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STUDY ON THE DYNAMIC CHARACTERISTIC OF COCONUT FIBRE REINFORCED COMPOSITES

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ABSTRACT

The goal of this paper is to determine the mechanical properties and dynamic characteristics of a proposed combined polymer composite which consist of a polyester matrix and coconut fibres (also known as coir fibres). The influence of fibres volume on the mechanical properties and dynamic characteristic of the composites was also evaluated. Composites with volumetric amounts of coconut fibre up to 15% were fabricated and they were arranged in randomly oriented discontinues form. Tensile test was carried out to determine the strength of material, while experimental modal analysis was executed to obtain the dynamic characteristics of the composite material. The acquired results show that the tensile modulus changes with the fibre content. The strength of coconut fibre reinforced composites tends to decrease with the amount of fibre which indicates ineffective stress transfer between the fibre and matrix. The stiffness factor also gives the same effect to the dynamic characteristic of composite where the natural frequency decreased with the increase of coconut fibre volume. However the damping peak was found to be increased by the incorporation of the fibre. When higher fibre content of 10% was used, the damping peak shows the maximum value for almost all the frequency mode. It was observed that the effects of reinforcing polyester matrix with the coconut fibres caused the composites to be more flexible and easily deform due to high strain values and reduction of high resonant amplitude.

Keywords: natural coconut fibres, tensile test, experimental modal analysis, natural frequency, damping

INTRODUCTION

Natural fibres can be easily obtained in many tropical and available throughout the world. Today these fibres are considered as environment friendly materials owing to their biodegradability and renewable characteristics. Natural fibres such as sisal, jute, coir, oil palm fibre have all been proved to be good reinforcement in thermoset and thermoplastic matrices (Varma *et al.* 1989; Joseph *et al.* 1996; Sreekala *et al.* 1997; Geethamma *et al.* 1998). Nowadays, the use of natural fibres reinforced composites is gaining popularity in automotive, cosmetic, and plastic lumber applications because it offers an economical and environmental advantage over traditional inorganic reinforcements and fillers (Murali & Mohana 2007).

In searching for such new material, a study has been made where coconut fibre (also known as coir fibre) is compounded with composite material. Coir is the natural fibre of the coconut husk where it is a thick and coarse but durable fibre. 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 fibre and coir pitch. Meanwhile, the investigation of the mechanical properties and dynamic characteristics of the coir fibre reinforced composites is vital. This is due to the fact that 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 materials (Shaikh *et al.* 2003). The example of application of coir fibre reinforced composites is in industrial automotive where it used to make seat cushions for Mercedes automobiles. Even though it has advantageous properties, the coir fibre 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 & Cheikh 2006). Therefore, a lot of efforts have been carried out to improve the performance of coir fibre reinforced composites.

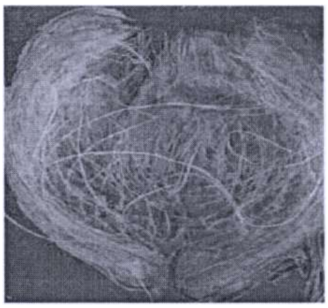


FIGURE 1 The outer husk of the coconut

This paper addresses the characterization and performance of natural fibre reinforced composite by analyzing the effect of fibre volume (%) on the composite mechanical properties and its dynamic characteristics. The composites were obtained by compounding polyester matrix and coir fibres 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.

RELATED WORKS

Natural fibres are environment friendly materials and have proved to be a competitor for glass fibre/polyester in terms of strength performance and cost (Baiardo *et al.* 2004; Brahim & Cheikh 2006; Idicula *et al.* 2006). Combination of natural fibre reinforced polyester composites has been demonstrated to be an effective method to design materials suited for various requirement. Earlier studies by Brahmakumar *et al.* (2005) proved that the coir fibres can be used as effective reinforcement and bonded in polyester matrix. These fibres were hybridized with the matrix to get a better mechanical performance. In the studies on mechanical performance and properties of short fibre reinforced polymer composites, Maries Idicula *et al.* (2006) have shown that both fibre length distribution and fibre orientation distribution play very important role in determining the mechanical properties. Sapuan *et al.* (2003) believed that mechanical properties of the natural fibre composites depend on several factors such as the stress-strain behaviours of fibre and matrix phases, the phase volume fractions and the distribution and orientation of the fibre or fillers relative to one another. He also found that the natural fibre composites demonstrate somewhat linear behaviour and sharp fracture.

Shaikh *et al.* (2003) indicated that the volume fraction of the natural fibre 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 fibre give a different effect to the composites structure and some of the natural fibres can give an opposite effect to the strength of composite. Brahim (2006) had pointed out that the longitudinal modulus and the longitudinal stress increase with the rise of the volume fraction in fibres. This is obvious since the mechanical properties of the fibres 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 fibres 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 the dynamic behaviour 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 fibres. Bledzki & Zhang (2001) had also investigated the dynamic mechanical behaviour of jute fibres reinforced epoxy foams.

For measuring the damping values, Gade & 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 is estimated from the decay of the free vibration response due to an impact excitation and the advantage of this technique is very fast and doesn't 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 does not have any 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 (Photana *et al.* 2003). This can be represented from the formula:

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

where tan 8_C is damping values of the composite, tan 5_f is damping values of the fibre, tan 8_m is damping values of the polymer, V_f is volume fraction of the fibre and V_m is volume fraction of the matrix.

In the first part of this work, the physical and mechanical properties of coconut fibres used to reinforce the studied composite material were present. An experimental investigation was carried out to study the effect of coir fibres volume (%) on the 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 fibres content and the relationship of mechanical properties on the dynamic characteristics of the developed material.

EXPERIMENTAL WORKS

Basically three main tasks were carried out to achieve the objectives of study. The first task 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 experimental modal analysis (EMA) was carried out to determine the dynamic characteristics of the studied composite. Figure 2 shows the whole processes of the study.

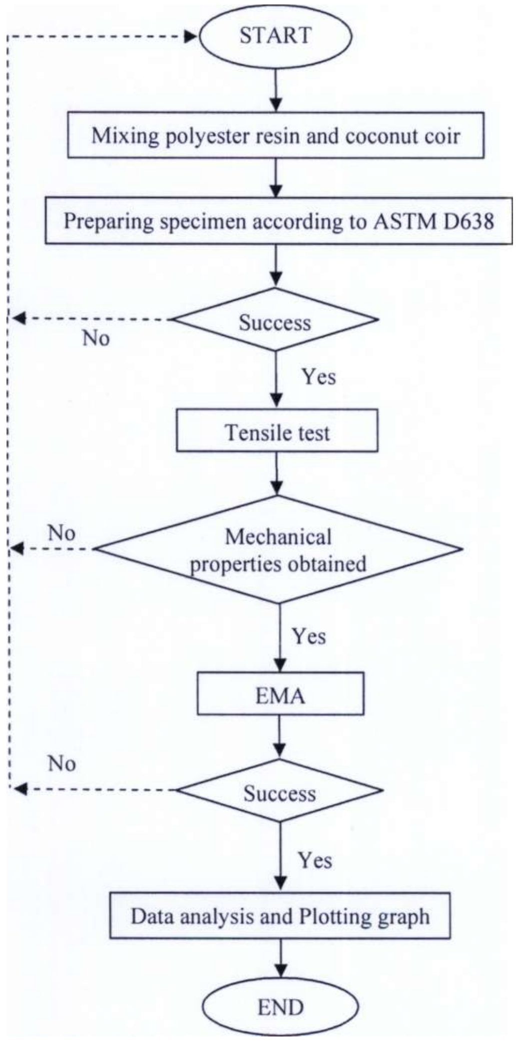


FIGURE 2 The flow chart of the study

Material

The studied composite material is made of polyester matrix reinforced with coconut fibres which were arranged in discontinuous randomly oriented configuration. Basically, the coir fibres obtained from the coconut husk which was abstracted from coconut fruit. After they had been abstracted, the coir fibres will be dried at 70°C to 80°C using drying oven. In order to avoid degradation factor, the coir fibres need to go through the treatment process. This process consists of immersing the coir fibres into 5% Natrium Hydroxide (NaOH) solution for 24 hours to remove the first layer of coconut coir fibres. After that, the obtained fibres 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 fibres were then soaked into 5% of silane and 95% of methanol solution for 4 hour and dried at 70°C for next 24 hours curing time. After the drying process finished, the coconut fibres 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 fibres and polyester in ASTM D638 Type 1 mould (Turtle 2004). The physical properties of coir fibres are shown in Table 1.

TABLE 1 Physical properties of coir fibres

Mechanical Properties	Coconut Coir Fibre
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 used, preferred material in industry and besides, it yields highly rigid products with a low heat resistance property. The polyester resin was prepared by mixing polyester of density 1.28 g/cm^3 with hardener 3554B of density 1.05 g/cm^3 at weight ratio 100: 1. The mechanical properties of polyester resin are given in Table 2.

TABLE 2 Mechanical properties of polyester resin

Properties	Polyester resin
Density (g/cm^3)	1.2 - 1.5
Young modulus (GPa)	2 - 4.5
Tensile strength (MPa)	40 - 90
Compressive strength (MPa)	90 - 250
Tensile elongation at break (%)	2
Water absorption 24h at 20 °C	0.1 - 0.3

Mould preparation

For tensile testing purpose the mould used for coconut fibres composite is made from mild steel which followed the ASTM D638 Type 1 standard as shown as in Figure 3. The mould was fabricated in machining lab using Advanced Machining Lab machine. In addition, for the modal testing, the mould used for coconut coir fibres composite is made from stainless steel square shape which length and width of 210 mm as shown as in Figure 4.

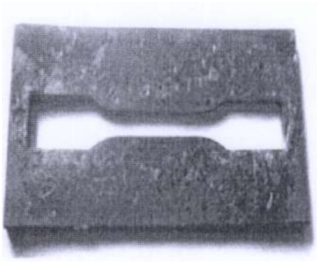


FIGURE 3 ASTM D638 Type 1

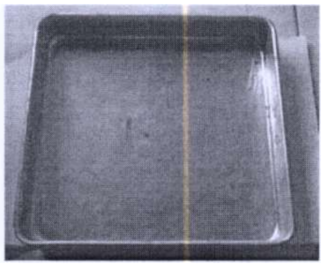


FIGURE 4 The mould for plate

Preparation of Composites

Composites having different fibres content were prepared by varying the fibres volume 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 fibres by using a special brush in the mixed container. The mixture was poured carefully into the moulds and flattened appropriately by using the roller before being dried for 24 hours. After the composites were fully dried, they were separated off from the moulds.

Mechanical testing

Tensile testing is the most common mechanical testing for determining the physical properties of materials such as strength, ductility, toughness, elastic modulus, and strain hardening. The tests consist of applying a constant strain on the fibres and measure the load. Universal Testing Machine was used with strain speed of 10 mm/min. The distance between clips was defined of 115 mm. Four specimens were prepared in the study for each percentage of coir fibres in order to get more accurate results.

Dynamic testing

Dynamic testing, sometimes called modal testing or experimental modal analysis is a method used to extract model 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 for modal testing, the composite plate having the dimension 210 x 200 x 2 mm was prepared. The plate was divided into 25 grid points as shown as in Figure 5 where at these points, Frequency Response Functions (FRF) 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.

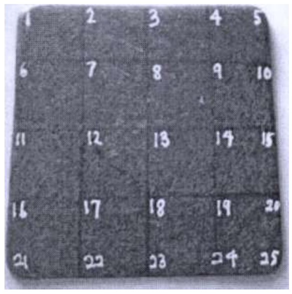


FIGURE 5 Measurement locations

For the excitation purposes, basically there are two methods that can be used which are impact hammer excitation method and shaker excitation method. In this case, the impact hammer excitation method was chosen to determine the modal parameter of composite structure. Figure 6 shows a typical experimental setup for impact hammer test. The specimen was placed on a sponge to form a free-free boundary condition. The accelerometer was mounted onto the specimen at point 1 using wax so that the accelerometer would have the same vibration. The modal parameters were then calculated using the Multi-Degree of Freedom (MDOF) method. Some manipulation was done to obtain the resonance peaks in the plot.

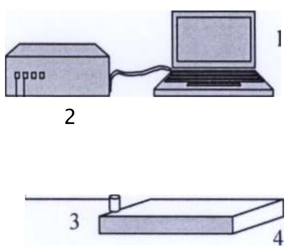


FIGURE 6 A typical experimental set-up for impact hammer test

RESULT AND DISCUSSION

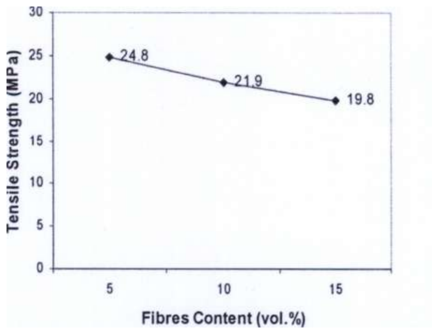
Mechanical properties

The mechanical properties of coir fibres reinforced composites are expected to depend on the content or volume fraction of the fibres in the composite (Murali & Mohana 2007). Even a small change in the physical nature of fibres for a given volume content of fibres may result in distinguished changes in the overall mechanical properties of composites. Therefore the influence of fibres content on mechanical properties of coir fibres reinforced composites was investigated. Table 3 shows the mechanical properties of coir fibres reinforced composites with fibres volume changing from 5 to 15%.

TABLE 3 Mechanical properties of composites with different coir fibres 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

Obviously, there is a good wetting between the fibre and matrix and a strong interface is created which is led to a strong bonding. However, high percentage of coir fibre will result in poor wetting between the coir fibre and polyester matrix. It was found lead to the less area of fibre being bonded by the matrix which can cause weak interface and thus lead to weak bonding. The composite will become more easy to deform and flexible towards the increase of fibres content. Figure 7 shows the effect of fibres volume on the tensile strength of the composite. It indicates that the tensile strength of composites decrease with increasing fibres volume. This agrees with the conclusion of earlier work by Murali and Mohana 2007 that coir fibres do not enhance the tensile strength of composite. This result reflects the lack of interfacial adhesion between matrix and fibres which behave like voids in the continuous phase. However this behaviour make the structure become more flexible. Figure 8 indicates that the coir fibre reinforced composites experience ductile fractures which increase with the increment of the fibres volume. The failure strain increases slightly from 3.9% to 4.8% when the volume percentages in fibres increases from 5% to 10% and then rises again to reach 6.1 for fibres percentage of 15%. It can be notified that the evolution of the composite failure strain with increasing of fibres volume is very significant since the strain at break of the coir fibres and the polyester resin are too distant.



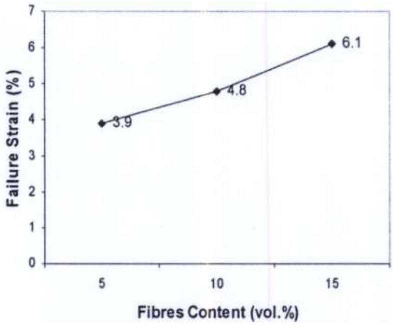


FIGURE 7 Tensile strength of composite FIGURE 8 Failure strain of composite

By the incorporation of coir fibres, the Modulus Young, E value of composites increases up to 633 MPa for a fibres volume of 5% but on further increasing the fibres content, the value decreases. Figure 9 shows that Modulus Young, E steadily decreases with increasing fibres content which indicated lesser contribution of the fibres towards the static mechanical properties of composites. The minimum value of Modulus Young was obtained at a fibres volume of 15% which specify ineffective stress transfer between the coir fibres and polyester matrix.

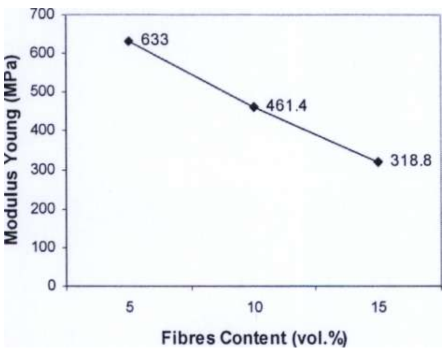


FIGURE 9 Young modulus of each percentage of coir fibre

Dynamic characteristics

The natural frequency of the each percentage of coir fibres can be determined from the plot of FRFs as shown in Figure 10. The value of the natural frequencies can be obtained by taking the frequencies corresponding to the resonance peaks. The range of frequency was setting up to 2500 Hz due to the usage of plastic tip. The metal tip was not using for excitation because it has the tendency to create double or multiple impacts when knocked onto the specimen even though it has a bigger range of frequency (Ewins 1984).

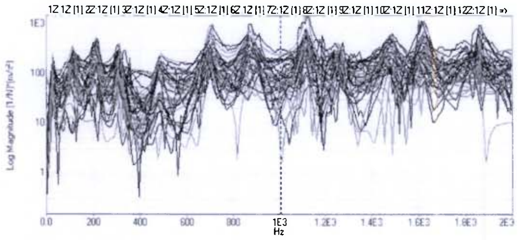


FIGURE 10 Superimposed FRF for composite plate

(a) Natural frequency

Table 4 shows the result of natural frequency of coir fibre reinforced composites for different fibre volume. Based on the data, there are inconsistent natural frequencies for each percentage of coir fibre. 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 fibres reinforced composites

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

Figure 11 illustrates the graph of different natural frequency versus percentage of coir fibres for all the frequency modes. Generally it indicates that the composite with 5% volume of coir fibres shows the maximum value of natural frequencies for the whole mode followed by 10% and 15% volume of coir fibres. The composite with the 10% volume of coir fibres shows a slightly higher frequency compared to 15% volume of coir fibres only for the first five mode frequency. Somehow for the higher mode, it founds that the composite with 15% coir fibres volume prove to have a higher value. 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 has been studied has its own density, hence a reinforcement of the natural fibres 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 fibres. From this result, it can be conclude that the composite with the low fibre volume is much stiffer which shows lesser contribution of the coir fibres towards the stiffness of the material. This also related to Modulus Young of the structure since the stiffness value always depend on Modulus Young. Thus, an increase of Modulus Young has been found to increase the natural frequency value indicating structure with high value of the Modulus Young and tensile strength is stiffer and linear proportional to the natural frequency value. From the tensile test, the results showed that 5% of coir fibre composite had a good strength and this identified the results taken from the experimental modal analysis was agreed with the theoretical formulation of the tensile strength of studied composite.

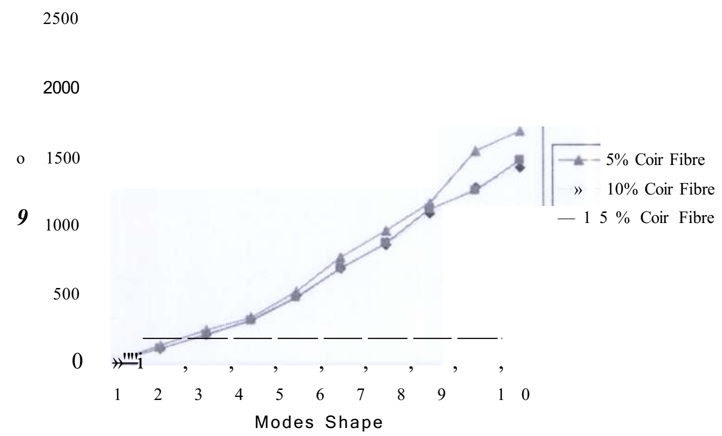


FIGURE 11 Natural frequencies of each percentage of coir fibres

(b) 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 12 shows the effect of fibres volume percentage on damping ratio for all the modes. By the incorporation of coir fibres, 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 fibres composite was found to decrease when the modes increase. The composite with the volume of 15% of coir fibre 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 increasing value of the damping ratio (Avitable 2001). By adding the coir fibre obviously gives the structure vibrating in less oscillatory motion. Therefore, it gives advantage to the structure in reducing the high resonant amplitude.

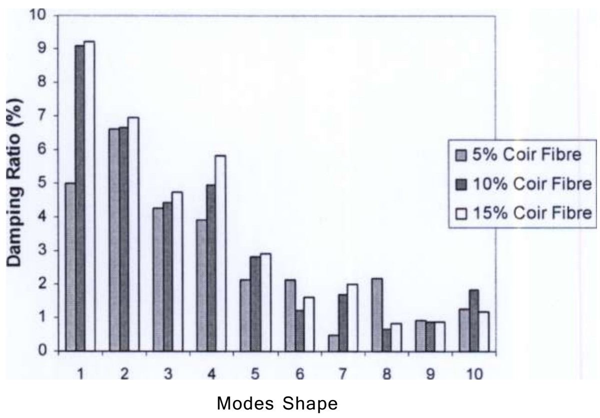


FIGURE 12 Damping ratio of each percentage of coir fibre

(c) Mode shape

Figure 13 shows the first four modes shape of coir fibre reinforced composite plate with varying the percentage of coir fibre volume. The contour represents the residue magnitude value where the red colour stands for the largest residue magnitude and blue colour stands for the minimum residue magnitude. For all the cases, the plate only experiences the global vibration where the whole structure is vibrating. The first four mode shapes of each percentage of coir fibres were observed which can be identified from 20-350 Hz. It was found that the first and second mode shape of the structure experienced the torsion mode. While for the third and fourth mode shapes of the structure were observed as bending mode.

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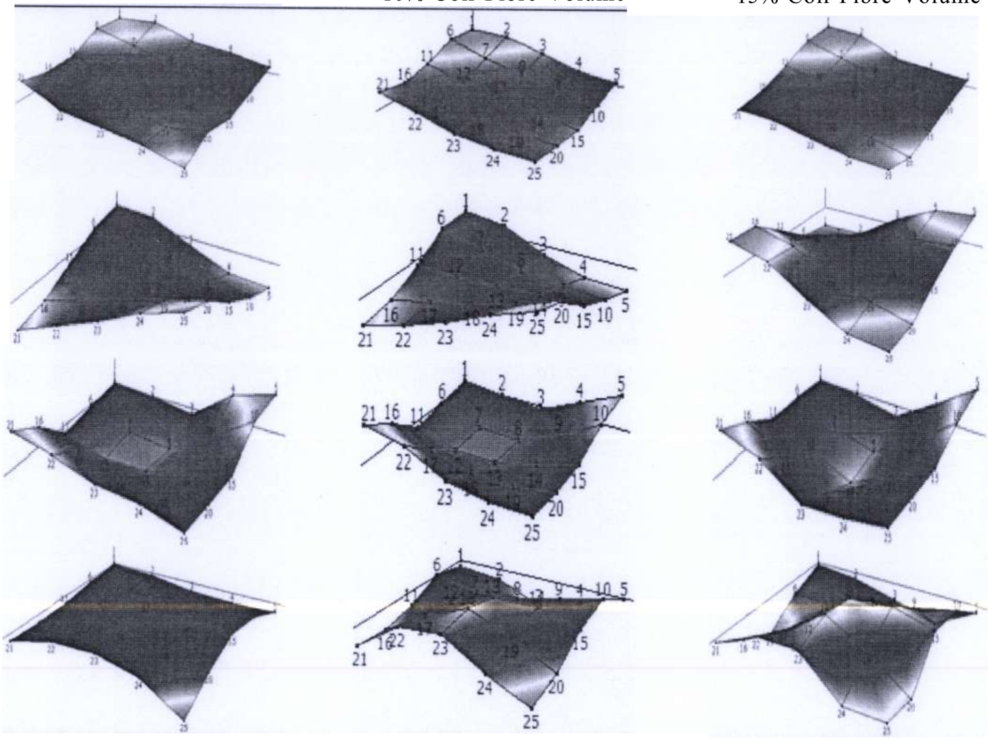

Mode	5% Coir Fibre Volume	10% Coir Fibre Volume	15% Coir Fibre Volume	Description of Mode Shape
				Torsion
				Torsion
				Bending
				Bending

FIGURE 13 Mode shape of composite plate reinforced coir fibre

CONCLUSIONS

The research was carried out to investigate the static and dynamic mechanical analysis of randomly oriented mixed coir fibres reinforced polyester composite. The effect of coir fibres volume on mechanical properties and dynamic characteristic of composite were studied. The results were 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 fibres. In general, the composite having a coir fibres volume of 5% showed the best result. The tensile strength and Modulus Young were found to be decreased with incorporation of coir fibres which again points to the ineffective stress transfer between fibres and polyester resin. However the increase of coir fibres will make the composite tend to have low stiffness and ductility. 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 linearly proportional to the natural frequency. Moreover, the damping ratio was found to be increased by incorporation of coir fibres which giving an advantage to the structure in reducing the high resonant amplitude.

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