Experimental investigations on mechanical properties of cotton/hemp fiber reinforced epoxy resin hybrid composites

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Abstract: In this experiment, epoxy resin, fine hemp fibre, and cotton fibres were combined to create bio-composites. The weight percentages of hemp fibre (0, 10, 20, 30 wt. percent), cotton fibres (35, 25, 15, 5 wt. percent), and epoxy resin have been varied to produce four composite mates. As per ASTM standards, composite specimens were prepared using the water jet machining process. Tensile, flexural, and impact tests were performed on the composite specimens in order to determine their mechanical properties and water absorption behaviour. Composites containing 20 wt.% fine hemp fibre in weight percentage showed significant improvements in tensile properties. Composites containing 30 wt% hemp fibre improve both flexural and impact properties, according to the test results.

Keywords: Mechanical properties, cotton fiber, hemp fiber, epoxy resin, hybrid composites.

1. Introduction
Research on biodegradable composites has increased significantly in recent years with the goal of developing pollution-free green composites and replacing polymer materials in commercial applications, among other goals. Natural resources as reinforcement materials are the subject of numerous research studies aimed at developing various natural composites [1]. The use of plant-based fibres as polymer reinforcement has grown in recent years due to their low cost, low density, and good mechanical properties, as well as their biodegradability and potential for sustainability [2]. Recyclability and energy recovery through incineration, as well as mechanical properties, are superior to glass fibre reinforced plastics in thermoplastic matrix composites [3]. They contain functional groups that are reactive, making them compatible with hydrophilic fibre surfaces [4]. Epoxy has the advantage of being cured in two or more stages, but it is not possible to preimpregnate them with epoxy in a partially cured state. Industrial hemp is one of the strongest natural fibres in terms of strength and stiffness [5]. 55 to 72 percent of hemp fibre is crystalline cellulose. In addition to hemicellulose (8–19%) and lignin (2–5%), hemp fibre contains a smaller number of waxy substances
As polymer composite reinforcement, natural lignocellulosic fibres have become increasingly popular in recent years [7], [8]. Civil construction [9], food packaging [10], [11], automotive components [12], [13] and ballistic armour [14], [15] are all potential applications [16], [17] for NLF reinforced composites. Bio-nanocomposites as well as biodegradable plastic films are being investigated by researchers using nanocellulose fibrils derived from NLFs [18], [19]. As a reinforcement material for polymer composites, hemp fibre has been the subject of numerous articles and reviews [7], [8]. A hemp fiber/polypropylene blend was once employed to make auto components. The remarkable mechanical properties of hemp fibre could be used to reinforce thermoset polymeric matrices such as epoxy or polyester [20]. Hemp fibre reinforced epoxy composites with a 30 vol% reinforcement showed superior strength to polyester composites. Epoxy composites have higher values for flexural and tensile strength than polyester composites, which have values of 49.1 and 25.4 MPa, respectively. For example, hemp fiber/epoxy composites with a 30 vol percent content of 3.8 GPa outperformed hemp fiber/polyester composites with 1.2 GPa in terms of elastic modulus [21]. Cotton fibre composites have been studied by a number of researchers [22]–[29] for their mechanical properties and energy absorption abilities. It is estimated that the global cotton trade generates US$67.9 billion annually (cotton fibre, yarn and woven fabrics, excluding apparel). Cotton is also used in textile manufacturing, such as geotextiles, filters, and composite composites, in addition to clothing. Compared to manmade or inorganic fibres used in composites [30], cotton-fiber reinforced composites have recently gained in popularity because of their biodegradability, good physical properties, and low cost. Due to the thermal and mechanical degradation that occurs during processing, they are not suitable for certain applications. Furthermore, natural fibre reinforced composites have a poor wettability and incompatibility with certain polymeric matrixes, along with a high moisture absorption rate [31]. Adhesion between fibres and matrix is a common problem as a result of their use. As a result of the issues surrounding natural fibre reinforced composites, several methods have been developed [32-42]. Using different amounts of hemp and cotton fibres as reinforcement, this study compares the mechanical properties of epoxy resin matrix composites.

2. Materials and Methods
Covai Seenu and Company in Coimbatore, Tamil Nadu, India, provided the epoxy resin and hardener for the matrix of the sculpture. Epoxy resin and hardener were mixed in 10:1 ratio on a mechanical stirring machine to ensure good adhesion of secondary reinforcement fibres (hemp fiber). To classify cotton fibres, refer to table 1.

### Table 1. Chemical Compositions of Cotton Fiber

| Contribution Elements                  | Epoxy Resin (wt%) |
|---------------------------------------|-------------------|
| Cellulose                             | 93.0              |
| Protein                               | 1.2               |
| Pectic substances                     | 0.8               |
| Inorganic substances                  | 1.3               |
| Wax                                   | 0.7               |
| Malic, citric and other organic acids | 0.9               |
| Total sugars                          | 0.35              |
| Other                                 | 1.75              |
| Total                                 | 100               |

The required amount of cotton fibers has procured in the form of mates. The hemp fiber that has used as secondary reinforcement materials has collected from natural fiber manufacturing region of Coimbatore, Tamilnadu, India. The collected hemp fiber is cleaned first by normal water and then it
has washed again with hot water to remove the presence of dust particles completely. After the washing process, it has allowed to dry at atmospheric temperature in an open space for 8 hours. After the drying process, the well dried hemp fiber has cut into required length. As a result, the long hemp fibres were cut into shorter ones with a mechanical scissor. This process has produced the required amount of fine hemp fibre. Table 2 lists the different chemical compositions of hemp fibres.

Table 2. Chemical Compositions of Hemp Fiber

| Contribution Elements       | Epoxy Resin (wt%) |
|-----------------------------|-------------------|
| Density (g/cc)              | 1.4               |
| Tensile Strength (MPa)      | 540 - 880         |
| Elastic Modulus (GPa)       | 70                |
| Specific Strength (s/g)     | 389-638           |
| Specific Modulus ("/g)      | 49                |
| Elongation at failure (%)   | 1.7               |
| Moisture absorption (%)     | 5-12              |

A compression moulding machine has used in this research work to produce the composite mates from the cotton fiber, epoxy resin and hemp fiber. The schematic of hot compression moulding technic is illustrated in figure 1. Initial stage of composite mates starts with the arrangement of cotton mates inside the compression moulding machine. Mates of cotton fibers have placed on the compression moulding machine surface table. The different compositions of the hybrid bio-composite specimens were shown in table 2.

Table 3. Composite specimen details

| Composite specimens | Epoxy Resin (wt%) | Cotton Fiber (wt%) | Hemp Fiber (wt%) |
|---------------------|-------------------|--------------------|-----------------|
| CFHF1               | 65                | 35                 | 0               |
| CFHF2               | 65                | 25                 | 10              |
| CFHF3               | 65                | 15                 | 20              |
| CFHF4               | 65                | 5                  | 30              |

After this arrangement, suitable amount of hemp fiber have dispersed on the cotton mates’ surface completely. Epoxy resin/hardener solution has applied over the hemp fiber dispersed surface for particular thickness. After the application of epoxy resin/hardener solution over the cotton mate and coconut shell powders, again the cotton mate has placed on the same coconut shell powder dispersed surface. The combined mate form of cotton fiber, epoxy resin/hardener and hemp fiber has allowed to heat up to 120°C for 45 minutes duration time at the compression moulding machine under the specific hydraulic pressure.
After the processing time of 45 minutes, the required composite mate has obtained and it has allowed for cooling at room temperature. Composite mate after cooling has taken over water jet machining process, and required composite specimens have been cut away as per ASTM standards. For the remaining three compositions, the same process was used. It was possible to test mechanical properties of the composites using well-prepared composite specimens that underwent tensile, flexural, and Izod impact tests. Three millimetres per second was used to load the composites in both tensile (ASTM D638) and flexural tests (ASTM D790-10). Izod impact testing was performed on the composite specimens in accordance with ASTM D256-10 standards. There is a color-coded graph in the Results and Discussions chapter that shows the results of the mechanical tests, including peak tensile, ultimate tensile, elongation and peak flexural loads, strengths, modulus and Izod impact strength.

3. Results and Discussions

Experimental studies on epoxy resin matrix, cotton/hemp fiber reinforced bio-composites has successfully carried out and the following results have acquired for the whole bio-composite specimens.

3.1 Peak Tensile Load

Effect of increasing hemp fiber weight percentage with epoxy resin-cotton fiber composites for peak tensile load has evidently illustrated in figure 2. It has observed that the overfed weight percentage of secondary reinforcement (hemp fiber) is enhancing the peak tensile load of the composite during the tensile test. Maximum peak tensile load of 679.192 N has found in CFHF3 composite specimen and the minimum value of 572.758 N peak load has observed in CFHF1 composite specimen respectively. The peak load magnitude for CFHF1, CFHF2, CFHF3, and CFHF4 secondary reinforcement (hemp fiber) on composites were in the range of 572.758, 638.166, 679.192 and 622.69 N correspondingly. Indicators of the maximum tensile load on composites are the fiber-to-matrix load shifts that occur.
3.2 Ultimate Tensile Strength
Strength exposed by the composites during the tensile test has illustrated in figure 3. Ultimate tensile strength of 46.52 MPa has noted in CFHF3 composites due to the most favorable availability of hemp fiber inside the composite specimens. Due to the absence of hemp fibre, CFHF1 composites have a minimum tensile strength of 39.23 MPa. It was found that the tensile strength of composites filled with composites made from the materials CFHF1, CFHF2, CFHF3, and CFHF4 was 39, 23, 43.71, 46.52 MPa, and 42.65 MPa, respectively." This stress transformation between matrix and fibre results in composites with maximum tensile strength.
3.3 Percentage of Tensile Elongation

Elongation in composites during the tensile test in terms of percentage has shown figure 4. Hemp fiber dispersed at CFHF3 in cotton fiber-epoxy resin composites reveals the better tensile elongation percentage of 2.98 than other composite specimens. The matrix no longer bears the tensile load, and the load has been transferred to the composites and secondary reinforcement (hemp fiber). Highest tensile elongation percentage has found in CFHF3 secondary reinforcement (hemp fiber) composites due to the above said cause. Minimum elongation percentage (2.62) of due to tensile load has noticed in CFHF1 composites, due to the nonexistence of the hemp fiber. The tensile elongation percentage for CFHF1, CFHF2, CFHF3 and CFHF4 composites has found in the range of 2.62, 2.82, 2.98 and 2.71 respectively.

![Figure 4](image)

**Figure 4.** Effect of elongation percentage on composite specimens for different weight percentages of cotton/hemp fiber

3.4 Peak Flexural Load

Ability of the composite specimens to withstand the maximum lateral loads and load at which the composite specimen’s letdown were established from the three-point bending test and it was illustrated in figure 5. Peak flexural load of 2674.52 N has found in CFHF4 composite specimens. Lower value of peak flexural load has observed in CFHF1 composite specimens. Ability of the optimal hemp fiber to observe the lateral load, which has applied on the composite’s specimens, is the source for the enhanced flexural load than other composite specimens. Peak flexural load of 1677.21, 1882.04, 2144.98 and 2674.52 N has observed for CFHF1, CFHF2, CFHF3 and CFHF4 composites specimens, which are reinforced with hemp fibers.
3.5 Flexural Strength

Figure 6 shows the flexural strength of the composite specimens during the three-point bend test. Composite specimens reinforced with 25 wt.% hemp fiber reveals the superior flexural strength of 65.81 MPa, due to the best possible amount of hemp fiber contents presence inside the composites.

The minimum flexural strength of 41.27 MPa have obtained in CFHF1 composite specimens due to the poor load carrying capacity of primary reinforcement (cotton fiber) and complete absence of secondary reinforcement contents (hemp fiber) inside the epoxy resin matrix of the composite specimens. Hemp fiber filled with epoxy resin matrix-cotton fiber reinforced composites in the weight percentage of CFHF1, CFHF2, CFHF3 and CFHF4 were exhibits the flexural strength of 41.27, 46.31, 52.78 and 65.81 MPa respectively. Distribution of applied load on the composite specimens in lateral directions are carried out by the finest amount of hemp fiber causes the enhanced flexural strength in the composite specimens considerably.
3.6 Flexural Modulus

Bending or flexural modulus of the composite specimens for different coconut shell weight percentages have shown in figure 7. Maximum and minimum three-point bending test modulus are observed in the range of 1.41 and 3.68 GPa in 0 and 30 wt.% hemp fiber filled composites respectively. The flexural moduli of CFHF1, CFHF2, CFHF3, and CFHF4 composites with 0, 10, 20, and 30% weight percent are respectively 1.41, 1.52, 2.31, and 3.68. Researchers found that adding hemp fibres to epoxy resin matrix and cotton fibre reinforced composites significantly increased the flexural modulus.

![Figure 7. Flexural modulus of composite specimens for different weight percentages of cotton/hemp fiber](image)

3.7 Impact Energy

Strength exposed by the composite specimens during the Izod impact test has depicted in figure 9. Using hemp fibre reinforced composites with a 30 wt. percent content, researchers measured maximum impact energy at 14.81 kJ/m2 and minimum impact strength at 6.21 kJ/m2, respectively. We measured impact strength at 6, 21, 8, 32, 11, 57, and 14, 81 kJ/m2 for composite specimens filled with hemp composites at 0, 10, and 20 wt.%, respectively.

![Figure 8. Impact strength attained by the composites intended for increasing cotton/hemp fiber weight percentage](image)

On the contrary, strength exposed by the composite specimens has gradually increased with reference to the increasing weight percentage of hemp fiber to the epoxy resin/cotton fiber reinforced...
bio composites. In the Izod impact test, cotton fibre reinforcements were subjected to excessive impact energy due to an uneven distribution of cotton fibre in epoxy resin matrix composites.

4. Conclusions
Different weight percentages of fine hemp fibre as a secondary reinforcement were studied for their mechanical properties in biocomposites with an epoxy resin matrix and cotton fibre reinforcement. Composites containing 20 wt.% of fine hemp fiber showed the improved peak tensile load, ultimate tensile strength, percentage of elongation when compared to other weight percentages of the fine hemp fiber incorporation into the epoxy resin matrix/cotton fiber composites. Composites containing 30 wt.% fine hemp fibre had superior flexural load, flexural strength, flexural modulus, and impact energy characteristics than composites containing other weight percentages of fine hemp fibre. It's the presence of fine hemp fibre in the composites that gives it its improved tensile, flexural, and impact properties, along with the good bonding between the matrix, cotton fibre, and hemp fibre.

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