Feasibility of using Natural Textile-based Composite for the Retrofitting of Reinforced Concrete Beams

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Abstract. In response to the growing demand for eco-friendly construction materials, natural fibers such as bamboo and jute have emerged as viable alternatives to traditional options like steel and concrete. These natural fibers offer several advantages, including high tensile properties, crack resistance, and moisture resistance, making them suitable for structural applications. This study explores the potential of bamboo textile-based composite and jute textile-based composite for retrofitting reinforced concrete beams. It was found that the 4-layer bamboo textile composite achieved a 50% increase in tensile strength and similarly, the 5-layer jute textile composite demonstrated a significant 90% increase in tensile strength. In this study, the optimized 4-layer bamboo textile and a 5-layer jute textile composite with are applied in a U-wrapping configuration for retrofitting purposes. Strengthened and preloaded beams were retrofitted and subjected to testing for comparison. The results indicate that the bamboo textile composite outperforms in terms of both strengthening and retrofitting applications.

1 Introduction

Retrofitting refers to the process of adding new features or technology to an existing structure. The term is commonly used in the context of building and construction, where retrofitting may involve adding new insulation, updating electrical or plumbing systems, or installing new windows or doors to improve energy efficiency. Retrofitting can also refer to modifying an existing product or system to make it more advanced, efficient, or compatible with new technology.

There are several methods of retrofitting beams, depending on the specific requirements and constraints of the structure. One common approach is to reinforce the beam by adding additional steel plates or rods to increase its strength and stiffness. This may involve drilling holes in the beam and inserting steel members, or attaching external plates to the beam using bolts or welding. Another method of retrofitting beams is using fibre-reinforced polymers (FRPs) to reinforce the existing beam. FRPs are composite materials that consist of high-strength fibres embedded in a polymer matrix. FRP composites can be reinforced with different types of fibres such as glass, carbon, and aramid fibres. Natural fibre composites,
made of natural fibres such as jute, hemp, flax, or bamboo, can also be used to reinforce the polymer matrix in FRP composites [1].

The manufacturing and use of artificial synthetic composites for retrofitting and rehabilitating infrastructure essentially corresponds to using materials like synthetic fibres and polymer epoxy as the matrix material, both of which are not sustainable in nature. Additionally, the production of these polymer epoxies is related to the generation of hazardous vapours, chemicals, and gases [4]. Fibres made of carbon, glass, and aramid are considered hot structural materials. Unfortunately, one of the main raw materials used to create these synthetic fibres is chlorine. Chlorine is linked to the creation of bio-accumulative and highly poisonous dioxins and furans. Particularly those who work in the glass and carbon fibre industry must deal with highly toxic substances that cause eczema and dermatitis. Furthermore, the high price of synthetic FRP sheet could make it difficult to use them in applications like small structures. The use of natural fibres instead of artificial ones could be one answer to the above-mentioned issues. The advantages of using sustainable natural fibre in raw form or textile are weight saving, lower raw material cost, thermal recycling etc. Among the various natural fibres, bamboo, coir, and silk are of great interest, as they have high impact strength.

The objective of the study is to compare the natural fibre composites of bamboo and jute for the retrofitting of reinforced concrete (RC) beams. An optimized layer of jute and bamboo fibre textile composite is used as the external U-wrapping technique. For the comparison study, the RC beams without preloading and preloaded up to 35% and 50% of the collapse load are wrapped using jute and bamboo fibre textile composite. Overall, retrofitting beams can help extend the life of a structure and improve its safety and performance.

2 Experimental study

2.1 Materials used

For the study, Portland Pozzolana Cement (PPC) was used for M25 grade concrete. Jute and bamboo fibre were purchased from Go Green Chennai, and for epoxy resin, EPOFINE 230 and FINEHARD 951 were obtained from Fine Finish Mumbai.

2.2 Design of beam

In this study, beams of size 150mm×100mm×1200mm were designed using M25 grade concrete and Fe500 grade steel, providing 2 numbers of 8 mm diameter bars as tension reinforcement and 2 legged 6 mm diameter bars as shear reinforcement.

Fig. 1 Cross-section of beam
To assess the feasibility of retrofitting RC beams with natural fibre textile composites, both non preloaded beams and preloaded beams were retrofitted.

2.3 Layer optimization of composite

The fabrication process followed the standards set by ASTM (American Society for Testing and Materials). A total of 7 layers of composite were fabricated for each type of material. In order to determine the optimal number of layers for each type, tensile tests were conducted on the specimens according to ASTM D3039, which is a standard test method for determining the tensile properties of polymer matrix composite materials. After conducting the tensile tests, the tensile stress values were obtained for each type of composite material. The results indicated that the optimal number of layers for the bamboo textile composite was determined to be 4 layers, achieving a tensile stress value of 52.73 MPa. On the other hand, the optimal number of layers for the jute textile composite was found to be 5 layers, resulting in a tensile stress value of 48.3 MPa. These values represent the maximum strength achieved by each composite material configuration. To further understand the behaviour of the composites, Figure 2 displays the crack patterns observed in the bamboo textile composite and jute textile composite. The crack pattern refers to the distribution and propagation of cracks within the composite material when subjected to tensile forces. By examining the crack pattern, it is possible to gain insights into the failure mechanisms and the overall performance of the composites. The crack patterns can provide information about the interfacial adhesion between the fibres and the matrix, the distribution of stress within the material, and any specific failure modes exhibited by the composites.

Fig. 2. Failure pattern of bamboo and jute textile composite

2.4 Preloading of beam

The beam was preloaded using a UTM (Universal Testing Machine) with a capacity of 1000 kN. The deflection at the centre portion was noted and a dial gauge was used for this purpose. The first crack in the beam was initiated using single-point loading, as shown in Figure 3. Based on the load-deflection behaviour of the control beams, the preloaded conditions selected for the study were 35% and 50% of the ultimate load. Out of all the beams, 2 sets were chosen for strengthening without any preloading.
The beams were preloaded up to the required percentage, and the crack pattern for each loading was given in Figure 4 and Figure 5. The preloaded beams were kept for 15 min in the UTM, and after releasing the load, the initial cracks disappeared.

<table>
<thead>
<tr>
<th>Beam ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB</td>
<td>Control beam</td>
</tr>
<tr>
<td>J0</td>
<td>Beam for strengthening</td>
</tr>
<tr>
<td>B0</td>
<td>Beam for strengthening</td>
</tr>
<tr>
<td>J35</td>
<td>35% preloaded beam</td>
</tr>
<tr>
<td>B35</td>
<td>35% preloaded beam</td>
</tr>
<tr>
<td>J50</td>
<td>50% preloaded beam</td>
</tr>
<tr>
<td>B50</td>
<td>50% preloaded beam</td>
</tr>
</tbody>
</table>

2.5 Retrofitting of beam

For retrofitting the RC beam, initially, the surfaces of the beam are dusted and cleaned using a wire brush and sandpaper before applying the resin. The resin-hardener mix is taken in a ratio of 10:1, mixed and applied directly to the surface of the beam using a brush. Then, an
initial layer of fibre textile is laid, and the resin mix is applied, with excess being removed using a roller. The process is repeated until the required layer is achieved. The retrofitted beam is tested after 7 days of curing. The retrofitted beams are shown in Figure 6.

Fig. 6 Beams after retrofitting

3 Results and discussions

The ultimate load-carrying capacity, load-deflection behaviour and the crack pattern of the strengthened and preloaded beams were observed using the load bending test. The results observed are given in Table 2. These findings provide valuable insights into the structural behaviour and performance of the strengthened and preloaded beams under load conditions.

3.1 Ultimate load-carrying capacity

The ultimate load-carrying capacity of control, strengthened and preloaded beams was observed and depicted in Table 2. Based on the experimental findings, it can be observed that the natural fibre composite has enhanced the ultimate strength of the beam. In all conditions, the ultimate load-carrying capacity has shown an increment compared to the control beam. The comparison of the ultimate load carrying capacity with the control beam is depicted in Figures 7, 8, 9.

<table>
<thead>
<tr>
<th>Beam ID</th>
<th>Ultimate load (kN)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB</td>
<td>28.82</td>
<td></td>
</tr>
<tr>
<td>J0</td>
<td>52.10</td>
<td></td>
</tr>
<tr>
<td>B0</td>
<td>55.70</td>
<td></td>
</tr>
<tr>
<td>J35</td>
<td>51.18</td>
<td></td>
</tr>
<tr>
<td>B35</td>
<td>54.18</td>
<td></td>
</tr>
<tr>
<td>J50</td>
<td>50.07</td>
<td></td>
</tr>
<tr>
<td>B50</td>
<td>52.42</td>
<td></td>
</tr>
</tbody>
</table>

The retrofitted beam exhibited ductile behaviour during the test, with the failure of the composite occurring through sudden rupture rather than debonding failure.
Based on the analysis of the bending test results, the strengthened beam exhibited significant improvements in load carrying capacity. The jute textile composite showed an increment of 80.77%, while the bamboo textile composite demonstrated a higher increment of 93.26%. Furthermore, when the beams were preloaded at 35%, the load carrying capacity increased by 77.59% for jute textile composite and 87.99% for bamboo textile composite. Similarly, with a 50% preload, the load carrying capacity increased by 73.73% for jute textile composite and 81.81% for bamboo textile composite. Notably, in both cases, the bamboo textile composite displayed a higher ultimate load carrying capacity compared to the jute textile composite.

### 3.2 Load - deflection behaviour

The load-deflection behaviour of the control beam is depicted in Figure 10. The curve represents the average of three tested beams. From the test result, the initial crack was
developed at 10.23 kN. The load-deflection graphs for strengthened beams and 35% and 50% preloaded beams were depicted in Figure 11.

![Load - deflection graph](image)

**Fig. 10** Load-deflection curve of control beam

![Load Deflection Curve](image)

**Fig. 11** Load-Deflection graph of retrofitted beams

The experimental findings revealed that the formation of cracks was delayed in both non-loaded and preloaded beams when utilizing natural fibre composites. This observation indicates that the incorporation of natural fibre composites has led to an increase in the load carrying capacity of the beams. Additionally, the beams exhibited a tendency to undergo bending at larger loads. This improved load-deflection behaviour suggests that the natural fibre composites effectively strengthened the beams and contributed to their enhanced structural performance under load conditions. Performance under load conditions.
Composites effectively strengthened the beams and contributed to their enhanced structural performance.

### 3.3 Crack pattern

The control beam was tested up to the ultimate load and the failure pattern of the control beam were shown in Figure 12. All the beams were preloaded up to the required percentage and are retrofitted. After retrofitting the beam, the crack pattern can’t be visible due to the wrapping method. Therefore, the crack pattern of the composite can be used for concluding the strengthening effect.

![Crack pattern of the control beam](image1)

**Fig. 12** Crack pattern of the control beam

The crack pattern of the retrofitted beam is shown in Figure 13 and Figure 14. The retrofitted beam displayed a ductile behaviour, which means it exhibited significant deformation before failure. Interestingly, the failure of the composite material used in the retrofitting process was characterized by sudden rupture rather than debonding failure. This indicates that the composite material maintained its structural integrity until it reached a critical point where it abruptly fractured. This behaviour suggests that the composite material possessed good tensile strength and bonding with the substrate, enabling it to withstand substantial loads before experiencing a catastrophic failure. The sudden rupture failure mode implies that the composite material was able to effectively distribute and dissipate the applied load, contributing to the overall enhanced performance and load-carrying capacity of the retrofitted beam.

![Failure pattern of J35 retrofitted beam](image2)

**Fig. 13** Failure pattern of J35 retrofitted beam

![Failure pattern of B35 retrofitted beam](image3)

**Fig. 14** Failure pattern of B35 retrofitted beam

### 4 Conclusion

In this work the behaviour of bamboo and jute fibre textile composite for the application of retrofitting of RC beam as external wrapping is compared. The following observations can be concluded:
The analysis of the bending test results demonstrated that the incorporation of natural fibre composites, specifically jute textile and bamboo textile composites, significantly improved the load carrying capacity of the non-preloaded beams of which bamboo give the better performance compared with jute [4].

When preloaded both composites show a substantial increase in the load carrying capacity. Particularly, the bamboo textile composite consistently displayed a higher ultimate load carrying capacity than the jute textile composite in all cases [10].

The delayed formation of cracks in both non-loaded and preloaded beams indicates that the incorporation of natural fibre composites effectively strengthened the beams and contributed to enhanced structural performance. The beams also exhibited improved load-deflection behaviour, suggesting that the composites effectively distributed and dissipated the applied load, further enhancing their load-carrying capacity [9].

The crack pattern analysis revealed that the retrofitted beams displayed a ductile behaviour, exhibiting significant deformation before failure. Interestingly, the failure of the composite material used in the retrofitting process was characterized by sudden rupture rather than debonding failure. This indicates that the composite material possessed good tensile strength and bonding with the substrate, enabling it to withstand substantial loads before experiencing catastrophic failure [8].

Overall, these findings highlight the effectiveness of natural fibre composites, particularly bamboo textile composite, in strengthening beams and improving their load carrying capacity. The use of such composites can have significant implications for structural engineering and retrofitting applications, offering enhanced performance and durability.

References


