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Evaluation of Mechanical properties of coir fiber reinforced polyester matrix composites

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Abstract— this paper "Evaluation Of Mechanical properties of coir fiber reinforced polymer matrix Composites" 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. The goal of this paper is to determine the mechanical (Static & Dynamic) properties 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 was also evaluated. Composites with volumetric amounts of coconut fibre up to 10% were fabricated and they were arranged in randomly oriented discontinues form. Tensile test was carried out to determine the strength of material by using Universal Testing Machine. 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.

It was observed that the effects of reinforcing polyester matrix with the coconut fibres causes the composites to be more flexible and easily deform due to high strain values. In fact, it may also be used to reduce high resonant effect.

Keywords- *Coconut Fiber, Polyester resign,Tensile test, Modal testing, Damping Ratio, Resonant.*

I. 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).

COMPOSITE MATERIALS

Fiberglass, developed in the late 1940s, was the first modern composite and is still the most common. It makes up about 65 per cent of all the composites produced today and is used for boat hulls, surfboards, sporting goods, swimming pool linings, building panels and car bodies. We also may be using something made of fiberglass without knowing it.

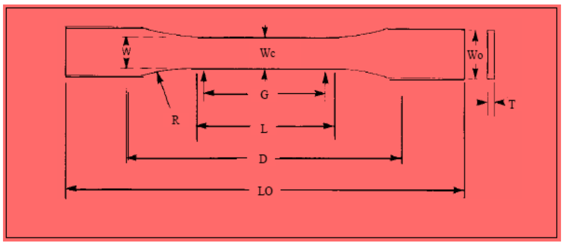
Composite material is a material composed of two or more distinct phases (matrix phase and dispersed phase) and having bulk properties significantly different from those of any of the constituents.

- **Matrix phase**
- **Dispersed (reinforcing) phase**

TESTING METHODS

All the mechanical testing methods that were carried out were base on American Standard Testing Methods (ASTM). There were three test performed, namely Tensile Test (ASTM D638), Flexural Test (ASTM D256) and Impact Test (ASTM D790). For morphology studies, Scanning Electron Microscope (SEM) was used.

Tensile Testing: In a broad sense, tensile test is a measurement of the ability of a material to withstand forces that tend to pull it apart and to what extent the material stretches before breaking. The stiffness of a material which represented by tensile modulus can be determined from stress-strain diagram.



Dumbell Shaped Specimen Dimension in ASTM D638

Dimensions	Value, mm(in)
Thickness <7mm (0.28in), T	1.00 ± 0.4 (0.13 ± 0.02)
Width of narrow selection, W	13 (0.5)
Length of narrow selection, L	57 (2.25)
Width overall, WO	19 (0.75)
Length overall, LO	165 (6.5)
Gauge length, G	50 (2.00)
Distance between grips, D	115 (4.5)
Radius of fillet, R	76 (3.00)

II. LITERATURE SURVEY

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).

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.

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.. 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.

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.

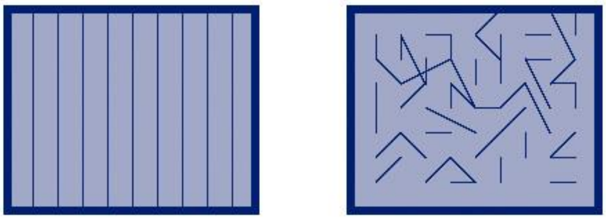
III. CLASSIFICATION OF COMPOSITES

Composite materials can be classified on the basis of the matrix material used for their fabrication:

1. Polymer matrix composites (PMC)
2. Metal matrix composites (MMC)
3. Ceramic matrix composites (CMC)

Composite Materials for Engineered Products

The reinforcing fiber provides strength and stiffness to the composite. The matrix material binds the fibers together, provides form and rigidity, transfers the load to the fibers, and protects the load-bearing fiber from corrosion and wear. For composites in structural applications, continuous or long-fiber configurations are typical, whereas for nonstructural applications, short fibers can be used.



Continuous-Fiber versus Short-Fiber Composites

Reinforced polymers with continuous fiber (% by weight)						
	Density g/cc(ρ)	Tensile strength MPa (σ)	Tensile modulus GPa (E)	Specific strength (σ/ρ)	Specific modulus (E/ρ)	Max. service temp (°C)
Glass/epoxy (35%)	1.81	0.87	39.5	0.48	21.8	80-215
Reinforced polymer with short fiber (% by weight)						
Glass/epoxy (35%)	1.90	0.30	25	0.16	8.26	80-200

IV. FIBER REINFORCED COMPOSITES

Examples of natural fibers are jute, flax, hemp, remi, sisal, coconut fiber (coir), and banana fiber (abaca). All these fibers are grown as agricultural plants in various parts of the world and are commonly used for making ropes, carpet backing, bags, and so on. The components of natural fibers are cellulose micro fibrils dispersed in an amorphous matrix of lignin and hemicelluloses. Depending on the type of the natural fiber, the cellulose content is in the range of 60–80 wt% and the lignin content is in the range of 5–20 wt%. In addition, the moisture content in natural fibers can be up to 20 wt%. The properties of coir fibers in use are given below.

Property	Coir
Density (g=cm3)	1.2
Modulus (GPa)	4-6
Tensile strength (MPa)	175
Elongation to failure (%)	30
Water absorption (%)	130-180

Properties of Coir Fibers

Natural Fibers in the Automotive Industries:

Ironically, early automobile-makers employed significant quantities of wood and natural materials in the manufacturing process. Wood, horsehair, animal glues, natural adhesives are but a few examples. It is interesting, nearly a century later, than the automobile industry is integrating natural materials into design and production.

Natural fibers (hemp, flax, jute, etc.) are lightweight, remarkably strong and relatively inexpensive. Now these materials (particularly in Europe) are being used for many automotive applications:

- Doorpanels
- Dashboards
- Seat backs
- Trunk liners
- Head liners
- Package trays

Composite materials may be either **isotropic** or **anisotropic**, which is determined by the Structure of composites.

Isotropic material is a material, properties of which do not depend on a direction of measuring.

Anisotropic material is a material, properties of which along a particular axis or parallel to a particular plane are different from the properties measured along other directions.

Density

$$d_c = d_m*V_m + d_f*V_f$$

Coefficient of Thermal Expansion

$$\alpha_{cl} = (\alpha_m*E_m*V_m + \alpha_f*E_f*V_f)/ (_m*V_m + E_f*V_f)$$

Modulas of elasticity

$$Ecl = \eta 0\eta LVf\, Ef + VmEm$$

Shear modulus

$$G_{ct} = G_f\, G_m/ (V_f\, G_m + V_m G_f)$$

Poisson's ratio

$$\mu_{12} = v_f\, \mu_f + V_m\mu_m$$

Tensile strength

$$\sigma_c = \sigma_m*V_m + \sigma_f*V_f*(1 - L_c/2L)$$

V. MANUFACTURING PROCESS

Open Molding: Hand Lay-Up Technique

Open Molding, also known as contact molding, open laminating, and wet lay-up, is the method used longest in the polymer-matrix composites industry to make thermo set composite products, and it is still the selected production process for a wide range of composite products. It is a basic process that provides many of the advantages of composites processing, using relatively basic materials technology and processing methods. The molding method involves placing reinforcements and liquid resin onto the surface of an open mold (which may or may not be pre-coated with gel coat), or onto other substrates, as, for example, when making a one-off sandwich construction, when making on-site repairs by applying a reinforcing vacuum-formed acrylic, corrosion-resistant lining on steel, or when making on-site repairs of tanks and pipes. The hand lay-up version involves applying the reinforcements and the resin by hand, while the spray-up version uses tailored spray equipment to deposit both reinforcements and resin on the mold or an alternative substrate.

MODELLING AND MANUFACTURING OF DIE

The composite die is modeled by using Catia-V5 software according to the drawing requirements as shown in fig

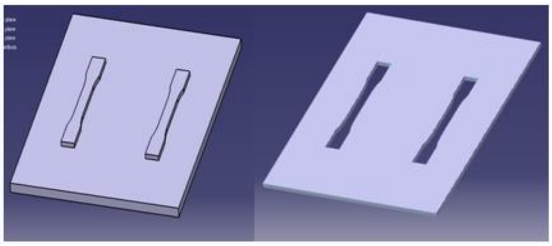
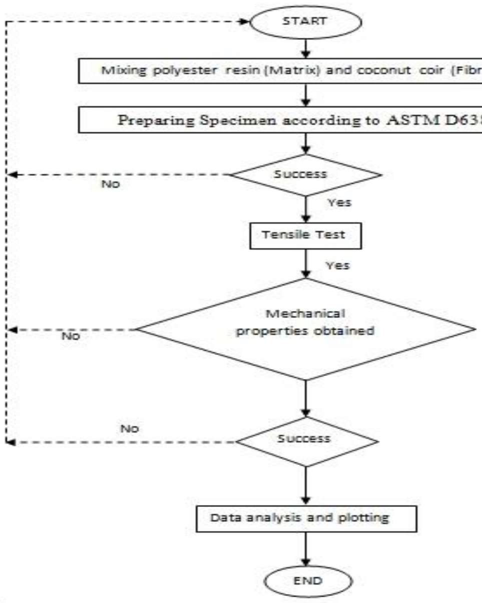


Fig: ASTM D638 Type 1 mould.

VI. EXPERIMENTAL PROCEDURE

Basically two 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 to determine the mechanical characteristics of the studied composite. Figure shows the whole processes 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.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 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 whiskers which its length is less than about 10 mm. The advantage of whiskers 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 polyester resin are shown in Table

Mechanical properties	Polyester Resin
Density (g/cm3)	1.2-1.5
Tensile Elongation at break (%)	2
Tensile strength (MPa)	40-90
Compressive Strength (MPa)	90-250
Young's modulus (GPa)	2-4.5
Water absorption (%) 24h at 20^{0}C	130-180

Mechanical properties of polyester resin

Preparation of Composites

Composites having different fibres content were prepared by varying the fibres volume from 5% to 10%. 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

VII. 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 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.

In this case, impact hammer excitation method was chosen to determine the modal parameter of composite structure.

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.

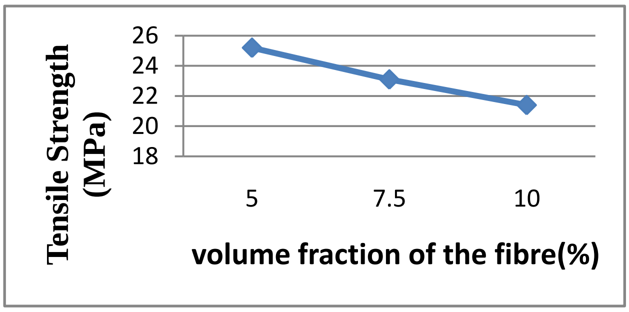
VIII. RESULT AND DISCUSSION

STATIC PROPERTIES

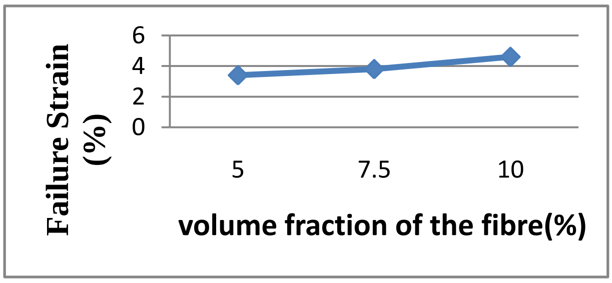
The static properties of coir fibres reinforced composites are expected to depend on the content or volume fraction of the fibres in the composite (Murali & Mohana 2007). Even a small change in the physical nature of fibres for a given volume content of fibres may result in distinguished changes in the overall mechanical properties of composites. Therefore the influence of fibres content on mechanical properties of coir fibres reinforced composites was investigated. Table shows the static properties of coir fibres reinforced composites with fibres volume changing from 5 to 10%.

Fiber content (% vol)	Tensile Strength (MPa)	Failure Strain (%)	Young's modulus (GPa)
5	25.2	3.4	630
7.5	23.1	3.8	544.2
10	21.4	4.6	460.6

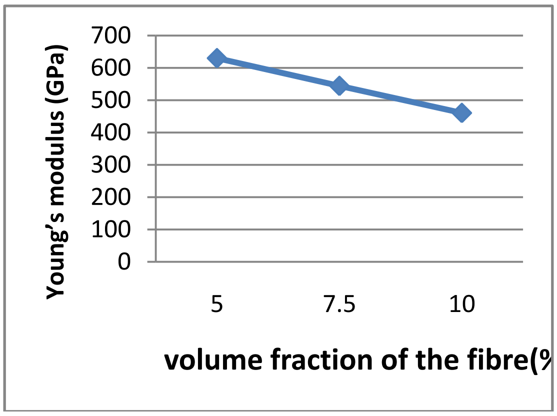
Obviously, there is a good wetting between the fibre and matrix and a strong interface is created which is lead to a strong bonding. However, high percentage of coir fibre will result in poor wetting between the coir fibre and polyester matrix. It was found lead to the less area of fibre being bonded 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 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 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 3.4% to 4.6% when the volume percentage in fibres increases from 5% to 10%. 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.



Tensile strength of composite



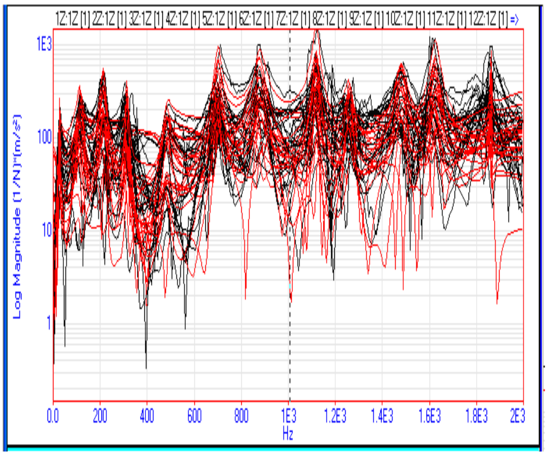
Failure strain of composite



Young modulus of each percentage of coir fibre

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 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.



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.

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
7.5 %	26.1	123.5	231.5	333	510	732.5	915	1129	1415	1551
10 %	25.5	117	218	326	492	694	868	1090	1280	1420

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% and 10% volume of coir fibers. The composite with the 7.5% volume of coir fibers shows a slightly higher frequency compared to 10% volume of coir fibers only for the first five mode frequency. Somehow for higher mode, it found that the composite with 10% coir fibers volume prove to have a higher value.

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. 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 10% 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.

IX. CONCLUSIONS

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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