Development of natural fibre reinforced hybrid composites and its characterization

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Abstract. An attempt was made in this study to fabricate natural fiber-strengthened epoxy composite material using hand-layup method. Four different natural fibers were used to develop the hybrid composites. The test specimens were prepared from the composites to carry out mechanical characterization according to the ASTM standard. Mechanical testing was performed to characterize the composites, namely tensile, flexural, impact and double shear. The results showed that Kevlar/Aloevera/palm/epoxy hybrid composite had superior mechanical properties relative to other hybrid composites. The tensile strength, flexural strength and load bearing capacity were increased by 50%, 14% and 54% respectively. To analyze the fracture surface of the tested samples, Scanning Electron Microscope was used. Fiber breakage and matrix cracking were the dominant failure mechanism of composites in tensile testing. Matrix cracking and delamination have been the dominant failure mechanism in impact testing.

1. Introduction
Recently, the benefits of natural fibers such as low cost, low density and high unique properties have attracted the attention of scientists and technologists. Natural fibers are biodegradable, non-abrasive, readily available, and their basic characteristics are similar to those of other fibers used for reinforcement. Such natural fibers are flax, cotton, jute, sisal, kenaf, coir, kapok, banana, aloevera, bamboo, palm, and many more. For the past few years, the manufacturing of natural fiber reinforced composites has been a topic of interest. A great deal of effort has been made to increase their mechanical, thermal, viscoelastic and machining performance in order to expand the potential and utilization of this material group. Uses of these composites have significantly increased, including structural member and underfloor panelling for vehicles, sporting goods and structural parts of boats and ships [1–4]. Through hybridizing one natural fiber in one matrix with another natural fiber/synthetic fiber, the hybrid composite is a distinctive product which exhibits superior performance compared to individual composites of fibre-strengthened polymer [5]. Aziz and Ansell [6] studied the
outcome of fiber orientation and alkalization on the mechanical behavior of kenaf and kemp bast fibre composites. Compared to composites made from as-received fibers, they reported that alkalized and long fiber composites provided higher flexural modulus and flexural strength. Chaitanya and Singh [7] examined the outcome of fiber weight fraction and fiber surface modification on the mechanical behavior of bio composites reinforced by Aloe Vera and Sisal fiber. They found that the characteristics of bio-composites enhanced by Aloe Vera fiber are similar to those of bio-composites enhanced by Sisal fiber.

Venkateshwarana et al [8] researched banana / sisal reinforced hybrid composites’ mechanical and water absorption behavior. They found that adding up to 50% sisal fiber by weight in banana/epoxy composites improves mechanical performance and decreases moisture uptake behavior. Moisia and Sirhabizu [9] attempted to describe and examine the mechanical properties of epoxy matrix composite strengthened by sisal/bamboo fibers. The result revealed that bamboo-sisal fiber reinforced epoxy composites manufactured to bamboo fibers with 25/25% sisal weight fraction, fibers stacked unidirectionally and cured at 25°C exhibit high tensile and bending strength. Okubo et al [10] explored the mechanical performance of polypropylene composites strengthened by bamboo fibre. They noted that composite tensile strength and modulus increased by about 15 and 30%. The influence of alkali treatment on the mechanical behavior of sisal/silk hybrid composites was explored by Noorunnisakahanam et al [11]. The mechanical behavior of the sisal/silk hybrid composites was significantly improved by these treatments. Akash et al [12] investigated the mechanical properties of hybrid composites reinforced by sisal/coir material. They found it necessary to hybridize fibers in natural fibers derived composite materials to achieve high mechanical strength. Navjot et al [13] studied the mechanical behavior of high-density polyethylene composite enhanced by hybrid sisal/hemp fiber and confirmed that hybrid composites are superior to single fiber composite. It was noted from the literature survey that no work on hybrid composite consisting of reinforced epoxy composite from Aloevera, Bamboo, Palm and Kevlar fibres is published. Thus, this study investigated the effect of various natural fibers such as Aloevera, Bamboo, Palm on the mechanical performance of epoxy composites.

2. Materials and methods

2.1. Materials
Aloevera, Bamboo, Palm and Kevlar fibers have been used for the production of composite laminates in the present investigation. These natural fibers were bought from M/s Sakthi industries, Erode, Tamil Nadu. The Kevlar fiber, epoxy resin (LY556) and hardener (HY951) have been purchased from M/s Sakthi Fiber Glass Ltd., Chennai. Natural fiber properties are shown in Table 1.

| Physical Property | Aloevera Fiber | Bamboo Fiber | Palm Fiber | Kevlar Fiber 129 |
|-------------------|---------------|--------------|------------|----------------|---|
| Density (g/cm³)   | 1.4           | 0.6-1.1      | 1.48       | 1.43           |   |
| Tensile strength (MPa) | 300          | 140-230     | 276        | 930            |   |
| Elastic modulus (GPa) | 45           | 11-17       | 3.85       | 53             |   |
| Elongation at break (%) | 2.5           | 1.4         | 12.8       | 1.6            |   |

2.2. Fabrication of composites
The one-sided glass mold (30 x 30 cm) used for fabricating the composite laminates by hand lay-up method. The composite laminate consisted of five layers in which Kevlar fiber layers were fixed respectively in the first, third and fifth layers of the laminate and the natural fibers such as Aloevera, Bamboo and Palm fibers were inserted in between Kevlar fiber layers. The epoxy resin and hardener
were mixed in a ratio of 10:1. Initially, the mold surface was sprayed with a releasing medium to avoid composites from adhering to the mold during the healing process and to make sure a smooth surface. The Kevlar fiber was placed on the mold and then on the Kevlar fiber resin was poured. The second layer of natural fiber was placed over the Kevlar fiber before the resin was completely dried, then resin was added and this cycle was also repeated for the next three layers. The formation of air gaps between the layers was gently squeezed during processing with the aid of the roller. Composite was then cured by applying equal load for 24 hours on top of the mold at room temperature, and composite laminates were also cured for 3 hours at 70°C after removal from the mold. The fiber-to-resin ratio was taken as 40:60 for each hybrid composite. Figure 1 shows the configuration of the composite laminate design.

2.3. Characterization of composites
For measure the hardness values of composite laminates, the Rockwell hardness testing machine was used. The Rockwell hardness test was conducted on composite laminates in compliance with the ASTM D2583 standard. Using universal tensile testing machine, the tensile properties were tested. The tensile test was conducted in accordance with ASTM D638 standards. The specimen has been prepared according to the specifications of the tensile test dimension shown in Figure 2.

Using universal tensile testing machine, the flexural test or three-point bending test was performed. The specimen's ability to withstand the load under deformation was measured in the flexural study. Figure 3 displays the sample for flexural testing in compliance with the ASTM D790 standards.
Figure 3. Flexural testing specimen.

The Charpy impact testing machine was used to carry out the impact tests. The impact test was executed to assess the impact strength of the composite in compliance with ASTM D256 requirements. This test also evaluates the total amount of energy that was absorbed during the material fracture. The impact test specimen is shown in Figure 4 as per ASTM standard.

Figure 4. Impact testing specimen.

The double shear test was followed using a universal testing machine based on the adapted methodology in accordance with ASTM standard D5379 and the test sample is displayed in Figure 5. The sample was put in a attachment and in order to generate shear, constant load was applied. The load has been increased to break and the corresponding load has been noted.

Figure 5. Double shear testing specimen.

Scanning electron microscopy (SEM) analyzed the fractography of the tensile and impact test specimens to understand the composite laminate failure mechanism.

3. Results and discussion

Figure 6(a) shows the variation in the Hardness values of the various composites. The composite laminates of Type-I showed the hardness value of 56 HRC which is the lowest of the hardness values reported in this study. For Type-II and Type-III laminates, the utilization of palm fiber as a strengthener increased the hardness values of hybrid composites. Type-III composites display the highest hardness value of 65 HRC, which is 16 % higher than Type-I composites, among the palm fiber reinforced composites. This is because of the greater density and hardness values of palm fibre in the hybrid composite laminate.

Figure 6(b) shows the ultimate tensile strength of the various composite laminates. For Type-I composite laminate, the lowest value of ultimate tensile strength 82 MPa is reported. The ultimate tensile strength improvement is observed for the palm fiber-reinforced hybrid composite laminate. For Type-III composites, which is 50 percent greater than Type-I composites, the maximum value of the
ultimate tensile strength 123 MPa is recorded. This is due to the higher strength and rigidity of palm fiber in the hybrid composite laminate. In addition, the strong bonding between fiber and resin also improved the load bearing capacity of hybrid composite laminates reinforced by palm fiber.

Figure 6. (a) Hardness and (b) Ultimate tensile strength of composite laminates.

Figure 7(a) shows the difference in flexural strength of the different composite laminates. It can be seen that when the palm fiber is used as one of the reinforcements, the flexural strength of hybrid composite laminates is increased. Type-I composite laminate consisting of Kevlar, Bamboo and Aloevera fiber as reinforcements showed as 184 MPa flexural strength. The presence of palm fiber in composite laminates Type-II and Type-III enhanced flexural strength. Type-III composite laminate shows the maximum flexural strength as 210 MPa which is about 14% higher than that of composite laminate Type-I. This is due to higher palm fiber strength and strong fiber-resin interface. Figure 7(b) indicates the difference in the impact strength of the different composite laminates. Composite laminate of Type-I displayed a maximum impact strength of 9.66 J relative to composite laminates of Type-II and Type-III. The presence of palm fiber reduced the hybrid composite laminates impact strength. For Type-II composite laminate, which is around 24% lower than Type-I composite laminate, the lowest impact strength of 7.33 J is observed.

The double shear testing findings of all the composites are presented in Table 2. The results showed that composite laminate Type-III had a maximum break load of 5.5 kN with a maximum displacement of 35.12 mm compared to other composite laminates. The presence of palm fiber slightly increased Type-II composite laminate's load-bearing capacity. The combination of fibers such as Kevlar, Aloevera and palm-reinforced epoxy increased the load-bearing capacity of Type-III composite laminate, which is 54% higher than that of Type-I composite laminate.

Table 2. Results of double shear test.

| Composite Laminates | Break load (kN) | Displacement at break load (mm) | Maximum displacement (mm) |
|---------------------|-----------------|---------------------------------|---------------------------|
| Type - I            | 2.52            | 4.25                            | 34.75                     |
| Type - II           | 2.92            | 4.88                            | 33.94                     |
| Type - III          | 5.5             | 4.89                            | 35.12                     |
The fracture surface of tensile test specimens of three different composites has been characterized by scanning electron microscope shown in Figure 8. The figure shows damage such as voids, fiber fracture, departed fiber, interfacial debonding, and matrix crack. Firstly, the crack begins in the matrix and then when the load is increased it propagates to fiber. The matrix-fibre interface is collapsed resulting in interfacial debonding. Lastly, the fiber fails with a rise in load due to fiber fracture. The composites dominant failure mechanism is due to breakage of fibers and cracking of matrices. All composite laminates are found to be failed in the same way.

![Figure 7](image1)

**Figure 7.** (a) Flexural strength and (b) Impact strength of composite laminates.

![Figure 8](image2)

**Figure 8.** SEM image of tensile test specimen of (a) Type - I, (b) Type - II and (c) Type - III composite laminates.
Scanning electron microscope image appeared in Figure 9 described the fracture surface of impact test samples of three different composites.

![SEM images of impact test specimens](image)

**Figure 9.** SEM image of impact test specimen of (a) Type – I, (b) Type - II and (c) Type - III composite laminates.

The damage such as fiber fracture, departed fiber, delamination and matrix crack are observed from the figure. The impact load applied to the sample produces a crack on the matrix which rapidly developed the delamination. Matrix cracking and delamination is the primary failure mechanism over fiber pull out, fiber breakage. All composite laminates were found to be failed the same way.

4. Conclusion

The Kevlar/epoxy hybrid composites reinforced by natural fibers were manufactured using hand-layup process. The effect of various natural fibers on mechanical properties of epoxy was investigated and the following conclusions were drawn.

- The results showed that Kevlar/Aloevera/palm/epoxy hybrid composite had superior mechanical properties relative to other hybrid composites.
- The tensile strength, flexural strength and load-bearing capacity of hybrid composites increased by 50 %, 14 % and 54 % respectively.
- Scanning Electron Microscopy study revealed that the composites primary failure mechanism was fiber breakage, matrix cracking, and delamination.
5. References

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