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# EFFECT OF OIL PALM FIBRES VOLUME FRACTION ON MECHANICAL PROPERTIES OF POLYESTER COMPOSITES

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The effect of two types of oil palm fibres (bunch and fruit) on mechanical properties of polyester composites is examined in the current work considering different volume fractions. Tensile, compression, and flexural properties of the composites were investigated. In addition to that, tensile strengths were calculated theoretically using Hirsch model. Scanning electron microscope (SEM) was used to observe the fracture mechanism of the specimens. Single fibre pull-out tests were performed to determine the interfacial shear strength between polyester resin and both types of oil palm fibres. Results revealed that both types of oil palm fibres enhanced the mechanical performance of polyester composites. At a higher volume fraction (40–50%), tensile strength of the polyester composite was improved, i.e., 2.5 times improvement in the tensile strength value. Experimental tensile strength values of oil palm bunch/polyester composites have a good correlation with the theoretical results, especially at low volume fractions of fibre. Flexural strength of polyester worsened with oil palm fibres at all volume fractions of fibre.

*Keywords*: Natural fibres; polyester composites; mechanical properties.

## 1. Introduction

Nowadays, fibre polymeric composites are widely used in several products and proved to be a good alternative to conventional materials. In recent years, a challenging issue is raised to replace the synthetic fibres with natural ones. Furthermore, polymeric composite with high performance based on free sources of reinforcement is an ambitious aim of many mechanical designers.[1] Natural fibres have many advantages such as renewability, environmental friendliness, low cost, flexibility of usage, volume lightness, natural recyclability and biodegradability, rendering natural fibres highly competitive with synthetic fibres.[1–5] Furthermore, the applications of such materials are increasingly implemented in numerous housing construction materials and automotive parts.[6] Their mechanical properties are an important factor in determining their scope of use. Therefore, the effects of natural fibres on mechanical properties of polymeric composites are the subject of extensive study. Previously, many types of natural fibres have been used to reinforce polymeric composites[1–3,6] and most agree that the presence of natural fibres in polymeric composites may indeed enhance some of the mechanical properties of neat polymer. For example, it has been reported that mechanical property of phenol-formaldehyde resin has been highly improved by utilizing oil palm bunch fibre as reinforcement.[7] In another work, the fatigue and tensile properties of oil palm bunch fibres reinforced epoxy composites was studied,[6] and it has been found that increasing the fibre volume ratio up to 35–55% reduced the tensile strength and the fatigue life of the composites. Moreover, it is found that natural fibres are highly hydrophilic and permeable to water. This leads to increase in the water sorption ability of the composites. Oil palm fibre is lignocellulosic, which have 65% cellulose and 19% lignin content[11] and these groups can hold water molecules, i.e., cellulose is a hydrophilic glucan polymer.

In Malaysia, oil palm fibres are the most available free natural fibres and there is no reported work on the possibility of using that fibre as reinforcement is not explored yet. This motivates the current work on the effect of oil palm fibres on the mechanical properties of polymeric composites. Polyester is selected as resin for the current work due to its competitive price and common applications such as ships, sliding, house goods ... etc. Two types of oil palm fibres were prepared as fruit and bunch in flax form. Tensile, compression and flexural tests were conducted considering different volume fractions of fibres.

## 2. Experimental Details

### 2.1. *Preparation of fibres*

The orthophalic unsaturated polyester (Revesol P9509) pre-promoted for ambient temperature and cured with the addition of Methyl Ethyl Ketone Peroxide (MEKP) as catalyst as well as the polyester materials were supplied by Kong Tat Company of fibreglass engineering (Malaysia). A raw oil palm fibre bunches were collected locally from farms in the city of Melaka, Malaysia. Oil-palm fibres (both fruit and bunch) were extracted by crushing the bunch fruit of the oil palm bunches. At the same time, the oil palm fruit were crushed and washed to separate the fibre from the seeds, soil and oil. This step was repeated three times to ensure that all the undesired materials were washed out. The extracted fibres were dried at room temperature (28°C) for 48 h and then cut into lengths of 10–20 mm. The fine fibres were socked in a solution of 0.1% NaOH for 24 h. The final prepared fibres were dried in an oven at 40°C for 24 h. Figures 1(a) and 1(b) show the SEM micrographs of the oil palm fruit and bunch fibres, respectively. The figure shows that a single oil palm fibre is a bundle of fine fibres. The tensile property of a single fibre was tested five times and a sample of a stress/strain diagram is shown in Fig. 2. The figure illustrates that higher tensile strength and elongation is found in oil palm fruit fibres compared to oil palm bunch fibres. A summary of the mechanical properties of single fibres is listed in Table 1.

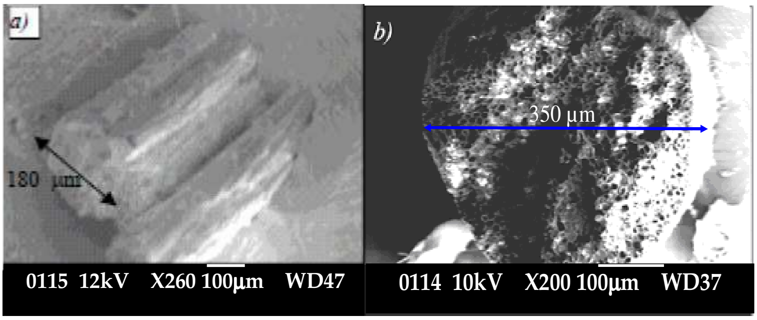



Fig. 1. SEM micrograph showing the two types of oil palm fibres as (a) fruit fibre and (b) bunch fibre.

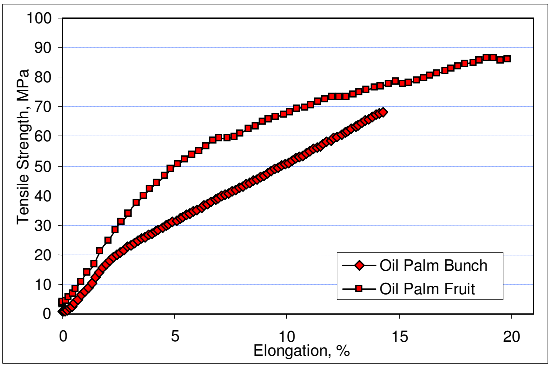



Fig. 2. Stress/strain diagram of single fibre.

Table 1. Tensile properties of the fibres.

| Fibre | Tensile strength (MPa) | Initial Modulus (GPa) | Elongation at the break (%) |
|---|---|---|---|
| Oil palm fruit | 85–90 | 0.9–1.1 | 19.85–21.514 |
| Oil palm fruit bunch | 50–55 | 0.57–0.59 | 0.3–16.2 |

## 2.2. *Fabrication of composites*

A hand-lay up technique was adopted to fabricate the composites, i.e., oil palm bunch and oil palm fruit fibres reinforced polyester composites. A metal mould with dimensions of 120 mm × 120 mm × 20 mm was designed for the composites fabrication. The entire surfaces of the mould were coated with a thin layer of wax as release agent. The prepared fibres were randomly arranged in the mould and pressed into a mat. The composite block was built up by impregnating the fibre mats with the polyester resin mixed with 2% hardener. Pure polyester block was prepared by pouring the polyester resin into the mould alone. All prepared composites were cured for 24 h at room temperature, 24°C. It was difficult to fabricate a composite in low volume fraction of fibres (below 30%), this is due to the floating of the fibres during the curing process, which makes the structure of the composite inaccurate. Therefore, in the present work, the volume fraction of fibre between 35–65% was chosen. In the fabrication processes, the desired amount of the fibres was put in the mould and pressed. This was followed by pouring of the polyester into the mould. Before curing process, a steel roller was used to distribute the fibres uniformly. However, it was hard to control it precisely. Five blocks of each composite were fabricated and the most suitable ones were chosen for the experiments. The blocks were machined into samples for tensile, compression and flexural tests.

### 2.3. *Fabrication of single fibre pull-out tests specimens*

For single fibre pull-out tests (SFPT), a metal mould with dimensions of 50 mm × 10 mm × 10 mm was used to fabricate the specimens. Both ends of the fibres were mounted into the middle plane of the rubbers which were placed at both ends of the mould. Pieces of rubbers served to prevent the resin from leaking out of the mould prior to solidification. A layer of wax was applied on the inner walls of the mould as a release agent. Polyester mixed with 2% hardener was stirred gently and poured into the mould. The prepared samples were cured at 24°C for 24 h. The desired embedded length (20 mm) was obtained by drilling a hole through the specimen to cut the embedded fibre, Fig. 3(a). The free end of fibre was placed and glued, using superglue, into the clamp of the 100Q Standalone Universal Test System. The loading speed was set to be 1 mm/min.

## 3. Experimental Procedure

Tensile, compression and flexural tests were conducted at room temperature using WP300 PC Aided Universal Material Test machine equipped with computerized data acquisition systems. In the tensile test, the grip forces were determined by testing a few specimens to prevent fracture due to the gripping force. The displacement load and strain were measured simultaneously. The load was subjected incrementally at a constant rate of 2 mm/min up to fracture. In the bending tests, the three-point flexural tests were performed at a crosshead movement rate of 1 mm/min. For each type of composite and volume fraction, the tests were repeated three times, and the average was determined.

## 4. Results and Discussion

### 4.1. *Single fibre pull-out tests*

Figure 3(b) shows a typical force-displacement curve obtained from the SFPT. The figure indicates that at the beginning of the test, the force varied linearly with the displacement until a maximum point and this followed by dramatically force drop and remained steady for a distance not more than the embedded length.

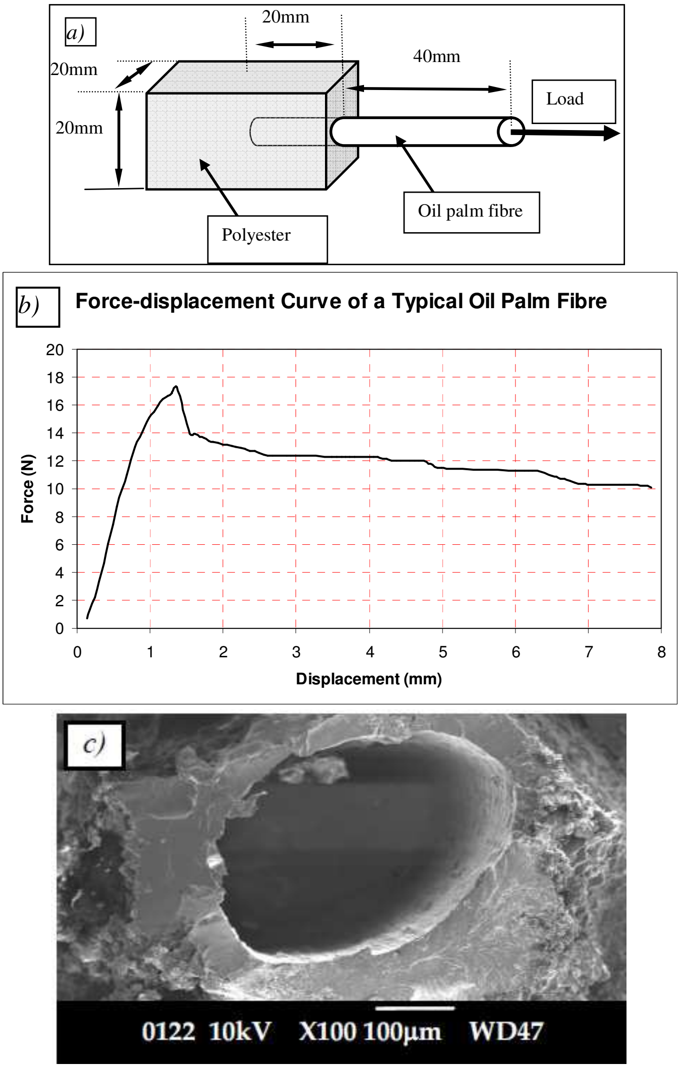



Fig. 3. Single fibre pull-out showing (a) schematic drawing describing pull out test and (b) pull-out force displacement curve of oil palm fibre (c) micrographs of the sample after test.

To achieve static equilibrium condition, equal and opposite forces must exist to counter the applied forces, which were those at the linear region on the force-displacement curve. Once it reached the maximum point, pull-out was initiated. There was less interpenetration between the surfaces of the resin and the fibre and hence the force dropped. After that, the mechanism changed from static motion to kinetic motion, where the fibre slid against the resin, and was observed to be almost constant. The fluctuation could be due to the irregularity of the fibre surface. The constant force represented that needed to overcome the resistance of the motion.

Therefore, it can be inferred that the maximum static force was recorded as 17.29 N and the kinetic force was estimated to be 12 N from this study. Having found that, the interfacial shear strength, $\tau_{IF}$ was determined as 1.77 MPa, by using the following equation[8–10]:

$$\tau_{IF} = \frac{F_{\max}}{d_f \cdot \pi \cdot L_e}$$

where

$$\begin{aligned} \tau_{IF} &= \text{interfacial shear strength} \\ F_{\max} &= \text{maximum force from force — displacement curve} \\ d_f &= \text{diameter of fiber} \\ L_e &= \text{embedded length} \end{aligned}$$

Micrograph of a pull out sample is shown in Fig. 3(c) showing that the outer layer of the fibres adhered to the matrix surface. This indicates that the adhesion between the outer surface of the fibres and the polyester matrix is strong. However, the inner fibres in the bundle were pulled out. Further investigation on the possibility of removing the outer layer of the fibres is important to overcome such problem.

## 4.2. *Tensile and compression results*

Tensile, compression and flexural tests were conducted for two types of oil palm fibres (bunch and fruit). The results of the experimental tests are presented against volume fraction of fibres in the matrix in Figs. 4–10.

### 4.2.1. *Experimental results*

Figures 4(a) and 4(b) show the variations of tensile strength, elongation at the break and compression strengths of different composites, i.e., oil palm fruit and oil palm bunch/polyester composites, against volume fraction, associated with maximum and minimum values at different volume fractions of fibres. In general, it can be seen that the presence of natural fibres in the matrix enhanced the tensile, compression and elongation properties of polyester composites. At the same time, addition of fibres enhanced the matrix ductility, where higher elongations are measured at the breaking values of composites. For oil palm fibres reinforced composites, it could be observed that increment of the oil palm fibres volume fraction ($\approx$41% for both fruit and bunch) produced higher tensile strength by about 2.5 times compared to neat polyester, as shown in Figs. 4(a) and 4(b). Meanwhile, higher volume fractions ($>$41–42%) worsened the tensile properties. Similar results were reported when the oil palm bunch fibre was used to reinforce epoxy,[7] where increment of the oil palm bunch fibres volume fraction which went up to 55% caused worsening of the tensile strength of the epoxy composites.

The compression strengths of oil palm fibres reinforced polyester composites decreased with increment of the fibre volume fraction. The Young's moduli of the

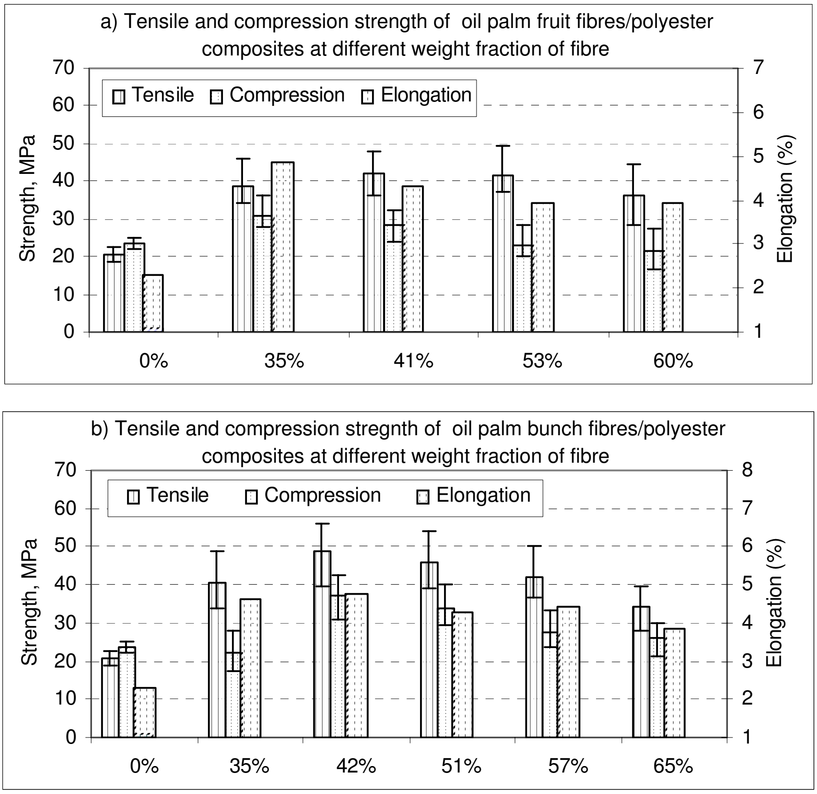



Fig. 4. Tensile and compression strengths associated with elongation (at the break) of the composites in different fibre volume fractions.

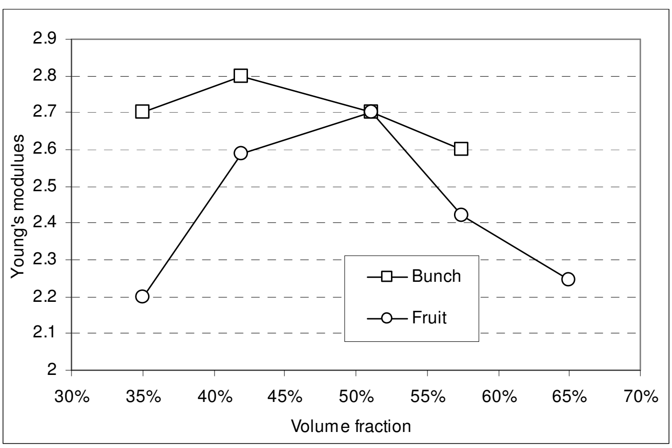
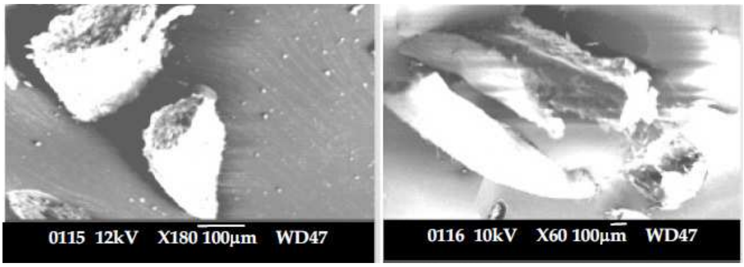
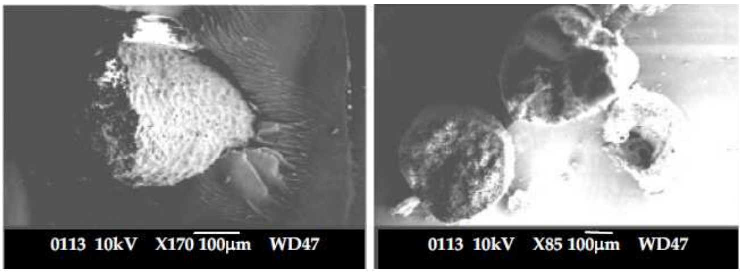



Fig. 5. Young's modulus of the composite at different volume fractions.




(a) Oil palm bunch fibre reinforced polyester composites.




(b) Oil palm fruit fibre reinforced polyester composites.

Fig. 6. SEM micrographs of fractured specimen after tensile test.

tensile tests of the composites are shown in Fig. 5. Higher values of Modulus of Elasticity (2.7–2.8 MPa) were evident at 40–52% volume fraction of the fibres for all composites.

The difference in the tensile strengths and elongation of different composites could be due to the difference in the strength of the fibres, Fig. 2. Besides, the adhesion characteristics between the fibre and polyester resin played a major role in controlling the results. This could be clarified with the assistance of the tensile fractographs of the composites as shown in Figs. 6(a) and 6(b) for oil palm bunch/polyester and oil palm fruit/polyester composites respectively. It could be seen from the said figures that the adhesion between both types of oil palm fibres and the polyester resin was very poor, i.e., they were pulled out and debonded.

#### 4.2.2. *Theoretical tensile strength*

There are many theoretical models developed to predict the tensile strength of composite materials. It has been reported that Hirsch's model is the most useful for randomly oriented fibres in the rigid matrix.[4] In the present work, the tensile strength of randomly distributed natural fibres reinforced polyester composite, according to Hirsch's model, can be calculated using the following equation

$$T_{\mathrm{comp}} = x(T_p V_p + T_f V_f) + (1-x)\frac{T_p T_f}{T_p V_f + T_f V_p}$$

where $T_{\text{comp}}$, $T_p$ and $T_f$ are the tensile strength of the composites, polyester and fibres respectively; and $V_p$ and $V_f$ are the volume fraction of polyester and natural fibres respectively. As reported by Joseph *et al.* in 2002, $x$ is a parameter between 0 and 1 and determines the stress transfer between the fibres and matrix. In the current composites, Hirsch's model is used to calculate the tensile strength of the developed composites theoretically. The $x$ parameter value was chosen to yield the best fitting values.

Figures 7(a) and 7(b) show the theoretical and experimental tensile strength of oil palm bunch and oil palm fruit fibres reinforced polyester composites in different volume fractions. It can be seen that for both types of oil palm fibres, there was significant variation in the experimental and Hirsch's model, where the theoretical model predicted increment of the tensile strength with increase the volume fraction of the fibres. In fact, there was reduction in the tensile strength of the oil palm/polyester composites when the volume fraction increased, Figures 4(a) and 4(b). These variations could be due to the poor adhesion between the oil palm fibres and polyester resin, since the failures in the oil palm/polyester composites were due to the pull-out and debonding of the fibres.

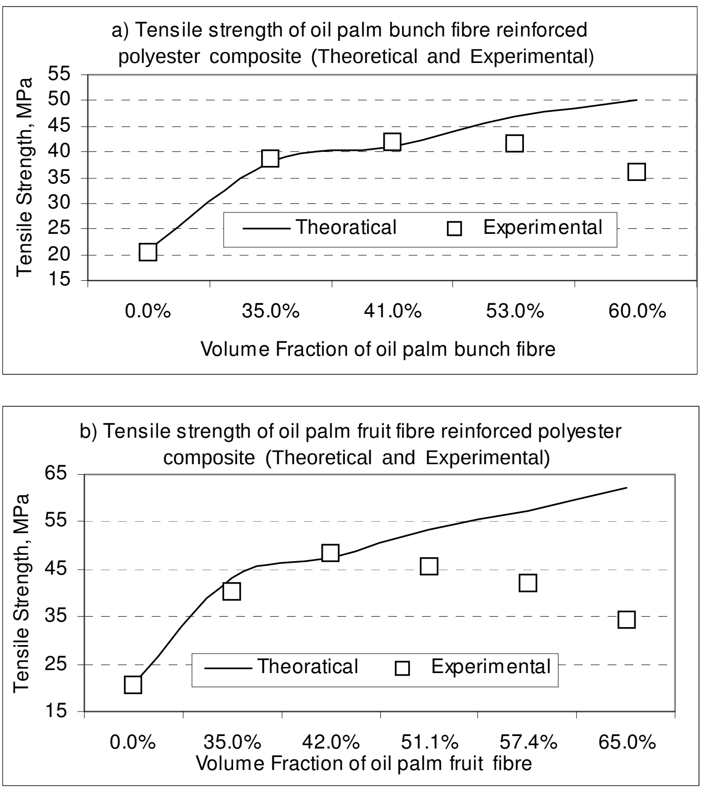



Fig. 7. Theoretical and experimental results of tensile strength against fibre volume fraction.

The agreement between theoretical and experimental values has been found only when the value of $x$ factor is 0.2. Furthermore, the value of $x$ is a determining factor in describing the real behaviour of short-fibre composites. At low fibre volume fraction the high agreement between the experimental and theoretical modeling value is due to the uniform stress or strain distribution in the composite. At higher volume fraction, agglomeration takes place and the applied load could not be distributed evenly between non-agglomerated and agglomerated fibres which in turn deviates the experimental data and from the theoretical one. The obtained results are highly in agreement with reported work by Joseph *et al.*[3]

### 4.3. *Flexural results*

Figure 8 shows the results of the three-points bending tests of neat polyester (oil palm fruit 42%, and oil palm bunch 41%) fibre reinforced polyester composites.

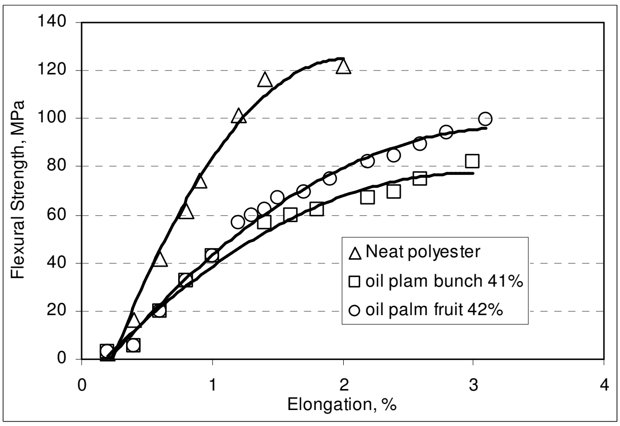



Fig. 8. Flexural stress-strain curves of the composites and neat polyester.

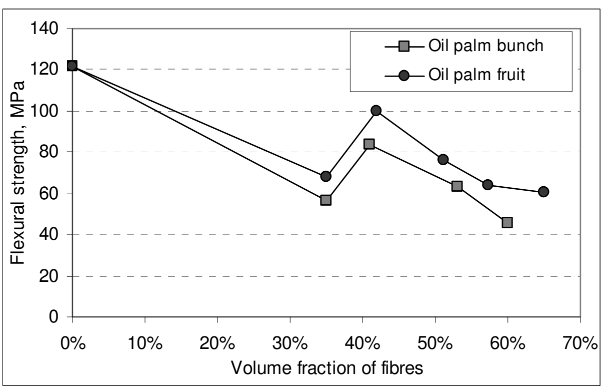
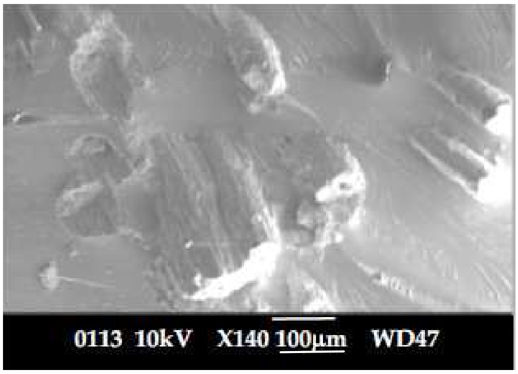
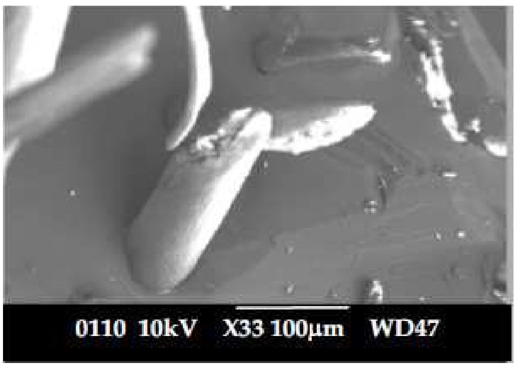



Fig. 9. Flexural strengths at the break of the composites at different fibre volume fractions.




(a) Oil palm fruit/polyester composite.




(b) Oil palm bunch/polyester composite.

Fig. 10. SEM images of the flexural composite specimens after test.

Furthermore, flexural strengths of all composites were plotted against volume fractions of fibres in Fig. 9. In general, there was a decrease in the flexural strength of the oil palm/polyester composites. Moreover, in spite of the reduction in flexural strength when polyester was reinforced by oil palm, the plasticity of the polyester composites improved, when the elongation increased.

The SEM micrographs of the failure specimens of oil palm fruit and oil palm bunch/polyester composites are shown in Fig. 10. It can be seen clearly from Fig. 10(b) that there was poor adhesion and interaction between the oil palm bunch and polyester resin. Therefore, it can be concluded that reinforcing polyester with oil palm fibres did not assist in improving the flexural strength of the polyester.

## 5. Conclusion

Based on the results obtained, the following conclusions can be drawn.

- Both types of oil palm fibres (bunch and fruit) are able to enhance the mechanical properties of neat polyester.

- Large increase in the volume fraction of oil palm fibres impairs the mechanical properties of the composites.
- Experimental results are in agreement with the theoretical results at low fibre volume fractions and contradictory at higher range.
- Flexural strength of polyester deteriorates with the addition of oil palm fibres at all fibre volume fractions.

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