

# Mechanical properties of unidirectional oil palm empty fruit bunch (OPEFB) fiber reinforced epoxy composite

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**Abstract.** Natural fibers have proven to be an excellent reinforcement material for various polymers. In this study, OPEFB fiber with unidirectional alignment was incorporated in epoxy and an investigation on tensile and flexural characteristics of the composite has been carried out. A fiber surface modification utilizing alkaline treatment with 1% sodium hydroxide solution was used in order to increase the fiber matrix bond in the composite. The investigation was carried out for 0°, 45° and 90° fiber orientation. Result showed that the higher the angle of the fiber orientation, the higher the tensile strength and flexural strength the composite will yield.

## 1. Introduction

Natural-fiber-reinforced polymer composites, or termed as bio-composites, have been gaining interest over the years due to the increases in environmental awareness and sustainability concept. Biocomposites materials consist of natural fibre embedded in a matrix. In bio-composites, fibres are the principal load carrying members, while the surrounding matrix keeps them in the desired location and orientation. Matrix also acts as a load transfer medium between the fibres, and protects them from environmental damages due to elevated temperatures, humidity and corrosion.

Malaysia has about 3.5 million hectares of oil palm producing annually over 10 million tons of crude palm oil. However, crude palm oil and its economic products such as palm kernel oil and palm kernel cake constitute only 10% of the crop, leaving the rest of the biomass to waste. This biomass also includes OPEFB fiber, being the residual bunch after removal of the fruit constituting 20% to 22% of the weight of the fresh fruit bunches (Ridzuan et al. 2002). Hence, utilization of OPEFB fiber not only create value added product but will also solve disposal problem.

Various researches have been conducted to produce OPEFB fiber reinforced polymer. (Ewulonu & Igwe, 2012) studied the properties of OPEFB fibre filled high density polyethylene by varying the filler content between 0 to 1.5 weight percent. Three particle size of OPEFB fibre were utilized, that is 0.15 mm, 0.212 mm and 0.3 mm. In addition, the effect of compatibilizer, Maleic anhydride-gpolyethylene (MAPE), on the composite properties also investigated. It is reported that for all three particle size, the tensile strength of the composite were found to be decreases with the increases of filler content. This is attributed to the poor bonding between the OPEFB fibre and the matrix, which might be due to the physical structure of the OPEFB fibre. The incorporation of MAPE was found to be able to improve the tensile strength of the composite. It is believed that there is reaction between maleic anhydride molecules from MAPE with the hydroxyl groups in the fibre which resulted in better bonding between the fibre and the matrix.

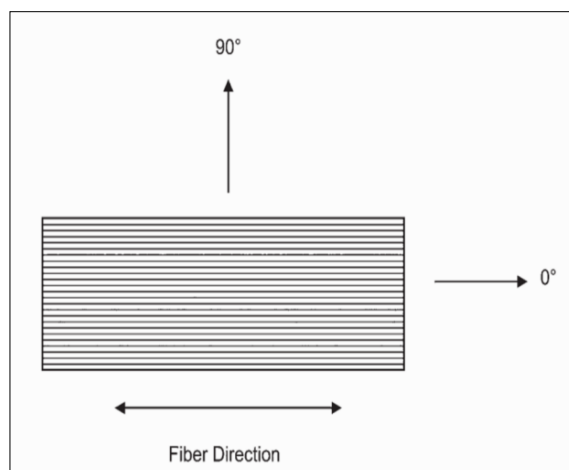
(Ngo W.L. et. al 2014) utilized OPEFB fibre as reinforcement filler for polylactic acid (PLA) and polystyrene (PS). The length and diameter of the OPEFB fibre used is in the range of 6-10 mm and



60100 $\mu$ m, respectively. The composites were fabricated using conventional vacuum press moulding with fibre loading of 20%, 40% and 60%. The composites were subjected to tensile and flexural test. It is reported that the tensile and flexural strength of the OPEFB fibre reinforced PLA composite increases with the increases of fibre loading up to 40%, however decreases with further increases of fibre loading. The high content of fibre would tend to aggregate in the composite which weaken the bonding between the fibre and matrix. Meanwhile, the utilization of OPEFB fibre to reinforce PS has resulted in even lower tensile and flexural strength as compared to the pure PS.

However, present researches are limited to the usage of discontinuous OPEFB fiber as the reinforcement material. Utilization of continuous OPEFB fiber to reinforced polymer has yet to be studied. Discontinuous-fiber composite are normally random in alignment, while continuous-fiber generally have preferred orientation. The random alignment of the discontinuous-fiber dramatically reduces their strength and modulus (Tanwer 2014).

One method of reinforcing as continuous-fiber is by unidirectional fiber alignment. Unidirectional fibers could be distinguished between its reinforcement angles. The reinforcement angles vary in the direction of load applied. The composites are said to be reinforced with 0° fiber alignment if the composite is loaded in the direction parallel to its fiber, or to be reinforced with 90° fiber alignment if the composite is loaded in the direction perpendicular to its fiber, as shown in figure 1. It is believed that the unidirectional fiber alignment would be able to provide the greatest strength in the direction of the fibers.



**Figure 1.** Unidirectional continuous-fiber angle definition (Campbell 2010).

In the applications where stiffness and strength is required, the unidirectional reinforcement of natural fibre is preferable. Many researches have been carried out utilizing unidirectional natural fibre to reinforce polymer in order to generate a stiffer yet lightweight material. As example, (Aldousiri, 2013) has fabricated composite composed of date palm fibre and recycled high density polyethylene (HDPE). Tensile behaviour of such composites were tested and analysed. The composite samples, pure HDPE and HDPE + 6% date palm fibre, were prepared using hot press technique. The date palm fibres were aligned in 0° alignment. It has been found that the incorporation of date palm fibre into the recycled HDPE with 0° fibre alignment has resulted in increases of tensile strength from 28 MPa to 38 MPa. Minimal fibre pull-out was observed through scanning electron microscope (SEM) which indicates that the fibre, when oriented parallel with the load applied, has effectively preserved the ductility of the HDPE.

The objective of this paper is to investigate the effect of fiber orientation on the tensile strength and flexural strength of the OPEFB fiber reinforced epoxy composite. It is expected that the unidirectional

composite with  $0^\circ$  fiber alignment to be stronger and stiffer as compared to composite with other fiber alignment angles. As fiber orientation changes from  $0^\circ$  to  $90^\circ$ , the properties of the fibers decline and the properties of the matrix dominate (Hedge 2015), hence, the load will be carried by the much weaker polymeric matrix (Campbell 2010).

## 2. Methodology

### 2.1. Fiber preparation

Fibers were washed in distilled water to remove all sorts of impurities such as residue oil as well as other large particles and were allowed to dry for 20 hours in room temperature. The fibers were then soaked in a 1% sodium hydroxide solution for 1 hour and were allowed to dry for another 24 hours in room temperature. The fibre treatment was performed in order to roughen the fiber surface which subsequently will contribute to a better interfacial bonding with the matrix.

The dried fibers were then straightened using a comb and by applying pressure at both ends of the fiber while placing them in straight position for approximately 8 hours duration.

### 2.2. Composite preparation

Epoxy and hardener were mixed in a ratio of 10:1, respectively, to form matrix. The fibers were aligned manually on the mold prepared prior to this process. The mixture of epoxy and hardener were then poured into the mould with OPEFB fibers. The mould was closed with designed lid and small pressure was applied to prevent air bubbles during the curing process. The composite were allowed to cure for 24 hours duration.

The composites were then cut based on the ASTM D638 Type I standard and ASTM D790 for tensile testing and flexural testing, respectively. Five composite samples were prepared for each fiber orientation;  $0^\circ$ ,  $45^\circ$  and  $90^\circ$ .

### 2.3. Tensile test

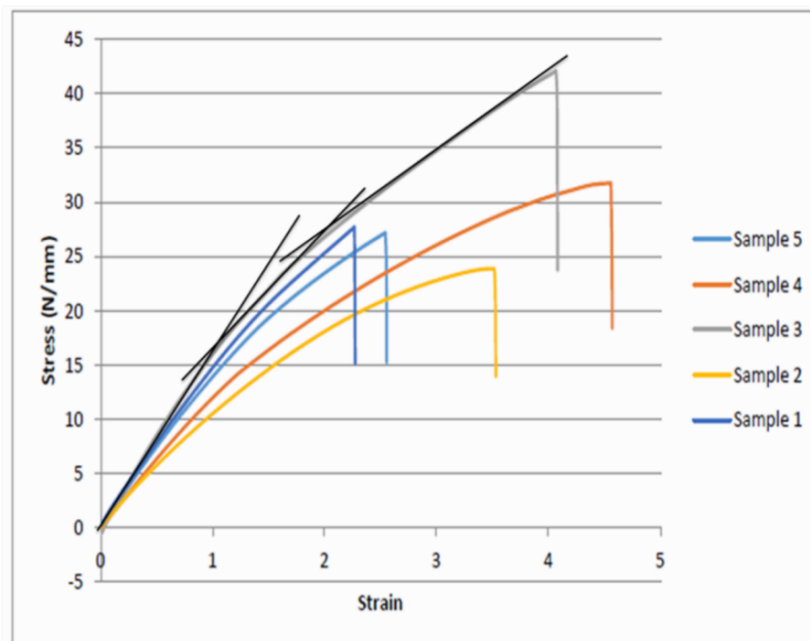
The obtained tensile specimens were tested using INSTRON 3366 10kN universal testing machine at a crosshead of 5 mm/sec and the data is recorded down.

### 2.4. Flexural test

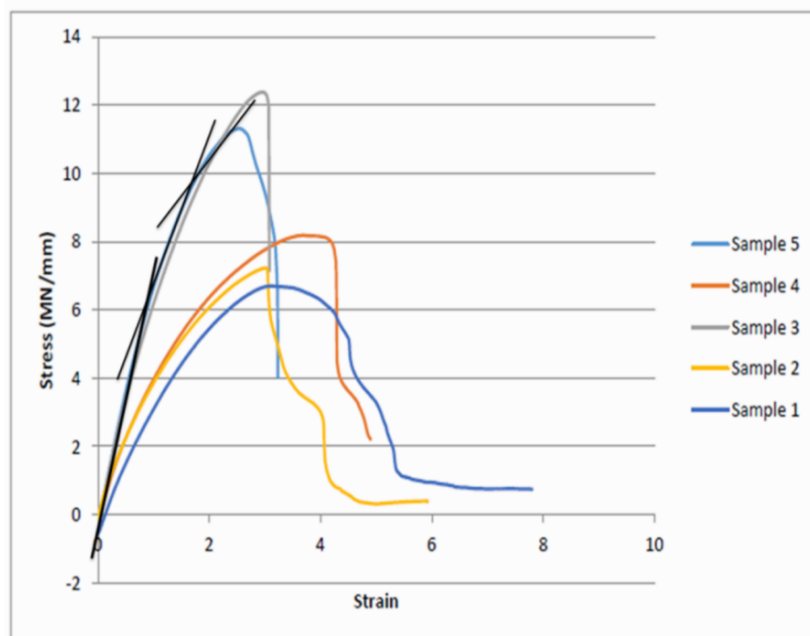
The obtained flexural specimens were tested using INSTRON 3366 5kN universal testing machine at a crosshead of 2 mm/sec and the data is recorded down.

## 3. Results and Discussion

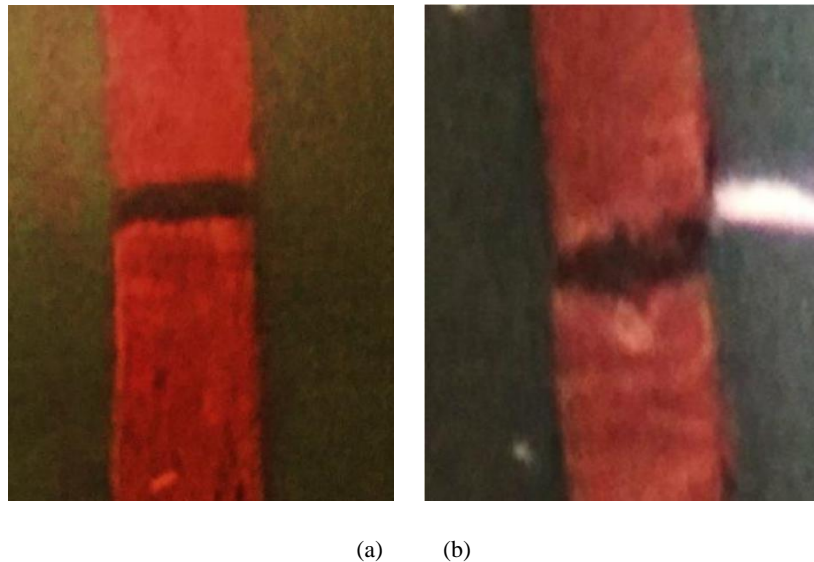
Figure 2 and figure 3 shows the stress strain curve obtained through tensile testing of the OPEFB fibre reinforced epoxy composite for  $0^\circ$  and  $90^\circ$  fibre orientation angle, respectively. Stress strain curve measure the relationship between the magnitude of the applied stress on a material and the resulting strain or elongation. Both stress strain curve shows nonlinear response, indicating there are reductions in modulus of elasticity before fracture. These reductions of modulus of elasticity reflect drops in stiffness of the composite.  $0^\circ$  fibre orientation angle exhibits brittle failure mode while  $90^\circ$  fibre orientation angle exhibits nonlinear behaviour before complete fracture. After the peak strength, both fibre and matrix are damaged and cracks are thoroughly connected. As can be seen from figure 4, the fractured surface of composite with  $0^\circ$  fibre orientation angle is rather smooth as compared to the composite with  $90^\circ$  fibre orientation angle which is brushier and dislodging.



**Figure 2.** Tensile Stress Strain Curve of the Unidirectional OPEFB Fiber Reinforced Epoxy Composites with  $0^\circ$  Fibre Orientation Angle

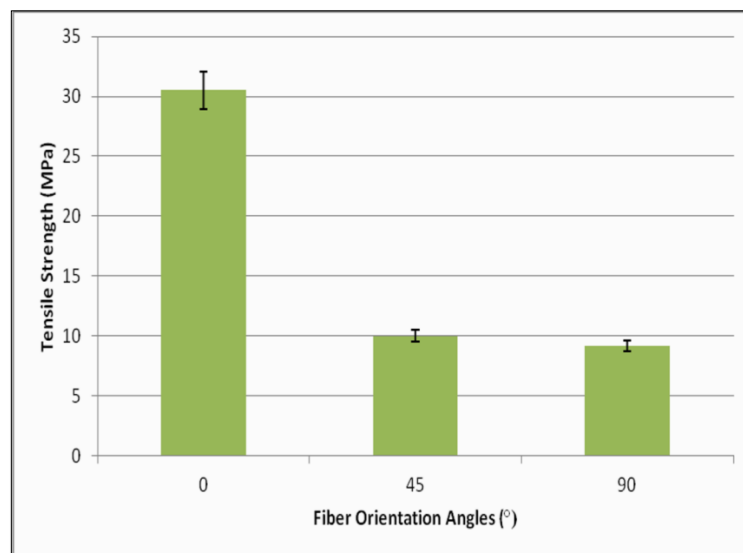


**Figure 3.** Tensile Stress Strain Curve of the Unidirectional OPEFB Fiber Reinforced Epoxy Composites with  $90^\circ$  Fibre Orientation Angle



**Figure 4.** Fractured Surface of the Unidirectional OPEFB Fiber Reinforced Epoxy Composites with (a) 0° Fibre Orientation Angle, and (b) 90° Fibre Orientation Angle.

Figure 5 shows tensile strength of the unidirectional OPEFB fiber reinforced epoxy composite. It can be seen that the tensile strength increases when the angle of the fiber orientation increases. The trend is similar to the finding by (Aldousiri, 2013) as elaborated earlier. It is observed that for all fibre orientations under tensile load, the composites have failed in shear which involving interfacial debonding and fibre pull out.



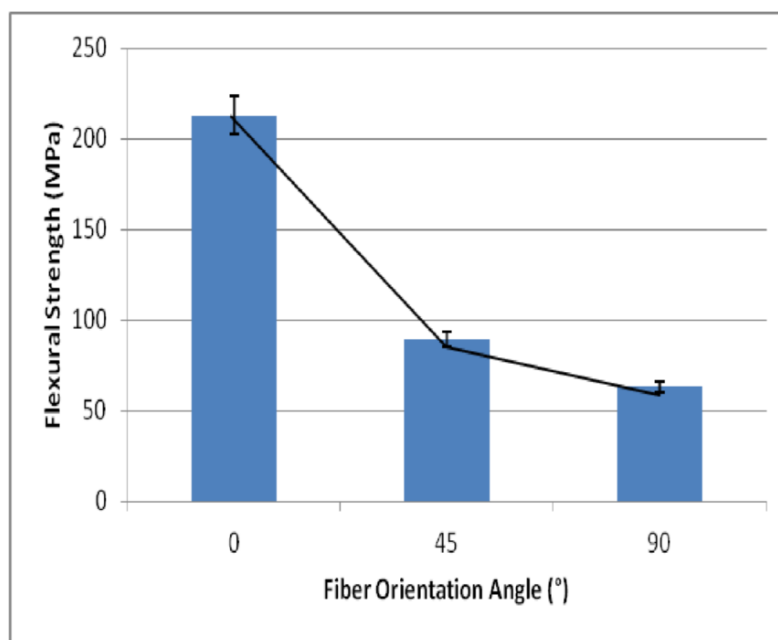
**Figure 5.** Tensile Strength of the Unidirectional OPEFB Fiber Reinforced Epoxy Composites

Fiber orientation at angle of 0° has the highest tensile strength value of 30.5 MPa followed by fiber orientation angle at 45° with value of 10 MPa. Fiber orientation at angle of 90° indicated the lowest

tensile strength of 9.2 MPa. This shows that the composite with fiber oriented at  $90^\circ$  are weakest when the tension of force pull perpendicular to the fiber direction and it takes shorter time to deform and eventually break apart. The transversely oriented fibers acts as a barrier and prevents the distribution of stresses throughout the matrix and this in turn causes higher concentration of localized stresses (Manikandan et al. 1996). This explains the reduction in tensile properties of the composite at  $45^\circ$  and  $90^\circ$  oriented fiber composite. Contrary, when fibers are aligned longitudinally and in the direction of the force applied, the properties of the fibers will be reflected significantly (Murray 1997). As such, the strength of the OPEFB fiber oriented in the longitudinal direction has produced a higher tensile strength for the composite.

The decreases in tensile strength of the OPEFB fiber reinforced epoxy composite is about 67% when the orientation of fiber in the composite changed from 0 to  $45^\circ$ . Meanwhile, the composite with  $45^\circ$  fiber orientation angle exhibited tensile strength higher by around 20% as compared to the composite with  $90^\circ$  fiber orientation. This finding is also in agreement with study done by other researcher. (de Oliveira et al. 2012) studied behaviour of isophthalic polyester matrix composites reinforced with unidirectional curaua fibers. The author reported that the strength of the composites experiences gradual depreciation when the reinforcement angle increased. There was a decrease of nearly 60% in strength when fiber oriented at  $15^\circ$  orientation as compared to the  $0^\circ$  orientation angle and another decreases of around 30% when the fiber changed from  $15^\circ$  to  $30^\circ$ .

Figure 6 shows the flexural strength of the unidirectional OPEFB fiber reinforced epoxy composite. It can be seen that the difference in the fiber orientation angles affect the flexural strength of the composites. Fiber orientation at angle of  $0^\circ$  has the highest flexural strength value of 213.04 MPa followed by fiber orientation angle at  $45^\circ$  with value of 89.38 MPa. Fiber orientation at angle of  $90^\circ$  indicated the lowest flexural strength of 63.18 MPa.



**Figure 6.** Flexural Strength of the Unidirectional OPEFB Fiber Reinforced Epoxy Composites

Fibers that are diverging from longitudinal axis resulted in stress transmission to the matrix. Hence composites with fibers parallel to the load are capable to withstand loads better than those with obliquely oriented fibers (Callister 1997).

#### 4. Conclusions

Tensile and flexural test has been conducted on the OPEFB fiber reinforced epoxy composites with 0°, 45° and 90° fiber orientation. It has been found that varying fiber orientation angle affect the properties of the composite. Fiber aligned in the direction of force applied, 0° orientation, showed higher tensile and flexural properties as compared to the fiber aligned in 45° and 90° orientation.

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