Kenaf/PP and EFB/PP: Effect of fibre loading on the mechanical properties of polypropylene composites

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Abstract: Kenaf and empty fruit bunch (EFB) fibre which are the important natural fibres in Malaysia were studied as nonwoven polymer composites. The effect of fibre loading on kenaf polypropylene and EFB polypropylene nonwoven composite was studied at different mixture ratio. Kenaf polypropylene nonwoven composite (KPNC) and EFB polypropylene nonwoven composite (EPNC) were prepared by carding and needle-punching techniques, followed by a compression moulding at 6 mm thickness. This study was conducted to identify the optimum fibre loading of nonwoven polypropylene composite and their effect on the mechanical strength. The study was designed at 40%, 50%, 60% and 70% of fibre content in nonwoven mat and composite. The tensile strength, flexural strength and compression strength were tested to evaluate the composite mechanical properties. It was found that the mechanical properties for both kenaf and EFB nonwoven composites were influenced by the fibre content. KPNC showed higher mechanical strength than EPNC. The highest flexural strength was obtained at 60% KPNC and the lowest value was showed by 40% EPNC. The tensile and flexural strength for both KPNC and EPNC decreased after the fibre loading of 60%.

Keyword: Tensile, Flexural, nonwoven

1. Introduction

The utilization of natural fibres as a reinforcement in composites as substitute for glass fibre has attracted the attention of scientists during the last decade [1-4]. The drawbacks of glass fibre such as non-biodegradability, non-recyclable, health risk if inhaled and high energy consumption contributes to the exploration of natural fibres as an alternative material to the glass fibre [1,2]. Hence, many attempts have been made to produce the natural fibre polymer composite by various processing such as extrusion, injection moulding, woven and nonwoven composites for various application such as building material and automotive component [2,9]. Besides the advantages posed by natural fibre such as biodegradability, low energy consumption, low cost and renewable, some of the natural fibre are comparable to glass fibre.
On the other aspect, the natural fibre composite has higher specific properties than other synthetic fibre composite and lighter in weight [10].

Oil Palm and Kenaf are regarded as an industrial and commodity crop in Malaysia which also grown in other part of the world. They are certainly the most important plant cultivated in Malaysia for the oil (for palm oil) and fibre based on their availability hence promoting the government policy. Kenaf was first introduced in Malaysia early 1970s and was highlighted in the late 1999 by the National Economic Action Council (NEAC) [5]. In 2000, Malaysian Agricultural Research and Development Institute (MARDI) coordinated a fast track research and development into the project. MARDI has successfully developed on variety screening, agronomic practices for Kenaf cultivation, harvesting and mechanization, fibre processing, and some downstream applications such as animal feed and biocomposite [5]. Presently, research on kenaf are highly focus on the production of biofuel, biocomposite materials and bioproducts [5].

On the other hand, the oil palm industry is an important economy generator in Malaysia with the GNI for about 8% with almost RM50 billion annually [16]. The industry continues to generate huge revenues for the country and is expected to grow further in the upcoming years. The oil palm industry also generates huge quantity of residues. In fact, the oil produced is only 10% from the total fruit bunches [6] while another 90% are in the form of the biomass residue materials such as in empty fruit bunches, palm oil trunks, palm oil fronds, palm shells, palm pressed fibres and palm oil mill effluent [7]. On average, 50 to 70 tonnes of biomass residues are produced from every hectare of palm oil plantation [8]. EFB is the most readily to be collected at oil palm mill as residue.

Although both kenaf and EFB have great potential to be used as natural fibre polymer composite materials due its long fibres and sustainable supply, there is no study has been found to compare the properties of these fibres so far. In producing a good polypropylene composite from kenaf and EFB that could be utilized automotive or construction application, a good mechanical property must be achieved. According to various studies conducted in natural fibre PP composite, interfacial bonding between fibre and matrix is the main factor effecting to mechanical properties [11]. The interfacial bonding can be improved by means of mechanisms of mechanical interlocking, electrostatic bonding, chemical bonding and inter-diffusion bonding [17]. Asumani et al 2012 [18] studied on chemical bonding and they concluded that alkali-silane treatment to nonwoven kenaf reinforced polypropylene composites exhibited better tensile and flexural properties than untreated composites. Chemical treatment is proven can improve the interfacial bonding between fibre and matrix. However, interface modification will cost extra time, energy and money which is not cost-effective and practical for industrial production [12]. The improvement of interfacial bonding through mechanical interlocking suggested in this study is expected to have more practicality for industrial application.

Natural fibre polymer composites are normally processes by injection molding or resin transfer molding technique [12]. In this study, the natural fibre polymer composites were processed by nonwoven processing technique which has not been paid much attention so far. The strength properties of composite is depending on the ability of the stress transferring between matrix to reinforcement fibre where high fibre loading will lead to more effective stress transfer [12]. The natural fibre loading in nonwoven is 50-70% as compared to injection moulding and resin transfer moulding usually up to 30%. With such a high fibre loading, kenaf and EFB therefore are dominant and most loading transfer component in KPNC and EPNC. However, too much fibre loading will effect on the wetting which leading to poor interfacial bonding and relate to lower strength [2,11]. The KPNC and EPNC were prepared at multi fibre content to study the optimum fibre loading for the optimum mechanical strength properties of the nonwoven polymer composites.
2.0 Material and experimental procedures

2.1 Materials
Kenaf fibre at 4 months old was obtained from Dynamic Agrofarm Sdn Bhd in a ribbon form with the length ranges between 2 to 3 meters. Kenaf fibres were cut into 60 mm length. EFB fibre was purchased from Ecofibre Sdn Bhd. The length of EFB fibre were in the range of 30 mm to 180 mm. PP fibre was supplied by Hua long Chemical Fibre Co. Ltd, De zhou, Shan dong, China with the average length of 60 mm, fineness of 10 denier and melting point of 165 °C. The fibres were opened and cleaned before processed into nonwovens. No chemical treatment on kenaf, EFB and PP fibres was applied.

2.2 Preparation of composites
The manufacture of KPNC and EPNC involved three steps which were carding, needle punching and heat compression. Kenaf and EFB fibre were manually opened and mixed with PP fibre at 40%, 50%, 60% and 70% fibre contents. The mixtures were then fed into Laboratory Nonwoven Machine which consisted of three sections: carding, cross-lapping and needle punching as shown in Figure 1. During carding, the mixture was further opened and individual fibres were combed to be parallel and the fibre web was carded for second times in the perpendicular direction to improve web isotropy. The web was transferred to cross-lapping section and subsequently to needle-punching section where punching depth, punching density and punching time was set at 14 mm, 104 punches/cm² and 2 times respectively.

Next, the composite were prepared from nonwoven Kenaf/PP and EFB/PP nonwoven mats. The nonwoven mats were cut into 30 cm x 30 cm and placed between two aluminum plates as shown in Figure 2. These two plates were then pressed between two platens heat compression machine with gauge length at 6 mm thickness. The pressure, temperature and time of the heat compression were set at 15 Mpa, 190 °C and 20 mins respectively. The 6 mm KPNC and EPNC were then cut into specific sizes for mechanical characterization.

![Figure 1. Nonwoven processing line](image1)

![Figure 2. Heat-press process](image2)
2.3 Physical and mechanical properties of fibres
Fibre diameter was measured using Olympus Stereomicroscope Model SZX10 equipped with a DFC350 FX fluorescence camera (Leica Microsystems Inc., Wetzlar, Germany) microscope. The tensile tests were performed in ambient condition using Electronic Single Fibre Strength Tester Shimadzu GX1000 20N Load Cell (Japan) according to ASTM D 3822-01 test methods. The test was conducted with 20 replicates. The gauge length and the cross-head speed were set at 20 mm and 2 mm/min respectively.

2.4 Tensile and Compressive properties of nonwoven composites
The tensile strength and modulus of the nonwoven composites were evaluated using a Shimadzu Universal Tester in accordance with the ASTM D 3039 polymer matrix composite materials. Material flexibility was measured according to ASTM D 790 for reinforced plastics three-point bending method. The compression of composite panels was tested according to ASTM D3410. Ten specimens were tested for each sample and the average values were reported.

2.5 SEM of KPNC and EPNC
The fibre fractured surface of the KPNC and EPNC composites after tensile tests were observed by using the scanning electron microscope instrument Hitachi T1000. All specimens were coated with a thin layer of gold.

3.0 Results and discussion
3.1 Mechanical properties of Kenaf, EFB and PP fibre
A tensile strength indicates how a material will react to the force applied in tension direction and important for fibre properties. Table 1 shows the tensile strength, tensile modulus and tensile elongation of kenaf, EFB and PP fibres. Kenaf fibre has the highest tensile strength that was 426.4 MPa followed by PP at 161.44 MPa and EFB at 150.9 MPa. Kenaf also has highest tensile modulus among others that was 30 MPa, followed by EFB and PP fibres that were 2.0 MPa and 1.6 MPa respectively. PP fibre has significantly higher tensile elongation of 210.9% than both of natural fibre. EFB considered as one of the natural fibre that has high tensile elongation of 30% similar to coconut coir [3].

| Fibre   | Tensile strength (MPa) | Tensile modulus (GPa) | Tensile elongation (%) |
|---------|------------------------|-----------------------|------------------------|
| Kenaf fibre | 426.4(37.2)           | 30.0(34.2)            | 2.9(24.4)              |
| EFB fibre  | 150.9(81.9)            | 2.9(68.1)             | 30(32.7)               |
| PP fibre   | 161.44(3.17)           | 1.6(23.3)             | 210.93(9.3)            |

( ) : Coefficient of Variance in percentage

Fibre strength influence the composite strength if the fibre is used as the reinforcement material. The properties of fibre such as tensile strength, flexural strengths, and rigidity depend on the alignment of cellulose fibrils, which are generally arranged along the fibre length [14]. The tensile strength and tensile modulus of the EFB was only about 1/3 and 1/10 of kenaf fibres, respectively. However, the tensile elongation of the EFB was about 10 times of the kenaf fibres. Alves Fidelis et al. 2013 [19] have found
that the tensile strength of individual fibre have correlation with their different morphologies such as the
number of lumens, the number and size of fibre-cells and the thickness of the secondary cell-walls. Kenaf
has thicker cell wall, less number of lumen and small area of lumen than EFB which led to kenaf has
better mechanical property than EFB. It is also known that the strength of fibre are influencing the strength
of composite where the fibre is important to receiving the load [20]. Hence, Kenaf is a better choice
between these two natural fibre since it has better tensile strength and modulus which contribute to good
mechanical property for composite panel.

3.2 The effect of fibres content mechanical properties of KPNC and EPNC
The effect of fibre content in KPNC and EPNC is shown in Figure 3. The highest tensile strength for
KPNC and EPNC were 31.6 MPa and 20.1 MPa at 50% and 60% fibre content respectively. The tensile
strength of EPNC was significantly lower than KPNC. The tensile strength of the reinforced fibre was
functioned as a load bearing and it has influenced on the tensile strength of composite [11]. Kenaf showed
almost 3 times higher in fibre tensile strength than EFB and this may resulted to higher tensile strength of
KPNC compared to EPNC. Both KPNC and EPNC showed increment in tensile strength from 40% to
50% fibre content. The tensile strength of KPNC dropped at 60% while EPNC dropped at 70% fibre
content.

![Figure 3. The effect of fibre content on tensile strength of the composites](image1)

![Figure 4. The effect of fibre content on tensile modulus of the composites](image2)

According to Akil et al. [15], kenaf bast fibre is known to have potential as a reinforcing fibre in
thermoplastic composites, due to its superior toughness and high aspect ratio in comparison to other fibres.
The reason why the mechanical properties of the composites with 70% kenaf fibres lower than 60% was
that the amount of resin was not enough to wet the fibre hence, leading to bad interface between the fibres
and resin. The insufficient wettability has affected the tensile strength and this is in agreement with
Shibata and co-worker [2] where low bulk density resulted to better wettability.

Tensile modulus of KPNC and EPNC are shown in Figure 4. A gradual decreased of tensile modulus can be seen in both KPNC and EPNC sample from 40% to 60% fibre content. The tensile modulus showed increment at 70% fibre content for both KPNC and EPNC. This pattern was due to straightening of nonwoven mats which result in stiffening materials and effect on the interlocking of fibre entanglement. In nonwoven mat, fibres were arranged in random distribution that affected the fibre slippage while matrix were being strengthened by the transferred load [11]. High entanglement was
expected in fibre content of 70% which increased the stiffness of KPNC and EPNC’s composite at 27.5 Mpa and 37.3 Mpa respectively.

The flexural strength behavior of KPNC and EPNC were evaluated from three point bending test as shown in Figure 5. Modulus of rupture for both nonwoven composites were significantly increased from 40% to 60% fibre content and decreased after the fibre content up to 70%. The highest modulus of rupture for KPNC and EPNC were 53.6 MPa and 42.4 MPa respectively. Compatibility between lignocellulosic fibre and PP polymer is important where the polymer matrix has functioned as an interface of stress transfer between reinforces fibre. Incompatibility and insufficient wettability of PP with lignocellulosic creates stress points at interfacial regions and this is translated in the reduction in mechanical strength [11]. In this study, the optimum fibre content for flexural strength was achieved at 60% which was believed that the transfer of stress was most efficient at this stage. However, the flexural strength decreased for those with 60 % or more of fibre content. This was probably due to the bulkiness of the kenaf fibre, which reduced the PP volume when more kenaf fibre was incorporated resulting in insufficiency of matrix to hold the fibre. This has affected the ability of the matrix to absorb and transfer the stress to the fibres.

![Figure 5. The effect of fibre content on flexural modulus of the composites](image5)

![Figure 6. The effect of fibre content on flexural strength of the composites](image6)

Figure 5. The effect of fibre content on flexural modulus of the composites

Figure 6. The effect of fibre content on flexural strength of the composites

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elongation of kenaf and EFB fibres, similar compression strength was probably contributed by these tensile properties.

![Bar chart showing compression strength of kenaf and EFB fibres](image)

**Figure 7.** The effect of fibre content on compression strength of the composites

3.3 Morphological properties

The surface appearances of the KPNC and EPNC at 40% and 60% are shown in Figure 8. It showed that the surface of the composite turns rougher with the increase of the fibre content. As we compared KPNC and EPNC surface, KPNC has smoother and finer surface than KPNC which was influenced by the diameter of both fibre.

![Surface appearances of KPNC and EPNC composites](image)

**Figure 8.** The surface appearances of KPNC composites with kenaf content of (a) 40%, (b) 60% and EPNC with EFB content of (c) 40%, (d) 60%
Kenaf has higher in diameter along the fibre length and finer than EFB and its diameter also closer to PP. This may effect on good entanglement between kenaf and PP and has improved the wettability of the fibre during the dispersion of PP at the heat compression stage. Figure 9 shows scanning electron microscopy images of KPNC and EPNC at 40%, 50%, 60% and 70% of fibre content. SEM micrographs revealed more fibre pullout in KPNC than EPNC where only fibre breakage can be observed on EPNC surface. Observation on KPNC showed that more fibre pull out at 40% and 70% while more fibre breakage can be seen at 50% and 60% of fibre content. This probably due to stronger fibre entanglement at 70% fibre content which strongly hold the fibre together for stronger reinforcement. In addition, the occurrence of fibre pullout in 70% was also probably due to poor wettability and matrix dispersion on fibre and subsequently reduced the bonding interface [12]. On the other hand, the more fibre pull out at 40% kenaf was resulted by less entanglement between fibre which reduced the strength of fibre holding. There were no significant differences between fracture surfaces of EPNC at different fibre content where only fibre breakage can be observed in all fibre content. This condition may due to lower fibre tensile strength of EFB fibre to bear the load than load on interface between matrix and fibre. The observation was correlated with the low tensile strength of the EPNC.

Figure 9. SEM Images of KPNC at (a) 40% (b) 50% (c) 60% (d) 70% at 500x magnification and EPNC at (e) 40% (f) 50% (g) 60% (h) 70% at 200x magnification

4.0 Conclusion
Fibre’s tensile properties showed that kenaf fibre tensile strength was significantly higher than EFB while EFB fibre presented significantly higher elongation. The results also indicated that the mechanical strength of KPNC and EPNC were influenced by the percentage of fibre content where 60% fibre content was the optimum for flexural, tensile and compression strength of
KPNC. All of the KPNC’s mechanical properties were superior to EPNC and this pattern may
due to the higher mechanical strength of kenaf fibre than EFB Fibre. The SEM micrograph
showed good interface bonding in composite. It also indicated that KPNC with highest tensile
strength showed more fibre breakage while other KPNC with low tensile strength showed more
fibre pull out. This result proved that optimum fibre content is important for wettability and
related to mechanical strength.

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