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Effect of fiber loading on physical and mechanical properties of unsaturated polyester/*Donax grandis* hypodermal fiber composite

Sofiyah Mohd Razali[1], Mahani Yusoff[2,*], Sitti Fatimah Mhd Ramle[2], Irshad Ul Haq Bhat[1], Abdul Hamid Mar Iman[1]

[1]Faculty of Earth Science, Universiti Malaysia Kelantan, Locked Bag No.100, 17600 Jeli, Kelantan, Malaysia
[2]Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Locked Bag No.100, 17600 Jeli, Kelantan, Malaysia

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⌧*Corresponding author:
Dr. Mahani Yusoff,
Faculty of Bioengineering and Technology,
Universiti Malaysia Kelantan,
Locked Bag No.100, 17600 Jeli,
Kelantan, Malaysia
Email: mahani@umk.edu.my

Abstract

The developments of natural fiber reinforced polymer composites have receive positive response in many applications over the synthetic fiber polymer composites. The aim of this paper is to study the effect of fiber loading on the mechanical properties of *Donax grandis* hypodermal fiber (*DGHF*) reinforced polyester composites. The composite was mixed and compressed in a mould (150mm x 150mm x 3 mm) with fiber loading compositions varied (20wt%, 25wt%, 30wt%) . The properties of the composite as thickness swelling, density, flexural and tensile were studied. The experimental results showed that both the flexural and tensile properties of the composites materials were found to be better at 25wt% of fiber loading. The density of composites was found to decrease with increase in fiber loading until 25wt% before increase at 30wt%. The thickness swelling properties shows an increment with the *DGHF* content.

1. INTRODUCTION

The use of natural fiber in composite offers good opportunities for utilising the agricultural by-product because of its availability and low cost. Alas, some shortcomings of natural fiber composite such as incompatibility of fibers with theair polymer matrices and high moisture absorption make them detrimental for certain applications. There is growing interest in the use of natural fibers as reinforcing components for thermoplastics and thermosets. The most widely use thermosets is unsaturated polyester resin (UPR), owing to its relatively cheap price, ease of handling and good stability of mechanical, electrical and chemical properties (Mishra *et al.*, 2003). However, there is limitation in using UPR as matrix because of its low toughness, highly flammable and low impact strength (Kagarzadeh *et al*., 2015; Gonçalves *et al*., 2017).

Donax grandis, synonyms as *Donax canniformis* or *Clinogyne grandis* from Marantacea family can be an alternative reinforcement fibers in polyester composite. It is widely distributed in the South East Asian region's jungle along the stream and sometimes at wet sites (Bharti *et al.*, 2012). Previous studies have shown most of its study had focused on it as medicinal alternative (Bharti *et al.*, 2012; Daud *et al.*, 2011; Ibrahim and Hamzah, 1999). By tradition, trunks and barks were used in roof making as it is strong. Thus, there is limited data on it uses as reinforced fiber in composite. However, generally natural fiber composites benefits in terms of high specific strength and modulus, low cost, light weight and recyclability which potential to be use as structural materials (Sreenivasan *et al.*, 2011).

Therefore, *Donax grandis* hypodermal fiber (*DGHF*) can be used in fabricating starch-based composite as suggested by our previous study (Razali *et al.*, 2016). By the result, it shown that *DGHF* has potential to be used as reinforcing materials. In natural fiber-polymer composite, the properties of the uses of natural fiber should have been studied. Thus, this research will focus on using *DGHF* as reinforcing component for unsaturated polyester resin. The mechanical and physical properties of the composite will be discussed.

2. MATERIALS AND METHODS

2.1. Raw materials

DGHF used as reinforcement was collected from Forest Research Institute Malaysia (FRIM), Batu Melintang, Jeli, Kelantan, Malaysia. The inner sap of *Donax grandis* was removed without damaging the outer sap. The fiber was oven-dried at 105°C and ground before placed in a shaker with sieves to pass through a No. 40 mesh sieve (425-μm) yet retained on a No. 60 mesh sieve to obtain short fiber in 250-µm size. Unsaturated polyester resin (UPR) and methyl ethyl ketone peroxide (MEKP) aqueous solution were obtained from Revertex Sdn. Bhd.

2.2. Composite fabrication

Hand lay-up method followed by compression moulding was adopted for composite fabrication. Curing reaction was performed by the addition of MEKP into UPR.The control sample of only UPR used was marked as 100:0.Composite having different fiber weight compositions was prepared by varying the weight fraction of fiber by 20%, 25% and 30%. The DGHF were mixed with UPR by simple mechanical stirring and the mixture is poured into mould. A mould having dimensions of 150 x 150 x 3mm is used for composite moulding. Releasing agent (wax) has been used for an easy removal of the composite from the mould. The mould was closed for curing at constant pressure of 1MPa. After curing; the composite of suitable dimension were cut as per ASTM standards for mechanical tests. The compositions and designation of composites used in this study is listed in Table 1.

2.3. Mechanical properties

The samples for tensile test and flexural strength were cut according to ASTM D638-03 test standard using three bending test by universal testing machine Instron M500-50CT, at room temperature and testing speed of 5 mm/min. Flexural strength of the composites were calculated according to Eq. 1 (Naguib *et al.*,2015):

$$\sigma_f = \frac{3FL}{2wt^2} \qquad \text{Eq.1}$$

where F is applied load (N), *L* is support span (mm), *w* and *t* are width and thickness of the specimen (mm), respectively.

2.4. Physical properties

2.4.1. Density

Density of UPR/*DGHF* composite was measured using density meter according to Archimedes' Principle. The principle says that the apparent weight of an object immersed in a liquid decreases by an amount equal to the weight of the volume of the liquid that it displaces. The density meter measures the mass and the volume of an object which are needed to calculate the density. The measurement was conducted at 27°C and five measurements were taken for average value.

2.4.2. Water absorption and thickness swelling

The water absorption and thickness swelling were conducted based on method conducted by the group studies of Then *et al.*, 2015; Sahari *et al.*, 2011; Sreekumar *et al.*, 2009. All of the specimens (10.0 mm x 10.0 mm x 1.0 mm) were immersed in distilled water for 24 h. The initial weight (w_1) and thickness (d_1) of the dried samples were measured using weighing balance and digital calliper, respectively. Then, the samples were removed from distilled water and wiped with tissue paper to remove excess water on their surfaces. The final weight and thickness were measured immediately. Water absorption and thickness swelling were calculated using Eqs. 2 and 3:

$$\text{Water absorption } (\%) = \frac{w_2 - w_1}{w_1} x100 \qquad \text{Eq. 2}$$

where w_1 is weight before soaking (g) and $w_2$is weight after soaking (g)

$$\text{Thickness swelling } (\%) = \frac{d_2 - d_1}{d_1} x100 \qquad \text{Eq. 3}$$

where $d_1$is initial thickness (mm) and d_2 is final thickness (mm)

3. RESULTS AND DISCUSSION

The effect of fiber loading (wt %) on the tensile strength and tensile modulus of *DGHF* reinforced polyester the composite is shown in Figures 1 and 2. The result indicates that as the *DGHF* content in composite increased, the tensile strength and Young's modulus of the composite increased suggested that UPR successfully transmits and distributes the applied stress to the fiber (Ramanaiah *et al.*, 2012b). This is because when the content of *DGHF* increased, the large area of resin was covered by the random fiber. The tensile strength of composite depends on the area of interfacial between matrix and reinforcement.

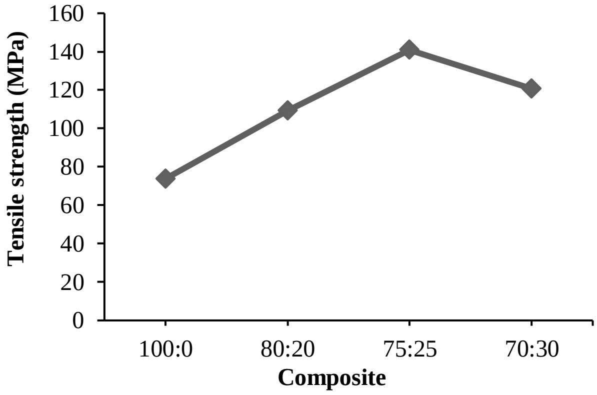

Figure 1: Tensile strength of UPR/*DGHF* composite

Thus, composite can sustain higher load before failure compared to 100:0 (control sample). The tensile strength is increased by 47%, 88% and 62% at 20wt%, 25wt% and 30wt% of fiber loading respectively. The tensile modulus of the composites is 1.5, 1.8 and 1.6 times of the control sample at fiber content of 20wt%, 25wt% and 30wt%, respectively. However, the increment reached maximum point at fiber weight fraction of 25% before decreased at 30wt%. This result is similar from previous studies (Hameem *et al.*,2016; Hussain *et al.*, 2012; Prasad and Rao, 2011), that the values of the tensile strength of

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composites increased with increasing fibre loading up to a maximum or optimum value before drop back. The composite with higher content *DGHF* transmits and accumulates at the end of short fiber which makes the transmission of the load from the matrix to the fibers reached the weakest. The tensile strength as well as tensile modulus of composite is better than coir but less than hemp composite (Eichorn and Young, 2004; Rout *et al.*, 2001).

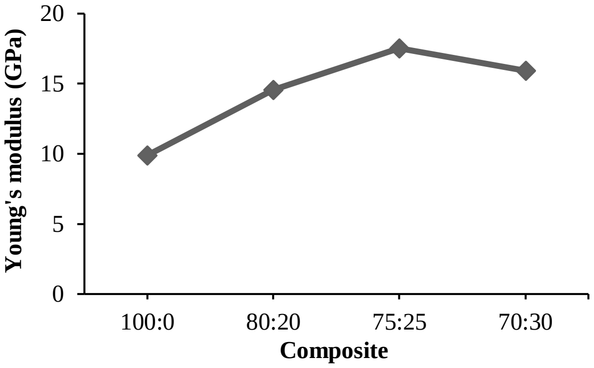

Figure 2: Young’s Modulus of UPR/DGHF composite

Figure 3 and 4 show the effect of fiber loading composition (wt %) on the flexural strength and flexural modulus of *DGHF* reinforced polyester composite. The maximum flexural strength is 414 Mpa given by the 25% of weight fiber composition. It is observed that the curve show a linearly increasing trend up to a certain value of fiber loading at 25% before drop back at 30% of loading for both flexural strength and modulus. For instance, flexural modulus of DGHF/UPR composite increased from 33.74GPa to 35.92GPa and decreased to 32.51GPa up to 30wt%. The plots exhibit the similar trend observed in Figure 1 and 2. The sudden drop of strength owed to failure of composite correspond to breakage end pull out of the fibers from UPR matrix (Hussain *et al.*, 2012; Prasad and Rao, 2011) during testing. The decreased in the flexural strength of composite is attributed to the inability of the fiber to support stresses transferred from the polyester matrix. Thus, resulting in poor interfacial bonding that generates partially space between between DGHF and matrix.

Figure 5 shows the density of composites with respect to the weight composition of the *DGHF*. There is decrement in the density with increasing *DGHF* content in polyester matrix. The density for 100:0 is 1.22g/cm^3 is comparable with the actual polyester density (Sreekumar *et al.*, 2009). The density for 80:20 which is 1.178g/cm^3 mostly given by the density of unsaturated polyester loaded. While, the 75:25 composite having the lowest density with 1.157g/cm^3 compared to other *DGHF* composites as the density of composite decrease with the fiber content as found by Ramanaiah *et al*. (2012a).

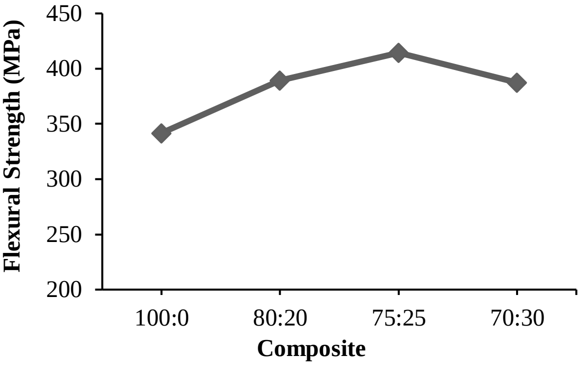

Figure 3: Flexural strength of UPR/*DGHF* composite

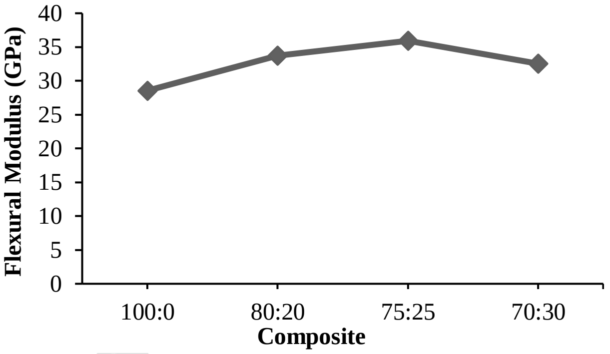

Figure 4: Flexural modulus of UPR/*DGHF* composite

Figure 6 shows the thickness swelling values of DGHF reinforced unsaturated composite with different compositions after 24hour of immersion in distilled water. The percentages of thickness swelling of composites were studied in order to determine the changes in its dimensional stability by introducing DGHF as the reinforcing materials. It can be obviously seen that the thickness swelling were directly proportional to the DGHF loading content. The thickness of all composites was increased from 0.3%, 1.6%, 2.2% and 2.6% following the fiber loading 0%, 20%, 25%, and 30%. Similar finding were reported on bagasse/polyester composite by Naguib et al. (2015). The 100:0 composite have very low thickness swelling (<0.5%) which is due to the polyester’s hydrophobic characteristic. The thickness swelling percentage of 70:30 is the highest due to the quantity of 30wt% DGHF content in the composite. As the 70:30 composite contains more fractions of lignocellulosic material, by means possessing more –OH groups, which is able to combine with water molecules. Therefore, when a composite containing lignocellulosic material is applied in moist areas, the composite will absorbs water and increase the water uptake cause the board to swell and led to increment in thickness swelling (Tay et al.,2014; Sahari et al., 2011). The value of thickness swelling was caused by the hydrophilic in nature of the fibres and not by the hydrophobic behaviour of the unsaturated polyester. All lignocellulosic contents play an important role in water absorption behaviour (Sahari et al., 2011).

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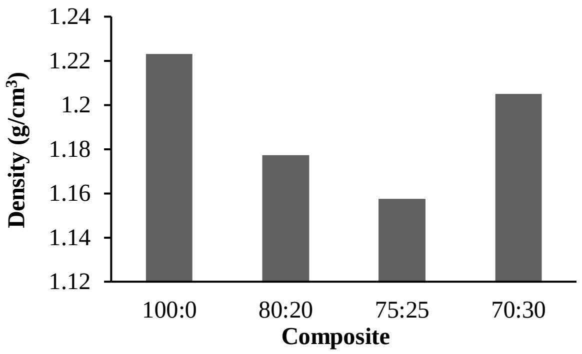

Figure 5: Density of UPR/*DGHF* composite

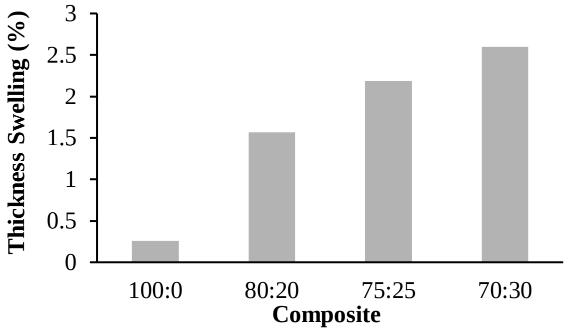

Figure 6: Thickness swelling of UPR/*DGHF* composite

4. CONCLUSION

In this study, the composites based on *DGHF* - unsaturated polyester were prepared by the loading of *DGHF* with 20%, 25%, and 30% by weight to the polyester resin. Result revealed that variation occurs in both mechanical properties with varied levels of fiber loading in composites. The uses of *DGHF* as reinforcing material increase the tensile and flexural properties of composite from its pure state, conformed the reinforcing ability of the fibers. The combination of materials' compatibility often related with improvement of mechanical properties of resulting composite.

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