

EFFECT OF WATER ABSORPTION ON TENSILE PROPERTIES OF KENAF FIBER UNSATURATED POLYESTER COMPOSITES

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Received: January 18, 2012; Revised: June 8, 2012; Accepted: July 20, 2012

Abstract

Physical and mechanical properties of kenaf fiber; namely, length, diameter, density, water absorption, tensile strength and Young's modulus were observed experimentally. The percentage ratio of holocellulose content, and of bast and core kenaf fiber was investigated. The water absorption characteristic had an effect on the tensile properties of Kenaf fiber composites, and the results showed that moisture uptake increased as fiber weight percentage increased in composite. The experimental data was cross-matched against composite models, such as Hirsch, Einstein-Guth, modified Bowyer-Bader, Kelly-Tyson, Parallel, modified Guth, Cox-Krenchel, and Halpin-Tsai. The results show a good correlation with Hirsch's model while the results obtained from Cox-Krenchel underestimated the experimental data.

Keywords: Kenaf-unsaturated polyester composite, water absorption, mechanical properties, zero-stress aging

Introduction

The growth of global environmental concern, high rate of depletion of petroleum resources, as well as new environmental regulations have forced the search for new fiber reinforced composite materials that are compatible with the environment. Biodegradable composite has been the driving force of the use of bio-composites consisting of biodegradable

plastics and natural fiber. Natural fiber combined with unsaturated polyester resin are widely introduced to the industries as they possess many advantages compared to other thermosetting resins, including room temperature cure capability, good mechanical properties and transparency. Kenaf was chosen for this study because, it is now a fiber

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crop grown commercially in the world. In tropical countries such as Malaysia, fibrous plants are available in abundance and at least some of them are agricultural crops. The main concern about the usage of these composites is related to aging at high humid environments and to lack of adhesion at fiber-matrix interface of fiber surface is not suitably prepared. When moisture diffuses into composites, it degrades fiber-matrix interfacial bonding, lowers the glass transition temperature, swells, plasticizes, hydrolyzes and sometimes micro-cracks the matrix (Grant and Bradley, 1995). Water in polymers can exist in several ways: as bound water, characterized by strong interaction of the molecule with matrix and free water, present in capillaries and micro cavities within the polymer (Fraga *et al.*, 2007). Several studies on the use of natural fiber reinforced polymeric composites have shown that the sensitivity of certain mechanical and thermal properties to moisture uptake can be reduced by the use of coupling agents and fiber surface treatments (Wambua *et al.*, 2003; Rashdi *et al.*, 2009). General moisture diffusion in composite depends on factors such as weight fraction of fiber, void volume, viscosity of matrix, chemical treatment of natural fiber, humidity and temperature (Najafi *et al.*, 2008). Several investigations have already been reported in the field of effect of water absorption on the mechanical properties of natural fiber reinforced unsaturated polyester composites and their results express that the tensile properties were affected by increasing temperature of water immersion. Generally, the tensile properties decreased with increasing immersion time (Dhakal *et al.*, 2007; Shenoy and Melo, 2009; Nóbrega *et al.*, 2010; Rashdi *et al.*, 2010). In this article, the physical and mechanical properties of treated kenaf fiber were studied. The water absorption in kenaf fiber unsaturated polyester composites in room temperature and the effects of water absorption on the tensile properties of kenaf unsaturated polyester composite were investigated. In this research, we made an effort to describe the relative ability of some selected-existing mathematical

models such as Hirsch, Einstein-Guth, modified Bowyer-Bader, Kelly-Tyson, Parallel, modified Guth, Cox-Krenchel, and Halpin-Tsai for dry composites specimens. In addition, fiber zero-stress aging model was investigated for water immersion composites specimens.

Materials and Methods

Unsaturated polyester (UP) and Methyl ethyl ketone peroxide (MEKP) were obtained from BORNEO INDAH SDN BHD Company. The kenaf natural fiber was received from the Kenaf Natural Fiber Industries Sdn. Bhd. Kenaf physical treatment was done by undergoing cleaning steps; fiber was chopped using the decorticating machine. The round vibratory sieves (Unit Test) machine was used to separate the clod of chopped kenaf bast fiber for sieves with sizes 600 μm . The resultant fiber lengths were 1-6 mm. The chopped kenaf fiber was soaked in 6 wt% concentration of NaOH solution in water where the temperature was maintained throughout at room temperature for 48 h, fiber: liquor ratio was 1:7 (by weight). Fiber was rinsed several times to remove any NaOH solution sticking to fiber surface and dried in an oven for 24 h at 100°C. This treatment consists of dissolving lignin and hemicelluloses in order to recover holocellulose fibers. Figure 1 expresses a comparison between the cleaning fiber and fiber ready to mix with UP to prepare the composite specimens.

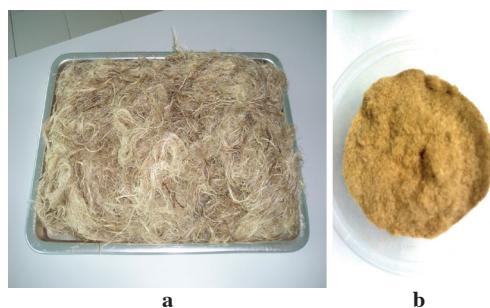


Figure 1. Kenaf fiber, a) kenaf fiber with physical treatment, b) kenaf fiber after treatment and chopping

Composites Fabrication

A compression moulding process was used for the fabrication process. Specimens from 0% to 40%, weight percentage of fibers were fabricated. The prepared resins were blended to fiber size 1-6 mm. Composite mixture was poured in the mold cavities. The mixture was then gently pressed using finger to make sure the cavity of mould was properly filled. Composites were left for a few minutes, allowing air bubbles to escape from the surface of resin. The top plate was put in place and mixture was left to relax for about 10 min. Top plate was screwed tightly in place. Composite was left to cure for about 24 h at 25±2°C. The specimens were ground to trim the flushes of matrix during fabrication process. Certain composites specimens were post cured in an oven for 5 h at 60°C.

Composite Water Absorption Test

The specimens' weight was measured to a precision of 0.0001 g using four digit balances. The specimens were placed in distilled water at 25°C. For weight measurement, specimens were removed from distilled water, surface water was wiped off using a soft dry cloth, and the specimens were weighed. After weight measurement, the specimens were immersed in water. The process was continued until saturation period was reached after 1010 h. Values of the water absorption were calculated using the following formula (Zabihzadh, 2010; Najafi and Kordkheili, 2011).

$$M_t \% = \left[\frac{M_w - M_{dry}}{M_{dry}} \right] \times 100$$

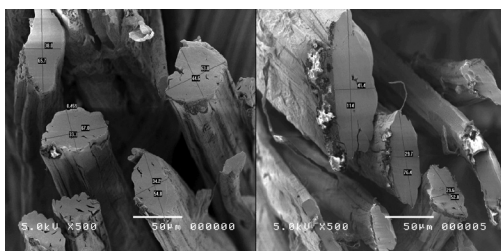


Figure 2. Cross section and diameters measurements of kenaf fiber

M_t , percentage weight gain (g), M_w is weight of specimen at time (sec), M_{dry} is the baseline mass (oven dry specimen mass) g.

Composite Tensile Testing

Tensile properties such as tensile strength, and tensile modulus, were determined by a static tension test in accordance with ASTM D608. A load cell of 50 kN was selected for this test. The specimens were loaded in tension at a constant stroke rate of 5 mm/min. An extensometer of 50 mm gage length was mounted on the specimen for measurement of strain.

Properties of Kenaf Fiber

Fiber Diameter

The purpose of this test is to determine the average diameter of kenaf fiber for single fiber tensile test. Diameters of selected fibers were then measured under microscope by means of a calibrated eyepiece with 100 times magnification power. Ten fibers with 50 mm length at 17 locations were measured. In addition SEM micrographs technique was used to study the cross section of fiber. Kenaf had an ellipse cross section as shown in Figure 2. It is interesting to note that for same bundle had different size of ellipse cross sections and even there is a circular section. It is evident that internal fiber structure varies between different parts of a plant as well as different plants. This strongly influences the mechanical properties of single fibres. The average diameter is taken in calculation of

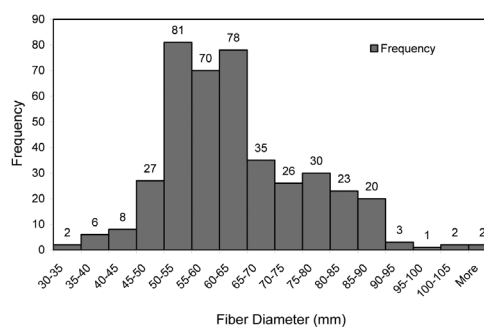


Figure 3. Histogram for kenaf fiber diameter

single fiber tensile test. Figure 3 demonstrate the results of measuring diameters of kenaf bast fiber. The range of fiber diameter is between 50-65 μm .

Holocellulose Extracted for Kenaf Fiber

Holocellulose is the main component of natural fibers. Therefore, to extract the holocellulose, two samples from alkali treated kenaf fiber 2 g each from bast and particles (core) with different sizes (0.15, 0.2, 0.3, 0.4, 0.6, 1, and 3 mm) were used. The first step was to wash the samples by adding 200 ml Ethanol/Toluene 1:2 mixing ratio at 100°C. The washing process was repeated 6 to 7 times and it took about 8-9 h. After the washing was done, the fibers were fully dried in an oven for 24 h at 100°C. The second stage involved adding 100 ml distilled water, 1.5 g sodium chlorite, and 5 ml 10% acetic acid solution to the fiber, and heating the mixture inside a boiling water bath. After 30 min, 5 ml of 10% acetic acid solution and 1.5 g sodium chlorite were added alternate acetic acid and sodium chlorite additions were continued at 30 min intervals until 6 g of sodium chlorite was added. After last addition of sodium chlorite the mixture was left in the boiling water bath for 30 min. The white residue and kenaf structure were retained. In the third stage the suspension was cooled in an ice bath to avoid the evaporation of sodium chlorite, and then filtered into a weighed fritted glass crucible (porosity 1) and washed with iced distilled water. Finally, was washed with acetone for fast drying. The residue was allowed to stand in the open laboratory until it was cooled and free of acetone. Then the extracted holocellulose was dried in an oven at 100°C for 12 h to ensure the holocellulose was fully dry. Table 1 shows the holocellulose percentage ratio of bast and core kenaf fiber. It can be seen that the holocellulose content of bast fiber is greater than core fiber.

Water Absorbing for Kenaf Fiber

Two samples, 2 g each, were used to

study the water absorption of bast and core kenaf fiber. A ceramic crisps were used as a container for the samples. The samples, were dried in an oven at 105°C for 5 h, and then kept in oven for cool-down to room temperature. The samples were weighed and left in the lab surrounding at room temperature. The first reading was after 5 h, and then the second reading was after 24 h, and then after 48 h and so on. The moisture content increased until reaching the saturation limit after 200 h, as shown in Figure 4. Kenaf bast fiber was the lowest one with water consumption from the surrounding, and the reason depends on the kenaf morphology which was holocellulose, hemicelluloses working as absorbing water agent, lignin, and pectin. Table 1 was clearly observed holocellulose ratio content for bast and core kenaf fiber, bast fiber was larger holocellulose than the kenaf core fiber; therefore the other fibers originated had limited ratio and limited affected fiber mechanical properties. Same impression was investigated for kenaf core fiber for different size for size 0.15-1 mm. There was an insignificant change for absorbing moisture content. Water consumption for 3 mm was almost very near from the absorbing ratio for bast fiber, as shown in Figure 4.

Single Fiber Tensile Testing

Elementary kenaf fiber was separated from their fibers bundles by hand, and mounted on 1mm thick cardboard mounting-

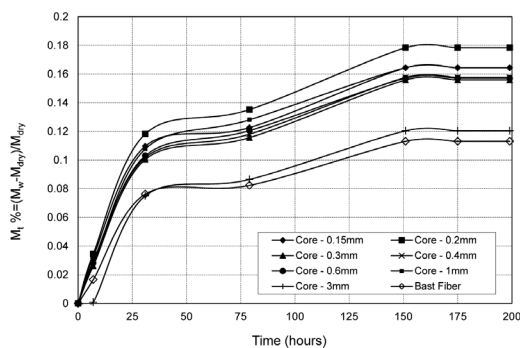


Figure 4. Moisture content as a function of time for core and bast kenaf fiber

cards as Figure 5 presents. Fiber was glued by PVC glue to the cardboard to the two edges on either side; fiber was carefully put into placed using a microscope to ensure that only a single fiber was present on each card. Tinius Olsen tensile machine with 10 N load cells was used for tensile test of a single fiber. Mounted fibers were placed in the grips of tensile testing machine, and then cut the cardboard with a scissors. Figure 6 expresses the stress-strain curves obtained using the results from forty specimens of treated kenaf fiber. Table 2 reveals the average of tensile strength and Young's modulus of kenaf bast fiber in comparison with the literature.

Kenaf Bast Fiber Density

Archimedes test using canola oil as an immersion fluid is a simple and effective method for general use in measuring kenaf fiber density; the procedure is:

- Minimum 0.5 g of kenaf fiber per specimen
- Soak samples in canola oil for 1 min
- Specimens placed in vacuum desiccators' for 5 min to remove trapped air from between fiber cells
- Completely immerse specimen in canola oil and take mass reading
- Fiber density calculated from canola oil density and ratio of recorded masses

The density of canola oil was 0.8828 g/cm³ as taken from the average of 10 samples. The density of canola oil was calculated using Equation (1)

$$\rho(f_i) = \frac{W}{V} \quad (1)$$

where, $\rho(fl)$ is the density of the sample, W is the mass, V is the volume

Density of kenaf bast fiber was calculated using Equation (2)

$$\rho = \frac{W(a) \cdot \rho(fl)}{0.99983 G} + 0.0012 \quad (2)$$

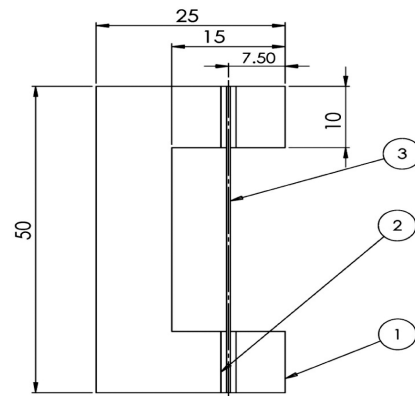


Figure 5. Kenaf single treated fiber mold

Table 1. Kenaf holocellulose content

Type of fiber	Holocellulose %	References
Bast fiber	66.2	Current research
Core fiber	57.2	
	60.8	(Du <i>et al.</i> , 2008)
	53.0-57.4	(Chen <i>et al.</i> , 1995)
	45-57	(Mokhtar <i>et al.</i> , 2007)
	65.7	(Batra 1983)
	47.6-49	(Ochi 2010)
Core fiber	50.6	(Du <i>et al.</i> , 2008)
	51.2	(Chen <i>et al.</i> , 1995)
	37-49	(Mokhtar <i>et al.</i> , 2007)

where, $W(a)$ the weight dry for samples, G is buoyancy of the sample, 0.0012 density of air under standard conditions, 0.99983 correction factor (Sartorius User's Manual, 2008). The same method was used to calculate the densities of KFUPC.

Results and Discussions

Densities and Void Content

Theoretical density of composites materials in terms of weight fraction can be obtained from Equation (3) (Roger *et al.* 1997)

$$\rho_{theor} = \frac{1}{\frac{w_f}{\rho_f} + \frac{w_m}{\rho_m}} \quad (3)$$

where, w and ρ represent the weight fraction and density respectively. The suffix f and m stand for fiber and matrix.

Void content of KFUPC was determined using Equation (4) (ASTM D2734-94).

$$V = 1 - \rho_c \left[\frac{w_f}{\rho_f} + \frac{w_m}{\rho_m} \right] \quad (4)$$

where, V represents void fraction (volume %), ρ_c , ρ_f and ρ_m are the densities (g/cm^3) of composites, fiber and matrix, respectively.

Figure 7 displays the densities of KFUPC. It can be seen from Figure 7 that the experimental density is lower than the theoretical one; two curves have the same trend. Both densities were found to increase as the percentage of kenaf weight fraction was increased. The results reveal that the void content is about 2.21-4.24%, the void content increased as the nominal fiber weight fraction

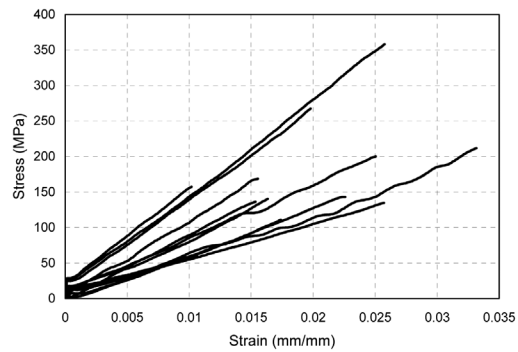


Figure 6. Maximum tensile stresses for single bast treated kenaf bast fiber

Table 2. Physical properties of kenaf fiber

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Young modulus (GPa)	Fiber diameter (mm)	Fiber length (mm)	References
Kenaf fiber	1.386	110-358	17-25	0.061	1-6	Current
	1.45	930	53	-	-	(Mohanty <i>et al.</i> , 2005)
	1.2	400	-	-	-	(Seber and Lolyd, 1996)
	-	250-600	14-39	-	-	(Ochi, 2008)
	-	335	22	0.106	-	(Shibata and Fukumoto, 2006)
	1.5	350-600	40	-	-	Kenaf Eco Fiber
	1.4	250	4.3	0.081	60	(Lee <i>et al.</i> , 2009)
	-	223	15	0.14	8-12	(Öztürk, 2010)
	1.04	448	24.6	0.078	-	(Cao <i>et al.</i> , 2007)
	-	135-232	15-24	0.024	2.48	(Harun <i>et al.</i> , 2009)
UP	1.12	39	3.231			(Osman <i>et al.</i> , 2011)

increased for a certain value of fiber, however the void contents in the latter weight fraction of fiber composites were reduced slightly and then increased after 30 wt% of kenaf weight fraction. In general, the voids are closely related to the processing conditions.

Water Absorption for KFUPC

Figure 8 summarizes maximum water up-take or moisture percentage as a function of weight fractions of fiber after 1106 h of immersion, the water up-take increases with the increasing immersion time, but after a certain period of time, the water up-take percentage was an insignificant change. This is because after achieving certain percentage of moisture up-take, fiber in composite becomes saturated. However, it was found that in the first few hours of the immersion, the increase in moisture content is very rapid, and this is due to the drying processes of fiber before fabrication as well as the pre drying of composites before immersion in water.

Effect of Fiber Loading

To study the effects of moisture absorption on tensile properties of KFUPC such as, Young's modulus (YM) and tensile strength (TS), tensile tests were performed for group of dry specimens at different weight fraction of fiber and six sets of KFUPC, 4 specimens for each set, was fabricated for immersion in distilled water for six weeks. Figures 9 and 10 present these results. Obviously, YM and TS

of KFUPC dramatically dropped compared to dry samples. The highest water absorption was in the specimen containing 40 wt% of kenaf fiber. Water absorption of composites was relatively high due to hygroscopic nature of fiber. As fiber content is increased, water absorption was expected to be increased (France *et al.*, 1983; LeVan and Winandy 1990). The moisture uptake, due to the immersion process, changes the structure and properties of fibers, matrix and the interface between them (Rashdi *et al.*, 2010). The YM increased as fiber loading was increased for all KFUPC dry samples as Figure 10 demonstrates, while YM was dropped compared to dry sample due to moisture uptake. High fiber content in the specimen leads to more water penetration into the interface through the micro cracks induced by swelling of fibers creating swelling stresses which leads to composites failure (Rashdi *et al.*, 2010). Tensile properties of KFUPC specimens were found to decrease with an increase in percentage moisture uptake, which is mainly due to degradation of composite (Rashdi *et al.*, 2009).

Effect of Immersion Time

There was an insignificant effect of water absorption on TS for UP samples. TS was rather increased after water immersion in the first three weeks. In week four, TS was decreased, then for week five and six TS increased again. This increase in TS for the

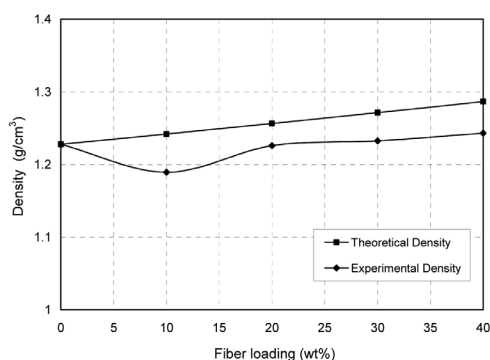


Figure 7. Theoretical and experimental densities of KFUPC

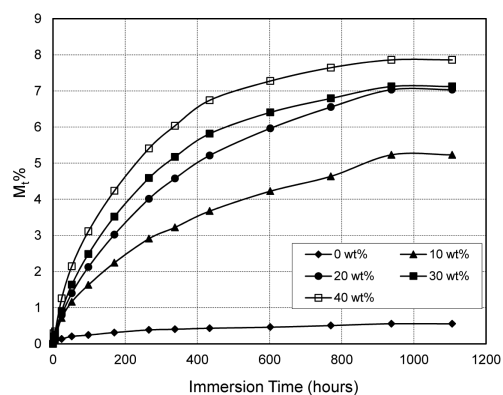


Figure 8. Moisture content as a function of Immersion time

UP sample implies that further crosslinking or other mechanisms are taking place, enhancing the material strength (Dhakal *et al.*, 2007) as Figure 11 shows. It can be clearly seen that, TS decreased for all weight fractions as the duration of immersion increased; all weight fractions followed the same trend. It is worth noticing that after exposure to water for over one week (168 h), the TS started to increase slightly. This is due to the plasticizing effect (Beg, 2007). TS decrease as fiber weight percentage increases because high content of fiber absorbs more water. During first week of immersion in water, mechanical properties for composites were dropped dramatically as Figures 11 and 12 express. The reduction in the TS and YM is attributed to the changes occurring in kenaf fiber, and the interface between matrix and fiber, as there is no

reduction effect on the UP after aging. Swelling of natural fiber as a result of prolonged immersion to water led to the reduction in YM of fibers and also in the development of shear stress at the interface that causes debonding of fibers from matrix (Rashdi *et al.*, 2010). The percentage reduction in TS and YM of UP and KFUPC is given in Table 3.

Zero-stress aging is defined as the reduction of TS and YM when no stress is applied during the time of exposure to a given environment (Kalaprasad *et al.*, 1997; Barbero and Damiani, 2003).

$$E(t) = E_0 (1 + \alpha t_a)^\beta \quad (7)$$

$$\sigma(t) = \sigma_0 (1 + \alpha t_a)^\beta \quad (8)$$

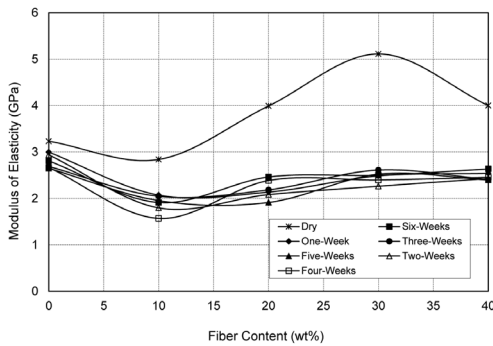


Figure 9. Young's modulus versus immersion time

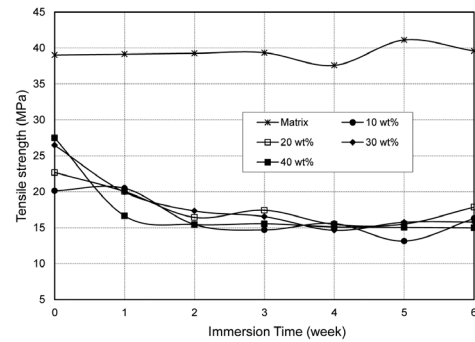


Figure 10. Tensile strength versus immersion time

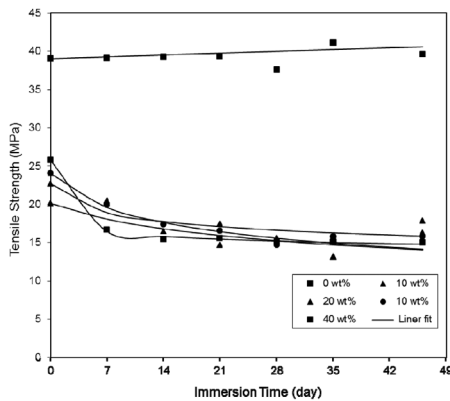


Figure 11. Variation of experimental and theoretical tensile strength

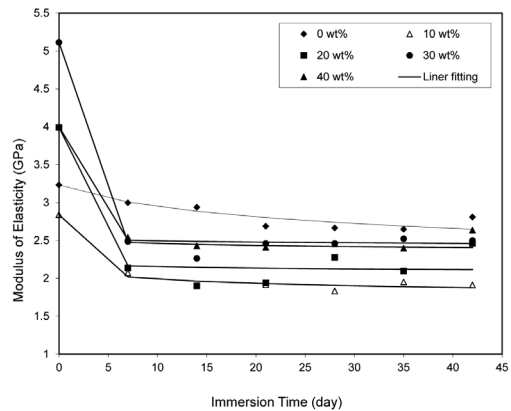


Figure 12. Variation of experimental and theoretical Young's modulus

where, E_o and σ_o are modulus and strength respectively, at time zero, at the environment of exposure, α and β are the empirical constants adjusted to fit the experimental data.

Figures 12 and 13 give a comparison of the variation in experimental and theoretical of tensile properties values of immersion time for 42 day. The results show that in all cases the experimental value has a good fit with the theoretical value. Table 4 displays the values of empirical constant for good fit.

Theoretical Modelling of Tensile Properties

Several research studies have explained a lot about theoretical models of tensile properties of composites materials. These equations are mainly used for theoretical calculation of the properties. In this article, several models were used for comparing experimental data with theoretical calculations.

Hirsch' Model

For modulus of elasticity

$$E_c = x(E_m V_m + E_f V_f) + (1-x) \frac{E_f E_m}{E_m V_f + E_f V_m} \quad (9)$$

For tensile strength

$$\sigma_c = x(\sigma_m V_m + \sigma_f V_f) + (1-x) \frac{\sigma_f \sigma_m}{\sigma_m V_f + \sigma_f V_m} \quad (10)$$

where, E_f and E_m are modulus, σ_f and σ_m are strengths, V_m and V_m are volume fractions of fiber and matrix, respectively. An empirical

parameter x is introduced in Hirsch's model that characterises the stress transfer between fiber and matrix, which depends on fiber orientation, fiber length and fiber distribution (Kelly and Tyson, 1969). The value of x can be varied from 0 to 1 to give best fit.

Einstein and Guth Equations (Anshid *et al.*, 2008)

$$E_c = E_m (1 + 2.5 V_f + 14.1 V_f^2) \quad (11)$$

$$\sigma_c = \sigma_m (1 - V_f^{2/3}) \quad (12)$$

Modified Bowyer and Bader's Model (Bos, 2004)

$$E_c = E_f K_1 K_2 V_f + E_m V_m \quad (13)$$

$$\sigma_c = \sigma_f K_1 K_2 V_f + \sigma_m V_m \quad (14)$$

where K_1 change from (0-1) and K_2 are the orientation factor and length factor of fiber, respectively.

$$\text{For fibers with } L > L_c; K_2 = L - \frac{L_c}{2L} \quad (15)$$

$$\text{For fibers with } L < L_c K_2 = \frac{L_c}{2L_c} \quad (16)$$

Kelly and Tyson's Model

$$\sigma_c = \eta_o \eta_{LS} \sigma_f V_f + \sigma_m V_m \quad (17)$$

where, η_{LS} and η_o are length efficiency factor and orientation factor of fiber, respectively.

Table 3. Percentage retention in tensile properties at week six

Kenaf wt%	Tensile Strength (MPa)			Young's Modulus (GPa)		
	Dry Sample	Wet Sample	Reduction Value (%)	Dry Sample	Wet Sample	Reduction Value (%)
0	39.021	39.254	1.413	3.231	2.807	13.101
10	20.132	16.278	19.141	2.838	1.911	32.663
20	22.681	17.867	21.221	3.991	2.461	38.323
30	24.025	15.782	34.310	5.112	2.498	51.129
40	25.7595	14.991	41.803	3.998	2.634	51.810

Parallel Model (Rowell *et al.*, 1999)

$$E_c = E_f + V_f + E_m V_m \quad (18)$$

$$\sigma_c = \sigma_f + V_f + \sigma_m V_m \quad (19)$$

Modified Guth Equation (Jeefferie *et al.*, 2011)

$$E_c = E_m (1 + 0.675 S V_f + 11.62 S^2 V_f^2) \quad (20)$$

where, S is defined as the ratio of the length-to-width of fiber.

Cox-Krenchel Model

$$E_c = \eta_0 \eta_L V_f E_f + (1 - V_f) E_m \quad (21)$$

$$\eta_L = \left[1 - \frac{\tanh(\beta l_f / 2)}{\beta l_f / 2} \right] \quad (22)$$

$$\beta = \frac{2}{d_f} \left[\frac{2G_m}{E_f \ln(\sqrt{\pi} X_1 V_f)} \right]^{\frac{1}{2}} \quad (23)$$

$$G_m = \frac{E_m}{2(1 + \nu_m)} \quad (24)$$

where, G_m is shear modulus of matrix, ν_m Poisson's ratio of matrix. The value of $X_i = 4.0$ for square packing of fibers was adopted in calculation. For random in-plane fiber reinforced composites, a fiber orientation factor $\eta_o = 0.375$ can be derived (Jeefferie *et al.*, 2011).

Halpin-Tsai Model

$$E_c = E_m \left(\frac{1 + A \eta V_f}{1 - \eta V_f} \right) \quad (25)$$

$$\sigma_c = \sigma_m \left(\frac{1 + A \eta V_f}{1 - \eta V_f} \right) \quad (26)$$

$$\eta = \frac{\frac{E_m}{E_f} - 1}{\frac{E_f}{E_m} + A} \quad (27)$$

where, A is the measure of fiber geometry, fiber distribution and fiber loading conditions (Jeefferie *et al.*, 2011). Figure 13 explains a comparison of the variation in theoretical and experimental TS values of random oriented composites with weight fraction of fibers. Theoretical values were calculated using various models. It can be seen that, in all cases, TS increases regularly with an increase in the weight fraction of fibers. A near correlation between theoretical and experimentally observed TS was seen in those models predicted using modified Bowyer- Bader for $L < L_c$ and Einstein-Guth equations. The curves showing modified Bowyer- Bader for $L > L_c$, Kelly-Tyson, Hirsch and Halpin-Tsai models agree the least with the experimental values. Usually, Hirsch model is a combination of parallel and series models, which are used to describe the strength of continuous fiber reinforced polymeric composites. The stress transfer mechanism of continuous fiber composites is different from that of short fiber composites. In the case of short fiber composites, the stress transfer depends largely on fiber orientation, stress concentration at fiber ends, critical fiber length (Rowell *et al.*, 1999). Figure 14 demonstrates a comparison of the variation in experimental and theoretical YM of random oriented short fiber composites with weight fraction of fibers. It was observed that a very reasonable correlation exists between theoretical and experimental values in models, such as modified Bowyer- Bader for $L > L_c$, Kelly-Tyson, Hirsch, Cox-Krenchel and Halpin-Tsai. A near agreement is seen in the case of modified Bowyer- Bader for $L < L_c$, Einstein-Guth, modified Guth and parallel models. In Hirsch's model, the agreement between theoretical and experimental values has been found only when the value of x in Equation (6) is 0.2. From this equation, it was found that x is a parameter which determines the stress transfer between fiber and matrix. It is assumed that the controlling factors for

the value of x are mainly fiber orientation, fiber length and stress amplification effect at fiber ends, Kalaprasad *et al.* (1997).

Conclusions

Mechanical properties, mainly tensile properties of KFUPC and a comparison between experimental results and the prediction from theory of the tensile properties have been presented. Some of the models present reasonable agreement with experimental tensile properties, while, other models show no-good correlation with experimental results of randomly oriented composites. The results of this study generally discussed the water absorption characteristics and environmental effects on tensile properties of KFUPC for

different fiber content, immersion time, and fabric pre-drying. Weight percentage of fiber content plays a role in the rate of moisture uptake and overall uptake at saturated points of KFUPC. Increasing the weight percentage of fiber loading, leads to the increase in the TS and YM of composites for dry specimens, whereas increasing the weight percentage of fiber load leads to decrease in tensile properties of composites for immersion specimen due to degradation of composites. Water uptake behaviour is radically altered at increased weight fraction of kenaf fiber, and exposure to moisture results in a significant drop in tensile properties for composites due to degradation of fiber-matrix interface. At the same time the results indicated that long time aging in water increased TS of UP resin. In conclusion,

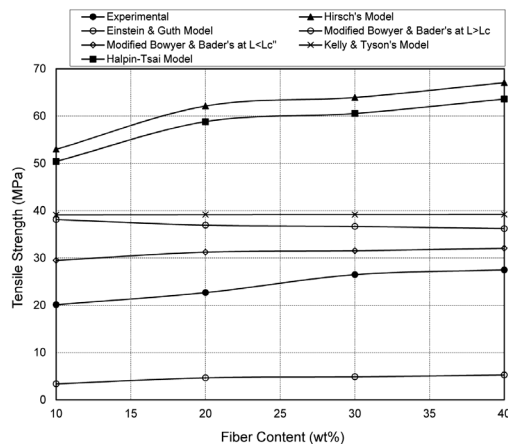


Figure 13. Variation of experimental and theoretical TS values as a function of weight fraction of fibers

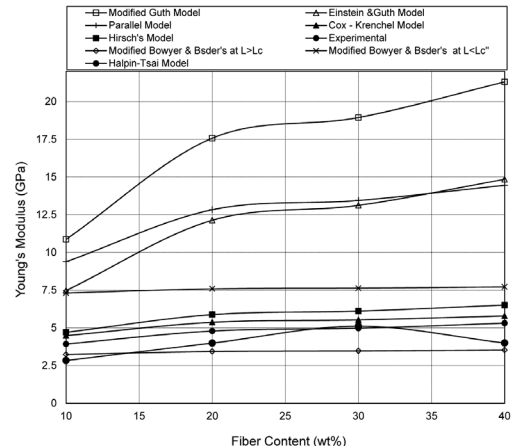


Figure 14. Variation of experimental and theoretical modulus of elasticity values as a function of weight fraction of fibers

Table 4. Zero-stress aging parameters for 42 day immersion in water

		Kenaf 0 wt%	Kenaf 10 wt%	Kenaf 20 wt%	Kenaf 30 wt%	Kenaf 40 wt%
Modulus (GPa)	α (1/sec)	0.1536	598.93	1E+20	1E+20	1E+20
	β	0.099116	0.0408	0.0127	0.015133	0.009755
Strength (MPa)	α (1/sec)	0.004	0.0926	0.7091	0.2159	408.739
	β	0.2329	0.21706	0.1022	0.2219	0.0564

KFUPC could be developed to provide best tensile properties in certain parameters. However, a best ratio of fiber-matrix is required to achieve the best properties and results.

Acknowledgment

The authors would like to express their gratitude to Swinburne University of Technology (SUT) for providing the financial support to this endeavor.

References

- Anshid, A., Haneef, A., Bindu, P., Aravind, I., and Thomas, S. (2008). Studies on tensile and flexural properties of short banana/glass hybrid fiber reinforced polystyrene composites. *J. Compos. Mater.*, 42(15):1471–1489.
- ASTM D2734-94. (2004). Standard Test Methods for Void Content of Reinforced Plastics.
- Barbero, J.E. and Damiani, T.M. (2003). Phenomenological prediction of tensile strength of E-glass composites from available aging and stress corrosion data. *J. Reinf. Plast. Comp.*, 22(4): 373-394.
- Batra, S.K. (1983). Other long vegetable fibers. In: *Handbook of Fiber Science and Technology*. Lewin M. and Pearce E.M. (eds.). Fiber Chemistry, Marcel Dekker, NY, 4:727-807.
- Beg, M.D.H. (2007). The improvement of interfacial bonding, weathering and recycling of wood fiber reinforced polypropylene composite, [Ph. D. thesis]. University of Waikato, New Zealand.
- Bos, H. (2004). The potential of flax fibers as reinforcement for composite materials, [Ph. D. thesis]. Technische Universiteit Eindhoven, Netherland.
- Cao, Y., Goda, K. and Chen, H. (2007). Research and development of green composites. *J. Mater. Res.*, 21(2):119-125.
- Chen, L., Columbus, E.P., Pote, J.W., Fuller, M.J., and Black, J.G. (1995). Kenaf bast and core fiber separation. Proceedings of international Kenaf Association conference Irving, TX, Mar 15-19.
- Dhakal, H.N., Zhang, Z.Y., and Richardson, M.O.W. (2007). Effect of water absorption on the mechanical properties of hemp fiber reinforced unsaturated polyester composites. *Compos. Sci. Technol.*, p. 1674-1683.
- Du, Y., Zhang, J., and Xue, Y.A. (2008). Temperature-duration effects on tensile properties of kenaf bast fiber bundles (Statistical Table). *Forest Prod. J.*
- Fraga, A.N., Frulloni, E., DeLa Osa, O., Kenny, J.M., and Zquez, A.V. (2007). Relationship between water absorption and dielectric behavior of glass fiber reinforced unsaturated polyester resin. *J. Compos. Mater.*, 41(4):393-402.
- France, P.W., Duncan, D.J., Smith, D.J., and Beales, K.J. (1983). Strength and fatigue of mulit-composites optical glass fibers. *J. Mater. Sci.*, 18:785-792.
- Grant, S.T. and Bradley, L.W. (1995). In-situ observations in SEM of degradation of figureite/epoxy composite materials due to seawater immersion. *J. Compos. Mater.*, 29(7):853-867.
- Harun, J., Paridah. M.T., NorAini, A.S., and Khalina, A. (2009). Kenaf-its establishment and journey towards energizing the wood-based and bicomposites industry in Malaysia. International Conference on Prospect of Jute and Kenaf as Natural Fibers; Feb 8-9, Dhakar, Bangladesh. <http://sperecycling.org/sites/sperecycling.org/files/gpec/GPEC2006/papers/13B.pdf>
- Jeefferie, A.R., Nurul, F.O., Mohd Warikh, A.R., Yuhazri, M.Y., Sihombing, H., and Ramli, J. (2011). Preliminary study on the physical and mechanical properties of tapioca starch/sugarcane fiber cellulose composite. *J. Eng. Appl. Sci.*, 6(4):7-15.
- Kalapasad, G., Joseph, K., and Thomas, S. (1997). Theoretical modelling of tensile properties of short sisal fibre-reinforced low-density polyethylene composites. *J. Mater. Sci.*, 32: 4261- 4267.
- Kelly, A. and Tyson, W.R. (1969) Tensile properties of fiber-reinforced metals: copper/tungsten and copper/molybdenum, *J. Mech. Phys. Solids*, 13:329-336.
- Lee, B.H., Kim, H.J and Yu, W.R. (2009). Fabrication of long and discontinuous natural fiber reinforced polypropylene biocomposites and their mechanical properties. *Fiber. Polym.*, 10(1):83- 90.
- LeVan, S.L. and Winandy, J.E. (1990). Effects of fire retardant treatment on wood strength: A review. *Wood Fiber Sci.*, 22(1):113-131.
- Mohanty, A.K., Misr, M., and Drzal, L.T. (2005). Natural fibers, biopolymers, and Biocomposites. CRC press, Boca Raton, Florida, p. 101-110.
- Mokhtar, M., Rahmat, A., and Hassan, A. (2007). Characterization and treatments of pineapple leaf fiber thermoplastic composite for construction application, Royal Military College RMC, Malaysia Available: <http://eprints.utm.my/2853/1/75147.pdf>
- Najafi, S.K. and Kordkheili, H.Y. (2011). Effect of sea water on water absorption and flexural properties of wood-polypropylene composites. *Eur. J. Wood Wood Prod.*, 69(4):553–556.
- Najafi, S., Sharifnia, H., and Tajvidi, M. (2008). Effect

- of water absorption on creep behavior of wood plastic composites. *J. Compos. Mater.*, 42(10): 933–1002.
- Nóbrega, M.M.S., Cavalcanti, W.S., Carvalho, L.H., and Lima, A.G.B. (2010). Water absorption in unsaturated polyester composites reinforced with caroá fiber fabrics: modeling and simulation. *Material Science and Engineering Technology*, 41(5):300-305.
- Ochi, S. (2010). Tensile properties of kenaf fiber bundle. SRX Materials Science, ID. 152526.
- Ochi, S., (2008). Mechanical properties of kenaf fibers and kenaf/PLA composites. *Mech. Mater.*, 40: 446–452.
- Osman, E.A., Vakhguelt, A., Sbarski, I., and Mutasher, S.A. (2011). Mechanical properties of kenaf - unsaturated polyester composites: effect of fiber treatment and fiber length. *Adv. Mater. Res.*, 311:260-271.
- Öztürk, S. (2010). Effect of fiber loading on the mechanical properties of kenaf and fiberfrax fiber reinforced phenol-formaldehyde composite. *J. Compos. Mater.*, p. 1-24.
- Rashdi, A.A.A., Sapuan, S.M., Ahmad, M.M.H.M., and Khalina, A. (2009). Water absorption and tensile properties of soil buried kenaf fiber reinforced unsaturated polyester composites (KFRUPC). *J. Agric. Environ.*, 17(3-4):909-911.
- Rashdi, A.A.A., Sapuan, S.M., Ahmad, M.M.H., and Khalin, M. (2010). Combined effects of water absorption due to water immersion, soil buried and natural weather on mechanical properties of kenaf fiber unsaturated polyester composites (KFUPC). *J. Int. Mech. Mater. Eng.*, 5(1): 11-17.
- Roger, M.R., Anand, R.S. and Daniel, F.C. (1997). Utilization of natural fibers in plastic composites: problems and opportunities. In *Lignocellulosic-Plastics Composites*. Leao, A.L., Carvalho, F.X., and Frollini, E. (eds.). USP and UNESP, Brazil.
- Rowell, R.M., Sanadi, A., Jacobson, R., and Caulfields, D. (1999). Test using canola oil. In: *kenaf properties, processing and products*; Mississippi State University. Ag. Bio Engineer., p. 381-392.
- Sartorius User's Manual. (2008). Density Determination Kit, 98647-002-37.0000.
- Seber, D.H. and Lolyd, D.H. (1996). East fiber applications for composites, In *Proceedings of Thirtieth International Particleboard/Composite Materials Symposium*; Pullman; Washington, p. 215-235.
- Shenoy, M.A. and DMelo, D.J. (2009). Effect of water on mechanical properties of unsaturated polyester-acetylates hydroxypropyl guar gum composites. *J. Reinf. Plast. Comp.*, 28(21):2561-2576.
- Shibata, S. and Fukumoto, I. (2006). Effects of bamboo and kenaf fibers on the mechanical properties of lightweight porous composites, GPEC conference Feb. 28 Orland, Florida, USA.
- Wambua, P., Ivens, J., and Verpoest, I. (2003). Natural fibers: can they replace glass in fiber reinforced plastics? *J. Compos. Sci. Technol.*, 63:1259–1264.
- Zabihzadh, M.S. (2010). Flexural properties and orthotropic swelling behavior of bagasse/thermoplastic composites. *BioResources*, 5(2):650-660.

