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Influence of Fiber Volume Fraction on the Tensile Properties and Dynamic Characteristics of Coconut Fiber Reinforced Composite

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Abstract

The utilization of coconut fibers as reinforcement in polymer composites has been increased significantly due to their low cost and high specific mechanical properties. In this paper, the mechanical properties and dynamic characteristics of a proposed combined polymer composite which consist of a polyester matrix and coconut fibers are determined. The influence of fibers volume fraction (%) is also evaluated and composites with volumetric amounts of coconut fiber up to 15% are fabricated. In this work, the tensile test was carried out to determine the strength of material, while modal testing was used to obtain the dynamic characteristics of the composite material. Results were found that the strength of the composites tends to decrease with the amount of fiber, which indicates ineffective stress transfer between the fiber and matrix. The dynamic characteristic of composite was also having a same effect where the natural frequency decreased with increase of coconut fiber volume. However the damping ratio was found to be increased by the incorporation of fiber. When higher fiber content of 15% was used, the damping ratio shows the maximum value for almost all the frequency mode. It was observed that the effects of reinforcing polyester matrix with coconut fibers lead the composites more flexible and easy to deform due to high strain values and low stiffness. In fact, it may also be used to reduce high resonant effect.

Keywords: Coir fibers, Tensile test, Modal testing, Damping Ratio, Resonant

1 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. Natural fibers can be easily obtained in many tropical and available throughout the world. 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 thermoset and thermoplastic matrices (Geethamma et al. 1998; Joseph et al. 1996; Sreekala et al. 1997; Varma et al. 1989). Nowadays, the increasing interest in automotive, cosmetic and plastic lumber application has heightened the need of natural fibers reinforced 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 (Ray 2005). Figure 1 shows the outer husk of coconut fruit which can be used as a source of fiber and coir pitch. Meanwhile, finding the mechanical properties and dynamic characteristics of coir fiber reinforced composites is vital because having a suitable stiffness and damping coefficients of composites can be applied to the certain applications which satisfy the needs of their characteristics such as strong, rigid, light weight, environmental friendly and so forth (Shaikh et al. 2003). The example of application of coir fiber reinforced composites is in industrial automotive where it used to make seat cushions for Mercedes automobiles. Even though it has advantageous properties, the coir fiber composites still have some undesirable properties such as dimensional instability, flammability which not suitable for high temperature application and degradability with humidity, ultraviolet lights, acids and bases (Brahim and Cheikh 2006). Therefore, a lot of efforts have been carried out to improve the performance of coir fiber reinforced composites.

Figure 1 The outer husk of the coconut

Recently there have been a lot of researches developed in the field of natural fiber reinforced composites (Geethamma et al. 1998; Joseph et al. 1996; Rao and Rao 2007; Ray 2005; Sreekala et al. 1997; Varma et al. 1989). However, most of them are based on the study of the mechanical properties of composites reinforced with short fibers. This paper addresses the characterization and performance of natural fiber reinforced composite by analyzing the effect of fiber volume (%) 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 chose 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.

2 RELATED WORKS

The history of natural fiber reinforced composite began in the last 20 years when there has been tremendous interest in the use of natural fibers for the manufacture of polymer bonded composites. They are environment friendly materials and have proved to be a competitor for glass fiber/polyester in terms of strength performance and cost. Combination of natural fiber reinforced polyester composites has been demonstrated to be an effective method to design materials suited for various requirement (Idicula et al. 2006). Earlier studies by Brahmakumar et al. (2005) proved that the coir fibers can be used as effective reinforcement and bonded in polyester matrix. These fibers were hybridized with the matrix to get a better mechanical performance. In the studies on mechanical performance and properties of short fiber reinforced polymer composites, Idicula et al. (2006) have shown that both fiber length distribution and fiber orientation distribution play very important role in determining the mechanical properties. Sapuan et al. (2003) who believed that mechanical properties of the natural fiber composites depend on several factors such as the stress–strain behaviors of fiber and matrix phases, the phase volume fractions and the distribution and orientation of the fiber or fillers relative to one another. He also found that the natural fiber composites demonstrate somewhat linear behavior and sharp fracture.

According to Shaikh et al. (2003) they indicated that the volume fraction of the natural fiber has a crucial effect on the composite strength where the strength of the composite raises linearly with the increase of volume fraction. However, different types of natural fiber give a different effect to the composites structure and some of the natural fibers can give an opposite effect to the strength of composite. Brahim and Cheikh (2006) had pointed out that the longitudinal modulus and the longitudinal stress increase with the rise of the volume fraction in fibers. This is obvious since the mechanical properties of the fibers are bigger than those of the polyester matrix. In the other hand, the strain decreases slightly from 2.7 to 2.3 when the fraction volume in fibers increases from 0% to 21% and then rises again to reach 3.1 for $Vf = 44\%$. However, the effect on dynamic characteristics of the composite was still not known. Therefore this problem has been considered in the study since dynamic behavior of composite structures is very important. Huang (2001) had carried out a micromechanical approach for investigating the dynamic response of laminated composite plates composed of randomly oriented fibers. Bledzki and Zhang (2001) also had investigated the dynamic mechanical behaviour of jute fibers reinforced epoxy foams.

For measuring the damping values, Gade and Herlufsen (1990) had compared between the Digital Filter (DF) techniques and the Discrete/ Fast Fourier Transform (DFT/FFT) techniques by using vibration decay measurements or bandwidth determination of measured modal resonances. In the DF technique, the damping was estimated from the decay of the free vibration response due to an impact excitation. The advantage of this technique is very fast and does not have limitations in dealing with very light damped systems. But, due to the poor resolution of DF analyzer, it is not well suited for bandwidth determination of measured modal resonances. For the FFT techniques the damping was measured using free vibration decay, curve fit of frequency response function measured using impact excitation and decay of impulse response function using pseudo random excitation with a shaker. The vibration decay method have no limitation with regard to low damping, but for high damping values, the limitation comes from the limited transfer rate of spectra, which depends on system measurement. Normally, the dynamic mechanical test method was employed to determine the structure relevant stiffness and damping characteristics for various applications in engineering. For the composite structure, the damping property can be obtained from the natural damping of its element (Pothana et al. 2003). This can be represented from the formula:

$$\tan \delta_c = V_f \tan \delta_f + (1 - V_f) \tan \delta_m \qquad (1)$$

where: tan δc = damping values of the composite
tan δf = damping values of the fiber
tan δm = damping values of the polymer
Vf = volume fraction of the fiber
Vm = volume fraction of the matrix

In the first part of this work, the mechanical properties of coconut fibers used to reinforce the studied composite material were presented. An experimental investigation was carried out to study the effect of coir fibers volume fraction (%) on strength of composite and the results were discussed in this paper. In the second part, the dynamic test was then performed to describe the effect of fibers content and the relationship with mechanical properties on the dynamic characteristics of the composites material.

3 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 2 shows the whole processes of the study.

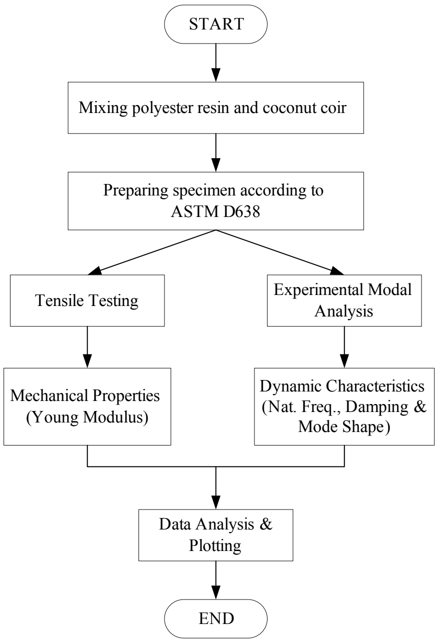

Figure 2 The flow chart of the study

3.1 Fiber Preparations

The composite material was made of polyester matrix reinforced with coconut fibers. They were arranged in discontinuous randomly oriented configuration. Basically, coir fibers were obtained from coconut husk, which was abstracted from coconut fruit. After they were abstracted, the coir fibers will be dried at 80˚C using drying oven to minimize the moisture content in the fibers which can prolong their span life. In order to enhance the bonding compatibility between the polyester and fibers, the coir fibers need to go through the treatment process. This process consists of immersing the coir fibers into 5% Natrium Hydroxide (NaOH) solution for 24 hours to remove the unwanted layer of coconut coir fibers. After that, the fibers were washed abundantly with water to remove the NaOH before they dried again in furnace at 70˚C to 80˚C for next 24 hours. The coir fibers were then soaked into the solution of 5% silane and 95% methanol for 4 hour and dried at 70˚C for next 24 hours curing time. After the drying process finished, the coconut fibers was inserted into the cutting machine to cut into smaller pieces. This form is called whickers which its length is less than about 10 mm. The advantage of whickers is that they can easily pour into the mixture of coconut fibers and polyester in ASTM D638 Type 1 mould (Tuttle 2004). The mechanical properties of coir fibers are shown in Table 1.

Table 1 Mechanical properties of coir fibers (Ray 2005)

Mechanical Properties	Coconut Coir Fiber
Density (g/cm^3)	1.2
Elongation at break (%)	30
Tensile strength (MPa)	175
Young modulus (GPa)	4 – 6
Water absorption (%)	130 – 180

The usage of polyester resin as a matrix was chosen because it is the standard economic resin commonly preferred material in industry. In fact, it yields highly rigid products with a low heat resistance property (Pothana et al. 2003). The polyester resin was prepared by mixing polyester of density 1.28 g/cm3 with hardener 3554B of density 1.05 g/cm3 at weight ratio 100: 1. The mechanical properties of polyester resin are given in Table 2.

Table 2 Mechanical properties of polyester resin (Pothana et al. 2003)

Properties	Polyester resin
Density (g/cm^3)	1.2 – 1.5
Young modulus (GPa)	2 – 4.5
Tensile strength (MPa)	40 – 90
Tensile elongation at break (%)	2
Water absorption 24h at 20 °C	0.1 – 0.3

3.2 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 3. While in preparing the samples for dynamic test, a 210 x 210 x 2 mm square steel mould is used.

3.3 Preparation of Composite

The composites having different fibers content were prepared by varying the fibers volume fraction from 5% to 15%. In the first process of preparing the composite, a release agent was used to clean and dry the mould before the polyester can be laid up on the mould. The polyester was then mixed uniformly with the coconut fibers by using a special brush in the mixed container. The mixture was poured carefully into the moulds and flattened appropriately by using the roller. The wet composites were then lightly compressed to squeeze out the excessive resin. Finally after the composites were fully dried, they were separated off from the moulds. 24 hours curing time was used to obtain an optimum composite hardness and shrinkage.

In this work, the volume based fibers reinforced composites were adapted for the analysis. The example of the calculations is as follow:

i. The total volume of the sample as in Figure 3 and 4 is calculated.
ii. 5% of the total volume which is occupied by the fiber is determined and then the volume of the fibers is converted to fiber weight using equation (1):

$$\text{Density, } \rho = \frac{m}{v} \tag{2}$$

where, m is the mass of the fibers and v is the volume occupied by the fibers.
iii. Fibers are then mixed with polyester resin and they are mechanically stirred to produce homogenous mixture.

3.4 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 3 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 3. 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.

Figure 3 Coir fibers reinforced polyester composite tensile test specimen

3.5 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 x 210 x 5 mm was prepared. The plate was divided into 25 grid points as shown as in Figure 4, where at these points; FRFs were measured in the range of 0-2000 Hz to identify the modal characteristics. This 25 grid points were chosen to give adequate spatial resolution to describe the global structural mode shapes.

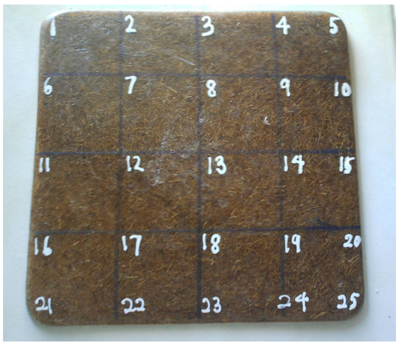

Figure 4 Measurement locations.

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 5 shows a typical experimental setup for impact hammer test. The sample was placed on the very soft sponge or polymeric foam to represent the free vibration test. In this type of testing, it is assumed that the sample can freely vibrate or rotate in all degree of freedom. A voltage type accelerometer was fixed at point number 1 using some bees wax in order to measure the response at single fixed point. A charge type force transducer was then mounted close to the tip of impact hammer and connected to the channel 1 of Data analyzer using cable. The hammer excitation will be roving from one point to another point to compute the FRFs. For the calculation of modal parameters, Multi-Degree of Freedom (MDOF) method was used. Some manipulation was done to obtain the resonance peaks in the plot.

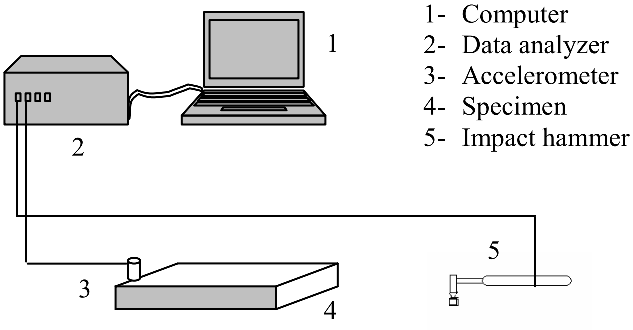

Figure 5 A typical experimental set-up for impact hammer test

4 RESULT 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.

4.1 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 3 shows the result of mechanical properties of coir fibers reinforced composites with fibers 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 3 is agreed with Baiardo et al. (2004); Brahim and Cheikh (2006); Ray (2005); Shaikh et al. (2003).

Table 3 Mechanical properties of composites with different coir fibers volume

Fiber content (vol %)	Tensile Strength (MPa)	Failure strain (%)	Young modulus (MPa)
5	24.8	3.9	633
10	21.9	4.8	461.4
15	19.8	6.1	318.8

Figure 6 shows the effect of fibers volume fraction on the tensile strength of the composite. It indicates that the tensile strength of composites decrease with increasing fibers volume. This agrees with the conclusion of earlier work by 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.

Meanwhile, Figure 7 indicates that the coir fiber reinforced composites experience ductile fractures which increase with increasing fibers volume fraction. The failure strain increases slightly from 3.9% to 4.8% when the volume percentages in fibers increases from 5% to 10% and then rises again to reach 6.1% 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.

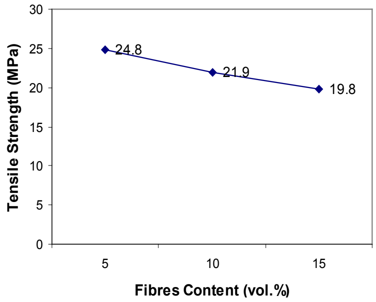

Figure 6 Tensile strength

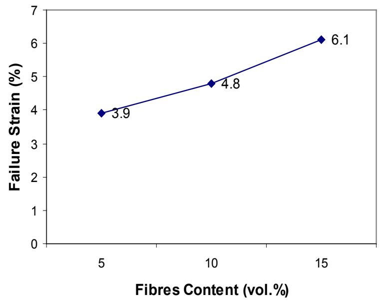

Figure 7 Failure strain

By the incorporation of coir fibers, the Young modulus, E value of composites goes on increasing up to 633 MPa for a fibers volume fraction of 5% but on further increasing the fibers content, the value was decreases. Figure 8 shows that Young modulus value steadily decreases with increasing fibers content which indicated lesser contribution of the fibers towards the static mechanical 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 Brahmakumar et al. (2005); Sapuan et al. (2003), they stated in their papers that 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.

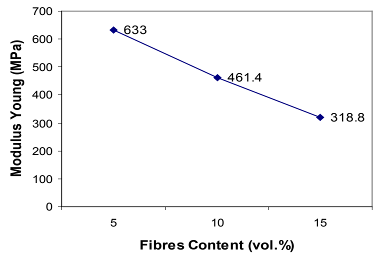

Figure 8 Young modulus of each percentage of coir fiber

4.2 Dynamic Characteristics

The natural frequency of the each percentage of coir fibers can be determined from the plot of superimposed FRFs as shown in Figure 9 which was obtained from point 1 until 25 during the impact hammer test. Obviously it can be easily identified by taking the frequencies corresponding to the resonance peaks (Ewins 1984). The frequency range was setting up to 2000 Hz.

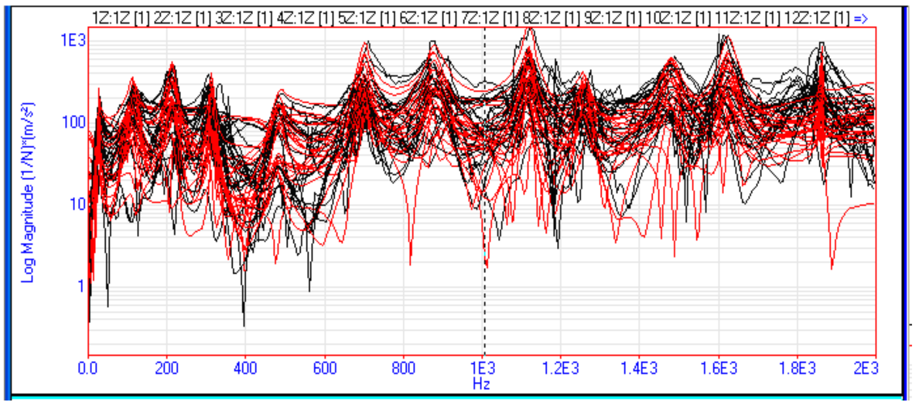

Figure 9 Superimposed FRF for composite plate

4.2.1 Natural frequency

Table 4 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 (Bishop 1979). Therefore if the material properties of the structure change, its modes will change.

Table 4 Natural frequencies of coir fibers reinforced composites

Fiber Content (vol. %)	Natural Frequency (Hz)									
	1	2	3	4	5	6	7	8	9	10
5%	26.8	130	245	341	529	771	960	1170	1550	1690
10%	25.5	117	218	326	492	694	868	1090	1280	1420
15%	24.6	113	213	315	480	700	879	1120	1260	1480

Figure 10 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 10% and 15% volume of coir fibers. The composite with the 10% 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.

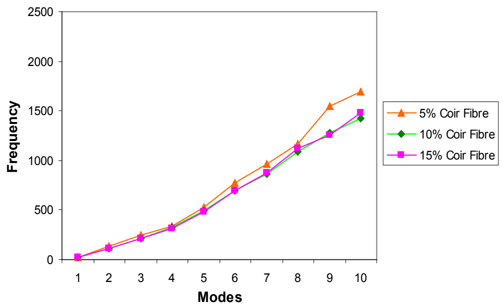

Figure 10 Natural frequencies of each percentage of coir fibers

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.

4.2.2 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 11 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 (Avitabile 2005). By adding the coir fiber obviously gives the structure vibrating in less oscillatory motion. Therefore, it gives advantage to the structure in reducing the high resonant.

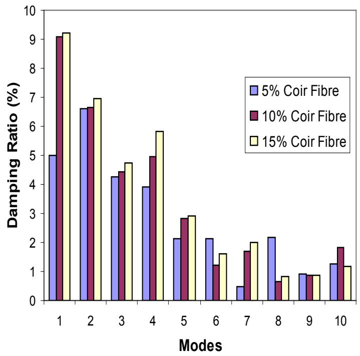

Figure 11 Damping ratio of each percentage of coir fiber

5 CONCLUSION

The research was carried out to investigate the static and dynamic mechanical behavior of randomly oriented mixed coir fibers reinforced polyester composite. The effect of coir fibers volume fraction on mechanical properties and dynamic characteristic of composite were studied. The results found that the mechanical properties have a strong association with the dynamic characteristic. Both of the properties are greatly dependent on the volume percentage of fibers. In general, 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. 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.

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