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Flexural properties of treated and untreated kenaf/epoxy composites

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ABSTRACT

In the current work, flexural properties of unidirectional long kenaf fibre reinforced epoxy (KFRE) composites are studied. The kenaf fibres were prepared into two types as untreated and treated (with 6% NaOH). The failure mechanism and damage features of the materials were categorized with the surface observation by scanning electron microscope (SEM). The results revealed that reinforcement of epoxy with treated kenaf fibres increased the flexural strength of the composite by about 36%, while, untreated fibres introduced 20% improvement. This was mainly due to the high improvement of the chemical treatment (NaOH) on the interfacial adhesion of the fibres and the porosity of the composites which prevented the debonding, detachments or pull out of fibres. For untreated KFRE, the fracture mechanisms were debonding, tearing, detachments and pull out of fibres. The developed composite exhibited superior properties compared to the previous composites based on natural and synthetic fibres.

1. Introduction

In recent years, natural fibres are drawing considerable attention as substitute candidate for synthetic fibres. The applications of natural fibres are growing in many sectors such as automobiles, furniture, packing and construction. This is mainly due to their advantages compared to synthetic fibres, i.e. low cost, low weight, less damage to processing equipment, improved surface finish of moulded parts composite, good relative mechanical properties, abundant and renewable resources [1,2]. Nowadays, plant fibres are the most commonly used natural fibres such as sisal, jute, coir and flax fibres which are used as reinforcement and filler for polymer composites. The main concept of reinforcing the polymer with such fibres is to enhance the mechanical properties of the polymers, i.e. tensile, impact and flexural properties [3,4].

The mechanical properties of natural fibre reinforced composites highly depend on the interface adhesion property between the fibres and the polymer matrix as have been reported by many researchers [5–8]. Natural fibres contain cellulose, hemicelluloses, pectins and lignin and are rich in hydroxy1 groups, natural fibres tend to be strong polar and hydrophilic materials whilst polymer materials are a polar and exhibit significant hydrophobicity. In other words, there are significant problems of compatibility between the fibre and the matrix due to weakness in the interfacial adhesion of the natural fibres with the synthetic matrices. Therefore, surface modification of natural fibres by means treatment is one of the largest areas of recent researches to improve compatibility and interfacial bond strength [9,10]. Chemical treatments as bleaching, acetylation and alkali treatment found to be a technique to enhance the matrix–fibre adhesion by increasing roughness through of clean the fibre surface from impurities and by disrupting the moisture absorption process through of coat of OH groups in fibre [11,12]. Many investigations have focused on the treatment of fibres to improve the bonding with resin matrix. From reported works on mechanical properties of polymeric composites based on natural fibres, the flexural strength of high density polyethylene (HDPE) composite increased by about 22% when treated henequen fibres were used as reinforcement in the composite [5]. In [13], Vilay et al. investigated the effect of fibre surface treatment (NaOH) and fibre loading (0–20 vol.%) on the flexural properties of bagasse fibre reinforced unsaturated polyester composites (BFRUSP). NaOH treated fibre composites showed better flexural strength and modulus (increase by about 11% and 20% respectively) compared to untreated fibre composites. These experiential results were resulted of the surface modification by treatment that improves the fibre–matrix interaction. In another work, the effect of concentration (1–10%) and period (24, 48 h) of alkalization treatment on the flexural properties of Alfa/polyester composites (40 wt.% Randomly orientated fibres) have been studied [14]. The flexural test results of that work showed that alkali treatment of fibres Alfa improves the quality of the fibre/matrix interface. Moreover, both NaOH concentration and time treatment have a significant effect on the flexural properties of Alfa fibres reinforced composites. For fibres treated with 10% NaOH for 24 h, the flexural strength and flexural modulus were improved by 60% and 62%, respectively, compared to the untreated fibre composites.

In polymeric composites based on natural fibres, the shapes of composite and its surface appearance were awarded by matrix

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while fibres act as carriers of load and stress (stiffness and strength) when composite is subjected to load. Therefore, the orientation of natural fibres has significant effects and plays an important role to enhancement the mechanical properties in polymeric composites based on natural fibres [15–17]. Brahim and Cheikh [15] studied the influence of fibres orientation on the mechanical properties of the Alfa/polyester composites with a volume fraction in fibres of 45%. All specimens made of unidirectional Alfa fibres and tested at different orientation angles (α) 0°, 10°, 30°, 45° and 90°. The reduction percentage of tensile strength (σ) with change angle from 0° (longitudinal specimens) 0 45° was 78% and it was 88% when change it to 90° (transverse direction). This is highly with the agreements of many published articles [16,17].

Kenaf fibres have very high characteristics compared to other natural fibres, i.e. long fibre, small diameter, and high interfacial adhesion to matrix [18]. However, there is less work has been done on the kenaf fibres to comprehensively understand the possibility of using such fibres for polymeric composites especially in flexural loading conditions. This paper is an attempt has been made to study the effect of untreated and alkali treated kenaf fibre on flexural properties of epoxy composites.

2. Materials and experimental details

Raw kenaf fibres were supplied by Malaysian Agricultural Research and Development Institute (MARDI). The supplied fibres were hand-washed, and dried at ambient temperature for 48 h. The density of kenaf fibres is approximately 620.26 kg/m^3. Portion of the cleaned fibres were treated with 6% NaOH solution. In the NaOH treatment process, the fibres were socked in 6% NaOH solution for 24 h, then washed and dried in an oven at 40 °C for 24 h. The matrix used is a combination of D.E.R.™ 331™ Liquid Epoxy Resin and Jointmine 950-3S as Hardener/Curing Agent/Accelerator. In the fabrication process, a metal mould ($100 \times 100 \times 10$ mm^3) was coated with a layer of release agent (WD-40). Epoxy/hardener (2:1) mixture was stirred, and poured into the mould. Mechanical properties of such materials is highly dependent on fibre alignment and the location of resin-rich areas, i.e. unidirectional long fibres tend to give better strength compared to the short and other orientations of fibres [19]. In the current work, the untreated kenaf fibres were prepared in unidirectional alignment, cut into lengths of 80 mm and placed in the mould. It is important to ensure that bubbles are not trapped in between the fibres; thus, a steel roller was moved on the composite to remove trapped air. Finally, the blocks of the composite pressed, and covered with mould cover and left to cure for 24 h. The same procedure was done for treated kenaf fibres as well. The volume fraction of the fibre was determined to be about 38–41%. For the neat epoxy (NE), the material was fabricated in the same procedure to the composites procedure without adding the fibres. The prepared blocks were machined into specimens with the size of 80 mm $\times$ 10 mm $\times$ 4 mm according to ASTM D790-07 flexural testing standard, i.e. 3-point flexural technique was adopted in the current experiments [20]. Lloyd LR50 K-Plus 50 kN Universal Testing Machine was used to perform the experiments. The cross-head speed was set to 2 mm/min which is recommended by [21,22]. Schematic drawing of the test technique is shown in Fig. 1. Scanning electron microscopy was used to observe the surface modification resulting from the aging effect.

3. Results and discussions

The effect of NaOH treatment on fibre surface morphology, the composite microstructure, and flexural properties will be addressed in the following sections.

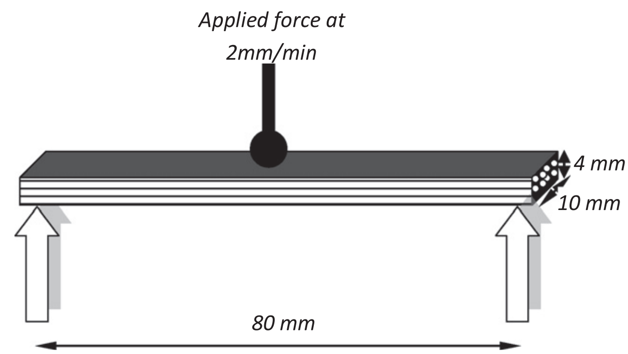

Fig. 1. Drawings and dimensions of bending equipment.

3.1. Influence of NaOH treatment on the surface morphology of the fibre and the composites

To clarify the effect of alkali treatment on kenaf fibre and the microstructure of the composite, surface examinations were carried out on the untreated and alkalized fibres and composites. The scanning electron microscope (SEM) photographs of morphology in diameter direction and in the cross-section of both untreated and alkalized surfaces are exhibited in Figs. 2 and 3. The alkali treatment leads to significant differences in the fibre surface morphology. As shown in Fig. 2a, the surface of untreated kenaf fibre was found to be considerably covered with waxy substances and impurities. Relatively, micrograph of the treated fibre (Fig. 2b) shows an improvement in the surface morphology after 6% NaOH treatment, i.e. using 6% NaOH treatment removed the waxy layer and impurities from surface and the treated surface of fibre becomes rather rougher and fibrillation as compared to that of untreated fibre. Moreover, it can be seen that the fibres have been spitted into finer fibres. This could lead to high interlock and adhesion between the fibres and the matrix. Fig. 3 shows the cross-section of kenaf/epoxy composites based on untreated (Fig. 3a) and treated fibres (Fig. 3b) and a penetration of epoxy into plant fibre cell walls. Both micrographs of the treated and untreated composite surfaces are taken at the same conditions where the composite surface were polished against smooth surface (AISI 304, 50 BH hardness and 0.09 μm Ra roughness) with an applied load of 50 N. Fig. 3b shows higher epoxy penetration into plant fibre cell walls in treated fibre than untreated fibre, Fig. 3a. The high epoxy penetration may be due to the leaching out of the wax substances and impurities and leading to fibre bundle fibrillation. Alvarez and Vazquez [23] reported that the remotion of the cementing material in the sisal fibres by alkaline treatment led to produce fibrillation and collapse the cellular structure, which leads to a better packing of cellulose chains.

3.2. Flexural properties

The mechanical properties of the pure epoxy, untreated kenaf fibre reinforced epoxy (UT-KFRE), and treated kenaf fibre reinforced epoxy (T-KFRE) composites are displayed in Fig. 4a–c. The figure shows the results of set of experiments conducted on each material. One can see that the variation in the results is remarkable. This indicates the accuracy of the machine and the homogeneity of the composites. Fig. 4a shows a ductile behaviour for the neat epoxy and the maximum strength is noticed at about 180–200 MPa when the deflection reached about 12.5 mm. Fig. 4b indicates that the addition of untreated kenaf fibres to the epoxy enhances the flexural strength and reduces the deflection, i.e. the maximum strength of the UT-KFRE is about 225–250 MPa. On the other hand, the treated kenaf fibres highly improved the flexural strength of the epoxy