Experimental and analytical study on hybrid composite and its performance on column

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Abstract. Composite materials are defined as the sum of matrix and reinforcement materials. Hand layup technique is mostly used by researchers for the fabrication of composite. The present work aims to determine the mechanical strength of hybrid composite (flax-glass-epoxy, jute-glass-epoxy, flax-epoxy, and glass-epoxy). Obtained experimental results were validated with finite element analysis using ANSYS software. Analytical study on performance of NSM GFRP bars along with hybrid composite as external strengthening for columns was evaluated using ANSYS software.

1. Introduction
Over the last years, the demand for natural fibre composites in the civil engineering field has increased. As, compared with synthetic composites, natural fibre composites [1,2,3,4] are sustainable materials with distinct advantages such as low cost, lightweight, recyclable, renewability, eco-efficiency, biodegradability and high specific properties. Composite materials are materials in which two or more different materials are combined together. Composite is defined as the sum of matrix and reinforcement materials. The fibres like glass [5], [6], [7], carbon [1], [8], basalt, flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie and bamboo are used as reinforcement. Meanwhile epoxy [1], [8], vinyl ester and polyester are mostly used matrix materials. Simple cold pressing method [9], vacuum-assisted resin transfer moulding (VARTM) [8], hand layup technique [1], [2] are the various methods for fabrication of composite materials. Among these hand layup techniques is common due to its simple procedure.

The recent studies mainly focus on the performance of fibre reinforced polymer (FRP) as external strengthening, seismic retrofit, tendons and rebar (internal strengthening of concrete), bridge components (deck slab, beam/girders, columns/piles). Even though strengthening of concrete beams and slabs using fibre-reinforced polymers (FRP) as longitudinal, near-surface mounted (NSM) bars has gained a lot of research interest as these bars provide good flexural strength to the column. However, due to the possibility of buckling of NSM bars/strips the method has not been effectively implemented for concrete columns. On the other hand, FRP-wrapping has been successfully used to enhance the axial capacity of concrete columns with limited effect on bending performance [10]. These transverse FRP wraps provide lateral support to the NSM bars and even protect existing steel bars against harsh environments. The FRP wrap also provides additional shear strength efficient confinement of the concrete core. The use of GFRP [11], CFRP [12], Hemp-FRP [13] as external confinement has been performed on columns by researchers, which gave promising results in earlier studies. The hybrid system can provide a durable and cost-effective solution for rehabilitation of bridge and waterfront structures.
The current research was carried out to determine the mechanical strength of hybrid composites (flax-glass-epoxy, jute-glass-epoxy) and the best among the hybrid composites was chosen. Obtained experimental results were validated with finite element analysis using ANSYS software. Finite element analysis using ANSYS software was also evaluated to study the performance of hybrid composite as external strengthening for columns.

2. Experimental investigation on composite materials

Hand layup technique was used for the composite production. The mould can be as simple as a flat sheet. The fibre plies were cut according to dimensions from the glass, flax and jute cloth. Depending on the thickness required numbers of fibre plies were taken. Matrix and hardener were mixed in respective ratio by using glass rod in a bowl. Before lay-up, a release sheet was placed in the mould to insure that the part will not adhere to the mould. A coat of laminating matrix was then applied by brush followed by the first layer of chopped mat one type fibre ply. Then the matrix was applied to the reinforcement so that the trapped air can be forced out using a roller. This procedure was continued for the next layer of fibre ply, until desired thickness was achieved. On the top of the last ply a matrix coating was done which serves to ensure a good surface finish. Finally a releasing sheet was put on the top and light rolling was carried out. Then a 20 kg weight was applied on the composite. Once finished, the resin was allowed to cure for 24 hrs and subsequent hardening. Finally, the Product was removed from the mould [1], [2].

The tensile test specimens were prepared according to ASTM D638-03. Specimens were cut in dog bone shape having dimension of (200 x60x5) mm for flax composite, (200x60x4) mm for flax-glass hybrid composite, (200x60x3) mm for jute-glass hybrid composite and glass composite. Tensile test was performed on a universal test machine with a load rate of 100kN. For every state, two samples were tested and the average was resolved and noted. The load was applied until the specimen breaks. The breaking load and corresponding deflection was noted [1], [6], [4].

The flexural test specimen was prepared according to ASTM D790 standard. Specimens were cut in rectangular shape having dimension of (400 x60x5) mm for flax composite, (400x60x4) mm for flax-glass hybrid composite, (400x60x3) mm for jute-glass hybrid composite and glass composite. For every state, two samples were tested and the average was resolved and noted. Clark Maxwell’s apparatus was used to determine the young’s modulus of the material. The corresponding deflection for increasing load at centre and quarter position till maximum bending achieved was noted and vice versa [1], [6], [4].

![Figure 1. Jute-Glass hybrid composite](image1)

![Figure 2. Flax-Glass hybrid composite](image2)
Figure 3. Flax composite

Figure 4. Glass composite

Table 1. Experimental tensile and flexural values of composites

| Fibre Composite               | Layers | Ultimate Tensile Strength | Flexural Strength E = 76851 |
|-------------------------------|--------|---------------------------|----------------------------|
|                               |        | Deflection (mm)           | Breaking Load (KN)         |
| Flax-Glass hybrid composite   | Core-4 | 12                        | 14.1                       | 3.422*10^{-3} |
|                               | Outer-4|                           |                            |
| Jute-Glass hybrid composite   | Core-6 | 9                         | 7.6                        | 4.065*10^{-3} |
|                               | Outer-4|                           |                            |
| Flax fibre composite          | 8      | 13                        | 3                          | 4.576*10^{-4} |
| Glass fibre composite         | 8      | 13                        | 23.3                       | 4.150*10^{-3} |

2.1 Finite element analysis on composites

2.1.1 Tensile test. According to ASTM D638-03 for tensile test, dimension was taken as (200x60x4) mm in dog bone shape. Flax-Glass hybrid composite (F-GFRP) was prepared using 4 layers of flax fibre mats at the core and 2 layers of glass fibre mats each at top and bottom reinforced with epoxy.

- Total thickness = 4mm
- Number of layers = 8
- Flax = 0.45mm/each layer
- Glass = 0.20mm/each layer
- Epoxy = 0.15mm/each layer

Fixed support was provided at one end and load was applied at free end for tensile test of composites. In FEM analysis, matrix (epoxy) and reinforcement fibres (glass, flax and jute) was provided as ply layers with respective thickness and fibre orientation was given as (0°, 90°) by default orientation.
Table 2. Mechanical properties of Epoxy, Glass, Flax and Jute

| Property               | Epoxy  | Glass  | Flax   | Jute   |
|------------------------|--------|--------|--------|--------|
| Density (g/cm³)        | 1.16   | 2.58   | 1.5    | 1.3    |
| Tensile strength (GPa) | 0.11   | 3.4    | 1.5    | 0.7    |
| Poisson’s ratio        | 0.3    | 0.2    | 0.41   | 0.36   |
| Tensile modulus (GPa)  | 4.1    | 72.3   | 27.6   | 26.5   |

Figure 5. Total deflection of flax-glass composite

Figure 6. Deformation-load curve of flax-glass composite
Jute-Glass hybrid composite (J-GFRP) was prepared using 6 layers of jute fibre mats at the core and 2 layers of glass fibre mats each at top and bottom reinforced with epoxy.

Total thickness = 4mm
Number of layers = 10
Jute = 0.25mm/each layer
Glass = 0.20mm/each layer
Epoxy = 0.15mm/each layer

Glass composite (GFRP) was prepared using 8 layers of glass fibre mats reinforced with epoxy.

Total thickness = 3mm
Number of layers = 8
Glass = 0.20mm/each layer
Epoxy = 0.15mm/each layer

Flax composite (FFRP) was prepared using 8 layers of flax fibre mats reinforced with epoxy.

Total thickness = 5mm
Number of layers = 8
Flax = 0.45mm/each layer
Epoxy = 0.15mm/each layer

| Table 3. Comparison of tensile values of flax-glass composite |
|--------------------------------------------------------------|
| Flax-glass composite | Deflection (mm) | Breaking load (kN) |
|----------------------|-----------------|-------------------|
| Experimental         | 12              | 14.1              |
| Finite Element Analysis | 11.962          | 14.8              |

| Table 4. Comparison of tensile values of jute-glass composite |
|--------------------------------------------------------------|
| Jute-glass composite | Deflection (mm) | Breaking load (kN) |
|----------------------|-----------------|-------------------|
| Experimental         | 9               | 7.6               |
| Finite element analysis | 9.71            | 7.99              |

| Table 5. Comparison of tensile values of glass composite |
|---------------------------------------------------------|
| Glass composite | Deflection (mm) | Breaking load (kN) |
|-----------------|-----------------|-------------------|
| Experimental    | 13              | 23.3              |
| Finite element analysis | 12.28          | 23                |

| Table 6. Comparison of tensile values of flax composite |
|--------------------------------------------------------|
| Flax composite | Deflection (mm) | Breaking load (kN) |
|----------------|-----------------|-------------------|
| Experimental  | 13              | 3                 |
| Finite element analysis | 13.1           | 3.2               |
2.1.2 Flexural test. According to ASTM D790 for flexural test, dimension was taken as (400x60x4) mm in rectangular shape. Flax-Glass hybrid composite (F-GFRP) was prepared using 4 layers of flax fibre mats at the core and 2 layers of glass fibre mats each at top and bottom reinforced with epoxy.

- Total thickness = 4mm
- Number of layers = 8
- Flax = 0.45mm/each layer
- Glass = 0.20mm/each layer
- Epoxy = 0.15mm/each layer

Simply support was provided at both ends and load was applied at (i) centre and (ii) quarter position for flexural test of composites.

M1 corresponds to the deflection at quarter position on the application of load at centre position and M2 corresponds to the deflection at centre position on the application of load at quarter position.

![Figure 7. Deflection (M1) for 0.5Kg load on flax-glass composite](image)

Jute-Glass hybrid composite (J-GFRP) was prepared using 6 layers of jute fibre mats at the core and 2 layers of glass fibre mats each at top and bottom reinforced with epoxy.

- Total thickness = 4mm
- Number of layers = 10
- Jute = 0.25mm/each layer
- Glass = 0.20mm/each layer
- Epoxy = 0.15mm/each layer

![Figure 8. Deflection (M2) for 0.5Kg load on flax-glass composite](image)
### Table 7. Comparison of flexural values of flax-glass composite

| Load         | Experimental Deflection (mm) | Finite element analysis Deflection (mm) |
|--------------|------------------------------|----------------------------------------|
|              | M1  | M2  | M1  | M2  |
| 0.0005 Tonne | 2.22| 2.75| 2.2186| 2.4989|
| 0.001 Tonne  | 5.45| 5.13| 5.0511| 4.8145|
| 0.00015 Tonne| 8.345| 8.08| 7.9371| 7.5914|
| 0.002 Tonne  | 10.77| 10.10| 10.102| 10.122|

### Table 8. Comparison of flexural values of jute-glass composite

| Load         | Experimental Deflection (mm) | Finite element analysis Deflection (mm) |
|--------------|------------------------------|----------------------------------------|
|              | M1  | M2  | M1  | M2  |
| 0.0005 Tonne | 5.495| 5.25| 5.7037| 5.3168|
| 0.001 Tonne  | 11.33| 9   | 11.407| 10.634|

Glass composite (GFRP) was prepared using 8 layers of glass fibre mats reinforced with epoxy.
- Total thickness = 3mm
- Number of layers = 8
- Glass = 0.20mm/each layer
- Epoxy = 0.15mm/each layer

### Table 9. Comparison of flexural values of glass composite

| Load         | Experimental Deflection (mm) | Finite element analysis Deflection (mm) |
|--------------|------------------------------|----------------------------------------|
|              | M1  | M2  | M1  | M2  |
| 0.0005 Tonne | 4.9 | 5.89| 4.1657| 5.6531|
| 0.001 Tonne  | 9.465| 11.185| 9.5777| 11.687|
| 0.0015 Tonne | 13.59| 15.30| 13.389| 15.145|

Flax composite (FFRP) was prepared using 8 layers of flax fibre mats reinforced with epoxy.
- Total thickness = 5mm
- Number of layers = 8
- Flax = 0.45mm/each layer
- Epoxy = 0.15mm/each layer

### Table 10. Comparison of flexural values of flax composite

| Load         | Experimental Deflection (mm) | Finite element analysis Deflection (mm) |
|--------------|------------------------------|----------------------------------------|
|              | M1  | M2  | M1  | M2  |
| 0.0005 Tonne | 10.16| 9.87| 10.047| 9.1481|


2.2 Finite element analysis on columns

Column with the inner diameter of 150 mm and height of 300 mm were used to determine compression strength by finite element analysis using ANSYS software. Total 10 set of specimens were modelled and tested. As per ACI 440.2R-17, the minimum dimension of the grooves should be taken at least 1.5 times the diameter of the FRP bar.

Diameter of bar = 16 mm  
Dimension of the groove = 16 x 1.5 = 24
Therefore 25 mm x 25 mm square groove was chosen.

300-mm long grooves with 25 mm x 25 mm cross-section were made in a radial arrangement accommodating 4, 6, or 8 nos. For strengthening, the grooves were partially filled with the epoxy adhesive, the 16 mm diameter NSM GFRP bars were placed into the centre of the groove, and then again groove was completely filled using epoxy adhesive. Flax-glass hybrid composite (8 layers) fabric and doubled flax-glass hybrid composite (16 layers) fabric was continuously applied in the hoop direction using the epoxy resin for external confinement of column to compare. The specimens were compressed until either the internal reinforcement began to crush, or the FRP wrap ruptures.

Target strength for M30 mix = 380 kN (as per ACI 211.1-91)  
$f_{cr} \geq 1.1f_c + 5 \text{MPa}$ for $f_c > 35 \text{MPa}$

| Table 11. Mechanical properties of GFRP bar and M-seal |
|-----------------|-----------------|-----------------|
| Property        | GFRP bar        | M-seal          |
| Density (g/cm³)  | 2.2             | 1.4             |
| Tensile strength (GPa) | 1.5             | 0.0055          |
| Poisson’s ratio  | 0.28            | 0.49            |
| Tensile modulus (GPa) | 60             | 0.05            |

For composite model Shell, 281 elements were used for providing layered composite. For concrete model Solid 65 element was used by considering the crack and crush property of concrete. Fixed support at bottom face and load was applied at top face for compression test of columns.

![Figure 9. Total deformation of NSM GFRP-4-W (flax-glass (8 layers) hybrid composite)](image-url)
Figure 10. Deformation-load curve of NSM GFRP-4-W (flax-glass (8 layers) hybrid composite)

Figure 11. Hoop stress of NSM GFRP-4-W (flax-glass (8 layers) hybrid composite)

Table 12. Compression strength and hoop stress of columns

| Specimen     | Failure load (kN) | Compression strength (N/mm²) | Hoop stress (MPa) |
|--------------|-------------------|-------------------------------|-------------------|
| Plain        | 400               | 5.65                          | -                 |
| NSM GFRP-4   | 520               | 7.35                          | -                 |
| NSM GFRP-6   | 520               | 7.35                          | -                 |
| NSM GFRP-8   | 520               | 7.35                          | -                 |
| NSM GFRP-4-W | 620               | 8.77                          | 109.88            |
| NSM GFRP-6-W | 620               | 8.77                          | 114.05            |
3. Conclusions

On determining experimentally the mechanical properties such as tensile and flexural strength of flax-glass hybrid composite, jute-glass hybrid composite, glass composite, flax composite it was found that glass fibre composite exhibit better tensile and flexural strength than flax fibre composite. For fibre hybrid composite tests, it was found that flax-glass hybrid composite exhibits better tensile strength than jute-glass hybrid composite. Even though natural fibres are sustainable materials with low cost, easy handling and eco-friendly but the tensile strength of glass fibres are higher than natural fibres. Therefore, fully replacing glass fibre with natural fibres may not be possible. So, by the use of flax glass hybrid composite, partial replacement of glass composite was made possible to a certain level. Therefore, flax-glass hybrid composite is chosen as hybrid composite in the work. Experimental results validated with finite element analysis using ANSYS software showed good comparison. Then analytical study on performance of NSM GFRP bars along with hybrid composite as external strengthening for columns by finite element analysis using ANSYS software was also done. It was found that providing NSM GFRP bars along with flax-glass hybrid composite compression strength has increased as compared to NSM GFRP bars alone. Also by doubling the layers of flax-glass hybrid composite compression strength has increased but there is no significant increase in load taking capacity by increasing the number of bars. Hoop stress is more when layers are increased and no of bars increased. From the results obtained, it was found that there was a significant increase of 45.98% in compression strength for 4 no of bars with doubled layer of flax-glass hybrid composite in comparison with plain specimen, 29.73% of increase for 4 no of bars with double layer of flax-glass hybrid composite in comparison with 4 no of bars specimen and 16.15% of increase for 4 no of bars with double layer of flax-glass hybrid composite in comparison with 4 no of bars with single layer of flax-glass hybrid composite. So, 4 no of bars with doubled layer of flax-glass hybrid composite column are best suited and these columns can be implemented as bridge columns and also as columns for coastal structures which are extremely vulnerable to corrosion. Further investigations can also be done on the application of different hybrid materials over GFRP, CFRP, BFRP.

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