WATER ABSORPTION BEHAVIOR AND ITS EFFECT ON THE MECHANICAL PROPERTIES OF KENAF NATURAL FIBER UNSATURATED POLYESTER COMPOSITES

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Keywords: *kenaf fiber, natural fiber composites, Water absorption, Flexural Strength, unsaturated polyester, Diffusion coefficient*

Abstract

Treated kenaf fiber reinforced unsaturated polyester composites at different weight fractions (0, 10, 20, 30 and 40wt %) are fabricated and evaluated by their immersion in tap water at two different temperatures of 25 ºC and 50 ºC. The results showed that the percentage of water absorption increases with increasing of fiber weight fractions and environmental temperature. The process of absorption of water was found to approach the Fickian diffusion behavior for both various temperatures. Water diffusion coefficients were evaluated and the results showed that they increase with the increasing environmental temperature and fiber weight fractions. Furthermore the results indicate that the flexural properties of the composites decreased drastically on exposure to moisture results due to degradation of the fiber-matrix interface. A scan electron microscopy SEM shows that at high environmental temperatures a deboning developed between the fiber and matrix, which is causing a majority of fiber to fail by fiber pull out mode failure. In addition microcracks developed at the interface between the fiber and the matrix.

1. Introduction

Kenaf fiber and its composites are hydrophilic materials. Moisture content in kenaf fiber composites significantly affects their physical and mechanical properties. Moisture transfer in these composites influences dimensional stability and durability. The absorbed moisture results in to the deterioration of mechanical properties since the water not only affects the unfilled polymer matrices physically and/or chemically but also attacks the hydrophilic natural fiber as well as the fiber-matrix interface [1]. Unsaturated polyester composites are known for their poor resistance to aromatic solvent, due to the styrene as a reactive diluent [2]. Based on experiments on moisture uptake and assuming one – dimension diffusion based on Frick’s law, several researchers have discussed characteristics of moisture absorption. Moisture diffusion in polymeric composites has been shown to be Fickian and non – Fickian [3-5]. It is important therefore that this problem is addressed in order that natural fiber may be considered as a viable reinforcement in composite materials. Flexural properties of kenaf unsaturated polyester composites have been reported by Ishak et al [6], and the overall results shows that the optimum fiber content was 10wt%. Water absorption and thickness swelling behavior of recycle natural fiber plastic composites have been reported by Tajvidi et al. [7], the result shows that for a given fiber loading depends on a wide array of factors including interface quality, chemical composition, fiber length and distribution and density, these results confirmed that generally the recycle process enhances water resistance and dimensional stability in the studied formulations. The mechanism of water transport in hybrid composites was investigated by Ghasemi et al. [8], who found that the water moisture absorption of all formulations approach the Fickian diffusion case. The aim of this research is to study the suitability of these composites in outdoor applications. Therefore, the water absorption behavior of kenaf fiber unsaturation polyester composites for two different temperatures of 25 ºC and 50 ºC and various weight fractions of fiber is investigated. Furthermore, the effect of water absorption on flexural properties, on kenaf fiber composites was reported.

2. Experimental

2.1. Composites Fabrication

A hand layup process was used for the fabrication process. Specimens from 0% to 40%, with increments of 10%, weight percentage of fibres were fabricated. The prepared resins were blended to fiber size (1-6) mm. Certain composites specimens were then post cured in an oven for 5 hrs. at 60 º C.

2.2 Water Absorption Test

Water absorption test were carried out according to ASTM D570-81. The specimens with dimensions of (127, 12.7, 3.2 mm) were selected and dried in an oven for 5 hr at 60 ºC. The weight was measured to a precision of 0.0001g using four digit balances. The specimens were then placed in tap water at 25 ºC (room temperate) and 50 ºC. For measurement, specimens were removed from the water, the surface water was wiped off using a soft dry cloth, and the specimens were weighed. After weight measurement the sample were immersed again in water. The process was continued until the saturation period was reached after 911 hrs. The values of the water absorption were calculated using the following formula [9, 10],

$$W(\%) = \frac{W_{(t)} - W_o}{W_o} \times 100 \qquad (1)$$

Where W_o and $W_{(t)}$ denote the oven-dry weight and weight after time *t*, respectively.

2.3 Flexural Test

Flexural strength was measured under a three-point bending approach using a universal testing T-machine according to ASTM D790. The dimensions of the samples were 127mm x 12.7mm x 3.2mm. The distance between the spans was 100mm, and the strain rate was 5 mm/min. Four specimens were tested for each case, the average was reported as a results.

3. Results and Discussions

3.1 Absorption Behavior

The percentage of water absorption in the composites depended on two parameters, fiber content and environment temperatures. The results show that the water absorption increases with increments of fiber content and surrounding temperature as shown Figs.1 and 2. It can be seen that the composites absorb water very rapidly at the initial stage, and later at 335 hrs. and 671 hrs at 50 °C and 25 °C, respectively a saturation level was attained without any further increase in water absorption.

3. 2 Mechanism of Water Transport

There are three major mechanisms of moisture absorption in natural fiber composites. First diffusion of water molecules inside the microgaps between polymer chains; second the capillary transport of water molecules into the gaps and flaws at the interface between fibers and the polymer due to the incomplete wettability and; finally the third mechanism is the transport of water molecules by micro cracks in the matrix, formed during the compounding process [11, 12, 13]. With this, there are three known cases of diffusion behavior [8, 14, 15] which are: Case 1 or Fickian diffusion, in which the rate of diffusion is much less than that of the polymer segment mobility. The equilibrium inside the polymer is rapidly reached and it is maintained with independence of time. Case 2 is relaxation control, in which penetrant mobility is much greater than other relaxation processes. This diffusion is characterized by the development of a boundary between the swollen outer part and the inner glassy core of the polymer. The boundary advances at a constant velocity and the core diminishes in size until an equilibrium penetrant concentration is reached in whole polymer. Case 3 is when anomalous diffusion occurs where the penetrant mobility and the polymer segment relaxation are comparable. It is then, an intermediate behavior between cases 1 and 2 diffusion. These three cases of diffusion can be distinguished theoretically by the shape of the sorption curve represented by:

$$\frac{M_t}{M_\infty} = kt^n \qquad (2)$$

and

$$\log(\frac{M_t}{M_\infty}) = \log(k) + n\log(t) \quad (3)$$

Where, M_t, M_∞, k, and n are the water absorption at time t, the water absorption at the saturation point, and constants, respectively. The value of n is different for each case as follows: case 1, n = 0.5, case 2, n > 0.5, and case 3, 0.5 < n <1. The coefficients (n and k) are calculated from slope and intercept of log plot of M_t/M_∞ versus time which can draw from experimental data. Fig. 3 is an example of the fitting of the experimental data for 20wt% at 25 ^{o}C and 50 ^{o}C environmental temperatures. Table 1 presents the values of k and n resulting from the fitting of formulations at different temperatures. The moisture uptake results in Table 1 show the values of slope for both various temperatures are closed to n= 0.5. Therefore, it can be concluded that the water and moisture absorption of all formulations approach the Fickian diffusion behavior. The diffusion coefficient (D) is the most important parameter of Fick's model, which shows the ability of the water molecules to penetrate inside the composite. The diffusion coefficient can be calculated using the following equation [16, 17].

$$D = \pi\left(\frac{mh}{4M_\infty}\right)^2 \quad (4)$$

Where, m is the initial slope of a plot of M_t versus $t^{1/2}$, and h is the thickness of the composite specimens. Fig. 4 shows the calculated values of D at different weight fractions of fiber and environmental temperatures. Figs. 5 and 6 show the diffusion curve fitting for composite for diffusion coefficients. The results show the water diffusion coefficients increase with the increment of fiber content for fixed environment conditions, and increases with temperature increase as Fig. 4 shows. This is due to increment in water uptake for higher temperatures.

3.2 Effect of Moisture Absorption on the Flexural Properties

The flexural strength and modulus versus fiber weight fraction results for these samples are shown in Figs.7 and 8. at different conditions. For dry fiber both flexural strength and modulus was found to increase significantly as the fiber weight fraction increased until 20wt%. The maximum flexural strength and modulus dry composites 69.6 MPa and 4.28 GPa, respectively. After this increment the flexural strength and modulus drops dramatically as the fiber weight fraction increases. The flexural properties of the composites decreased drastically on exposure to water immersion, with increasing of fiber content and environmental temperatures. At 20wt% the flexural strength was 25.17MPa and 16.44MPa at 25 °C and 50 °C, respectively as Fig. 7 shows. The same trend appears for flexural modulus, with 1.67 GPa and 1.18 GPa at 25 °C and 50 °C, respectively. Decreased in flexural properties after water immersion due to formation of hydrogen bonding between the water molecules and cellulose fiber [18, 19]. This leads to dimensional and colour variation of composites product and poor interfacial bonding between the fiber and matrix, causing a decrease in the flexural properties.

3.3 Morphology

Fig. 9 shows the SEM micrograph of the bending fractured surface of kenaf fiber composite for 20wt% fiber content at various temperatures. In this case fiber fracture and pull out were noticed and the sudden failure of the bending specimen caused the fiber to split; resulting in fine fibrils being exposed. It could be observed that in the all cases the fibers were still embedded in the resin together with some cavities left by pulled-out fibers. Fiber debonding was observed in Fig. 9 b. In addition, it could be seen there was a fiber misalignment and entanglement. Fiber alignment factors play a crucial role in the overall properties of composites. The random orientation of fibers produces lower mechanical properties compared to long uni-directionally orientated fibers. This fiber entanglement can create resin rich areas, which can contribute to the formation of voids and porosity [11]. At high environmental temperatures a deboning developed between the fiber and matrix, causing a majority of fiber to fail by fiber pull out mode failure as shown in Fig 9b. It is interesting to note that there is a resin particle on the surface of fiber at 25 ^{o}C as shown in Fig. 10a. The reason is due to microcracks that developed at the interface between the fiber and the matrix. As the cracks developed material was lost, most likely in the form of resin particles.

4. Conclusions

The effect of water absorption on the flexural properties of kenaf fiber reinforced unsaturated polyester composites have been studied following immersion at two temperatures of 25 °C and 50 °C. It shows that moisture uptake increases with fiber weight fractions due to increased voids, cellulose content and poor interfacial bonding between the fiber and matrix. In addition the moisture uptake increases with rising environmental temperature due to increase the velocity of water motion inside the composites. The water absorption patterns of these composites at both temperatures are found to follow Fickian behavior. The values obtained for diffusion coefficients are in agreement with the range of values reported, in the order of 10^{-12} m^2/sec. The flexural properties of the composites decreased drastically on exposure to moisture results due to degradation of the fiber-matrix interface.

5. Acknowledgments

The authors wish to acknowledge Swinburne University of Technology (SUT) for financial support.

6. References

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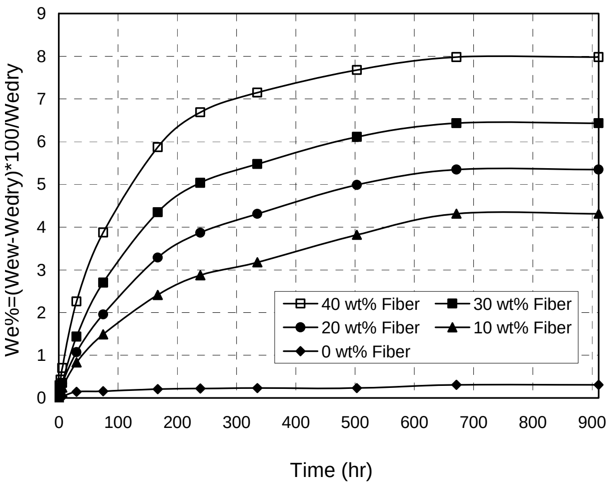


Fig.1. Water absorption of kenaf/unsaturated polyester composites for temperature 25 ºC

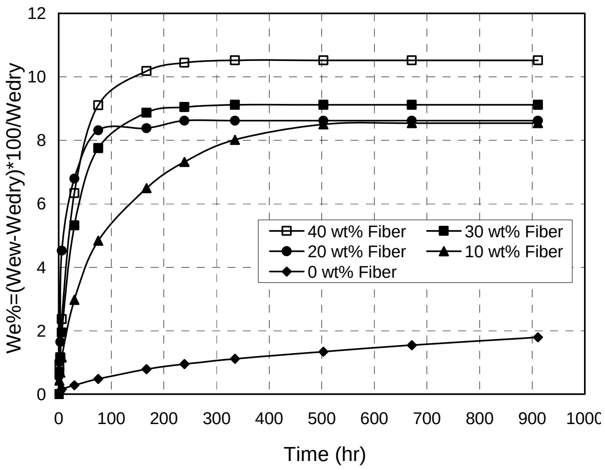


Fig.2. Water absorption of kenaf/unsaturated polyester composites for temperature 50 ºC

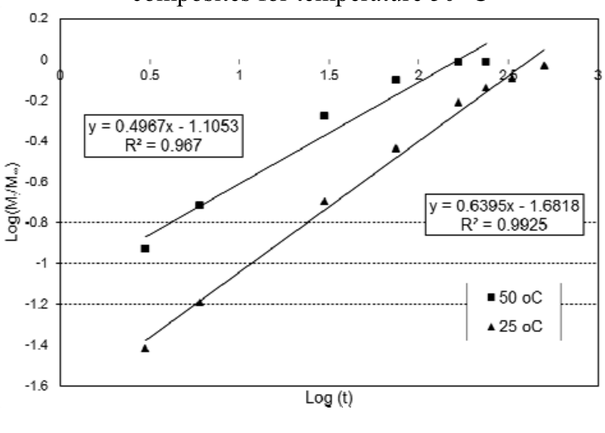


Fig. 3. Diffusion curve fitting plots for 20wt% fiber composites for various temperatures to determine constant *n* and *k*

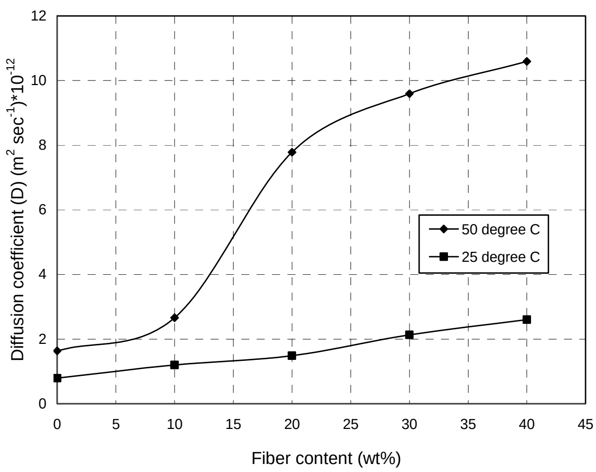


Fig.4. Diffusion coefficient for composites at various temperatures

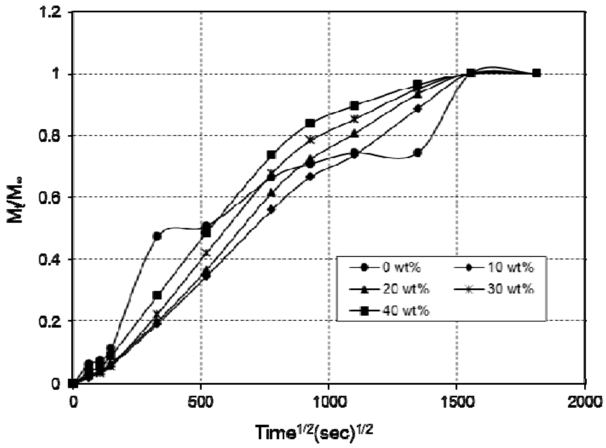


Fig. 5 Diffusion curve fitting plots for composite diffusion coefficient at 25 ^{o}C

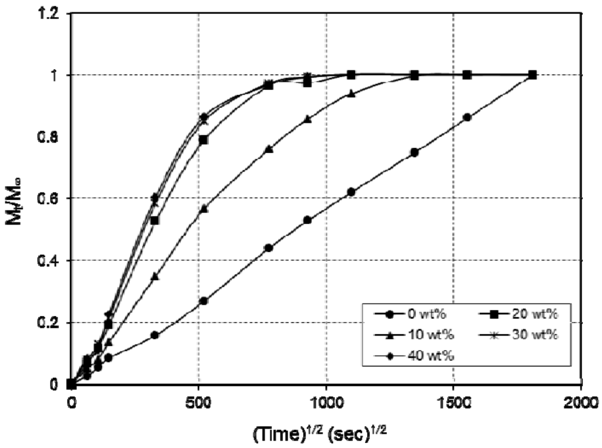


Fig. 6 Diffusion curve fitting plots for composite diffusion coefficient at 50 ^{o}C

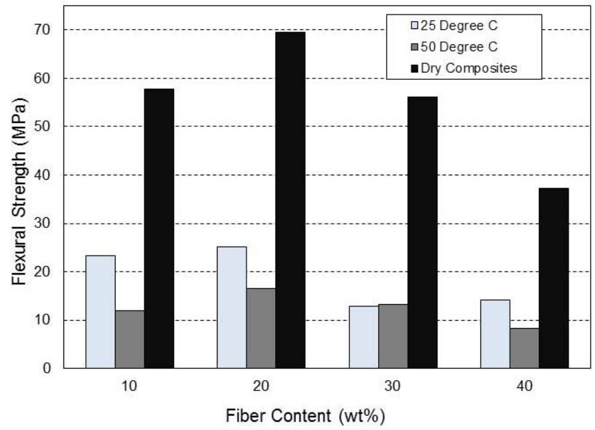


Fig. 7 effect of moisture uptake on the flexural strength

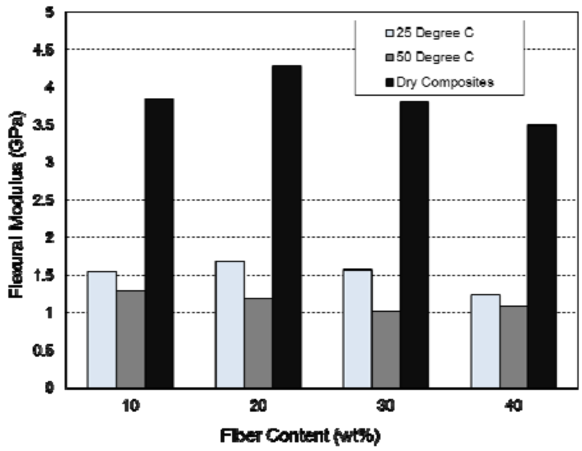
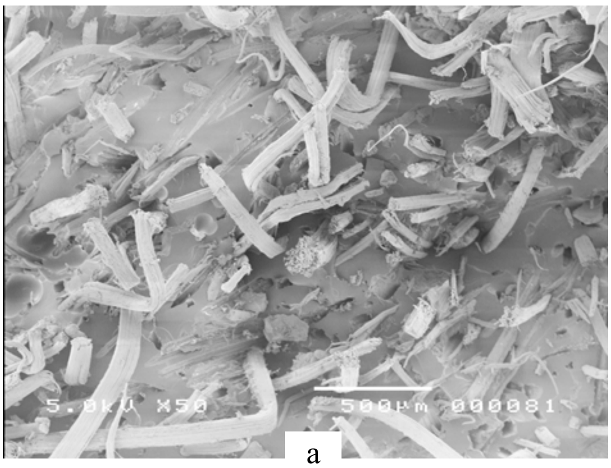


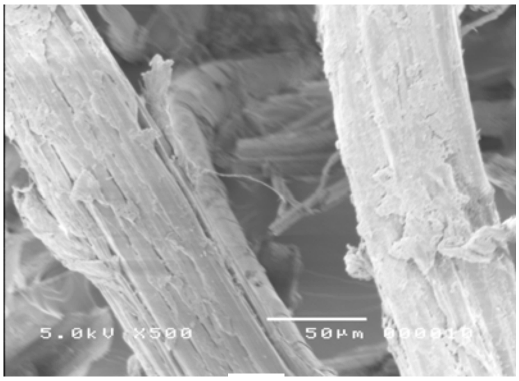
Fig. 8 Effect of moisture uptake on the flexural Modulus



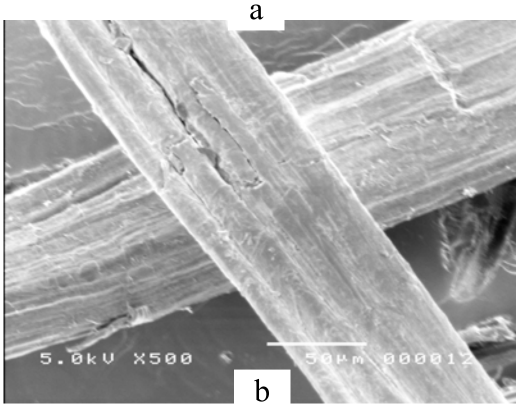
a

b

Fig. 9 SEM micrograph of bending fractured surface of the composites: (a) 25 °C at 37 days, (b) 50 °C at 37 days



a



b

Fig. 10 SEM micrograph of fiber surface, a) 25°C at 37 days, b) 50°C at 37 days

Table 1 Moisture sorption constant for all formulations

Fiber wt%	25°C		50 °C	
	n	k	n	k
0	0.4032	1.1128	0.5111	1.5073
10	0.6256	1.6823	0.4986	1.2605
20	0.6395	1.6818	0.4967	1.1053
30	0.685	1.7543	0.4783	1.0482
40	0.5838	1.486	0.4976	1.0829