Influence of eggshell particles on mechanical and water absorption properties of hemp-glass fibres reinforced hybrid composites

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Abstract. The objective of this work is to analyze the mechanical strengths and water absorption characteristics of sodium hydroxide (NaOH) treated hemp natural fibre (HNF) and eggshell particles (ESP) reinforced polymer composites. The composites were fabricated with and without ESP (0%, 7%, 14% and 21%) by hand-lay process and the tensile, shear, flexural and impact strengths and water absorption characteristics of samples were analyzed. The HNF with 0% ESP composites exhibits the superior tensile strength of 80.46 MPa and holds the maximum shear strength of 1.48 KN, followed by 14% of ESP composites withstands the bending load of 0.19 KN. The samples contains 21% of ESP absorb the high impact energy of 10 joules. The morphological characteristics were analyzed by scanning electron microscopy (SEM) analysis.

Keyword: Hemp fibre; Glass fibre; Eggshell particles; Mechanical properties; SEM studies

1. Introduction
Nowadays most of the researchers and industries are focusing their interest to develop the natural fibres based green composites for structural applications in order to reduce the unpleasant environmental conditions [1-4]. The advantages of natural fillers are greater extend to improve the strength of the components and to reduce the cost. The mechanical strength of natural fibre reinforced composites are improved by adding the synthetic fibres and fillers [5-6]. The natural fibre and fillers are bio-degradable, light weight, high density, easily available, low cost and high specific modulus when compared with manmade fibres [6-7]. HNF composites have finding applications in the diverse field ranging from home appliances to aviation industries [1, 10]. ESP can be cost effective natural fillers than others because it should be a commercial and domestic waste. The HNF treatment was carried with 5 wt% of NaOH solution to improve the bonding action between fibre and matrix [4]. The mechanical properties of woven HNF composites are analyzed and results showed the improved tensile and flexural strengths because of silane treatment of fibres. The surface morphological properties were studied by using FTIR spectroscopy and SEM analysis [3].
2. Materials and Methods

2.1. Materials
The materials for this experimental work, HNF, E-glass fibres with 300 gsm, Araldite LY556 epoxy resin, Aradur HY 951 were purchased from M/s. Go Green Fibres, Chennai, India. The hardener, thinner, polishing wax and NaOH pellets were purchased from M/s. Sunshine Chemicals, Chennai, India. The eggshells were collected from poultry farms at Namakkal District, Tamil Nadu, India. The properties of long HNF are listed in Table 1.

Table 1. Properties of hemp fibres [7, 8, 10, 12-17]

| Properties          | Range     | Properties          | Range   |
|---------------------|-----------|---------------------|---------|
| Cellulose (wt%)     | 55-90     | Tensile strength (MPa) | 310-1235 |
| Hemicellulose (wt%) | 7-22.4    | Young’s modulus (GPa) | 20-70   |
| Lignin (wt%)        | 4-13      | Failure strain (%)  | 0.9-4.2 |
| Pectin (wt%)        | 0.8-1.6   | Specific modulus (GPa-cm³/g) | 0.8 |
| Waxes (wt%)         | 0.8       | Micro fibril angle (°) | 6.2     |
| Moisture (wt%)      | 9-12      | Length (mm)         | 8.3-14  |
| Density (g/cm³)     | 68-81     | Diameter (µm)       | 17-24   |

2.2. Processing
The fibre constituents like wax, lignin, celllose and hemicelllose were removed by immersing with 4% of NaOH solution for 12 h in order to increase the bonding between fibre and matrix [1-3, 8-10]. Then the fibres were washed with distilled water to remove the deposited chemicals on the outer surfaces. The HNF and ESP has been dried in order to remove the moistures at 100°C and 200°C in an hot oven. The treated fibres were kept under controlled temperature for 48 h to remove the moisture. Then they have been weaved as bi-directional mat and the weight ratios have been maintained [7, 11]. The ESP was prepared by ball milling process with the particle size of 700 nm to reinforce and increase the strength of the composites. The standard mixing ratio of resin and hardener was maintained as 10:1.

2.3. Fabrication
By hand-lay process, initially the wax coating was applied over a base plate to avoid sticking of laminates then the HNF mat was placed over base plate followed by glass fibre mat [10,12, 15-16]. The ESP has been mixed with resin for getting even distribution of ESP over entire laminates [14]. Then the mixtures were applied evenly over the treated HNF and glass fibre mats and same process were followed for alternate layers. Each laminates consists with 3 layers of HNF mat and 2 layers of glass fibre mat with different weight percentage of ESP. Finally, the fabricated laminates are kept under constant loading for 48 h to get the uniform cross section.

3. Result and Discussion
In this study, there are four laminates have been fabricated by reinforcing the treated HNF (0%, 7%, 14% and 21%) of weight of ESP by hand lay process. Three samples from each laminate were prepared as per the ASTM standards. The readings of tensile, shear and flexural strengths were noted by conducting experiments and the energy absorbed by the samples were noted. The observed mechanical strengths and percentage of water absorption are listed in the Table 2.

Table 2. Mechanical strengths of treated HNF/glass fibre composites
### 3.1 Tensile strength analysis

Three samples from each laminate were prepared based on ASTM D638 standards for conducting tensile test [2, 3, 6, 7, 10, 13, 15-16]. The tensile strength of all tested samples are listed in Table 2 and compared the results in Figure 1. The results showed that 0% ESP and treated HNF samples holds the tensile strength range of 53.20-89.32 MPa, followed by 14% of ESP and treated HNF samples in the range of 52.16-84.95 MPa. Because of the woven mat the load evenly distributed in all directions which improves the strength during the tensile loading. It was found that the increasing in percentage of ESP, the tensile strength of composite samples was decreased.

![Figure 1. Tensile strength comparison of the composites](image)

### 3.2 Shear strength analysis

The samples were prepared based on ASTM D2344 standards for conducting double shear test [10, 15-17]. The shear strengths of all samples has been noted by applying shear loading. The shear strengths of all tested samples from each laminates were listed in Table 2 and then results are compared in Figure 2. The readings of 0% ESP and treated HNF samples were holds the maximum shear strength in the range of 0.80-1.48 KN, followed by 14% of ESP samples were holds the range of

| Composition | Tensile strength (MPa) | Shear strength (KN) | Flexural strength (KN) | Impact strength (Joules) | Water absorption (%) Before | Water absorption (%) After |
|-------------|------------------------|---------------------|------------------------|--------------------------|---------------------------|--------------------------|
| HNF+0% ESP  | 80.46                  | 1.48                | 0.16                   | 6                        | 2.256                     | 2.279                    |
| HNF+7% ESP  | 64.56                  | 0.72                | 0.18                   | 10                       | 2.354                     | 2.398                    |
| HNF+14% ESP | 66.51                  | 0.81                | 0.15                   | 8                        | 2.241                     | 2.290                    |
| HNF+21% ESP | 81.92                  | 0.83                | 0.19                   | 8                        | 2.258                     | 2.305                    |
| HNF+30% ESP | 84.95                  | 1.00                | 0.19                   | 8                        | 2.437                     | 2.445                    |
| HNF+40% ESP | 52.16                  | 0.86                | 0.18                   | 8                        | 2.498                     | 2.538                    |
| HNF+50% ESP | 78.67                  | 0.96                | 0.19                   | 8                        | 2.418                     | 2.464                    |
| HNF+60% ESP | 73.94                  | 0.95                | 0.18                   | 8                        | 2.603                     | 2.635                    |
| HNF+70% ESP | 74.12                  | 0.85                | 0.18                   | 10                       | 2.630                     | 2.668                    |
| HNF+80% ESP | 61.91                  | 0.79                | 0.15                   | 10                       | 2.563                     | 2.592                    |
0.86 - 1.0 KN. The distributed ESP between HNF and glass fibres and thus increases the load sharing capability. Similarly it was found that the increasing in ESP in matrix, the shear strength of composite samples has been decreased.

![Shear load of treated fiber](image1)

**Figure 2.** Shear strength comparison of the composites

### 3.3 Flexural strength analysis

The samples were prepared based on ASTM D790 standards for conducting flexural test [2, 3, 6, 7, 10, 13, 15-17]. The flexural readings were noted by applying three point bending load. The flexural readings of all samples were listed in Table 2 and the comparison of results is presented in Figure 3. From the results, it is noted that almost all the values are close to each other. The 14% ESP and treated HNF samples were holds the range between 0.18 to 0.19 KN, followed by 7% of ESP and treated HNF samples were holds the range of 0.15-0.19 KN. The flexural readings show the improvement while increasing the percentage of ESP in the composites.

![Flexural load of treated fiber](image2)

**Figure 3.** Flexural strength comparison of the composites
3.4 Impact strength analysis
The samples were prepared based on ASTM D 256 standards for conducting charpy impact test [6, 10, 15-17]. The V-grooves were cut on the longer side of sample in order to initiate the crack when load was applied. The absorbed impact energies are listed in Table 2 and the results are compared in Figure 4. The results show that the 21% of ESP and treated HNF samples absorbs the maximum energy in the range of 8-10 joules. Similarly, the 7% and 14% of ESP samples holds the average energy of 8 joules. It is found that the increased impact energy of all tested samples while increasing the percentage of ESP in composites.

![Figure 4](image-url)

**Figure 4.** Impact strength comparison of the composites

3.5 Water absorption analysis
The samples of size 20 x 20 x 3mm were prepared based on ASTM D5229 standards [2, 6, 7, 10]. The specimens were immersed in water for 24 h in an open atmosphere conditions. Before and after the immersion the specimen weight has been noted. The water intake of all samples was listed in Table 2 and the results are compared in Figure 5. From the results, noted that the 21% of ESP samples absorb less amount of water followed by 14% of ESP samples. The ESP has been increased the bonding between HNF and matrix of the composites. Due to this the energy absorbing characteristics of samples also increased.

![Figure 5](image-url)

**Figure 5.** Water Absorption of treated fiber in percentage
3.6 Morphological analysis

The interfacial characteristics like matrix failure, fibre fracture, distribution of ESP, pull out of fibre and matrix, voids in the samples were analysed by using SEM analysis [2, 3, 7-10,13, 15-16]. The alternate layers of bi-directional HNF mat are clearly seen and evenly distributed ESP has been clearly visible in the SEM image presented in Figure 6 (a). The fractured epoxy resin matrix and fibres of samples due to loading were visible in the image presented in Figure 6 (b).

![SEM images of the tested composite samples](image)

Figure 6. SEM images of the tested composite samples

4. Conclusion

The ESP incorporated HNF composite has been fabricated and the mechanical strengths and water intake characteristics are analyzed. The superior tensile and shear strength of the treated HNF with 0% ESP and 14% ESP has been observed. The increased flexural and impact strengths of samples has been obtained by increasing the ESP in the composites. The water absorption results revealed that decreased water intake while adding ESP in the HNF composites. Thus, the treated HNF composites with 14% of ESP exhibits the superior mechanical strengths and it can be suggested for structural applications in automotive and construction industries. The morphological characteristics were analyzed and noted the distributions of ESP, voids, matrix fractures, pullout of fibre and the orientations by SEM.

5. References

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