Tensile and Interlaminar Shear Strength of Unidirectional Kenaf Fibre Reinforced Polymer with Overlapping Joint

Safarina Haslimawaty Hamdan, Anwar Zainal Abidin and Zakiah Ahmad

Abstract Natural fiber has been chosen to replace the use of synthetic fiber because of its characteristics and the fact that it is environmentally friendly. Natural fiber has limited length which differs from synthetic fibers which can be fabricated with the desired length. Therefore, there is a need to join the length of natural fiber in the manufacturing of the plastic composite. Forming a longer length fiber plastic composite by using the method of jointing might results in lower strength compared to full length fibers. Therefore, this paper reported the investigation made on the tensile strength and interlaminar shear strength of kenaf fiber reinforced plastic composite by jointing the fibers through co-cured in-line joint by overlapping the fibers with different overlapping length (0, 10, 20, 30, and 40 mm). The effects of pre-treatment of the fibers with sodium hydroxide were also studied. The results shows that the composites can be manufactured by joint the fibers with maximum length of 20 mm overlapping length. Beyond that length, the specimens failed at outside the overlapping area.

Keywords Epoxy resin · Fiber · Interlaminar shear stress · Kenaf · Reinforced polymer · Tensile strength · Weight loss

S. H. Hamdan · Z. Ahmad (✉)
Institute of Infrastructure Engineering and Sustainable Management, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
e-mail: zakiahah@hotmail.com

A. Z. Abidin
Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

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1 Introduction

Fiber such as glass, carbon, aramid, etc. has been used in the fiber reinforced polymer composites because of their favourable mechanical properties. However, these synthetic fibers are quite expensive. Therefore natural fibers such as jute, flux, hemp, kenaf etc. can be the alternative fibers in order to reduce the cost of the composites [1]. The emergence of these lignocellulosic fibres as a viable replacement for glass fibre in reinforcing polymeric matrices has attracted the interest of researchers over the past few decades [2, 3]. These fibres are known to deliver similar performance to glass fibres and can be 25–30 % stronger than glass fibres for the same weight [4]. The elastic moduli for natural fibres are comparable to those of E-glass, with flax having potentially the highest value compared to the other fibres The main advantages of natural fibers include acceptable specific strength properties, low density, high toughness, good thermal properties, lightweight, non-corrosive, low cost and so on [5]. The low specific weight of natural fibers which resulted in a higher specific strength and stiffness compared to glass fiber and this is the characteristic that is important for designing the bending stiffness [6]. Kenaf is the crops that has been planted in Malaysia as alternative crops to replace tobacco for its fibers. Kenaf fiber has been shown to have good tensile strength and modulus of elasticity of 11.9 and 60 GPa respectively [7].

Besides having good mechanical properties, the properties of composites depend on the properties of the matrix and also their interfacial compatibility. However, adhesion between the hydrophilic fiber (such as jute fiber, sisal fiber) and hydrophobic matrix (such as polypropylene, polyester, epoxy) is poor [8]. Therefore, the bond between them needs to be improved. This may be improved by alkali treatment. It is believed that the alkali treatments results in an improvement in the interfacial bonding by giving rise to additional sites for mechanical interlocking, hence promoting more matrix/fiber interpenetration at the interface [3]. Alkali treatments may change the structure, accessibility, morphology and reactivity, in cellulosic fibres depending on factors such as treatment temperature, alkali concentration, its degree of polymerisation and the physical state of the material [9–11]. Silva and Al-Qureshi [12] analysed the mechanics of wetting systems of sisal fibre bundles in epoxy resin by comparing untreated fibres with those treated using 5 % NaOH solution. There was a decrease in the tensile strength of the fibres of approximately 14 % after treatment which may be due to the loss of hemicellulose and lignin.

The application of unidirectional fiber in the composites requires the fiber to be jointed in order to have a longer length composite. The strength of the composite will depend on the strength of the joint. Therefore an experimental investigation was performed to determine the tensile strength properties of unidirectional co-cured in-line joint of kenaf fiber reinforced plastic composites with different overlapping length (0, 10, 20, 30, 40 mm). The interlaminar shear stress plays a very important role in the damage of composite laminates. With higher interlaminar shear stress, delamination can easily occur on the composite interface. Therefore this study also looked at the interlaminar shear strength of the composite.

2 Experimental

2.1 Materials

Kenaf fibers were collected from Lembaga Kenaf located in Kota Bahru, Kelantan. The supplied kenaf was processed by water retting in order to get the long fiber. The resin was two parts epoxy resin with based resin, Asasin 8505 and hardener, Asahard 8505 supplied by SIKA Malaysia. The mould release agent used was Frekote 700-NC.

Epoxy resin was prepared by mixing two components, based epoxy resin, Asasin 8505 and harderner, Asahard 8505 at ratio 70:30 respectively thoroughly at room temperature. The resin was placed in a vacuum oven to remove any bubbles formed during the mixing process.

2.2 Treatment of Fiber

Fibre samples were immersed in an aqueous alkaline solution of 0.06 M sodium hydroxide (NaOH) mixed with distilled water for about 24 h at room temperature. The fibre was washed with running tap water and then neutralised with an acetate buffer containing 0.01 mol/l of acetic acid and 0.01 mol/l of sodium acetate (pH 5.0). The fibre sample was sufficiently washed with distilled water until the pH value of the solution indicated 7.0. The fibers were dried at room temperature by placing them in between layers of tissue for 2 days, before further drying in an oven at 80 °C for 24 h.

2.3 Moisture Content

In order to determine the weight loss of fibers during alkali treatment, the moisture content (MC) of the fibers was first calculated. The moisture content of the fibers was calculated according to Eq. (1). Firstly, the fibers were conditioned at room temperature for 24 h and weighed (w_1). Then they were dried at 105 °C for 4 h. The fibers were weighed again (w_2) after cooling down in a desiccator.

$$\text{MC}\ \% = \frac{w_1 - w_2}{w_2} \quad (1)$$

The measurement was performed three times for each sample to obtain a mean value.

Fig. 1 Single strand kenaf fiber mounted on coupon

2.4 Weight Loss in Percent

The weight loss of the fibers during alkali treatment was determined. The as received kenaf fibers of 0.25 g were conditioned at room temperature for 24 h and the weight was taken and denoted as w_m. The weight of the dried fibers (w_d) was calculated according to Eq. (2).

$$w_d = w_m - (w_m \times MC) \tag{2}$$

Then the fibers were treated with NaOH as explained in Sect. 2.2 and dried. The weight of the dried fibers after treated was measured and denoted as w_3. The weight loss of the fibres was calculated according to Eq. (3).

$$Weight\ loss = \frac{(w_d - w_3)}{w_3} \tag{3}$$

The measurement was performed three times for each sample to obtain a mean value.

2.5 Tensile Strength of Fiber

The single strand of both treated and untreated kenaf was taken and attached on a manila-card coupon (Fig. 1) by using high performance glue. The tensile test was conducted according to ASTM D885 (1995) using Shimadzu Machine from Civil Engineering Fabrication Lab. The ends of the manila-card coupons were gripped by hydraulic clamps to align the fibre with the machine axis. The sides of the hole on the coupon were cut with a pair of scissors to allow load transfer to the fiber during tensile testing. The specimens were loaded with a crosshead speed of 1 mm/min. Ten (10) specimens, which were five treated and five untreated kenaf fibers were used in this test.

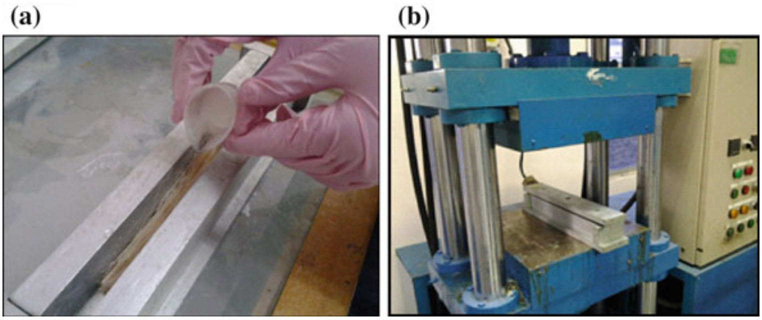


Fig. 2 Manufacturing the KFRP specimen; **a** Epoxy resin poured over layer of kenaf in a zig-zag pattern and **b** specimen allowed to rest before applying pressure

2.6 Preparation of Kenaf Fiber Reinforced Plastic Composite

The composites were manufactured using unidirectional kenaf fibre bundles with epoxy resins as the matrix materials. The untreated and treated fibers were combed to make them straight. All the combed kenaf fibers were cut to required length based on the different overlapping length (0, 10, 20, 30 and 40 mm) as well as control samples and to make samples of length 250 mm. The fibers were divided into several bundles with approximately equal weight.

The mould was cleaned using a soft scraper prior to clean off any residue left on the mould surface. A release agent, Frekote was applied to all surfaces exposed to the resin to make the process of releasing the composites easier, and prevent damage to the mould.

The composites were manufactured using a stainless steel mould as shown in Fig. 2a. The fibers were then inserted layer by layer into the mould, with a layer of epoxy matrix between the layers of the fiber bundles. At the bottom of the first fiber bundles and the top of last fiber bundle, no resin was introduced. The resin was allowed to rest for 3 min before the top cover was placed to avoid loose of resin in the mould. Once the top cover was placed onto the mould, the composite was rested for another 2 min before applying the full pressure of 60 bars (Fig. 2b) until the resin began to feel sticky. The samples were left for 24 h before demoulding. The samples prepared were of size 20 mm (width) × 4 mm (thick) and 250 mm (length).

2.7 Tensile strength of KFRP

The static tensile strengths of the different KFRPs were measured using BS EN ISO 527-5 (1997) using straight edge specimens as shown in Fig. 3. The composites were fitted with 1.6 mm thick aluminium end tabs which were bonded with Sikadur resin to minimize damage to the outer fibers and matrix.

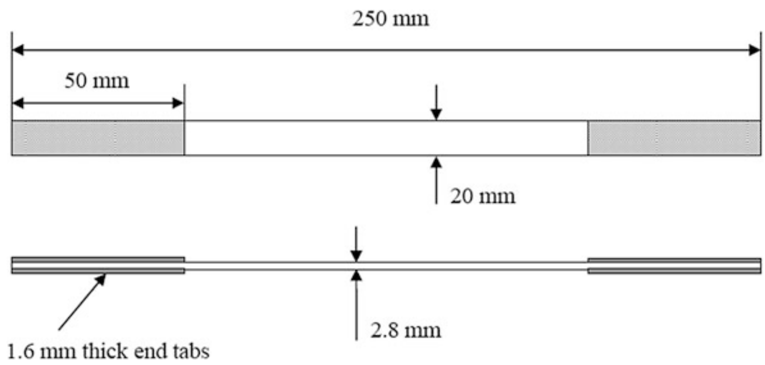


Fig. 3 Tensile test specimen

The tensile test was conducted using Universal Testing Machine Instron at a rate of loading of 1 mm/min.

2.8 Interlaminar Shear Strength

The apparent interlaminar shear strength is defined as the value of the apparent interlaminar shear stress at failure or when the load reaches a maximum value. Interlaminar shear test was carried out in accordance with BS EN ISO 14130. The specimens were cut from the prepared specimen in Part F to a size of 40 mm length × 20 mm width × 4 mm thick to give a bending specimen with span to depth ratio of 5:1 mm. The test was conducted on an INSTRON 100kN (3,382) with speed of the testing was 1 mm/min. All the samples' fracture surfaces before and after testing was examined by using Scanning Electron Microcopy (SEM). This value is determined using Eq. (4) as shown below.

$$\tau_M = \frac{3F_M}{4bh} \tag{4}$$

where F_M is the failure or maximum load, in Newtons, b is the width of the test specimen and h is the thickness of the test specimen.

3 Results and Discussions

3.1 Effect of Treatment on the Physical Properties of Kenaf Fiber

The weight loss of the kenaf fiber after treatment with NaOH was found to be 1.8 %. This reduction may be due to loss of the carboxyl group containing fiber molecules [13]. Figure 4 shows the surface morphology of the kenaf fiber bundle,

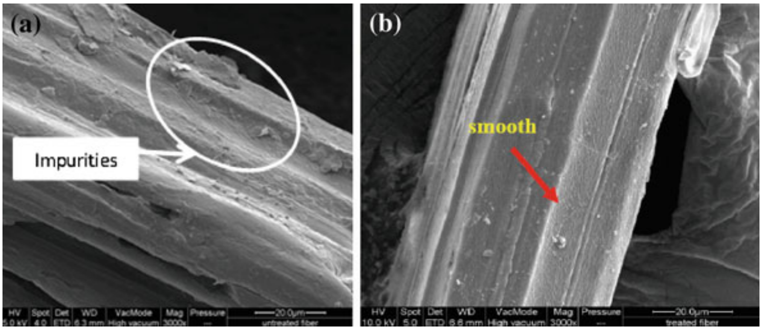


Fig. 4 SEM scans of kenaf fiber; **a** untreated fiber bundle and **b** treated fiber bundle showing the *impurities* and *smooth surface* respectively

untreated and treated with NaOH. A closer look of the treated fiber shows the effect of the NaOH on the surface. The smoothness and lack of debris on the surface due to attack by the alkali (Fig. 4b) as compared to the roughness of the untreated fiber (Fig. 4a) which can be associated with the weight loss and has been associated with better wetting of such fibers (Arnold 2008) can be clearly observed in Fig. 4b.

3.2 Effect of Treatment on the Tensile Strength of Kenaf Fiber

The tensile strengths of the treated and untreated kenaf fiber bundles were determined using the cross-sectional areas with the diameter of the fibers obtained using the microscopy methods. It can be observed that the average tensile strengths obtained for untreated fiber is 15.48 kN (140 MPa) which is 6.2 % higher than untreated fiber (14.57 kN, 132.5 MPa). This indicates that the treatment with NaOH decreased the tensile strength of the fiber. The density of the untreated and treated fiber is 1.19 and 0.75 g/cm^3 respectively and this reflected in the value of tensile strength. The higher the density the higher the tensile strength.

3.3 Tensile Strength of KFRP Composite

The tensile test results for the treated and untreated KFRP have been plotted in Fig. 5 as a function of overlapping length. From this figure, it is clear that the KFRP with treated fiber are higher than KFRP with untreated fiber except for control samples which is quite surprising. For control specimens, KFRP with untreated fiber have tensile strength of 15.8 % higher than KFRP with treated

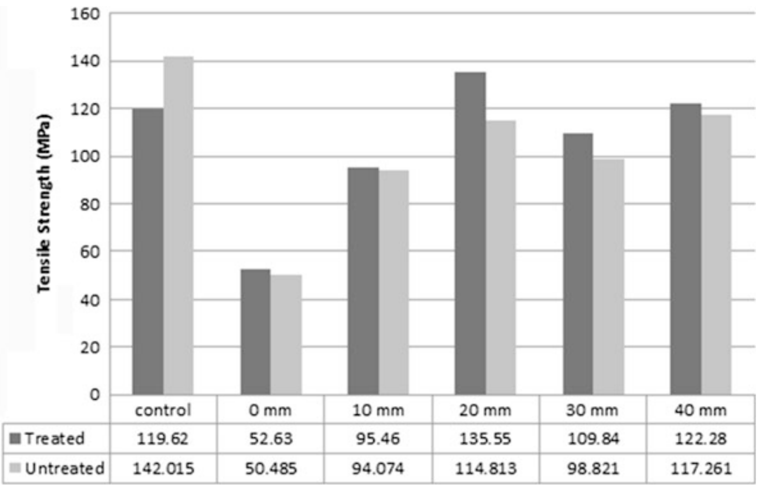


Fig. 5 Tensile strength of KFRP composite with treated and untreated fibers

fiber. This may be due to the tensile strength of untreated kenaf fiber is higher than treated fiber.

However as the overlapping length increases, for both KFRP composites, the tensile strength of the composites with treated and untreated fibers are increasing as the overlapping length increases up to 20 mm overlapping length excluding the control specimens.

When jointed with 20 mm overlapping length, the tensile strength of KFRP with treated fiber has no significant different in the tensile strength with that control KFRP with untreated fiber but higher than the control sample with treated fiber. The result also shows that fiber length has profound impact on the properties of the jointed composites. In small overlapping size, tensile strength is low due to the fact that length may be not sufficient enough for proper distribution of stress. As proper length is not available for stress distribution, failure occurs easily. But as the fiber length longer than 20 mm, the tensile strength decreases at the overlapping area as at that area, the density is high and the weak area will be outside the overlapping and induce weakness and the specimens mostly failed around those areas. Figure 6 shows the failure modes of the tensile specimens with different overlapping length. Both types of KFRP composites have similar failure patterns.

At the same time, the matrix resin need to hold the fibers together, therefore, the matrix has the important function of transferring applied load to the fibers. The efficiency of a fiber reinforced composite depends on the fiber–matrix interface and the ability to transfer stress from the matrix to the fiber [13]. The increase in tensile strength for the alkali treated kenaf fiber bundles in epoxy resin composites is linked to the improvement of surface properties. Treatment of kenaf fiber with low concentration of NaOH has been reported to improve the mechanical

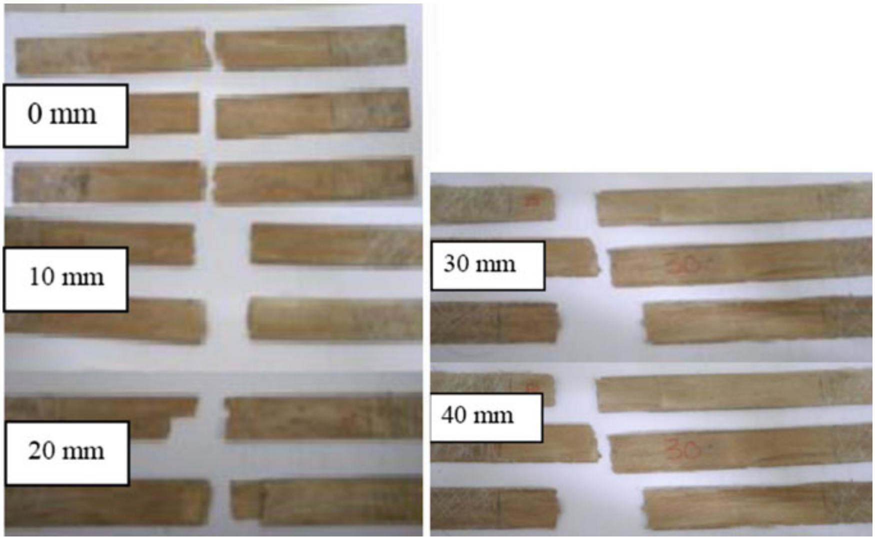


Fig. 6 Failure modes of tensile specimens

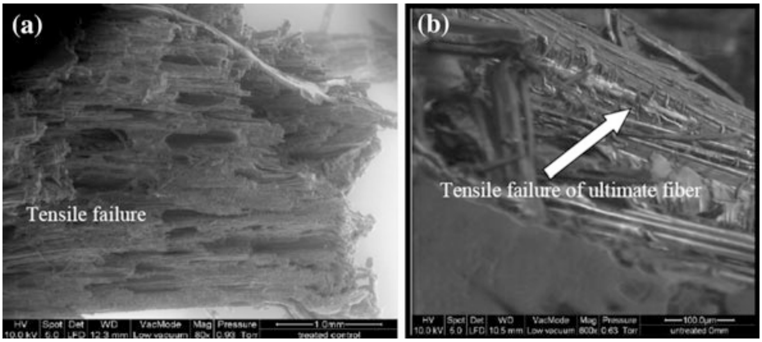
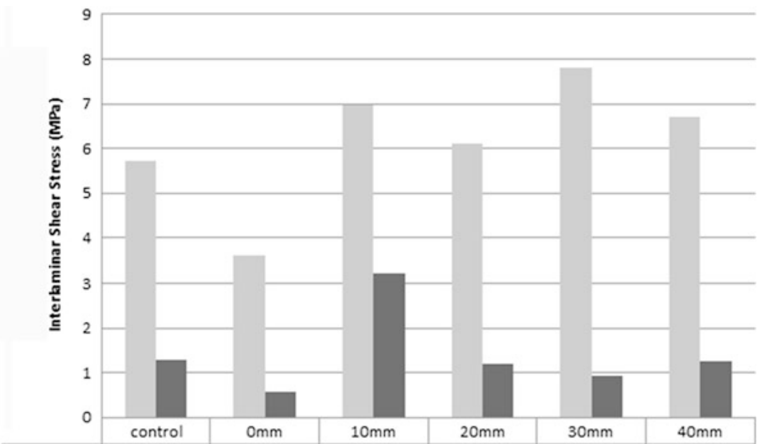


Fig. 7 Tensile failure of **a** treated kenaf fibre KFRP composite and **b** untreated kenaf fibre KFRP composite after tensile test

properties of natural fibers by improving their internal properties by facilitating rearranging of crystallites into well-ordered states [14, 15]. They suggested that the orderly rearrangement of crystallites reduces the number of weak points on the fiber surface resulting in better stress distribution along the fiber length.

The KFRP composite for both treated and untreated fiber suffered tensile failure as shown in Fig. 7a and b respectively. There is no visible evidence of single fiber pull-out from both untreated and treated fiber-epoxy resin composites which indicate good bonding between the fibers and the matrix. The good bond strength is evident from the extent of damage observed on the fiber surfaces of treated and



	control	0mm	10mm	20mm	30mm	40mm
Untreated	5.721	3.618	6.973	6.104	7.79	6.696
Treated	1.293	0.563	3.229	1.203	0.918	1.266

Fig. 8 Interlaminar shear stress for KFRP composite with different overlapping length

untreated KFRP composite. There is pull-out of ultimate fibers from the fiber bundles as shown in Fig. 7b coupled with tearing of fiber cell walls.

3.4 Interlaminar Shear Strength

The interlaminar shear stress plays a very important role in the damage of composite laminates. Figure 8 shows the result for interlaminar shear strength of KFRP composites with treated and untreated kenaf fiber as well as for different overlapping length.

From Fig. 8 it can be seen that the interlaminar shear strength of KFRP composite with untreated fiber is higher than KFRP composite with treated fibers. This provides evidence that the low in tensile strength of the composite since with high interlaminar shear stress, the delamination can easily occur on the composite interface. This also indicates the bonding of the treated KFRP composite is not as good as the KFRP composite with treated fiber.

4 Conclutions

The following conclusions can be drawn from this study:

1. The weight loss of the kenaf fiber after treatment with NaOH was found to be 1.8 % which can be seen from the smoothness and lack of debris on the surface due to attack by the alkali through SEM micrograph.
2. The average tensile strengths obtained for untreated fiber is 15.48 kN (140 MPa) which is 6.2 % higher than untreated fiber (14.57 kN, 132.5 MPa). This indicates that the treatment with NaOH decreased the tensile strength of the fiber. The density of the untreated and treated fiber is 1.19 and 0.75 g/cm^3 respectively.
3. The tensile strength of kenaf fiber reinforced plastic composite without joint (control specimens) with untreated fiber has higher tensile strength than KFRP with treated fiber. However as the overlapping length increases, the tensile strength of the composites with treated and untreated fibers are increasing as the overlapping length increases up to 20 mm overlapping length excluding the control specimens.
4. The interlaminar shear strength of KFRP composites with untreated fiber is higher than KFRP composite with treated fibers. This provides evidence that the low in tensile strength of the composite. This also indicates the bonding of the treated KFRP composite is not as good as the KFRP composite with treated fiber.

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