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# Theoretical Modeling and Experimental Verification of Mechanical Properties of Natural Fiber Reinforced Thermoplastics

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**Abstract**

Development of biocomposites has a wide interest as inexpensive and minimum environmental pollution. The present research work focused on study the mechanical properties of biocomposite using available theoretical models and experimental verification of mechanical properties. The theoretical model used are parallel & series, Halpin-Tsai, modified Halpin-Tsai and Hirsch model for evaluation of mechanical tensile properties (Tensile strength & Tensile modulus).
Compression molding machine (hot press type) technique was used for preparation of sample specimens. Experimental mechanical characterization carried out as per ASTM D638 -01 using universal testing machine. Evaluated tensile modulus and tensile strength results of theoretical models are compared with experimental results of mechanical characteristics.


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*Keywords*: Theoretical model; Natural fiber; Mechanical characteristics;

## 1. Introduction

Here introduce the one of constitutes of fiber and matrix is from natural origin called biocomposite. The main motivation of using natural fibers in composites are low cost, low density (~1/2 of glass), good specific strength properties, and renewable [1, 2]. Na Lu et al. [3] were prepared hemp reinforced composites using both recycled

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high density polyethylene (rHDPE) and virgin high density polyethylene (vHDPE). Seena Joseph et al. [4] were fabricated composites using banana fibre and glass fibre with varying fibre length and fibre loading. H. Ku et al. [5] It discovered that the rule of mixture (ROM) predicted and experimental tensile strength of different natural fibers reinforced HDPE composites were very close to each other. G. C. Mohan Kumar [[6] was prepared areca fiber composite laminates with randomly distributed fibers in Maize stalk fine fiber and Phenol Formaldehyde. Composite laminates were prepared with different proportions of phenol formaldehyde and fibers. Tensile test, moisture absorption test, and biodegradable tests on these laminates were carried out.

C. Baley [7] used micro-mechanical equations, to estimate the Young's modulus of a flax fibre by taking into account the composition of the fibre and the evolution of the orientation of the fibrils during a tensile test. A good agreement is found between experimental and calculated results. Harjeet S. Jaggi et al. [8] studied composite fabricated of Hydroxyapatite (Hap) filled high density polyethylene (HDPE) by extrusion mixing followed by injection molding. Theoretical models were used to analyze Young's modulus and yield strength data for the estimation of various phase-adhesion parameters. Vemu Vara Prasad et al. [9] was studied effect of acetic acid, Nitric acid, hydrochloric acid etc as chemical resistance of Bamboo/Glass reinforced epoxy hybrid composites. The Tensile properties of these composites were also studied. Sanjay Choudhry et al. [10] mixed human hair fibres into polypropylene (PP) at 3, 5, 10 and 15 % by wt. using two roll mill and then compression molded. The specimen tested for analyzing the mechanical properties as tensile strength and flexural modulus.

The focus of study is to characterize mechanical properties of biocomposite. Mechanical performance of biocomposite with coir fiber and polypropylene-PP matrix was studied using available theoretical models. Compression molding method was used for Coir-PP specimen preparation. For experimental verification of biocomposite the mechanical properties investigated are tensile modulus and tensile strength.

**Nomenclature**

| | |
|---|---|
| $M_c$ | tensile modulus of composite |
| $M_m$ | tensile modulus of matrix |
| $M_f$ | tensile modulus of fibre |
| $T_c$ | tensile strength of the composite |
| $T_m$ | tensile strength of the matrix |
| $T_f$ | tensile strength of the fibre |
| $V_f$ | volume fraction of fiber |

## 2. Materials & Methods

### *2.1. Materials*

The coir fibers with length of 110-120 mm were obtained from the coconut husks abstracted from the coconut fruits. Coir fibers are obtained from local market sources and it look like as shown in Fig. 1 (a). Matrix used in this study as shown in fig 1(b) is Polypropylene (PP-H110 MA) with density 0.900 g/cc, MFI 11g/10 min (at 230 $^0$C/2.16 Kg) supplied by Reliance Industries Ltd., India. The properties coir and Polypropylene are listed in Table 1 and Table 2 respectively.

Table 1. Physical and mechanical properties of coir fiber.

| Diameter (μm) | Density (g/cc) | Tensile modulus (GPa) | Tensile strength (GPa) | Elongation at yield (%) |
|---|---|---|---|---|
| 100-300 | 1.20 | 5 | 0.175 | 15 |

a)  b) 


Fig. 1. (a) Coir fiber; (b) Matrix Polypropylene (PP).

Table 2. Physical and mechanical of Polypropylene (PP).

| Matrix | Melt Flow Index (g/10 min) | Density (g/cc) | Tensile modulus (GPa) | Tensile strength (GPa) | Elongation at yield (%) |
|---|---|---|---|---|---|
| PP | 11 | 0.9 | 1.47 | 0.036 | 10 |

*2.2. Methods*

*2.2.1. Theoretical modeling*

The mechanical properties of fiber reinforced composites can be derived from a variety of mathematical models or experimentally determined. The advantage of a comprehensive mathematical model is it reduces costly and time-consuming experiments. A mathematical model may be used to find the best combination of constituent materials to satisfy material design considerations. These models can yield information in the fundamental mechanisms of reinforcement.

Micromechanical composite models are derived based on the properties of the individual components of the composite and their arrangement. Properties such as the elastic modulus of fiber (Ef) & Matrix (Em), Tensile strength of fiber (Tf) & matrix (Tm) and the relative volume fractions of fibre (Vf) & matrix (Vm) are the fundamental quantities that are used to predict the properties of the composite. In some cases, fibre aspect ratio and fibre orientation are also required.

The different theories are used to models the mechanical properties of fiber reinforced composites as

- Series and parallel model
- Hirsch's Model
- Halpin–Tsai equation
- Modified Halpin-Tsai equation
- Bowyer Bader's Model

1. Series and parallel model: According to these model tensile modulus and tensile strength are calculated by using equation as [8].

Series model:

$$M_c = M_f V_f + M_m V_m \tag{1}$$

$$T_c = T_f V_f + T_m V_m \tag{2}$$

Parallel model:

$$M_c = \frac{M_m M_f}{M_m V_f + M_f V_m} \tag{3}$$

$$T_c = \frac{T_m T_f}{T_m V_f + T_f V_m} \tag{4}$$

Where $M_c$, $M_m$, $M_f$ are the tensile modulus of composite, matrix and fibre respectively. $T_c$, $T_m$, $T_f$ are the tensile strength of the composite, matrix and fibre respectively. Assumption for parallel model, strain was uniform through lamina and for series model, stress was to be uniform in lamina.

2. Hirsch's model: it is combination of series and parallel model. Equation for calculation of tensile modulus and strength are as follows [11]:

$$M_c = x\left(M_m V_m + M_f V_f\right) + \left(1 - x\right)\frac{M_m M_f}{M_m V_f + M_f V_m} \tag{5}$$

$$T_c = x\left(T_m V_m + T_f V_f\right) + \left(1 - x\right)\frac{T_m T_f}{T_m V_f + T_f V_m} \tag{6}$$

Where when the value of x in above equation is 0.4 for longitudinally oriented composites and x in equations 05 and 06 is 0.1 for randomly oriented composites. From this equation, it was found that x is a parameter which determines the stress transfer between fibre and matrix. [11]

3. Halpin–Tsai equation: According to Halpin-Tsai, tensile modulus and strength of the composite is given by equations as [11]:

$$M_c = M_m\left(\frac{1 + A\eta V_f}{1 - \eta V_f}\right) \tag{7}$$

$$T_c = T_m\left(\frac{1 + A\eta V_f}{1 - \eta V_f}\right) \tag{8}$$

$$\eta = \frac{(M_f / M_m) + 1}{(M_f / M_m) + A} \tag{9}$$

$$\eta = \frac{(T_f / T_m) + 1}{(T_f / T_m) + A} \tag{10}$$

Where, η is given by Equations 9 and 10, and accounts for the relative module of fibre and matrix and A is the measure of fibre geometry, fibre distribution and fibre loading conditions. The value of A is determined from the Einstein coefficient K [11].

4. Modified Halpin-Tsai equation: according to this model [11]:

$$T_c = T_m \left( \frac{1 + A\eta V_f}{1 - \eta\psi V_f} \right) \tag{11}$$

$$M_c = M_m \left( \frac{1 + A\eta V_f}{1 - \eta\psi V_f} \right) \tag{12}$$

Where, ψ depends upon the particle packing fraction.

5. Bowyer Bader's Model: According to Bowyer and Bader's model [11]:

$$M_c = M_f K_1 K_2 V_f + M_m V_m \tag{13}$$

$$T_c = T_f K_1 K_2 V_f + T_m V_m \tag{14}$$

Where, $K_1$ is the fibre orientation factor and value for fibre arranged in the random way is 2.0. $K_2$ is the fibre length factor.

All above theoretical model's encoded in MATLAB R2009a for calculation of tensile properties of short coir fiber reinforced with Polypropylene matrix.

*2.2.2. Experimental*

- Preparation of composite

The composites were produced using coir fiber as reinforcement in PP matrix material. The uniformly mixed fiber and polypropylene was taken into the mould. The mould was placed in compression molding machine (hot press type) as shown in Fig. 2 (a).

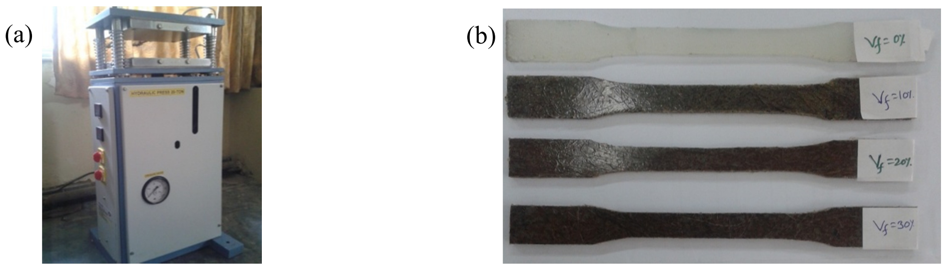


Fig. 2. (a) Compression molding machine (hot press type); (b) Actual specimen of tension test.

- Characterization

The tensile test is performed on specimens according to ASTM test standard D638-01 on a universal testing machine MCS NE-20. The specifications of specimen as per standard and actual specimen are shown is Fig. 2 (b).

## 3. Results and Discussions

As Bowyer and Bader's model equations are function of length of fiber. The present analysis has been carried out by assuming volume fraction (20%) and varying length of fiber (10-50 mm) in calculation of tensile modulus and strength. it is observed that from Fig. 3 (a) and Fig. 3 (b) both tensile modulus and strength increases with increase in length of fiber up to 30 mm and further it is decreases with increasing the length of fiber above 30 mm.

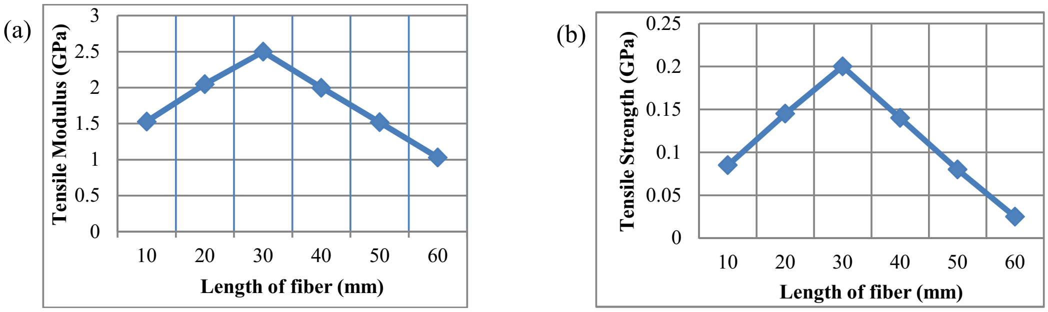


Fig. 3. (a) Variation of tensile modulus of coir/PP as a function of fibre length; (b) Variation of tensile strength of coir/PP as a function of fibre length.

It can be seen from Fig. 4(a) and Fig. 4(b) that, at low volume fraction of the fibres, the models shows a good agreement. This may be due to uniform distribution of fiber (random) at applied load. It can also be seen that in all the cases the tensile modulus and strength increases regularly with increase in the volume fraction of fibres. Hence it is stated that, tensile properties of randomly oriented composites showed a reasonably good agreement with all the models at low volume fraction of fibres.

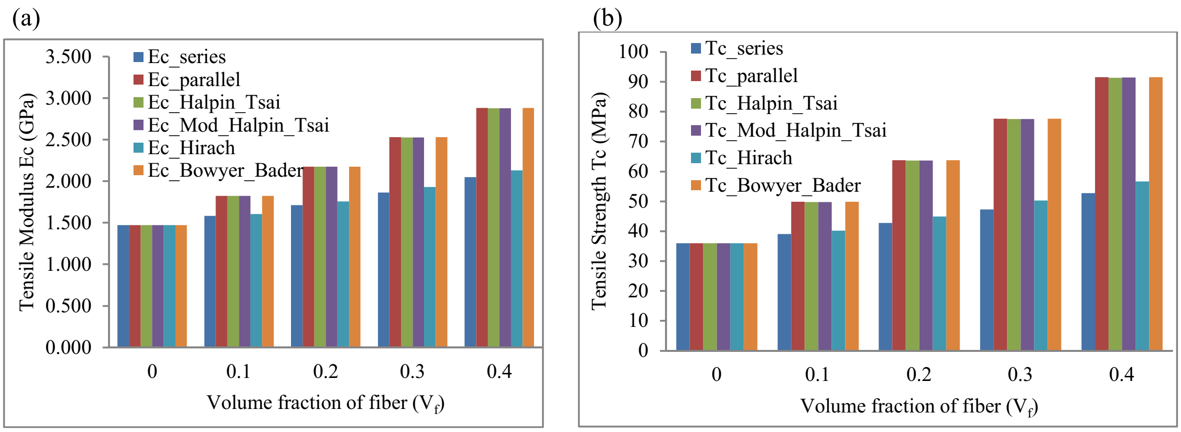


Fig. 4. (a) Variation of theoretical tensile modulus values of coir/PP as a function of volume fraction of fibres; (b) Variation of theoretical tensile strength values of coir/PP as a function of volume fraction of fibres.

From tensile test results (load deformation curve), tensile strength values are tabulated in Table 3 for variation of fiber loading. In comparison, it is observed that the obtained results has similar trend as of theoretical results with marginal agreement. Hirach's model's values of tensile modulus and tensile strength are closer to experimental investigation.

Table 3. Tensile strength of coir/PP composites at different fibre loading

| Fibre loading (Vf) | Tensile strength (MPa) | Elongation at break (%) |
|---|---|---|
| 0 | 13.94 | 9.96 |
| 0.1 | 18.57 | 2.10 |
| 0.2 | 26.53 | 1.94 |
| 0.3 | 37.90 | 1.49 |

## 4. Conclusion

The present work clearly shows that the coir fiber will become a future alternative for the conventional materials due to its enhanced mechanical properties and availability.

- Mechanical properties viz., Tensile strength (TS), Tensile Modulus(TM) of the coir fiber reinforced PP composite material is greatly influenced by fiber length as well as fiber volume fraction.
- The maximum tensile strength and modulus of the coir fiber/Polypropylene (PP) composite is achieved at the 30 mm fiber length
- From theoretical models it is found that the increase in the fiber volume fraction increases the tensile strengths and tensile modulus.
- Experimental investigation proved that tensile strength increases with increase in of volume fraction up to 30%.

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