Universiti Malaysia Terengganu Journal of Undergraduate Research *eISSN: 2637-1138*
Volume 2 Number 2, April 2020: 23-32

AN INVESTIGATION OF KENAF PLANT FIBRES AS REINFORCEMENTS IN INTERWOVEN KENAF/POLYETHYLENE TEREPHTHALATE (PET)/EPOXY HYBRID GREEN COMPOSITES

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Abstract: Renewable materials have some bearing on the environment and have since increased research works related to polymer composites. This work was conducted to investigate the effects of interwoven kenaf fibres and the use of kenaf fibres in composites. In this research, interwoven between kenaf and polyethylene terephthalate (PET) was prepared and epoxy was used as the polymer matrix to form composites. The kenaf fibre composites with various kenaf fibre contents (2, 5, 8, and 10 wt %) interwoven with (PET) fibres were prepared by using open mould method. The properties of kenaf/PET/epoxy composites (KPTE) were studied. The kenaf fibre composites characterization was determined based on their mechanical properties, water absorption, morphology and thermal properties. The tensile strength test was performed using Testometric machine. The finding shows that the strength increases as the amount of kenaf fibres in the composites increases. The composites with 10% kenaf fibres interwoven PET displayed the highest tensile strength (85.3 ± 2.9 MPa) while unfilled epoxy show the lowest tensile strength (64.1 ± 16.5 MPa). The addition of kenaf fibres minimally increases the water absorption up to about 1.4%. The increases of kenaf fibres also reduces the overall thermal stability of the composites compared to the PET and epoxy resin composites. The morphology properties of KPTE composites support the tensile properties surface of the composites. This study assists to propose the kenaf fibres as a potential filler for properties improvements in epoxy-based composites contributing to the development of another environment-friendly material.

Keywords: Composites, reinforcement, Kenaf plant fibres, PET, epoxy

Introduction

Plant fibres have become a magnet for many researchers to study these renewable materials as an alternative for reinforcement in polymer composites due to their notable properties i.e. bio-degradable, low in weight, good mechanical properties and non-abrasive. The examples of these fibres are banana, pineapple, hemp, coir, and kenaf fibres. In this work, the plant fibres used are kenaf fibres. Kenaf fibres are known to be free from health hazard, strong, and hence have potential to be used as materials for building materials, shipping, packaging and automotive applications (Akil *et al.,* 2011; Marzuki *et al.,* 2018). Despite the advantages, kenaf fibres suffer from some limitations such as poor moisture resistance especially absorption and low strength compared to synthetic fibres such as glass (Abdul Khalil *et. al,* 2010). Researchers have investigated that plant fibres can be hybridised with synthetic fibres and the performance of plant fibres can been enhanced by treatment. A series of works on developing natural fibre composites have been noticed by combining different types of fibres and resins (Jawaid *et al.,* 2011; Ahmad *et al.,* 2018). The orientation of the fibres in polymer composites could also affect the performance of the polymer. Hence, this study presents the investigation of the kenaf plant fibres as renewable materials interwoven with PET and epoxy as their polymer matrix in order to investigate their performance as hybrid polymer composites.

Materials and Methods

Materials

Materials used in this study were kenaf plant fibres, PET and epoxy resin. The kenaf fibres, PET, and epoxy resin were obtained from a local supplier in Malaysia. MIRACON epoxy resin was used as the polymer matrix and mixed with hardener 8161.

Methods

Interwoven fabrics were produced using wooden frames measuring 400 x 400 mm. Interwoven kenaf with the percentage weight of 2, 5, 8 and 10 with PET was produced. The orientation is as follows:

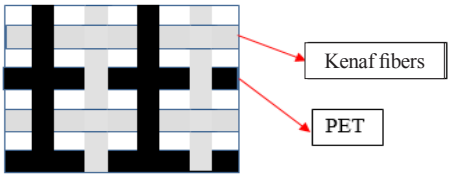


Figure 1: The interwoven fabric containing kenaf and PET fibres

The epoxy matrix for this study was prepared by using the ratio 2:1 by weight for resin and hardener 8161. The epoxy and hardener were mixed and stirred up for ten minutes in a mix container. The internal surface of the glass mould was sprayed with a release agent and the resistance transparent plastic (mylar) was placed at the bottom of the mould prior to pouring the mix into the mould and the woven kenaf/PET fabric was then positioned in the mould. Then, the balance of matrix solution was poured in that mould. The mylar was put at the top of the specimen and the prepared composites were compressed using an 18 kg weight. The weight was left at half an hour. Then, the composites were left at the room temperature for 24 hours. The composites were cut into rectangular size for testing and characterization of water absorption, tensile, morphological and thermal properties.

Tensile testing on interwoven kenaf/PET/epoxy hybrid green composites was performed in order to establish the mechanical properties of the composites. The tensile strength, the Young's Modulus and elongation at break of the kenaf/PET/epoxy composites were investigated using a Testometric M350-10CT Universal Testing Machine. Specimens with dimensions of 130 x 19 x (3.2 ± 0.4) mm^3 were prepared using a cutting tool. An average value from five replicates was determined. Tensile testing was performed on unfilled epoxy resin, woven PET/epoxy and interwoven kenaf/PET/epoxy composites at following kenaf fibres contents 2, 5, 8 and 10%.

Scanning electron microscopy (SEM) was used to investigate the tensile-fractured surface of different hybrid composites. For each composite material, there are different magnifications were used to investigate the morphology of the composite's surfaces.

Thermal property analysis was performed using TGA Q500 machine. The thermal investigation was performed under nitrogen at a flow rate of 20 ml/min. Heating of the specimen on a platinum pan was carried out to maintain its temperature during the measurements. At a heating rate of 10°C/min, the specimen was then heated from 30 to 800°C.

The water absorption of the composites was determined whereby each specimen, measuring 30 x 30 x (3.2 ± 0.4) mm, was submerged in a container of purified water, at room temperature (25°C), for a period of up to 350 hours. The water absorbed was then recorded in mass and the moisture content percentage was calculated using the following equation:

$$\Delta(t)=[(M_t - M0)/M0]\text{x}\,100 \quad (1)$$

where M_0 and Mt are the masses of the dry sample and immersed sample, respectively, at any specific time.

Results and Discussion

Mechanical Properties

Tensile Strength

Figure 2 shows the tensile strength of interwoven kenaf/PET/epoxy (KPTE) composites with different contents of kenaf fibres. Composites with 10 wt% kenaf fibres (KE) displayed the highest tensile strength as compared to the composites with 2, 5 and 8 wt% kenaf fibres (KPTE) composites which is 85.3 ± 2.9 MPa. Unfilled resin (0 wt% kenaf fibres) displays the lowest tensile strength (64.1 ± 16.5 MPa).

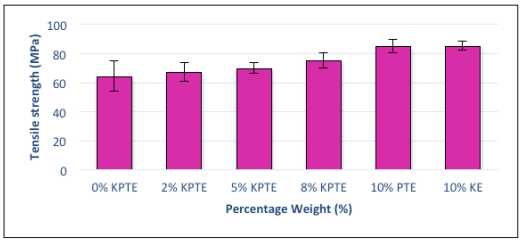


Figure 2: Tensile strength of epoxy and epoxy-based composites

The tensile strength increases as the amount of kenaf fibres in the composites increases. Strength of the composites can be increased by increasing of kenaf fibres content in the composites (Mahjoub *et al,* 2013). This is due to kenaf fibres are well bonded by matrix and thus good matrix adhesion occur. A similar study also reported that as the content of kenaf fibres increased, the tensile modulus, tensile strength and flexural properties also increased (Jawaid *et al.,* 2011).

Figure 2 also indicates that the tensile strength of composites with 10 wt% PET/epoxy (PTE) have higher tensile strength than that of KPTE composites (0, 2, 5 and 8 wt%) but lower than that of composite (10 wt% KE) which is 84.8 MPa. Two composites namely 10 wt% PET/epoxy (PTE) and 10 wt% KE composites have a little difference in terms of tensile strength which is only 0.5 MPa. The inclusion of PET can also increase the strength of the composites. This is quite expected, since other studies have also indicated that the synthetic fibres like polypropylene, polyethylene, notably PET are used in various applications due to their good mechanical properties and relatively low cost of production (Mather & Wardman, 2011). However, synthetics fibres like PET is not good to the environmental and health. The uses of synthetic fibres in industry cause problems with respect to health and safety such as skin irritations during handling of fibre products and processing of fibre reinforced parts (Kim *et al.,* 2012).

From Figure 2, the addition of 2, 5, and 8 wt% KPTE hybrid composites also increases the tensile strength of the composites. However, from the observed SEM image it is obvious that more fibres were pulled out for composites with 8 wt% kenaf fibres (Figure 9) as compared to that of 10 wt% kenaf fibres (Figure 7). Many fibres pull outs as shown by the large number of unbroken fibres sticking out of the fracture surface suggest that there is a lack of bonding between kenaf fibres with PET and the composite matrix. Kenaf fibres are not well bonded by matrix with PET and hence contributes to a poor matrix adhesion. The couplings constraints between kenaf fibres and synthetic PET fibres are due to the difference in structure between these two fibres resulting in an ineffective stress transfer. There are several factors affecting composites performance such as orientation, strength, physical properties of fibres and interfacial adhesion (Kakroodi *et al.,* 2014).

Young's Modulus

Figure 3 shows that the inclusion of kenaf & PET fibres increases the Young's modulus of the composites. The highest value of Young's modulus is at 10 wt% KE which is 2115.2 MPa, while the lowest value is for unfilled epoxy resin (0 wt% kenaf fibres) which is 1528.48 MPa. The inclusion of kenaf fibres and PET as well their combination increases the rigidity of composites. It is reported that an increase in composite fibre contents results in increment in composites' stiffness and stress transfer (Shinoj *et al,* 2011).

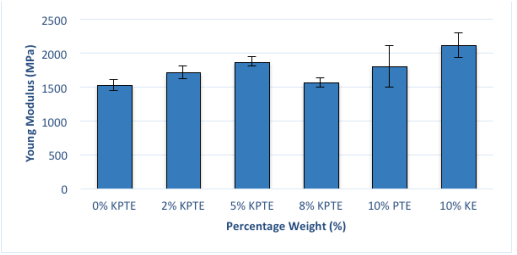


Figure 3: Young's modulus of epoxy and its composites

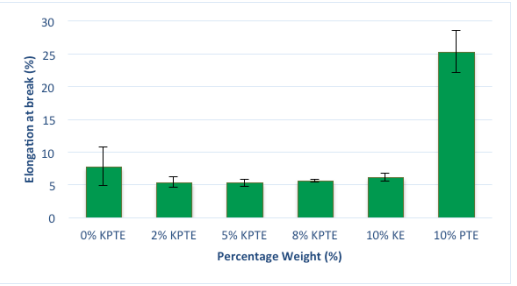


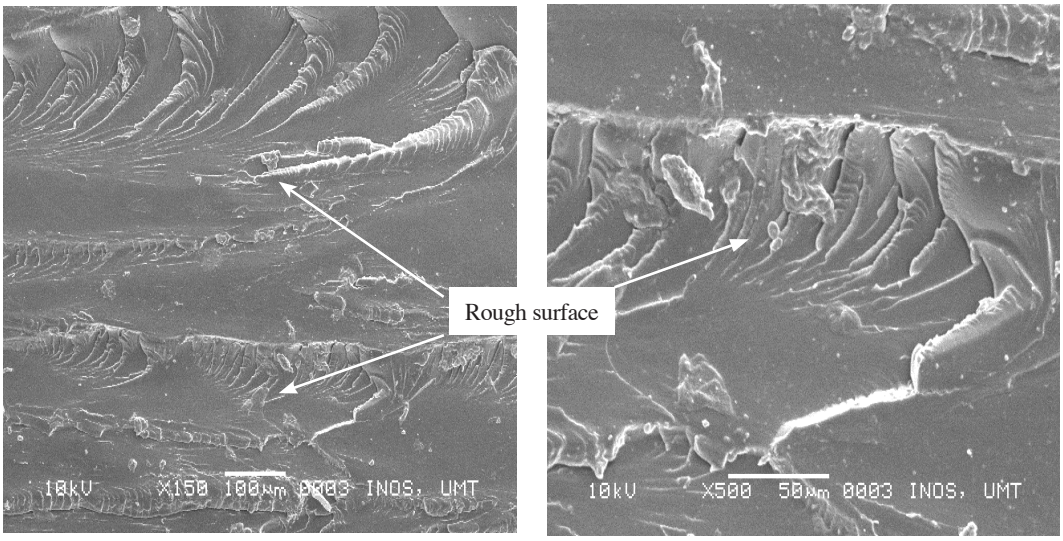
Figure 4: Elongation at break of epoxy and its composites.

Elongation at Break

From Figure 4, the incorporation 10% PTE into epoxy resin as polymer matrix resulted in the maximum elongation at break which is 25.3%. The incorporation of 2, 5, 8 and 10 wt% fibres in KPTE composites slightly decreases the elongation at break of the composites. The decrease may be attributed to the increase of a rigid interface between the fibres and matrix material. An observation has been reported that almost all filled composites where elongation decrease with addition of more fibres content in the polymer (Kakroodi *et al.,* 2014). The inclusion of PET to the kenaf fibre/epoxy composites do not increase the elongation at break as they are not well bonded together.

Morphological Observation of KPTE Composites

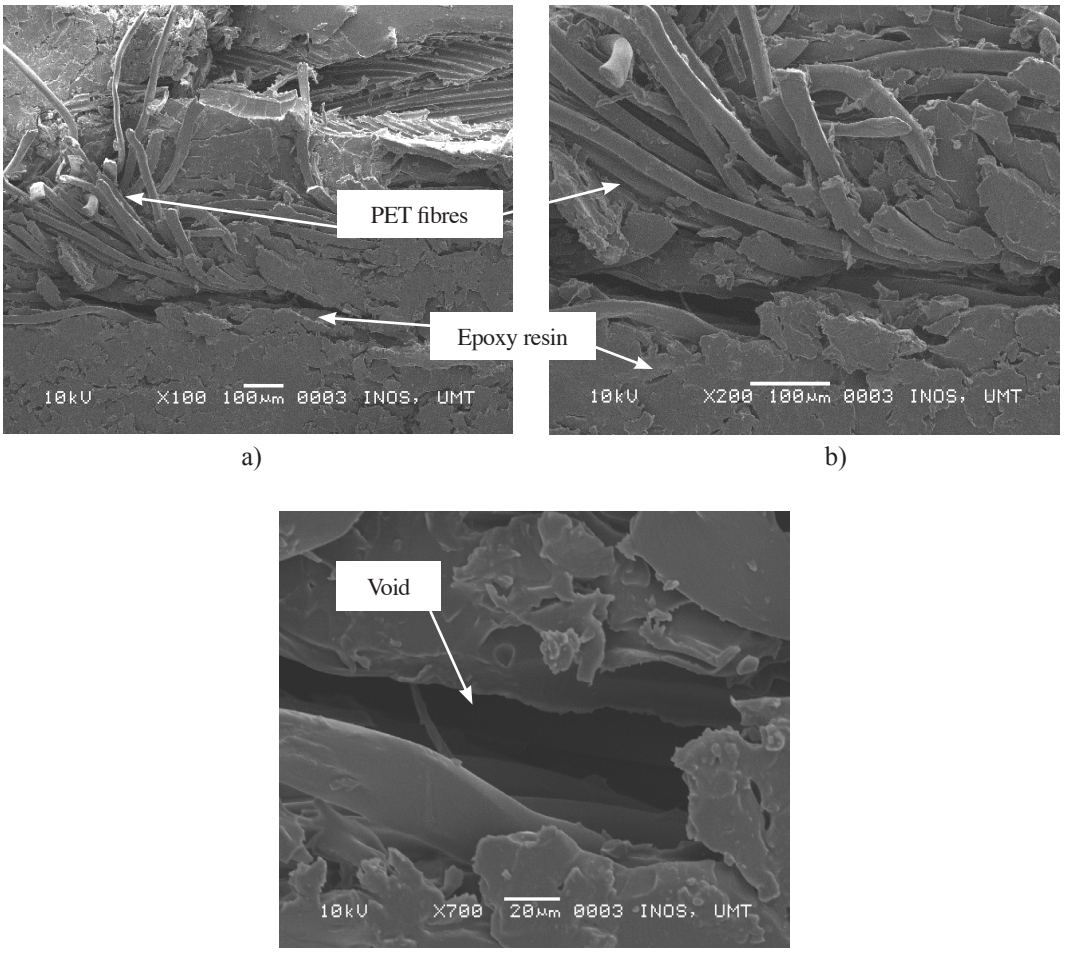
Figure 5 (a, b) shows the SEM micrographs of neat resin epoxy-based composites. From the figures it clearly indicates that there are no pores in epoxy based composites. This is due to process of experimental which the bubbles have been removed during the preparation of pure epoxy resin. However, the surface is rough and wrinkles which strongly associates with the mechanical properties of brittle materials such as epoxy resin.



a) b)

Figure 5: SEM micrograph of the cross section of pure resin under a) 150 × magnification and b) 500× magnification

Figure 6 shows the SEM micrograph of interwoven PET/epoxy (PTE) composites. From the figures, it is observed that the composites appear to be well-bonded together with polymer matrix. This bonding contributes to good adhesion between them. However, there are voids exist in the composites which may result in the failure of the composites. The voids result from debonding which occurs along the fibres due to lack of interactions at the interface. This clearly indicates that one of the mode failures is through the fibre pull out.



a) b)

c)

Figure 6: SEM micrograph of the cross section of 10 wt% PET/epoxy (PTE) composites at a) 100× magnification b) 200× magnification and b) 700× magnification

Figure 7 shows the SEM micrograph of interwoven kenaf/epoxy (KE) composites. From the figures, the composites with kenaf fibres appear to have good fibre-matrix interfacial adhesion. According to Wambua *et al.* (2003), the composite matrix transfers the load to the fibres at the interface through shear stresses. This load transfer process needs the presence of good adhesion between the matrix and the fibres. The figure also shows a view of the tensile fracture section of the 10 wt% kenaf/epoxy (KE) composites. There was hardly any fibre pull outs indicating the presence of strong adhesion between epoxy matrix and kenaf fibres.

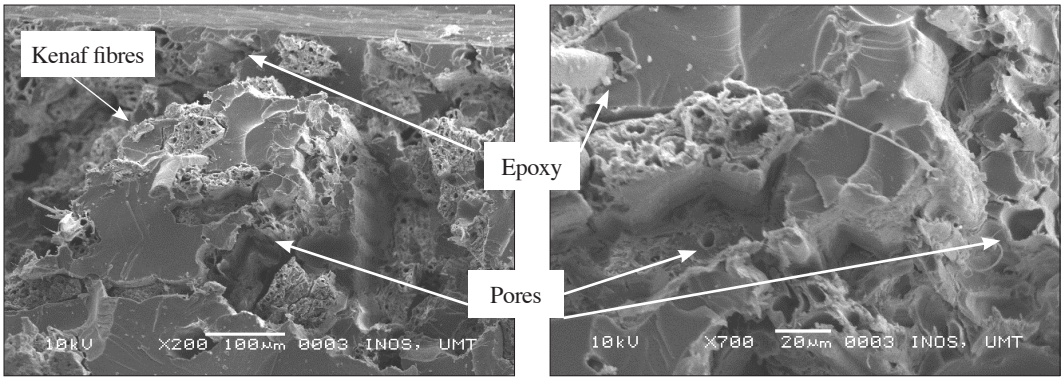


Figure 7: SEM micrograph of the cross section of 10 wt% kenaf/epoxy (KE) composites at a) 200 × magnification and b) 700 × magnification

Figure 8 shows micrographs of tensile fractured surfaces of the 8% kenaf/PET/epoxy (KPTE) composites. It is observed that these composites have very poor fibre-matrix interfacial adhesion as there are many fibre pull outs for 8 wt% kenaf fibre loading. The fibres sticking out of the fracture surfaces and the holes in the matrix are evident in Figure 8 (a, b). The presence of holes is the results from debonding which may be attributed to the lack of interactions at the interface. As there was no coupling agent used in the preparation of samples, mechanical interlocking may be the main factor responsible for the adhesion. The voids may be another reason for the low tensile strength as they may increase the stress that brings about rapid failure (Lee et al., 2008).

Conversely, the 10 wt % kenaf fibres composites clearly indicate the break of fibres on surface during fracture proving the strength of fibre and matrix interface.

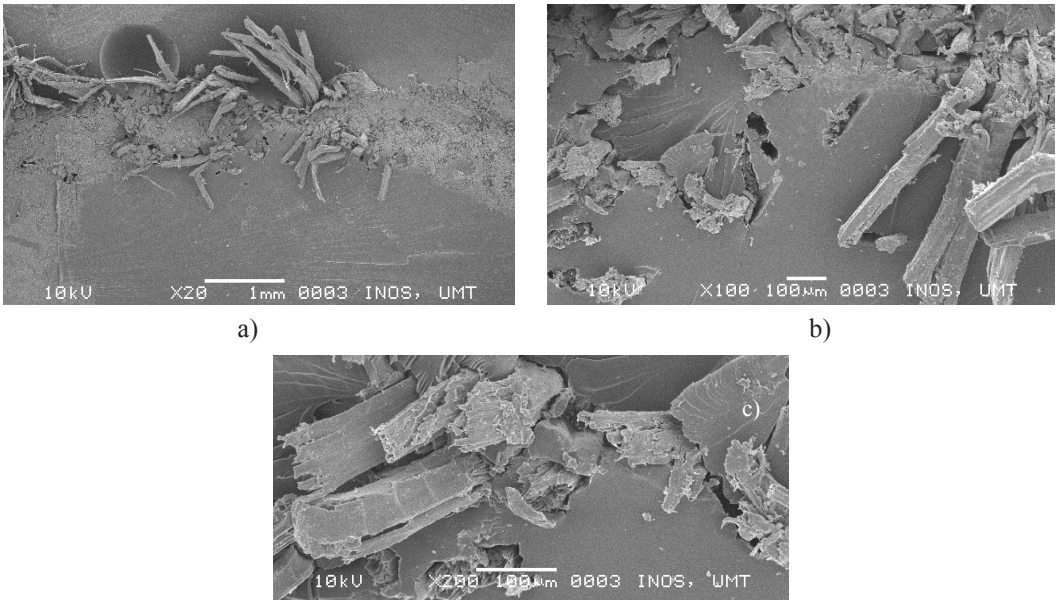


Figure 8: Micrographs of the cross section of 8% kenaf/PET/epoxy (KPTE) composites at a) 20× magnification b) 100× magnification and c) 200 × magnification

Thermal Stability of KPTE Composites

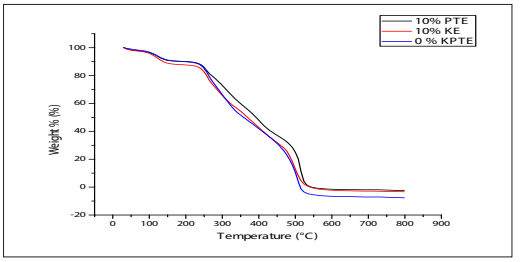


Figure 9: Thermal stability curve of (0 and 10 wt%) kenaf fibres composites and 10 wt% PET composites

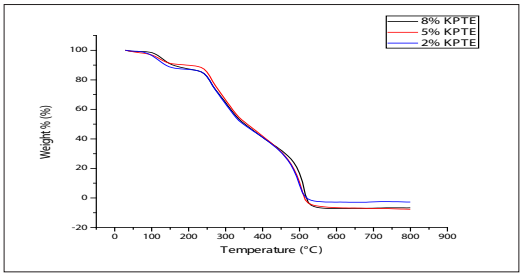


Figure 10: Thermal stability curve of (2, 5 and 8 wt%) kenaf fibres epoxy composites

Figure 9 shows the degradation pattern for (0 and 10 wt%) kenaf fibres composites and 10 wt% PTE composites at specific temperatures. From graph, it can be seen that 10 wt% kenaf fibres (KE) degrades faster than 10 wt% PTE composites and unfilled pure resin. This is due to presence of kenaf fibre constituents such as hemicellulose and pectins. The 10 wt% KE composites started to lose weight earlier than the other samples which is due to the high moisture content of kenaf fibres. Another possible cause is the porous space between the fibre-matrix interfaces relating that the addition of fibre reduces the overall thermal stability of the composite's material.

Figure 10 shows the degradation pattern for (2, 5 and 8 wt%) kenaf fibres (KPTE) composites at specific temperature. From graph, the same general shape occurs, suggesting that the decomposition mechanism is the same. This is because the maximum content of fibres used was only 10 wt%. According to Zainudin *et al.* (2009) the addition of natural filler in polymer can affect the thermal performance of composites.

Water Absorption of KPTE Composites

Figure 11 shows the water absorption percentage for various woven composites immersed in purified water at room temperature.

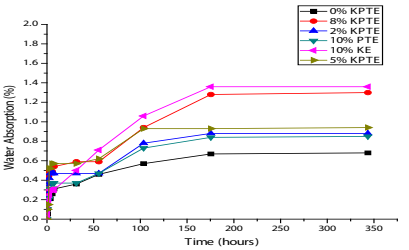


Figure 11: Graph of water uptake of kenaf/PET/epoxy composites

The plots show that the absorbed water content increases with increasing immersion time before adsorption reaches saturation. The addition of kenaf fibres minimally increases the water absorption up to about 1.4% as compared to 0.6% for unfilled epoxy. Generally, the water absorption of the composites was linear at the beginning, especially in the 10 wt% kenaf fibres and 8 wt% kenaf fibres composites as shown in the Figure 11 denoting the fast water absorption. The water absorption then decreased prior to saturation after a period. The water absorption of woven kenaf composites increases as the content of kenaf fibres increases due to the increase of cellulose content which is hydrophilic in nature. (Akil *et al.,* 2011). Hydroxyl groups which present in a hydrophilic polymer react with water molecules to form hydrogen bonds (–OH). In the presence of water, these bonds allow the kenaf fibres composites to absorb a relatively large amount of water. Therefore, the increase in cellulose content in the composites further increase water penetrating into the fibre-matrix interface.

Conclusion

As conclusion, the use of kenaf plant fibres up to 10 wt% which attained 85.3 ± 2.9 MPa was effective as reinforcement in the hybrid kenaf-PET/epoxy composites as the strength increases as the kenaf fibre content increases. However,

the addition of kenaf fibres marginally increased the water absorption up to 1.4%. The increase of kenaf fibres slightly decreased the overall thermal stability due to the decomposition of hemicellulose, cellulose and lignin. The use of PET together with kenaf fibres presents an improved tensile strength of hybrid composites as compared to pure epoxy resin.

Acknowledgements

The authors would like to thank Universiti Malaysia Terengganu (UMT) for the opportunity in supporting the implementation of this study.

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