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

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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 (Wambia 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 distil 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).

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

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 2. Cross section and diameters measurements of kenaf fiber

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 crisples 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-
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/cm$^3$ as taken from the average of 10 samples. The density of canola oil was calculated using Equation (1)

$$\rho(f_l) = \frac{W}{V}$$  \hspace{1cm} (1)

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

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

$$\rho = \frac{W(a)\rho(f_l)}{0.99983 \ G} + 0.0012$$ \hspace{1cm} (2)

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**Table 1. Kenaf holocellulose content**

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

\[
\rho_{\text{theor}} = \frac{1}{w_f + w_m} \left( \frac{\rho_f}{w_f} + \frac{\rho_m}{w_m} \right)
\]

(3)

where, \( w \) and \( \rho \) 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).

\[
V = 1 - \rho_c \left[ \frac{w_f}{\rho_f} + \frac{w_m}{\rho_m} \right]
\]

(4)

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](image)

**Table 2. Physical properties of kenaf fiber**

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Density (g/cm³)</th>
<th>Tensile strength (MPa)</th>
<th>Young modulus (GPa)</th>
<th>Fiber diameter (mm)</th>
<th>Fiber length (mm)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenaf fiber</td>
<td>1.386</td>
<td>110-358</td>
<td>17-25</td>
<td>0.061</td>
<td>1-6</td>
<td>Current</td>
</tr>
<tr>
<td>1.45</td>
<td>930</td>
<td>53</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>(Mohanty <em>et al</em>., 2005)</td>
</tr>
<tr>
<td>1.2</td>
<td>400</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>(Seber and Lolyd, 1996)</td>
</tr>
<tr>
<td>-</td>
<td>250-600</td>
<td>14-39</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>(Ochi, 2008)</td>
</tr>
<tr>
<td>-</td>
<td>335</td>
<td>22</td>
<td>0.106</td>
<td>-</td>
<td>-</td>
<td>(Shibata and Fukumoto, 2006)</td>
</tr>
<tr>
<td>1.5</td>
<td>350-600</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Kenaf Eco Fiber</td>
</tr>
<tr>
<td>1.4</td>
<td>250</td>
<td>4.3</td>
<td>0.081</td>
<td>60</td>
<td>-</td>
<td>(Lee <em>et al</em>., 2009)</td>
</tr>
<tr>
<td>-</td>
<td>223</td>
<td>15</td>
<td>0.14</td>
<td>8-12</td>
<td>-</td>
<td>(Öztürk, 2010)</td>
</tr>
<tr>
<td>1.04</td>
<td>448</td>
<td>24.6</td>
<td>0.078</td>
<td>-</td>
<td>-</td>
<td>(Cao <em>et al</em>., 2007)</td>
</tr>
<tr>
<td>-</td>
<td>135-232</td>
<td>15-24</td>
<td>0.024</td>
<td>2.48</td>
<td>-</td>
<td>(Harun <em>et al</em>., 2009)</td>
</tr>
<tr>
<td>UP</td>
<td>1.12</td>
<td>39</td>
<td>3.231</td>
<td>-</td>
<td>-</td>
<td>(Osman <em>et al</em>., 2011)</td>
</tr>
</tbody>
</table>
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
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 in no reduction effect on the UP after aging. Swelling of natural fiber as a result of prolonged immersion to water leaded 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).

\[ E(t) = E_0 (1 + \alpha t)^\beta \]  
\[ \sigma(t) = \sigma_0 (1 + \alpha t_0)^\beta \]

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 $\sigma_o$ are modulus and strength respectively, at time zero, at the environment of exposure, $\alpha$ and $\beta$ 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, $\sigma_f$ and $\sigma_m$ are strengths, $V_m$ and $V_f$ 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)

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

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

**Modified Bowyer and Bader’s Model** (Bos, 2004)

$$E_c = E_f K_1 K_2 V_f + E_m V_m$$

$$\sigma_c = \sigma_f K_1 K_2 V_f + \sigma_m V_m$$

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

For fibers with $L > L_c$ ; $K_2 = \frac{L - L_c}{2L}$

For fibers with $L > L_c$ $K_2 = \frac{L_c}{2L_c}$

**Kelly and Tyson’s Model**

$$\sigma_c = \eta_0 \eta_{LS} \sigma_f V_f + \sigma_m V_m$$

where, $\eta_{LS}$ and $\eta_o$ are length efficiency factor and orientation factor of fiber, respectively.

---

**Table 3. Percentage retention in tensile properties at week six**

<table>
<thead>
<tr>
<th>Kenaf wt%</th>
<th>Tensile Strength (MPa)</th>
<th>Young’s Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry Sample</td>
<td>Wet Sample</td>
</tr>
<tr>
<td>0</td>
<td>39.021</td>
<td>39.254</td>
</tr>
<tr>
<td>10</td>
<td>20.132</td>
<td>16.278</td>
</tr>
<tr>
<td>20</td>
<td>22.681</td>
<td>17.867</td>
</tr>
<tr>
<td>30</td>
<td>24.025</td>
<td>15.782</td>
</tr>
<tr>
<td>40</td>
<td>25.7595</td>
<td>14.991</td>
</tr>
</tbody>
</table>
Effect of Water Absorption on Tensile Properties of Kenaf Fiber

Parallel Model (Rowell et al., 1999)

\[ E_c = E_f + V_f + E_m V_m \]  \hspace{1cm} (18)

\[ \sigma_c = \sigma_f + V_f + \sigma_m V_m \]  \hspace{1cm} (19)

Modified Guth Equation (Jeefferie et al., 2011)

\[ E_c = E_m (1 + 0.675 SV_f + 11.62 S^2 V_f^2) \]  \hspace{1cm} (20)

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

Cox-Krenchel Model

\[ E_c = \eta_0 \eta_L V_f E_f + (1 - V_f) E_m \]  \hspace{1cm} (21)

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

\[ \beta = \frac{2}{d_f} \left\{ \frac{2G_m}{E_f \ln(\sqrt{\pi} X_i V_f)} \right\}^{\frac{1}{2}} \]  \hspace{1cm} (23)

\[ G_m = \frac{E_m}{2(1 + V_m)} \]  \hspace{1cm} (24)

where, \( G_m \) is shear modulus of matrix, \( \nu_m \) 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

\[ E_c = E_m \left( \frac{1 + A \eta V_f}{1 - \eta V_f} \right) \]  \hspace{1cm} (25)

\[ \sigma_c = \sigma_m \left( \frac{1 + A \eta V_f}{1 - \eta V_f} \right) \]  \hspace{1cm} (26)

\[ \eta = \frac{\sigma_m / \sigma - 1}{\sigma_m / \sigma + A} \]  \hspace{1cm} (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 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,

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

<table>
<thead>
<tr>
<th></th>
<th>Kenaf 0 wt%</th>
<th>Kenaf 10 wt%</th>
<th>Kenaf 20 wt%</th>
<th>Kenaf 30 wt%</th>
<th>Kenaf 40 wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus (GPa)</td>
<td>α (1/sec)</td>
<td>0.1536</td>
<td>598.93</td>
<td>1E+20</td>
<td>1E+20</td>
</tr>
<tr>
<td></td>
<td>β</td>
<td>0.099116</td>
<td>0.0408</td>
<td>0.0127</td>
<td>0.015133</td>
</tr>
<tr>
<td>Strength (MPa)</td>
<td>α (1/sec)</td>
<td>0.004</td>
<td>0.0926</td>
<td>0.7091</td>
<td>0.2159</td>
</tr>
<tr>
<td></td>
<td>β</td>
<td>0.2329</td>
<td>0.21706</td>
<td>0.1022</td>
<td>0.2219</td>
</tr>
</tbody>
</table>

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**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
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.

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References


