Retraction

Retraction: Mechanical and Acoustical Properties of Short Oil Palm Frond Fibre Reinforced Polyester Composites (IOP Conf. Ser.: Mater. Sci. Eng. 1082 012013)

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The authors neither agree nor disagree to this retraction.

[1] Valliyappan D. Natarajan, Rozli Zulkifli et al, 2005, “Mechanical Properties Of Short Oil Palm Frond Fibre (Untreated)-Polyester Composites.” in Proceedings of National Conference on Advances in Mechanical Engineering (NAME 2005), Volume 2, Kuala Lumpur, Malaysia, May 18 – 20, 2005, pp. 705 – 712. (ISBN: 967-958-177-2)

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Mechanical and Acoustical Properties of Short Oil Palm Frond Fibre Reinforced Polyester Composites

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Abstract. This paper presents the determination of tensile, flexural, and acoustical properties of short oil palm frond (OPF) fibre reinforced polyester composites and issues that have to be controlled in order to improve those properties. Three composite samples were fabricated using fibre content of 5%, 10% and 15% (by mass fraction) each. The tensile strength and elastic modulus of the composites were determined by tensile test conforming to the ASTM D638 standard and the flexural strength was measured by the three-point bending test method in accordance to ASTM D790 standard whereas the acoustical properties were determined by transfer function method conforming to the ISO 10534-2 standard. It is showed that the OPF-polyester composites possess greater tensile strength and flexural strength at lower fibre content while the elastic modulus registered increment with higher fibre loadings. Reduction in tensile and flexural strengths at higher fibre content is caused by poor stress transfer mechanism as the combined effect of inadequate fibre/ matrix interface adhesion and stress concentration spots. Fibre agglomeration, which causes hindrance to the polyester macromolecule chain mobility, is accounted for the increment in stiffness properties as the amount of fibre is increased. From the measurement of the acoustical properties shows that the sound absorption coefficient is a function of incidence frequency. The normal incidence sound absorption coefficients for different frequencies tend to increase with increasing frequency operation. There is an excellent agreement between the absorption coefficient and the input frequency.
1. Introduction

Composites are a new class of material made from the combination of different basic resources such as metals, plastics, glass or ceramics. The objective of this coalition is to gain the synergy from the components to form a new material that has superior performance than the individual components in terms of mechanical and acoustical properties, performance to weight ratio and feasibility of process. Among the possible combinations, the utilization of plastics as the matrix reinforced with synthetic fibres such as glass mat or carbon is more conventional. Commodity thermoplastics such as polyethylene (PE), polystyrene (PS), poly-vinyl-chloride (PVC) and polypropylene (PP) are commonly reinforced with glass-fibre-mat (GMT) for various applications and have been dominion in the plastics market for years [1]. Thermoset plastics such as polyester and epoxy also have wide application domains due to its high viscosity characteristics, suitable to be reinforced with intermediate and long fibres using hand lay-up fabrication method [2]. Enstomers like natural rubber (NR) blended with thermoplastics have been extensively utilized for research purposes [3,4].

Natural fibre, as in composite application for mechanical and structural engineering, can be defined as reinforcing agents extracted from naturally occurring resources such as agricultural dregs or agriculture based industrial residues. Natural fibres therefore also called agro-based fibres. These materials are in their own composites made from lignin matrix bounded by cellulose fibres [5].

There is a wide variety of agro-based fibres and they should be considered for composites fabrication to take advantage of the unique fibre properties, local source of availability and cost. Flax, bamboo, rice husk, wood flour, oil palm frond and empty fruit bunch (EFB), sugarcane and coir are among the popular choices found in the literature [1,4,6]. The serious consideration given to these potential alternatives are due to the inherent drawbacks in the processing, utilization and disposal of the synthetic fibres’ composites.

The main advantages of using lignocelluloses fibres are its low density, superior specific properties, environmental friendly, greater fibre loading possibility, variety of fibres available, low energy consumption in extraction, low decomposition rate and show less concern with personal safety and health. Besides that, the fibres are non-abrasive hence minimizes processing tool impairment in short term. In fact, the downstream processing of waste natural resources into value-added products will generate extra income for the plantation sector.

2. Theoretical Consideration

Palm trunks and fronds are obtained from the plantation ground whereas EFB, shells and mesocarp fibres are common residues found in the mills [3]. Table 1 below shows the nominal fibre dimensions of oil palm trunk, frond and bunches.

| Dimension     | Trunk | Fronds | Bunches |
|---------------|-------|--------|---------|
| Length, mm    | 1.22  | 1.52   | 0.89    |
| Width, µm     | 35.3  | -      | 25.0    |
| Thick, µm     | 4.5   | -      | 2.8     |

Oil palm by-products are usually converted into value-added products in the downstream processes. The attempt to renovate these by-products into useful raw materials had been initiated since the 1970’s. Peh et al. (1976) had studied the possibility of producing pulps from EFB by chemical-modification means. Khoo and Lee (1991) have described the methods of extracting the oil palm trunks, fronds and EFB to manufacture pulp and paper. Besides this, oil palm by-products have also been utilized to produce particleboards, cement tiles, reconstituted boards, chemical and fuel. The availability, potentials and consistency in supply of the oil palm by-products are crucial to sustain the relevance of oil palm lignocelluloses residues to those industries.
Nicolais and Nicodemo (1973) suggested the following equations which relate the tensile strength of the composite to the matrix:

\[ \sigma_c = \sigma_p (1 - a \phi^b) \]  

(1)

where \( \phi \) is the fibre volume fraction and constants \( a \) and \( b \) represent the stress concentration factor and filler geometry, respectively.

Elastic modulus of a two-phase composite can be predicted using the Einstein’s equations:

\[ E_r = 1 + \phi \]  

(2)

\[ E_r = 1 + 2.5 \phi \]  

(3)

where \( E_r \) is the composite’s modulus (\( E_c \)) relative to the matrix’s modulus (\( E_p \)). Equation (2) is deemed for the case of non-adhesion at the fibre/matrix interface while Equation (3) is considered if a good adhesion at the interface is expected by means of fibre surface modification or at the presence of a coupling medium. Haji A. et al. (2005) cited another formulation which accounts for planar fibres as given below:

\[ E_c = E_p (1 - \phi) + E_f \phi \cdot \text{MRF} \]  

(4)

MRF in equation (4) represents the modulus of reduction factor that depends on the aspect ratio of the flakes and percentage of fibre loadings.

The measurement of normal incidence absorption coefficient of materials using the two-microphone method or transfer function method is shown schematically in figure 1. A sample of the material to be tested is placed in a sample holder and mounted to one end of a straight tube. A rigid plunger with an adjustable depth is placed behind the sample to provide a reflecting surface. A sound source, typically a high-output acoustic driver, is connected at the opposite end of the tube. A pair of microphones is mounted flush with the inner wall of the tube near the sample end of the tube.

![Figure 1](image)

**Figure 1.** The two-microphone impedance measurement tube testing according to ISO 10534-2.

A multi-channel spectrum analyzer is used to obtain the transfer function (frequency response function) between the microphones. In this measurement, the microphone closer to the source is the reference channel. From the transfer function \( H_{12} \), the pressure reflection coefficient \( R \) of the material is determined from the following equation:
where \( L \) is the distance from the sample face to the first microphone and \( s \) is the distance between the microphones, \( k = 2\pi f/c \), \( f \) is the frequency, and \( c \) is the speed of sound. From the reflection coefficient, the absorption coefficient \( \alpha \) of the sample may be determined from the following equation:

\[
\alpha = 1 - \left| R \right|^2
\]

### 3. Materials and Method

Raw oil palm (\emph{Elaeis guineensis}) fronds were initially threshed into smaller sections using the RLL-3 Portable Crusher. Fronds, which have harder skin, were slightly hammered and teased in order to gain the fibre clumps and strands insight. The fibrous strands obtained were washed to remove the dirt and unwanted matters. The strands were then dried in the oven at 363 K for about 24 hours before crushing them to obtain short oil palm frond fibres (OPF). The nominal diameter of the fibre is 30 \( \mu \)m and 0.8 mm in length.

Revelsol P9509 unsaturated polyester was chosen as the matrix. Three samples were fabricated based on different fibre mass fraction (\( m_f \)) i.e. 5 \%, 10 \% and 15 \%. Another sample consisting 100 \% polyester was also manufactured for comparison purposes. The samples were fabricated using the hand lay-up method collectively with hot pressing technique so as to obtain specimens with even surface and thickness. Appropriate amount of polyester and OPF, accordingly to the mass fraction, were first blended manually and 2 ml of hardener (Butanox M50 Methyl-Ethyl-Cetone-Peroxide, 33 \% in dimethyl phthalate) were mixed utterly into the former mixture. The final mixture was left in the ambient temperature for 1 minute to coagulate and then released into the dumbbell shaped mould. The mould was pressed at 30 MPa, 301 K for nearly 4 hours using GOTECH Hot Press Machine. The fabrication process was reiterated with the fibre fractions stated above.

Tensile tests were performed on the samples in conformance to the ASTM D638 standard. The Universal Testing Machine 10 kN, Testometric Micro 500 (UK) were used for the tests. Three specimens from each sample were tested at a strain rate of 1 mm/min. The flexural strength of the samples was determined by the flexural test, which was done according to the ASTM D790 – 92 standard, Test Method in. Figure 2 illustrates the experimental set-up. The support-span to depth ratio was set as 3:1. The nominal length and thickness of the specimens were 150 mm and 3 mm, respectively. Rate of cross-head motion was 5.3 mm/min.

![Figure 2. Three-point loading system.](image)
lowering of the energy content of the pulsating air as it encounters a porous or flexible medium, it should be recognized as being completely different from most other type of “absorption”. A blotter, for example, can absorb liquids when only a corner is immersed into the fluid, but sound absorbing materials cannot pull sound out of the air.

Sound is a source of energy which can only be reduced when it is actively directed into and through a medium in which it experiences frictional resistance, in which its kinetic energy is converted to heat. There is an optimal airflow resistance for the absorption of sound at any particular frequency. A very porous material with a very low airflow resistance is the common household furnace filter. Sound will pass through such a filter with negligible reduction. At the other extreme, if a material has a very high flow resistance, the sound cannot readily penetrate to be absorbed and must of necessity reflect back and add energy to the space from which it came. Sound absorption coefficient is a fraction of the incident sound energy absorbed by a material of any size. It can be measured using impedance tube as shown in figure 3, based on the transfer function between two microphones.

Figure 3. Schematic diagram for measuring sound absorption coefficient in impendence tube

4. Results and Discussion

Table 2 shows the results of the tensile and three-point flexural tests. Elastic modulus of the samples increased as the fibre mass fraction is greaterened. An optimum increment of 77 % was registered for the 10 % m_f sample as compared to the plain (100 %) polyester. Enhancement of the stiffness properties with fibre addition is, fundamentally, due to the effect of fibre agglomeration in the polyester matrix. Fibre addition into the polyester causes obstruction to the polyester macromolecule chain mobility.

Table 2. The tensile and flexural properties of short oil palm frond fibre reinforced polyester.

| Fibre Mass Fraction ( % ) | Tensile Test | Flexural Test |
|---------------------------|--------------|---------------|
|                           | Tensile      | Elastic       | Flexural      |
|                           | Strength     | Modulus       | Strength      |
|                           | (MPa)        | (GPa)         | (MPa)         |
| 0                         | 16.50        | 2.11          | 65.7          |
| 5                         | 15.20        | 3.61          | 25.6          |
| 10                        | 8.00         | 3.73          | 25.3          |
| 15                        | 7.10         | 3.70          | 20.1          |

The partiality in the dispersion of the fibre is the main factor that restricts the mobility of the chain. Short fibres, which are naturally fine and have small surface area, tend to form fibre aggregates by way of hydrogen bonding at the hydrophilic surface of the fibre. Subsequently, a group of aggregates, of its own accord, fuse to form a larger structure called agglomerate [6]. It is this
agglomeration effect that hinders the polymer chain mobility. This also causes the elongation at break to be reduced. Since the elongation is limited, the ductility of the samples is affected resulting in a more rigid material.

The tensile strength of the composites, as shown in Table 2, was found to be somewhat inversely proportional to the fibre loading. Among the factors that influence the reduction in tensile strength is the emergence of stress concentration points arising from weak fibre/matrix interface adhesion. Besides that, deterioration of the crystallinity of the matrix in the presence of fibre could also be the reason for the decrement in the tensile strength. The fibre dispersion, which is not equal in all directions, develops agglomeration spots where phase discontinuities occur (figure 4).

Discontinuities can also crop up between fibres of different geometry. These discontinuities impede the matrix-to-fibre stress transfer mechanism hence causing applied stresses to concentrate at the fibre/matrix interface. This in turn prompted the composites to fail at an early stage of extension. One prevalent remedy to reduce the agglomeration effect and stress concentration spots is to chemically modify the fibre surface using suitable coupling agent, silane for instance. The coupling agent acts to modify the fibre surface by forming organosilanol and siloxanes groups to promote the interface adhesion, which eradicates, to the minimum level, stress concentration points in the composites [2].

Figure 4. Photograph of the fibre agglomeration in the composite.

Increment in fibre mass fraction also leads to a reduction in flexural strength as shown in figure 5. Compared to the reduction in the tensile strength of only 8% from 0% to 7% m_f samples, the flexural strength reduced 60% for the same range. However, the values of the flexural strength remained superior to those of tensile strength. Thus, it is apparent that OPF/polyester composites are stronger in bending mode than in tensile mode.

Figure 5. Tensile and flexural strength of OPF/polyester composite.
From the measurement of the acoustical properties show that the sound absorption coefficient is a function of incidence frequency. The normal incidence sound absorption coefficients for different frequencies tend to increase with increasing operation frequency. Figure 6 shows that the normal incidence sound absorption coefficients for working frequency range from 125 – 4000 Hz.

Figure 6. Sound absorption coefficient for OPF/polyester composite.

As can be seen, there is an excellent agreement between the absorption coefficient and the input frequency, especially for frequency below 2000 Hz, but unfortunately, the test materials exhibit low absorption at frequency upper than 2000 Hz.

5. Conclusions

The tensile and flexural properties of OPF/polyester composites were determined. It has been observed that the modulus of elasticity is directly proportional to the fibre mass fraction in the composite whereas strength, in both the tensile and bending mode, are reduced by fibre addition. Hence, higher amount of fibre loadings produces stiffer but weaker composites. The hydrophilic trait of the fibres in tandem with its high moisture content creates agglomeration issues whereby the fibre/matrix interface bond is affected. Although this yields a rigid composite, the formation of stress concentration points in fact diminishes the composite’s strength. Thus, the overall mechanical performance of the composite system is ought to be controlled by the strong interface bonding and uniform dispersion of the fibres. In order to gain these qualities, fibre surface modification is indispensable. Utilization of coupling agent, such as silane, that facilitates the development of a sturdy bond between the hydrophilic fibre and hydrophobic matrix is recommended in the literature. From the measurement of the acoustical properties show that the sound absorption coefficient is a function of incidence frequency. The normal incidence sound absorption coefficients for different frequencies tend to increase with increasing frequency operation. There is an excellent agreement between the absorption coefficient and the input frequency.

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Reference

[1] Chauhan V, Kärki T, and Varis J, 2019, Review of Natural Fiber Reinforced Engineering Plastic Composites, Their Applications in The Transportation Sector and Processing Techniques, Journal of Thermoplastic Composite Materials, 41, 0001 – 0041, DOI: http://dx.doi.org/10.1177/0892705719889095.

[2] Kicki F K, and Astrom B T, 1997, Manufacturing and Applications of Structural Sandwich Components. Composites Part A, 28(2), 97 – 111, https://doi.org/10.1016/S1359-835X(96)00098-x

[3] Kamaruzzaman S, Rozli Z, Sahari, and Othman, 1998., Thermal Performance of Thermoplastic Natural Rubber Solar Collector. AMPT '98, 6, 247 – 253.

[4] Kobayashi Y et al, 2015, Thermomechanical Pulping and Its Application to Empty Fruit Bunches of Oil Palm. Proc. National Symposium on Oil Palm By-prod. For Agro-based Industries, 11, 67 – 78.

[5] Heru S, Eko M, Yudy S I, and Rudy S, 2014, Morphology, Structure, and Mechanical Properties of Natural Cellulose Fiber from Mendong Grass (Fimbristylis globulosa), Journal of Natural Fibers, 11(4), 333 – 351, DOI: 10.1080/15440478.2015.879087.

[6] Maiti S N, and Singh K, 1986, Influence of Wood Flour on the Mechanical Properties of Polyethylene, Journal of Applied Polymer Science, 32, 4285 – 4289.

[7] Roger M R, Anand R, Sanadi, Daniel F C, and Rodney E J, 1997, Utilization of Natural Fibres in Plastic Composites, http://www.fpl.fs.fed.us/documents/PDF1997/rowel97d.pdf.

[8] Peh T B, Khoo K C, and Lee T W, 1976, Pulping Studies on Empty Fruit Bunches of Oil Palm, The Malaysian Forester, 39(1), 22 – 30.

[9] Khoo K C, and Lee T W, 1991, Pulp and Paper from the Oil Palm, Appita, 44(6), 385 – 388.

[10] Ahmad F, Omar M Y, Ishak S, and Omar M A, 1994, Application of Rice Husk Ash as Fillers in Polypropylene: Effect of Silane Coupling Agents, Journal of Science Technical Dev, 115 – 140.

[11] Haji A, Abdullah, and Othman H, 2005, Development of Short Fibre Thermoplastic Natural Rubber Composites, Proc. ICAST’05, 251 – 255.

[12] Muhammad H, Zakaria, and Abdul H H, 2015, Potentials of Oil Palm By-Products as Raw Materials for, Agro-Based Industries, Proc. National Symposium on Oil Palm By-prod. For Agro-based Industries, 7, 15.

[13] Jain S, and Kumar R, 1992, Mechanical Behaviour of Bamboo and Bamboo Composite, Journal of Materials Science, 27, 4508 – 4604.

[14] Rozli Z, Fatt L K, Che H A, and Jualani S, 1998, Effect of Natural Rubber on the Interlaminar Fracture Properties of Fibre Reinforced Thermoplastic Composites, AMPT ‘98, 232 – 238.

[15] ASTM D638-14, 2014, Standard Test Method for Tensile Properties of Plastics.

[16] ASTM D790-99, 1999, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

[17] ISO 10534-2, 2001, Acoustics - Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes - Part 2: Transfer-function method.