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Research Paper

EXPERIMENTAL ANALYSIS OF COIR-FIBER REINFORCED POLYMER COMPOSITE MATERIALS

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Fiber-reinforced polymer composites have played a dominant role for a longtime in a variety of applications for their high specific strength and modulus. Past studies show that only synthetic fibers such as glass, carbon, etc., have been used in fiber-reinforced plastics. Although glass and other synthetic fiber-reinforced plastics possess high specific strength, their fields of application are very limited because of their inherent higher cost of production. An attempt has been made to utilize the coir, as natural fiber abundantly available in India. Natural fibers are not only strong and lightweight but also relatively very cheap. The present work describes the development and characterization of a new set of natural fiber based polyester composites consisting of coir as reinforcement and epoxy resin. Coir composites are developed and their mechanical properties are evaluated, at five different volume fractions and lengths. The tests were carried out and the results were presented. Experimental results showed tensile, static and Dynamic properties of the composites are greatly influenced by the increasing percentage of reinforcement, lengths of the fiber and indicate coir can be used as potential reinforcing material for many structural and non structural applications.

Keywords: Natural coconut fibers, Polyester matrix, Different volume fractions and lengths of reinforcement, Mechanical properties

INTRODUCTION

The composite material has been used from centuries ago, and it all started with natural fibers. Natural fibers have become important items in the economy and in fact, they have turn out to be a significant source of jobs for developing countries. Today, these fibers are assessed as environmentally correct materials owing to their biodegradability and renewable characteristics. For example, natural fibers like sisal, jute, coir, oil palm fiber have all been proved to be good reinforcement in thermo set and thermoplastic matrices. Nowadays, the increasing interest in automotive, cosmetic and plastic lumber application has heightened the need of natural fibers reinforced

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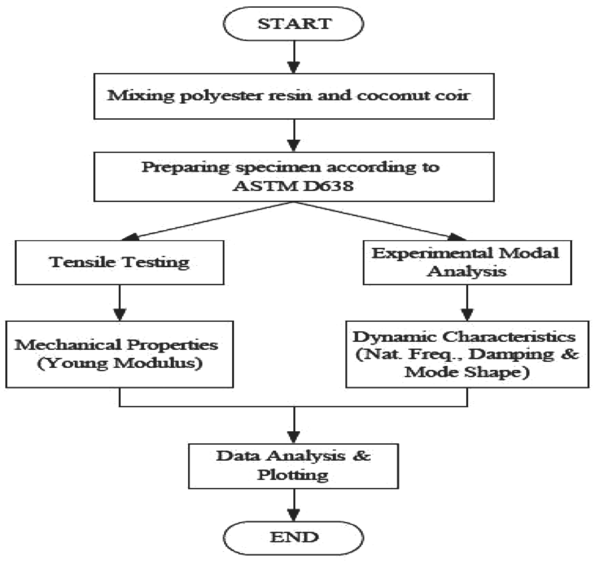
composites in these regimes as it offers an economical and environmental advantage over traditional inorganic reinforcements (Rao and Rao, 2007). Therefore, many industrial companies are looking for new composites material which has good and specific properties like mechanical, chemical and dynamic characteristic. In searching for such new material, a study has been made where coconut fiber (also known as coir fiber) is compounded with composite material. Coir is the natural fiber of the coconut husk where it is a thick and coarse but durable fiber. It is relatively water-proof and has resistant to damage by salt water and microbial degradation.

This paper addresses the characterization and performance of natural fiber reinforced composite by analyzing the effect of fiber volume (%), length on the composite mechanical properties and its dynamic characteristics. The composites were obtained by compounding polyester matrix and coir fibers in a batch mixer to obtain a randomly oriented discontinue form. The choose of polyester as a matrix is based on economic interest because it offers a very cheap resin, available with good mechanical properties and used in many applications such as transport, marine and sport.

EXPERIMENTAL

Basically there are three main stages that were carried out to achieve the objectives of study. The first stage was the preparation of composite material by combining the polyester and coconut coir. Then it was continued by performing the tensile test, and lastly the modal testing was carried out to determine dynamic characteristics of studied composite. Figure 1 shows the whole processes of the study.

Figure 1: The Flow Chart of the Study



Mould Preparation

To produce tensile test samples, the steel mould is fabricated and used which is follow the ASTM D638 Type 1 standard as shown as in Figure 2. While in preparing the samples for dynamic test, a 210 × 210 × 2 mm square steel mould is used.

Figure 2: Coir Fiber Reinforced Polyester Composite Tensile Test Specimen

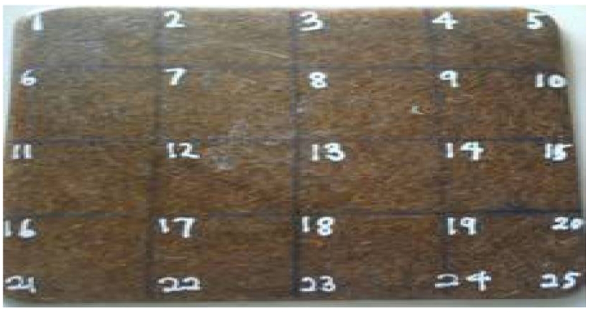
Mechanical Testing

Tensile test is the most common mechanical test for determining the mechanical properties of materials such as strength, ductility, toughness, elastic modulus, and strain hardening. There are 5 samples for each fiber volume fraction and the average values obtained from those samples were determined. The sample used for tensile test was ASTM D638 Type 1 as shown in Figure 5. The tests consisted of applying a constant strain on the fibers and measure the load. It was tested using Universal Testing Machine (UTM) with strain speed of 10 mm/min. Stress versus strain diagram was produced automatically from the UTM machine and the mechanical behavior of the composites are interpreted from the diagram.

Dynamic Testing

Dynamic test, sometimes called modal testing is a method used to extract modal parameters such as natural frequency, damping value and mode shape from the structure experimentally. The Frequency Response Function (FRF) is a fundamental measurement produced by the testing where the displacement, velocity, or acceleration response of a structure can be measured. In the preparation of sample, the composite plate which having dimension of 210 × 210 × 5 mm was prepared. The plate was divided into 25 grid points as shown as in Figure 3, where at these points; This 25 grid points were chosen to give adequate spatial resolution to describe the global structural mode shapes For excitation purposes, basically there are two methods can be used which are impact hammer excitation and shaker excitation. In this case, impact hammer excitation method was chosen to determine the modal parameter of composite structure.

Figure 3: Measurement Locations



RESULTS AND DISCUSSION

This section focuses on presenting the observations and findings gathered during the course of experiments. The data analysis provides the basis and justification for the conclusion drawn in this study. Two type of experiments were carried out which are tensile test for determining mechanical properties and modal testing for determining dynamic characteristics of the composite.

Mechanical Properties

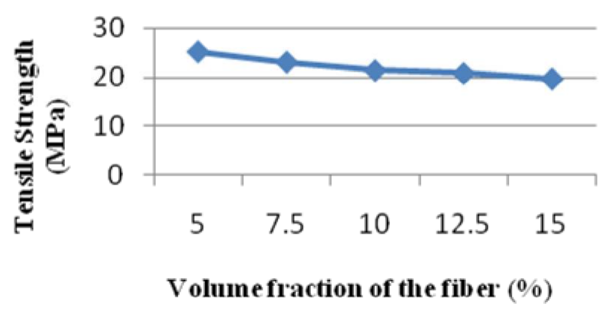
The mechanical properties of coir fibers reinforced composites are expected to depend on the content or volume fraction of the fibers in the composite (Rao and Rao, 2007). Even a small change in the physical nature of fibers for a given volume content of fibers may result in distinguished changes in the overall mechanical properties of composites. Therefore the influence of fibers content on mechanical properties of coir fibers reinforced composites was investigated. Table 1 shows the result of mechanical properties of coir fibers reinforced composites with fibers

Table 1: Mechanical Properties of Composites with Different Coir Fibers Volume

Fiber Content (% vol)	Tensile Strength (MPa)	Failure Strain (%)	Young s Modulus (GPa)
5.0	25.2	3.4	630.0
7.5	23.1	3.8	544.2
10.0	21.4	4.6	460.6
12.5	20.8	5.8	379.2
15.0	19.7	6.2	315.3

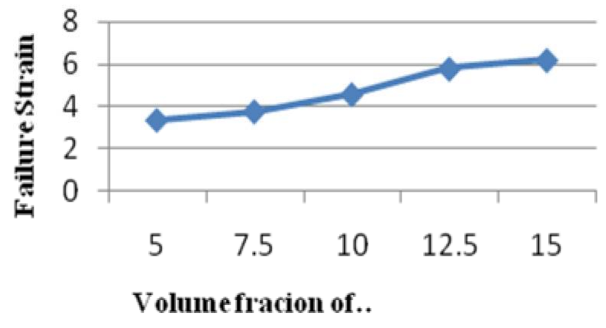
volume changing from 5 to 15%. It is shown that the tensile strength and Young's Modulus decreased as increasing of the fiber volume fraction. The decrement is due to poor interfacial bonding between fibers and matrix. The brittleness of the fibers also contributed to low mechanical strength because higher fibers contain higher possibilities of the fibers to sustain higher loads. Failure strain increased when fiber volume fraction is increased. This is because fibers provided a toughening or building mechanism to strengthen or prolong the composite life. The result in Table is agreed with (Shaikh *et al.*, 2003; and Brahim and Cheikh, 2006). Figure 4 shows the effect of fibers volume fraction on the tensile strength of the composite. It indicates that the tensile strength of composites decrease with increase in fibers volume. This agrees with the conclusion of earlier work (Rao and Rao, 2007) that coir fibers do not enhance the tensile strength of composite. This result reflects the lack of interfacial adhesion between matrix and fibers which behave like voids in the continuous phase. However this behavior make the structure become more flexible.

Figure 4: Failure Strain



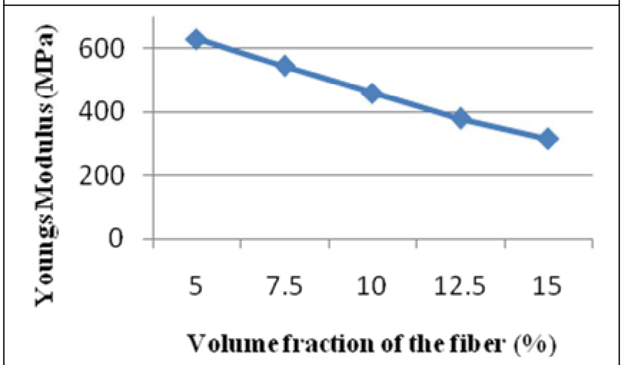
Meanwhile, Figure 5 indicates that the coir fiber reinforced composites experience ductile fractures which increase with increasing fibers volume fraction. The failure strain increases slightly from 3.4% to 5.8% when the volume percentages in fibers increases from 5% to 12.5% and then rises again to reach 6.2% for fibers percentage of 15%. It can be notified that the evolution of the composite failure strain with increasing of fibers volume fraction is very big since the strain at break of the coir fibers and the polyester resin are too distant.

Figure 5: Tensile Strength



By the incorporation of coir fibers, the Young modulus, E-value of composites goes on increasing up to 630 MPa for a fibers volume fraction of 5% but on further increasing the fibers content, the value was decreases. Figure 6 shows that Young modulus value steadily decreases with increasing fibers content which indicated lesser contribution of the fibers towards the static mechanical

Figure 6: Young Modulus of Each Percentage of Coir Fiber



properties of composites. The minimum value of Young modulus was obtained at fibers volume of 15% which specify ineffective stress transfer between the coir fibers and polyester matrix. This is also due to the incompatibility bonding between both materials matrix and fibers. According to (Sapuan *et al.*, 2003; and Brahmakumar *et al.*, 2005) their statements and papers theoretically Young modulus will increase as fibers volume fraction is increased. However, in reality this assumption is not really true because interfacial bonding at interface between fiber and matrix play an important role in determining the composite strength.

Mechanical Characteristics of Composites While Considering the Fiber Length

The characterization of the composites reveals that the fiber length is having significant effect on the mechanical properties of composites. The properties of the composites with different fiber lengths under this investigation are presented in Table 2.

Table 2: Mechanical Properties of Composites with Different Coir Fiber Lengths

Composites	Hardness (Hv)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Impact Energy (KJ/m^2)
C1	15.0	3.208	1.331	25.41	16.0
C2	12.6	9.155	1.518	31.28	16.5
C3	16.9	13.05	2.064	35.42	17.5

Effect of Fiber Length on Micro-Hardness

The measured hardness values of all the three composites are presented in Figure 7. It can be seen that the hardness is decreasing with the increase in fiber length up to 20 mm. However further increase in fiber length increases the micro hardness value.

Effect of Fiber Length on Tensile Properties

The test results for tensile strengths and moduli are shown in Figures 8 and 9, respectively. It is seen that the tensile strength of the composite increases with increase in fiber length. There can be two reasons for this increase in the strength properties of these

Figure 7: Effect of Fiber Length on Micro-Hardness of the Composites

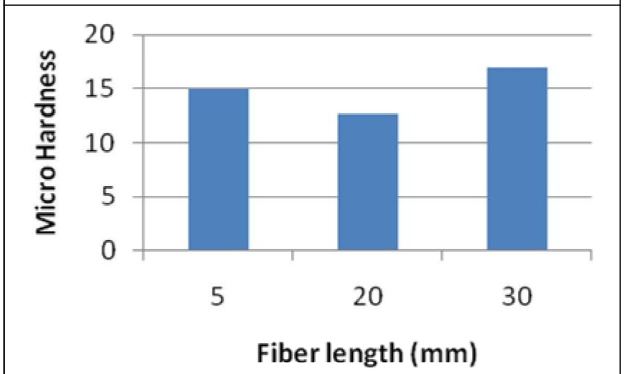


Figure 8: Effect of Fiber Length on Tensile Strength of Composites

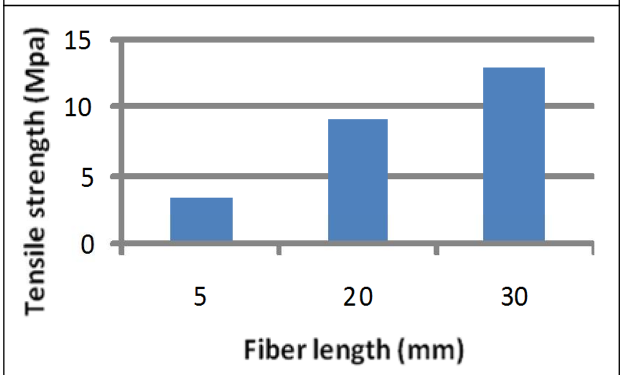
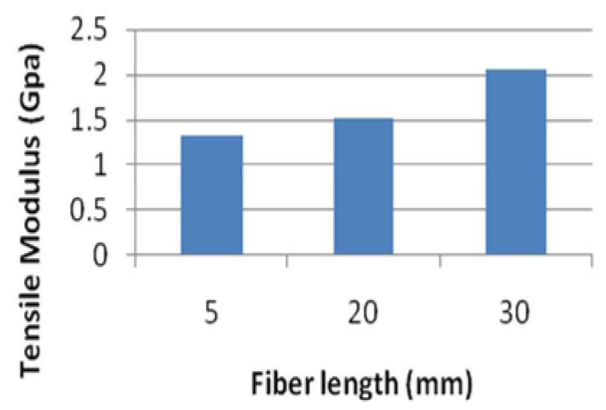


Figure 9: Effect of Fiber Length on Tensile Modulus of Composites

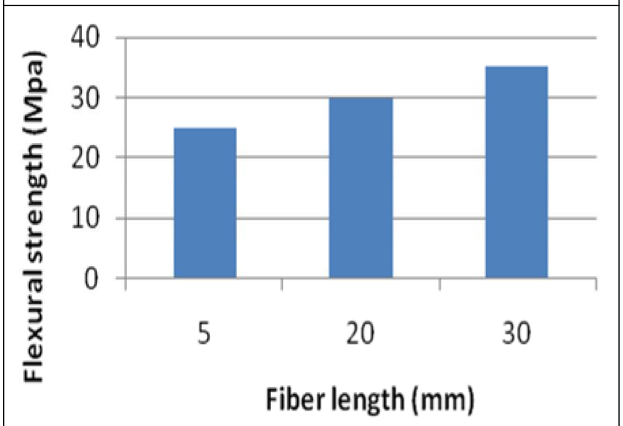


composites compared. One possibility is that the chemical reaction at the interface between the filler particles and the matrix may be too strong to transfer the tensile. From Figure 9 it is clear that with the increase in fiber length the tensile moduli of the coir fiber reinforced epoxy composites increases gradually.

Effect of Fiber Length on Flexural Strength

Figure 10 shows the comparison of flexural strengths of the composites obtained experimentally from the bend tests. It is interesting to note that flexural strength increases with increase in fiber length.

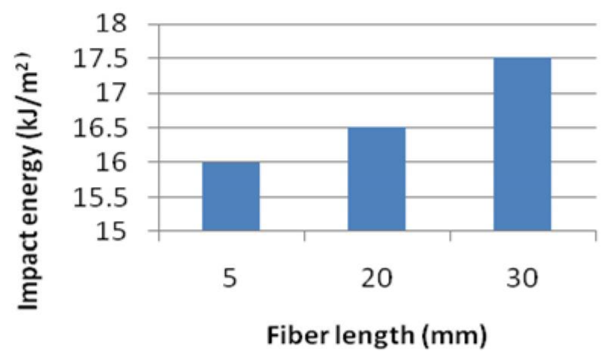
Figure 10: Effect of Fiber Length on Flexural Strength of Composites



Effect of Fiber Length on Impact Strength

The impact energy values of different composites recorded during the impact tests are given in Table 2. It shows that the resistance to impact loading of coconut coir fiber reinforced epoxy composites improves with increase in fiber length as shown in Figure 11. High strain rates or impact loads may be expected in many engineering applications of composite materials. The suitability of a composite for such applications should therefore be determined not only by usual design parameters, but by its impact or energy absorbing properties.

Figure 11: Effect of Fiber Length on Impact Strength of Composites



Dynamic Characteristics

Natural Frequency

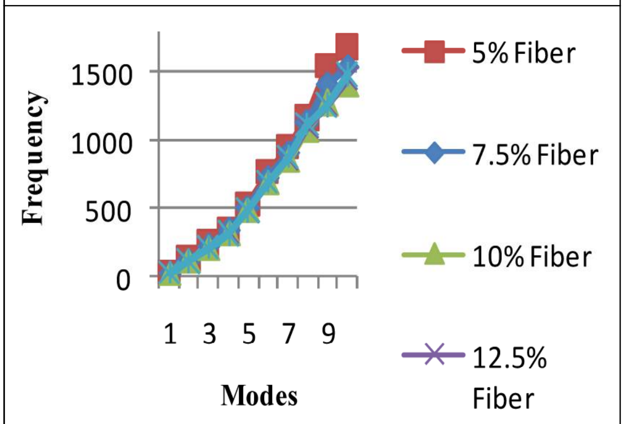
Table 3 shows the result of natural frequency of coir fiber reinforced composites for different fiber volume. Based on the data, there are inconsistent natural frequencies for each percentage of coir fiber. This is true since the modes or resonances are inherent properties of the structure. Resonances are determined by the material properties and the boundary conditions of the structure. Therefore if the material properties of the structure change, its modes will change.

Table 3: Natural Frequencies of Coir Fibers Reinforced Composites

Fiber Content (vol %)	Natural Frequency (HZ)									
	1	2	3	4	5	6	7	8	9	10
5.0%	26.8	130.0	245.0	341.0	529	771.0	960.0	1170	1550	1690
7.5%	26.1	123.5	231.5	333.0	510	732.5	915.0	1129	1415	1551
10.0%	25.5	117.0	218.0	326.0	492	694.0	868.0	1090	1280	1420
12.5%	25.1	115.0	216.0	321.5	486	697.0	873.5	1105	1270	1451
15.0%	24.6	114.0	215.0	317.0	481	702.0	879.0	1123	1264	1482

Figure 12 illustrates the graph of different natural frequency versus percentage of coir fibers for all the frequency modes. Generally it indicates that the composite with 5% volume of coir fibers shows the maximum value of natural frequencies for the whole mode followed by 7.5%, 10%, 12.5% and 15% volume of coir fibers. The composite with the 12.5% volume of coir fibers shows a slightly higher frequency compared to 15% volume of coir fibers only for the first five mode frequency. Somehow for higher mode, it found that the composite with 15% coir fibers volume prove to have a higher value.

Figure 12: Natural Frequencies of Each Percentage of Coir Fibers

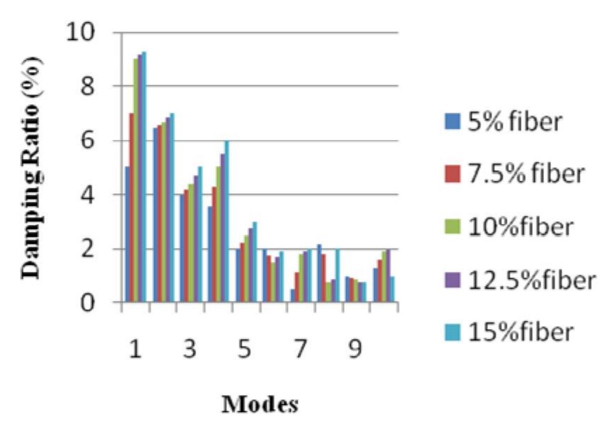


Based on the frequency's theoretical formula, the natural frequency of the structure depends on the stiffness and the mass of the structure. Therefore, an increasing of the stiffness will influence the natural frequency which increased the value. While for the mass; an increment of the mass value will reduce the natural frequency of the structure. As we know, each material that been studied has its own density; hence a reinforcement of the natural fibers will affect the mass of the structure where any additional density value gives an increasing to the mass of the structure (Iglesias, 2000). However in this case, the mass of the composites were setting almost the same for all the three percentage of coir fibers. From this result, it can be conclude that the composite with the low fiber volume is much stiffer which shows lesser contribution of the coir fibers towards the stiffness of the material. This also related to Young modulus of the structure since the stiffness value always depend on this E-value. Thus, an increase of Young modulus has been found to increase the natural frequency value indicating structure with high value of Young modulus and tensile strength is stiffer and linear proportional to the natural frequency value. From the tensile test, the results showed that 5% of coir fiber composite had a good strength and this identified the results taken from the modal testing was agreed with the theoretical formulation of the tensile strength of studied composite.

Damping Ratio

Based on the theoretical formulation for the damping ratio, the stiffness, mass and damping peaks can give an effect to the damping ratio value. Figure 13 shows the effect of fibers volume fraction on damping ratio for all the modes. By the incorporation of coir fibers, it appears that the damping ratio of composite is increasing only for the first five modes. However for next higher modes, the results of damping ratio are found inconsistent. In all cases, the peaks of damping ratio for each percentage of coir fibers composite was found to decrease when the modes increase. The composite with the volume of 15% of coir fiber shows the high damping ratios. These values are agreed with the theoretical formulation since any decrement of the stiffness and the mass will give an increment value of damping ratio. By adding the coir fiber obviously gives the structure vibrating in less oscillatory motion.

Figure 13: Damping Ratio of Each Percentage of Coir Fibers



Therefore, it gives advantage to the structure in reducing the high resonant.

CONCLUSION

- The results found that the mechanical properties have a strong association with the dynamic characteristics. Both of the properties are greatly dependent on the volume percentage of fibers. The composite having a coir fibers volume of 5% showed a significant result compared to high fiber loading composites due to the effect of material stiffness.
- It has been noticed that the mechanical properties of the composites such as micro-hardness, tensile strength, flexural strength, impact strength, etc., of the composites are also greatly influenced by the fiber lengths.
- Dynamic characteristics such as natural frequency of the composite can be predicted by analyzing the mechanical properties. The tensile strength of composite was found to be a linear proportional to natural frequency. Moreover, the damping ratio was found to be increased by incorporation of coir fibers which giving an advantage to the structure in reducing the high resonant.
- By the experimental characteristics it was clearly observed/concluded that the natural coconut coir fiber matrix material is best suitable for structural and non structural applications.

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