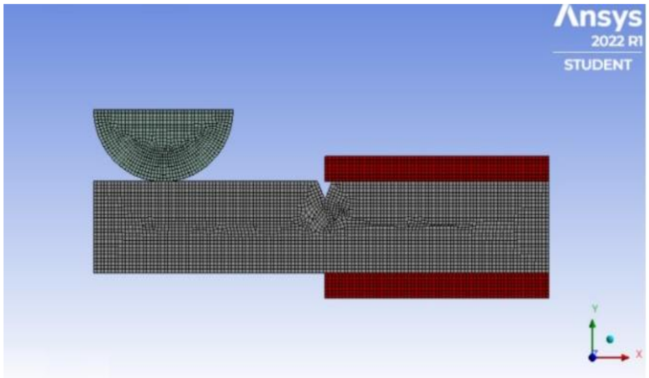

Fig. 5 Meshed model (converged) of impact test specimen

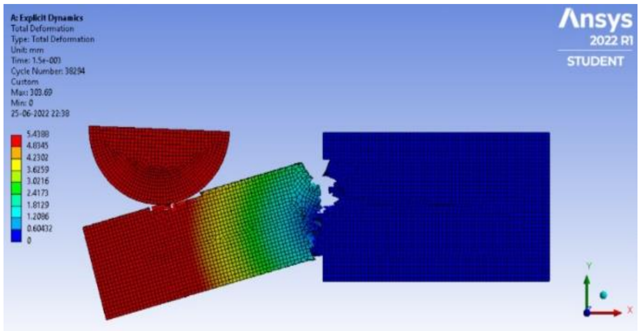

Fig. 6 Breaking of specimen C1 due to impact

There is a vertical constraint given on the striker's movement. The supports that hold the specimen are fixed and constrained to all degrees of freedom. In the analysis settings, the end time was given as 5e-4s. In erosion controls, the option “On material failure” was enabled to check the failure of the specimen once the load is applied. Then the problem was solved. Figure 6 shows the failure of the specimen at the V-notch due to the impact load. Figure 7 shows the stresses developed in specimen C1 due to the impact load of 2462.5 MPa. The specimen experienced stress levels exceeding the material's strength, resulting in erosion at the highest stress concentration, specifically at the V-notch.

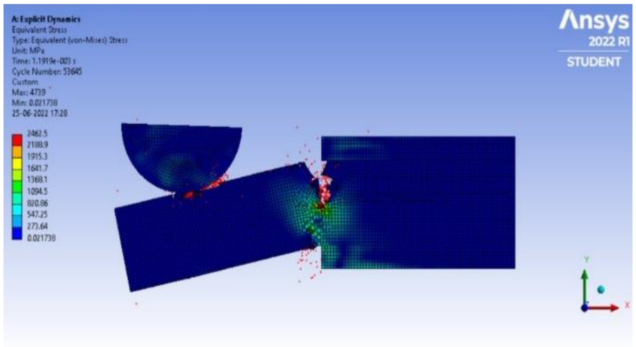

Fig. 7 Stresses developed in specimen C1 due to impact load

Ansys's energy summary is used to derive the energy that the specimen has absorbed. Figure 8 shows the energy summary for the material C1. It is a plot between the energy in Joules on the y-axis and the time of impact in seconds on the X-axis. Figure 8 shows the total four energies. They are kinetic energy, internal energy, hourglass energy, and contact energy (frictional energy).

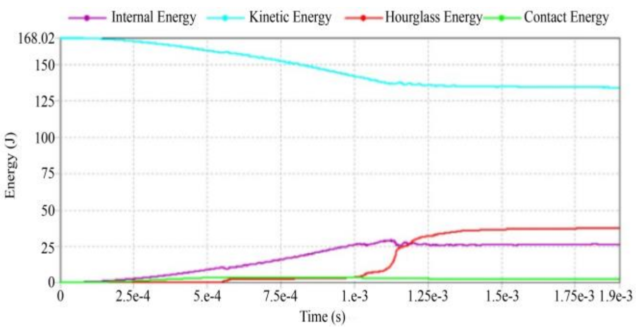

Fig. 8 Internal energy of C1 (J) from Workbench

Kinetic energy is the energy of the elements associated with the striker. It was observed that the maximum kinetic energy of the striker is 168.02J, which matches the experimental value. Internal energy is the energy of the elements associated with the specimen. Hourglass energy is due to the absence of deformation energy in elements. It is also called the "zero energy mode" in FEA. But the energy of the hourglass is not equal to zero. The friction between the striker and the specimen causes the contact energy. Positive contact energy builds when friction is included in a contact definition owing to the dissipative friction energy. This friction energy is not recovered even after the objects are no longer in contact.

The maximum energy absorbed by specimen C1 before breaking is 28.75 J, which was observed from its internal energy curve. The point where the internal energy curve and hourglass energy curve intersect shows the failure of the specimen. Before the specimen fails, the total energy is simply the sum of kinetic and internal energies and thus doesn't include such contributions as hourglass energy and contact energy. From Figure 9, the maximum energy absorbed by specimen C5 before breaking was found as 27.5J.

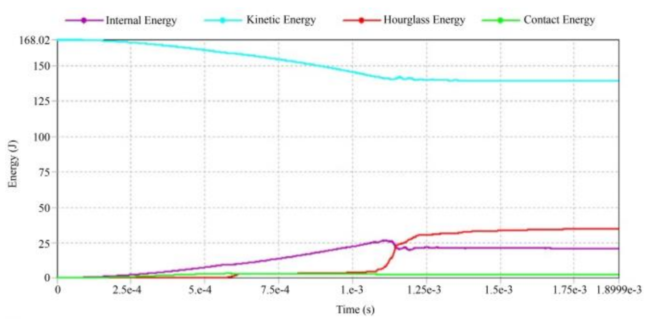

Fig. 9 Internal energy of C5 (J) from Workbench

5.3. Comparison of experimental and ANSYS results

Table 1 shows the comparison of energy absorbed by the specimen from the experiment and that obtained from Workbench. The experimental and Workbench values are in good agreement, with the maximum deviation of 9.6 % for C1 and the minimum deviation of 0.3 % for C3. The implementation of the finite element method Workbench R22.1 has been successfully observed in determining the impact energy of hybrid composite materials.

Table 1. Comparison of the impact energy absorbed from the experiment and the Workbench

Specimen Designation	Energy absorbed from impact test (J)	Energy absorbed from Workbench (J)	% deviation
C1	26	28.75	9.6
C2	19.2	20	4
C3	21.2	21.25	0.3
C4	23.2	23.5	1.3
C5	25.2	27.5	8.4
C6	24	24.2	0.9

6. Conclusion

From the impact test results, it was concluded that among the tested composites, C1 exhibited the highest energy absorption at 26J. Comparatively, C5 absorbed 25.2J under the impact load, showcasing an impressive 96.9% impact resistance relative to C1. So, the impact test outcomes illustrate that introducing a single layer of woven jute at the 8th position C5 results in a minimal 3.1% reduction in impact strength, indicating a minor deviation from C1.

Noteworthy is C5's specific impact strength, exceeding that of C1 by 0.24%. The finite element software, Ansys 2022 R1, effectively predicts the energy absorption in hybrid composites. A comparison between experimental values and those derived from Ansys revealed that the deviations are within acceptable limits, with a maximum deviation of 9.6% for impact energy absorption.

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