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# Shear strengthening of reinforced concrete beam using natural fibre reinforced polymer laminates

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## HIGHLIGHTS

- High strength NFRP laminates for shear strengthening of RC beam.
- Laminates were fabricated using kenaf, jute and jute rope fibres.
- NFRP laminates increased shear capacities of beams significantly.
- The laminates also increased ductility of shear strengthened RC beam.
- NFRP laminates were comparable with CFRP in shear strengthening of RC beam.

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## ABSTRACT

Shear strengthening of reinforced concrete beam using externally bonded steel plate and carbon fibre reinforced polymer laminate (CFRP) is the common practices in construction industry. However, high expense of CFRP laminate and corrosion of steel plate are the drawbacks of those materials. Thus, natural fibre based composite plate could be the alternative for shear strengthening of reinforced concrete structure. The aim of this research work was to develop high strength natural fibre based composite plates for the possible application in shear strengthening of reinforced concrete structure. In the experimental programme, the plates were fabricated using kenaf, jute and jute rope fibres in treated and untreated conditions. A total of eight beam specimens were prepared to investigate the structural behaviour, the beams were shear strengthened using treated and untreated natural fibre composite plates and CFRP laminates including control beam. Embedded connectors were used to eliminate debonding failure of the laminates. The shear strengthened beams with untreated kenaf, jute and jute rope composite plates had shown 35%, 36% and 34% higher failure loads as compared to control beam respectively. The structural behaviour of strengthened beams with treated composite plates was found to be comparable with those of untreated. Beam with jute rope composite plates showed lower failure load as compared to those of fibres due to fracture of plate followed by shear failure. Strengthened beams with natural fibres composite plates had shown higher ductility and higher failure loads as compared to those of CFRP laminates. The failure load, ductility, crack patterns and strain characteristics of strengthened beams with natural fibre composite laminates were found to be closely comparable with CFRP laminate strengthened beam.


## 1. Introduction

Strengthening and retrofitting of existing structures is one of the major part of construction industry now a days. It is an emerging demand for the continued growth of modern urban life where the number of structures continues to increase. Thus, repair and upgrade the existing structures increases due to environmental factors, design life of structure reached its end, increasing the loading on the structure by changes its usages and the needs to extend the structural life time. Therefore, a large number of strengthening methods and materials have been developed for both flexural and shear strengthening of structures. The methods include enlarging sections, shortening the span, externally bonded steel tension reinforcement using bolts and adhesive, and adhesively bonded fibre reinforced plates and wraps [1]. There have been a series of studies in the past for shear strengthening of RC beams using externally

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**Nomenclature**

| | |
|---|---|
| $M_{max}$ | moment resisting capacity of beam |
| $T$ | tensile force of flexural reinforcement |
| $Z$ | moment arm |
| $A_s$ | cross sectional area of flexural reinforcement |
| $f_{tk}$ | tensile strength of flexural reinforcement |
| $d$ | effective depth of beam |
| $x$ | depth of neutral axix |
| $b$ | width of beam |
| $f_{ck}$ | concrete compressive strength based on cylinder test |
| $V_{max,d}$ | maximum design shear force |
| $V_d$ | design shear force |
| $V_{y,link}$ | shear force of beam due to yielding of shear reinforcement |
| $A_{s,link}$ | cross sectiona area of shear link |
| $f_{y,link}$ | yield strength of shear reinforcement |
| $N$ | number of shear link that resist shear |
| $d'$ | depth of compression reinforcement (topbar) |
| $s$ | spacing of shear link |
| $V_{nfrp}$ | shear force resisted by NFRP laminate |
| $T_{nfrp}$ | shear force resisted by single plate NFRP laminate |
| $E_{nfrp}$ | modulus of elasticity of NFRP laminate |
| $A_{nfrp}$ | cross sectional area of NFRP laminate |
| $s_{nfrp}$ | spacing of NFRP laminate |

bonded steel plate and CFRP laminates [2,3]. In general CFRP laminate has superior physical and mechanical properties in terms of strength to weight ratio and non-corrosive nature. Those properties of CFRP laminate have gained popularities for external use in structure specially for strengthening of RC structure.

Composites help to achieve the desired properties by combining totally different materials in an exceedingly even handed manner. Traditional polymer composites, which contain synthetic fibres, such as carbon fibre composites and glass fibre composites are in modern industry as an alternative to metals and that have the desired properties. Each sort has its own vary of applications and limitations. In spite of the advantages of synthetic fibre composites; they are not easily recyclable, reusable and bio degradability after end of their life span. Still, synthetic fibres are doubtless risky to human health since they release airborne reparable fibres during throughout their production, usage, repair and removal [6]. Moreover, because of higher stiffness, CFRP laminate had shown less effective for shear strengthening of RC beam due to premature debonding failure. All these issues have led to explore of possible alternatives green and bio-based composites natural fibres materials as the reinforcement replacing some of the traditional engineering materials that are not environmentally friendly which used and resolve these issues [7–9].

Over the last few years, research works have been conducted to develop biodegradable natural fibre composite plates for automotive industry [4,5]. It was also found that natural fibre reinforced polymer composite provide a good alternatives to synthetic fibre composites and it has been accepted as a repairing and strengthening materials for structures in the construction industry [10,11]. The need for the world to become environmentally friendly made the natural fibre reinforced composites growing rapidly. The availability of natural fibres in Asia is more and also has some advantages over traditional reinforcement materials in terms of low cost, low density, renewability, recyclability, abrasiveness and biodegradability. This material shall warrant high specific strength and high specific stiffness of the structural materials provide a possible alternative to synthetic fibres, which cannot be achieved with conventional materials [12–14]. There are many varieties of natural fibre exist and the most common natural fibres used in industrial application are baste fibres obtained from the outer cell layers of plant stems, such as hemp, jute, flax, kenaf, and sisal [15].

Natural fibres have a drawback of high moisture absorption and poor mechanical properties due to poor interfacial adhesion between the fibre and the resin. Many studies have been conducted to improve the mechanical properties of fibres by chemical treatment [16–20]. Treatment by alkaline is one of the most common and popular chemical treatment of natural fibres with least environmental effect [21]. The alkaline treatment increases surface roughness by modifying the disruption of hydrogen bonding in the fibres network. This treatment removes lignin, wax and oils on the external surface of the fibres [22]. Several researchers have reported that the mechanical properties of composite plates have been enhanced with the increases of surface roughness of the fibres. Alkaline treatment is by soaking fibres in NaOH solution for a period of time at room temperature. It was found that, the treated fibres with alkali have shown an improvement on fibre strength and stiffness as compared to untreated fibres [23–25]. Edeerozey et al. [26], studied the effects of alkaline treatment on kenaf fibre. In general 5% and 6% NaOH solutions have been used to treat the fibres. It was found that, the treated kenaf fibre with 6% NaOH solution was effective at cleaning the fibre surface as compared to 9% NaOH solution which damage the fibre and reduces their strength [26].

Although, a significant number of research works have been conducted to develop composite plates using natural fibres for automotive industry, however, fabrication of high strength natural fibre based composite plates for shear strengthening of reinforced concrete structure is seldom found. Moreover, research to develop natural fibre non-biodegradable composites for strengthening application is still at infancy stage. The objectives of this research were to fabricate high strength composite plates using treated and untreated natural fibres kenaf, jute and jute rope for shear strengthening of reinforced concrete beam. The structural behaviour of shear strengthened reinforced concrete beams using developed natural fibre composite plates had also been experimentally investigated.

## 2. Proposed design model for shear strengthening of RC beam using natural fibre reinforced polymer laminates

In general, externally bonded shear strengthened beam failed due to debonding of externally bonded laminate with lower strain as compared to yield strain of shear reinforcement [27]. However, because of lower stiffness of natural fibre reinforced polymer (NFRP) laminates, the debonding strain of externally bonded laminate could be higher as compared to yield strain of shear reinforcement. Thus, the dimension of NFRP laminates for shear strengthening of reinforced concrete beam could be obtained through the new proposed guideline as shown below. The fundamental assumption of the proposed guideline is the laminate would not debond before the beam failed by flexure.

### 2.1. Maximum design shear capacity of shear strengthened beam

The shear capacity of reinforced concrete beam could be increased up to the maximum flexural capacity of the beam. The