Investigation of Hybrid Natural Fibre Reinforced Composite for Impact Energy Absorption

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Abstract. In this paper, the low-velocity impact properties of jute/ramie fiber reinforced composites were tested by drop weight method, and the effects of mixing ratio on impact properties and energy absorption of composites were also studied. A series of impact energies ranged from 2 to 20 J were applied on five composites including jute fibre reinforced composite, ramie fibre reinforcement composite and three hybrid composites. When the jute fiber reinforced composite material is mixed with the ramie fiber reinforced composite material, energy absorption capacity of ramie fibre reinforced composites were enhanced with hybridizing this two fibre fabric together. The damage area was assessed using an ultrasound c-scan instrument. The results show that the hybrid laminate with a volume fraction of ramie fiber of 55% has better impact energy absorption and impact resistance. It was found that hybridizating different fiber together can effectively solve the problem of insufficient rigidity of jute fiber reinforced composite material and high ramie of ramie fiber reinforced composite material.

1. Introduction
In recent years, there is a greater need for weight savings and impact protection with lightweight materials. The application of cellular materials in impact energy absorbing structures has attracted more and more attention. It is important to understand the behavior of natural porous materials during impact can they be widely used in energy absorbing systems. In order to evaluate the potential of natural fibers as reinforcing materials in polymers, many studies have been carried out, and comparative studies between laminates and polymers with different types of natural fiber reinforcement have been published. [1-3]. Over the years, there has been increasing interest in the performance of hybrid composites such as those formed by combining different types of fibres or different laminating materials [4, 5]. Currently, most hybrid composites are made only between synthetic fibers, for example Kevlar and carbon, or plant fiber with synthetic fibers. Naik et al. [6] studied the impact behavior and post-impact compression properties of glass-carbon/epoxy composites in different stacking orders. Sarasini et al. [7] further tested the impact properties of woven basalt-carbon/epoxy composites. The results show that the sandwich laminate structure has better energy absorption capacity and damage tolerance, while the sandwich laminate structure has better bending resistance. Suresh Kumar et al. [8] pointed out that cannabis basalt/epoxy composites have advantages over non-hybrid composites in terms of residual flexural strength and impact properties. From the aspects of microstructure, yarn structure, fabric structure, etc., plant fibers are more different than synthetic fibers, resulting in different energy absorption and synthetic fibers. [9]. In addition, different plant fibers have different mechanical properties due to their different structures during natural growth. For example, ramie and flax fibers have better mechanical properties due to their smaller diameter and flow path size. Sisal and jute fiber have better energy absorption properties due to their multi-lumen...
structures, more energy can be dissipated during their composite damage propagation. Therefore, a good composite design can combine the advantages of various fibers to improve the overall performance of the composite. In addition, the base can be prevented from cracking and the fracture toughness of the composite material can be improved.

The purpose of this study was to investigate the behaviour of plant fiber-ramie /jute hybrid laminates under low-velocity impact. The woven and jute/epoxy composites were prepared by sandwich-type hybrid structure, and the low-velocity impact was carried out by using the drop weight impact device.

2. Experimental

2.1. Materials
Ramie plain fabrics and jute plain fabrics were supplied by Hunan Huasheng Dongting Ramie Textile Co., Ltd and Anji Zhengxing Fabric Co., Ltd, respectively. The basic parameters of ramie and jute fabrics are listed in Table 1. Epoxy resin E51, together with MeTHPA curing agent and DMP-30 tertiary amine accelerator were supplied by Shanghai Zhongsi Industry Co., Ltd.

| Table 1. The properties of ramie and jute fabrics |
|-----------------------------------------------|
| Weave | Ramie fabric | Jute fabrics |
|-------|--------------|--------------|
| Areal density (g/m²) | 255.6 | 116.7 |
| Warp yarns (yarns/dm) | 205 | 52 |
| Weft yarns (yarns/dm) | 228 | 58 |
| Filament diameter (μm) | 15.93 | 35.68 |

2.2. Composites Fabrication
Two types of fabric were all preimpregnated with the mixed epoxy resin system by hand stacking process. The hybrid laminates were fabricated by laying up the appropriate number of preregs in a steel frame mould (typically 350×300 mm²), and preheated in a hot compaction machine at the temperature of 90°C with a pressure of 1 MPa for one hour for ensuring good wetting, and cured at 120°C using a pressure of 6 MPa for two hours. After that, the mould was cool slowly to the room temperature in the press. Five types of laminates with different hybrid ratios shown in Table 2 were produced to investigate the effect of mixing ratio on the impact response of the laminates which included pure jute fiber reinforced polymer composite (JFRP), 3 kinds of ramie/jute fiber reinforced hybrid polymer composites and pure ramie fiber reinforced polymer composite (RFRP). The fiber volume percentage of ramie and jute in the composites were varying while the total fiber volume fractions of the composites were kept the same, which were approximately 50%. Fibers are layed up as a sandwich-like sequence with ramie fibre layers (skins) and jute fibre layers (core) for composites with three mixing ratios. The thickness of the laminates were 4.15±0.08 mm. Another three kinds of hybrid composites were fabricated to investigate the effect of stacking sequences on the impact energy absorb properties on hybrid laminates as shown in Table 3. The total fiber volume percentage and fiber volume fractions for each type fibers were unchanged. The total fiber volume percentage was 50%, jute fibre and ramie fibre were 23% and 27%, respectively.

| Table 2. Different hybrid ratios of five types of hybrid composites. |
|---------------------------------------------------------------|
| Designation | Volume fraction ratio \( V_r (\text{Rami}e/\text{Jute}) \) | Ply number ratio \( \text{(Rami}e/\text{Jute}) \) | Stacking sequence |
|--------------|------------------|------------------|------------------|
| JFRP         | 0/100            | 0/8              | \([J]_8\)        |
| 6R6J         | 30/70            | 6/6              | \([R_3/J_6/R_3]\) |
| 12R4J        | 55/45            | 12/4             | \([R_6/J_4/R_6]\) |
| 18R2J        | 80/20            | 16/2             | \([R_9/J_2/R_9]\) |
| RFRP         | 100/0            | 22/0             | \([R]_{22}\)     |
Table 3. Hybrid composites with different stacking sequences.

| Designation | Stacking sequence   |
|-------------|---------------------|
| 12R4J       | [R_6/J/R_6]         |
| 4J12R       | [J_2/R_12/J_2]      |
| 2RJ         | [R_2/J/R_2/J/R_2]   |

Figure 1. Comparison of (a) ramie fabric and (b) jute fabric in macroscopic scale

2.3. Low-Velocity Impact Test
According to ASTM D7136 standard, a series of low-velocity impact tests were carried out on plant fiber reinforced composite laminates, and their impact properties and damage mechanisms were studied. The laminate was subjected to a low-velocity impact test using the CEAST 9350 drop hammer tower. A hemispherical indenter (steel material) is attached to a 16 mm diameter impactor, the total mass of the impactor was 2.4 kg. The sample was placed in a steel bracket with 75 x 50 mm squares sandwiched between the four corners. The anti-rebound system of the impact machine captures the crosshead and prevents it from colliding with the sample again. The load time tracking during the test was recorded by the computer. In order to evaluate the damaged area, an ultrasound c-scan (NAUT21, Japanese probe) was used when examining the impact sample.

3. Results and Discussions

3.1. The Low-velocity Impact Response of JFRP and RFRP
Typical force–time histories under impact tests of JFRP and RFRP panels with impact energy between 2 to 20 J are shown in Figure 2. It can be seen from Figures 2 (a) and (b) that some initial oscillations in the curves, this is probably owing to the ringing inside of the load cell and dynamic effects in the plate. The figures show that increasing the impact energy leads to increase in the impact force and the impact duration before being perforated. It can be seen from Figure 3 (a) for RFRP laminates, no energy can be recovered and perforated at 20 J. However, during the unloading process, the displacement of the RFRP laminate under four impact energies returned to the axial origin, indicating that it can self-recover through its own elasticity. JFRP has good compatibility with itself and can perform higher overall deformation, so it can absorb more energy.
Figure 2. Typical load vs. time curves for (a) JFRP and (b) RFRP following different impact energies.

Figure 3. Typical load vs. deformation curves for (a) JFRP and (b) RFRP following different impact energies.

Figure 4. Photos of damage progression on front and rear faces of JFRP and RFRP.
Increase the impact energy, JFRP and RFRP laminates will produce different damage modes and corresponding damage, as shown in Figure 4. Penetration of the indentor through the laminate thickness was accompanied by cracks, fibre breakage was observed on JFRP composites following an impact test of 20 J. With same impact conditions, RFRP laminates showed a cross-shaped crack with associated matrix cracking but without evidence of penetration, this indicates that RFRP composites process superior impact resistance compare to JFRP.

3.2. Effect of Hybrid Ratios on Impact Properties of Composites

It can be seen from Figure 5 that increase the volume percentage ratio of ramie fibre up to 55% (12R4J), laminates exhibit a residual elastic response when the impact energy of laminate was 20 J. Figure 6 shows that the mixing ratio has an enhanced effect on the impact properties of the composite ramie/jute fiber. The magnitude of this maximum impact force is positively correlated with the relative volume of the ramie fiber, so the lower laminate has a higher load carrying capacity when the Vr level is higher, as shown in Figure 6(a). The RFRP laminate has a lower displacement, while the JFRP and hybrid laminates have better compliance and absorb energy through overall deformation. According to Figure 6(b), JFRP and hybrid laminates are more advantageous in terms of overall deformation, fiber breakage and splitting, so they can absorb more energy than RFPR. Three hybrid laminates show similar energy absorption capacity to the RFRP composites following impact energy up to 14 J. However, the hybrid composite show superior energy absorption ability compare to the RFRP when impact with an energy of 20 J, the absorbed energy of 6R6J (Vr % =30%) even higher than JFRP. It can be seen from Figure 7 that 6R6J laminate was also perforated when the impact energy of laminate was 20 J. This breakage of ramie fibres in hybrid composite dissipated more energy than that of in JFRP laminate. In fact, it can be seen from Figure 8 that the damaged area for 12R4J laminates is the smallest among five composites, suggesting that volume fraction ratio of ramie fiber is 55% (12J4R) is the optimized hybrid ratio for the ramie/jute hybrid composites.

![Figure 5. Force and displacement traces of five type of composites](image-url)
Figure 6. Bar chart of (a) Maximum force vs. Impact energy and (b) Absorbed energy vs. Impact energy.

Figure 7. Damage area vs. Impact energy bar chart of five composites.

4. Conclusion
In this paper, the low-velocity impact response of ramie/jute fiber reinforced epoxy composites and the effect of ramie/jute fiber hybridization were studied. Three different hybrid ratio laminates have been prepared: the volume friction of ramie was 30%, 55% and 80%. Impact damage caused by the same energy level can lead to penetration on the jute laminate, while the mixed laminate and the ramie laminate have cross-shaped cracks on the front side, but there is no evidence of penetration. Compared to jute laminates, the hybridization of ramie and jute fibers prevents the penetration of the whole jute composite and the low ramie volume fraction mixed laminate, and the peak force is increased. Ramie/jute volume friction of 55/45 was the optimized hybrid ratio for this type of hybrid composites.

5. Acknowledgements
This research received grant from National Natural Science Foundation (11302151), the Fundamental Research Funds for the Central Universities and Shanghai Rongtai Health Technology Co., Ltd.

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