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# A Study on Vibrational Properties of Hemp Reinforced Polymer Composite with Cenosphere as Filler Material

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***Abstract – In the present work, effect of cenosphere on tensile and vibrational properties of hemp polymer composites are studied. Hemp fiber with two different polymer matrix (epoxy and vinyl ester) and with different percentages of cenosphere as filler were fabricated by hand lay-up technique. Tensile properties were determined by using UTM as per ASTM D-3039 standards. Vibrational analysis of these materials was carried out by using FFT analyzer for fixed-free condition to determine damping ratio and modal natural frequencies. Modal natural frequencies determined experimentally are compared with theoretical and numerical results. Variation of tensile properties, damping ratio with variation of cenosphere in hemp polymer composites were studied. Results revealed that Ultimate tensile strength, Young's modulus, damping ratio of hemp/epoxy composite are higher compared to hemp/vinyl ester composite for the same percentage of cenosphere. For hemp/epoxy composites ultimate tensile strength, Young's modulus, damping ratio goes on decreases as the percentage of cenosphere increases however for hemp/vinyl ester composites Ultimate tensile strength, Young's modulus, damping ratio values increases. Modal natural frequencies determined by different methods are found to be in agreement.***

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## 1. INTRODUCTION

Composite materials have come to fore a few decades ago due to the increase in demands of both consumers and industries for highly performing materials and structures that have superior mechanical properties. In industrial areas, synthetic polymer composite materials are widely used because of their lightweight and high strength. However, with the increasing amount of synthetic polymer material used throughout worldwide, environmental issues such as disposal treatment, waste disposal services and increase in pollution are becoming increasingly important. Due to this natural fiber are replacing synthetic fibers as reinforcing material in composites.

Natural fibers are substances produced by plants and animals that can be spun into filaments, threads or ropes and then into woven matts. Natural fiber sources from plants include cotton, flax, hemp, sisal, jute, kenaf and coconut. Cellulose, hemicellulose, lignin and pectin are primary constituents of plant fibers.

Vibration is an element that is hard to avoid in practice. Excitation to resonant frequencies of some structural parts can occur with existence of vibration even it is a small insignificant vibration, then it can be amplified into major vibration and noise sources. It is necessary to know the vibration characteristics of structural elements, which may be subjected to dynamic loads. If the frequency matches one of the resonant frequencies of structure, large translational/torsion deflections and internal stresses can occur which may lead to failure of structural components. It is important to determine: a) natural frequencies b) modal shapes c) damping factors, to avoid the problems caused by vibrations.

M.M. Kabir, K.T. Lau [1] et al investigated chemically treated single hemp fibers for their tensile properties by varying the fiber diameters. A Etaai, H Wang [2] et al investigated damping properties of noil hemp fiber composites with varying fiber contents and compatilizers using free vibration testing and dynamical mechanical analysis methods. J. Alexander and B. S. M. Augustine [3] carried out work on BFRP and GFRP composites to compare the vibration characteristics of both composites at various boundary conditions. Hemalata Jena, Arun Kumar Pradhan [4] et al investigated the damping properties of bamboo fiber reinforced epoxy composite with cenosphere as particulate filler material. N.P.G. Suardana, Jae Kyoo Lim [5] et al investigated the mechanical properties of hemp/polypropylene composite with effects of chemical treatment on hemp fibers. Itishree Mishra and Shishir Kumar Sahu [6] investigated the free vibration of Glass/Epoxy composite plates with free-free boundary conditions. In the present work, at first tensile test was conducted to obtain tensile properties then vibrational characteristics were found by vibration test. Effect of cenosphere filler on the tensile properties and vibrational characteristics were studied. Modal natural frequency obtained from experimental vibration test was compared with values obtained theoretical and numerical methods.

## 2. MATERIALS AND FABRICATION

### 2.1 Materials

Materials used are Hemp fibers as reinforcement material. Epoxy and Vinyl Ester as matrix and cenosphere as filler for composite preparation.

### 2.2 Fabrication of composite:

Hemp fibers were obtained from local store. Hemp was cleaned then they were combed to separate fibers from each other. The weight percentage of hemp fiber and epoxy resin used was 35:65. Then different percentages of cenosphere were added to epoxy (3%, 6% and 9%). A granite mold of size 300×300mm is used. A mylar sheet was placed on a flat plywood and a small film of releasing agent was gently applied on the mylar sheet and granite mold. Hemp mats of size 300×300mm were prepared along with blend of epoxy resin and hardener in the proportion of 100:10. Weight fractions of 35:65 for reinforcement and resin were used to find the weight of reinforcement and resin required. Different percentages of cenosphere are blended thoroughly with resin. At first a layer of epoxy and hardener mixture was covered over mylar sheet. On this layer, a hemp mat was placed and another layer of epoxy was applied over the hemp mats by smooth roller. This procedure was continued for total number of hemp mats. Finally, a mylar sheet was placed on the final layer of resin. Releasing agent was applied on the mylar sheet. A constant weight was kept on the plates for 48 hours before removing weight and plate was dried in sunlight. Same procedure was followed to prepare hemp reinforced polymer composite with vinyl ester as matrix.

**Figure 1: Hemp/Epoxy polymer composite**

### 2.3 Specimen preparation

Tensile test specimens are prepared according to ASTM D 3039 and vibration test specimen of size 50×10×290mm has been prepared by cutting the composite plate.

**Figure 2: Hemp/Epoxy polymer composite specimen for tensile test**

**Figure 3: Hemp/Epoxy polymer composite specimen for vibration test**

## 3. TESTING AND ANALYSIS

### 3.1 Tensile test process

To determine the mechanical properties like tensile strength, elastic modulus tensile tests were conducted by KALPAK’S KIC-2-1000-C computerized universal testing machine. Tensile test was conducted for all composition.

### 3.2 Vibration analysis by FFT analyzer

Vibrational analysis is carried out by using FFT analyzer. FFT analyzer measures the input and output signals and gives frequency response functions, from which modal parameters can be measured. OROS OR24 PC-Pack is used for measurement of noise and vibration, which has 4-channel and is very compact. It also has signal condition, digital signal processor, precision acquisition front end, power supply and cooling fan. It interfaces with any PC which has PCI card. FRF graphs allows us to determine the natural frequencies of the specimen. This is done by fixing the specimen in supports. Input load (pulse) to the specimen is given by an impact hammer and a definite frequency range is set in the signal analyzer. Accelerometer is used to record the response and condition amplifier is used to amplify the signals. Thus FRF graphs are obtained using the high-resolution signal analyzer.

The specimen is fixed at one side so that it behaves like a cantilever beam. The accelerometer is mounted on the specimen at the end to measure acceleration of vibration. Specimen can be excited for vibration by using impulse hammer and response is observed using OROS software for coherence. Once coherence is observed, the result is stored. There are two channels used in this setup. Channel one is connected to impulse hammer which is used for exciting the specimen for vibrations. Channel two is connected to the accelerometer which is used for measuring response.\

**Figure 4: Experimental setup**

### 3.3 Theoretical calculations

There will be an infinite number of normal modes for any beam. Each normal mode will have one natural frequency. Natural frequencies of the beam are computed from Equation [14].

$$f_n = \frac{(\beta_n l)^2}{2\pi}\sqrt{\frac{EI}{\rho_c A l^4}}$$

Here we consider that specimen is isotropic material. The value of (βn l) changes for different boundary conditions and n = 1, 2, 3, 4…

$(\beta_n l)$ Values for Cantilever beam are given below.
$\beta_1 l = 1.8751$, $\beta_2 l = 4.694$, $\beta_3 l = 7.8547$ and $\beta_4 l = 10.9955$.

### 3.4 Numerical method

In numerical method, SOLID EDGE software was used to make CAD model and saved as a STEP format file. The CAD model was imported to ANSYS workbench software to perform modal analysis. Engineering data of composite specimen was entered. The model was meshed and boundary conditions were applied to carry out modal analysis. Modal natural frequencies and mode shapes were found.

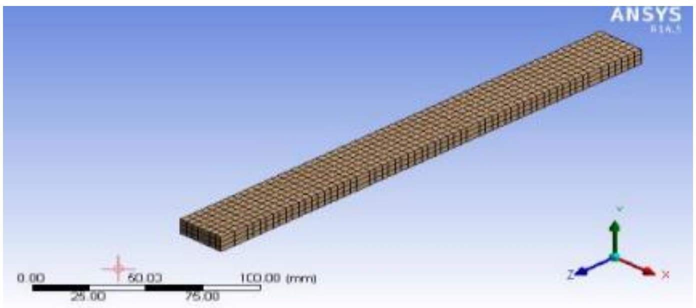


Figure 5: Meshed model

**Figure 5: Meshed model**

## 4. RESULTS AND DISCUSSIONS

### 4.1 Tensile test results

The tensile strength and Young's modulus of hemp reinforced polymer composites are shown in table 1 and 2. The tensile tests were carried out as per ASTM D3039 standards. Results show that ultimate tensile strength and Young's modulus decreases in hemp/epoxy polymer composites as the percentage of cenosphere increases. Whereas for hemp/vinyl ester polymer composites as the percentage of cenosphere increases, ultimate tensile strength and Young's modulus increases.

**Table 1: Tensile1test results1for hemp/epoxy polymer composites**

| Diff % of cenosphere | Ultimate1tensile strength (MPa) | Young's modulus (MPa) |
|---|---|---|
| 0 | 39 | 1978.68 |
| 3 | 30.59 | 1938.72 |
| 6 | 25.25 | 1214.99 |
| 9 | 26.83 | 1359.1 |

**Table 2: Tensile1test results1for hemp/vinyl ester polymer composites**

| Diff % of cenosphere | Ultimate tensile strength (MPa) | Young's modulus (MPa) |
|---|---|---|
| 0 | 16.68 | 858.54 |
| 3 | 30.25 | 707.15 |
| 6 | 28.25 | 937.25 |
| 9 | 26.78 | 934.94 |

### 4.2 Vibration test results

Vibration test was conducted by FFT analyzer to obtain FRF graphs from which damping ratio, modal natural frequencies were found. The specimens were fixed at one end and free at other end. . Figure 6 -8 shows FRF graphs obtained from the FFT analyzer for hemp/epoxy polymer composite specimens with 0% cenosphere.

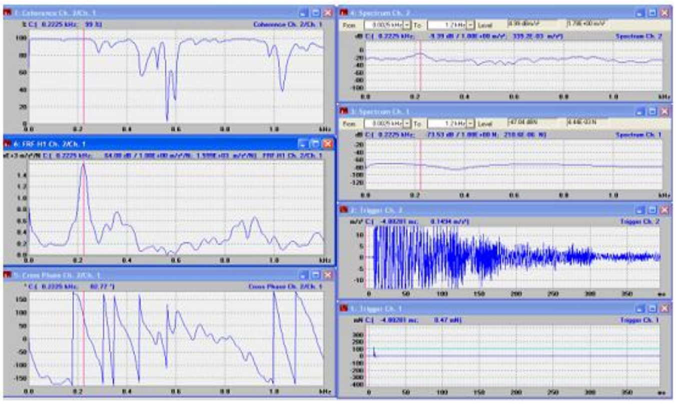

**Figure 6: Total FRF response of hemp/epoxy composite with 0% cenosphere**

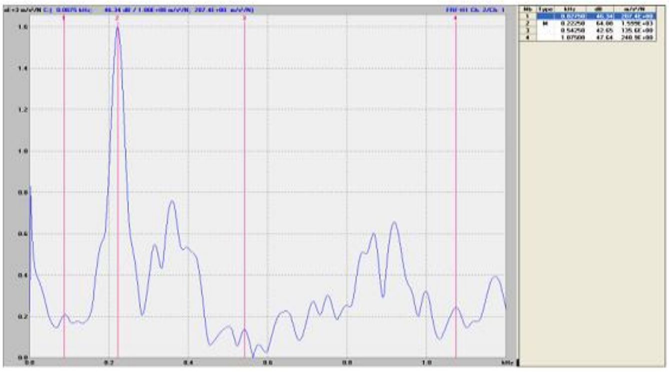

**Figure 7: Modal natural frequencies of hemp/epoxy composite with 0% cenosphere**

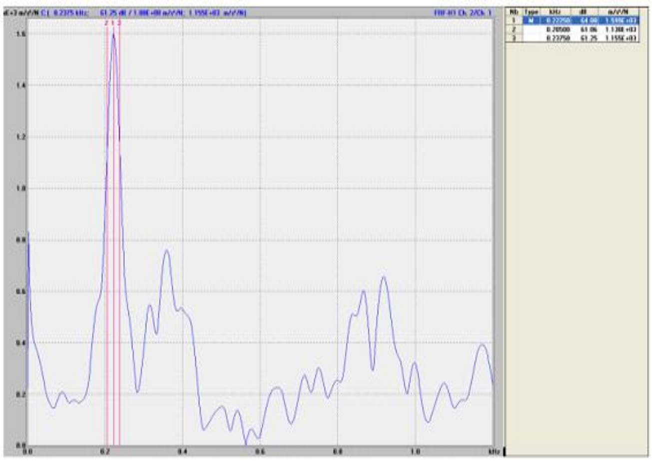

**Figure 8: Natural frequencies for damping ratio of hemp/epoxy composite with 0% cenosphere**

**Calculation for damping ratio:**

$$\text{Damping ratio } \xi = \frac{\omega_2 - \omega_1}{2\omega_n}$$

Similarly, damping ratio is calculated for all the compositions. Table 3 shows the damping ratio of hemp/epoxy and hemp/vinyl ester polymer composites for different percentages of cenosphere.

**Table 3: Damping ratio of composites for different percentages of cenosphere**

| % Cenosphere | Hemp/Epoxy | Hemp/Vinyl ester |
|---|---|---|
| 0 | 0.073 | 0.0368 |
| 3 | 0.0571 | 0.03125 |
| 6 | 0.0426 | 0.0325 |
| 9 | 0.0212 | 0.0393 |

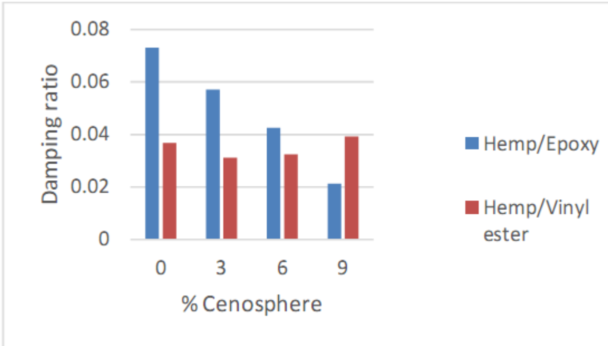


**Figure 9: Variation of damping ratio for different percentages of cenosphere for composite**

### 4.3 Numerical results

Modal analysis was carried out to find the modal natural frequencies and to show mode shapes by ANSYS workbench. Figure 4 shows different mode shapes obtained for hemp/epoxy polymer composite specimens with 0% cenosphere

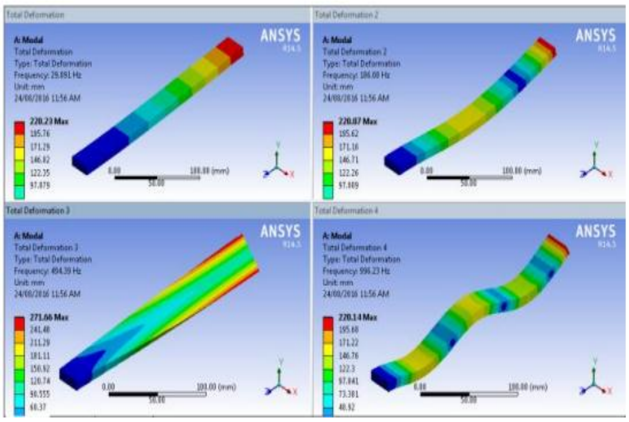

**Figure 10: Mode shapes for hemp/epoxy polymer composite with 0% cenosphere**

### 4.4 Comparison of modal natural frequency values

Table 4 and 5 shows comparison of modal frequency values obtained through different method for hemp/epoxy and hemp/vinyl ester composites respectively.

**Table 4: Modal frequencies of Hemp/Epoxy polymer composite (Hz)**

| % Cenosphere | Mode no | Experimental | Theoretical | Numerical |
|---|---|---|---|---|
| 0 | 1 | 27.5 | 29.82 | 29.89 |
| | 2 | 222.5 | 186.89 | 186.08 |
| | 3 | 542.5 | 523.23 | 494.39 |
| | 4 | 1072.5 | 1025.4 | 996.23 |
| 3 | 1 | 25 | 29.88 | 29.95 |
| | 2 | 202.5 | 187.29 | 186.48 |
| | 3 | 565 | 524.36 | 495.46 |
| | 4 | 1182.5 | 1027.6 | 998.38 |
| 6 | 1 | 28 | 24.03 | 24.09 |
| | 2 | 182.5 | 150.66 | 150.01 |
| | 3 | 488.75 | 421.79 | 398.55 |
| | 4 | 975 | 826.63 | 803.1 |
| 9 | 1 | 22.5 | 25.78 | 25.84 |
| | 2 | 186 | 161.58 | 160.88 |
| | 3 | 487.5 | 452.37 | 427.44 |
| | 4 | 927.5 | 886.55 | 861.32 |

From table 4 and 5, the experimental modal natural frequencies are in good agreement with theoretical and numerical modal natural frequencies.

**Table 5: Modal frequencies of Hemp/Vinyl ester polymer composite (Hz)**

| % Cenosphere | Mode no | Experimental | Theoretical | Numerical |
|---|---|---|---|---|
| 0 | 1 | 19 | 20.52 | 20.57 |
| | 2 | 142 | 128.65 | 128.08 |
| | 3 | 321 | 360.16 | 340.28 |
| | 4 | 756 | 705.37 | 685.69 |
| 3 | 1 | 18 | 18.85 | 18.90 |
| | 2 | 144 | 118.18 | 117.67 |
| | 3 | 303 | 330.87 | 312.64 |
| | 4 | 625 | 648.44 | 629.99 |
| 6 | 1 | 24 | 21.98 | 22.03 |
| | 2 | 125 | 137.77 | 137.17 |
| | 3 | 416 | 385.71 | 364.45 |
| | 4 | 749 | 755.91 | 734.39 |
| 9 | 1 | 24 | 22.22 | 22.28 |
| | 2 | 138 | 139.30 | 138.7 |
| | 3 | 379 | 389.99 | 368.49 |
| | 4 | 784 | 764.29 | 742.54 |

## CONCLUSIONS

Hemp reinforced polymer composites with filler as cenosphere were developed using hand layup process. Two groups of composites with thermosetting matrix i.e. epoxy and vinyl ester are used for fabrication. It is observed that density of the developed composites decreases with increase in percentage of cenosphere. By adding cenosphere as filler material, composite weight has been reduced.

Tensile test results show that ultimate tensile strength and Young's modulus decreases in hemp/epoxy polymer composites as the percentage of cenosphere increases. Whereas for hemp/vinyl ester polymer composites as the percentage of cenosphere increases, ultimate tensile strength and Young's modulus increases.

Vibration test results shows that in hemp/epoxy composite as the percentage of cenosphere increases, damping ratio (ξ) decreases. A decrease of 70% in damping ratio was found between composite with 0% cenosphere and 9% cenosphere. Whereas for hemp/vinyl ester polymer composite damping ratio increases as the percentage of cenosphere increases.

The modal natural frequencies obtained from different methods i.e. experimental, theoretical and numerical are in good agreement.

Thus, from experimental vibration test it is found that damping properties of hemp reinforced polymer composite depends on the percentage of cenosphere in composite and type of thermosetting matrix used.

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