Influence of resin system on the energy absorption capability and morphological properties of plain woven kenaf composites

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Abstract. Due to both environmental and technical advantages, natural fibers are being used as reinforcement of polymeric composite in many industries. The flexibility of the most natural fibers is one of the important technical characteristic which allows them to resist impact forces. An investigation was carried out to compare the energy absorption capability of kenaf/PVB film and kenaf/epoxy composites. The hot and cold press techniques were used to fabricate the specimens with 35% kenaf fibre weight fraction. The charpy impact test was performed on forty notched specimens using a pendulum impact tester with different hammer energy. The results showed that the kenaf/PVB film composite has the highest energy absorption, strength and toughness compared with the epoxy composite. At high energy levels, the impact strength and toughness of the kenaf/PVB film was six times of kenaf/epoxy composite. In addition, the scanning electron microscopy was assessed to demonstrate the different failure in fracture surfaces. It was found that the kenaf/PVB film composite failed by fibre fracture while kenaf/epoxy composite failed by a combination of fibre pull-out and fibre fracture as well as crack propagations through the matrix.

1. Introduction
Capability of composite energy absorber is completely affected by a fibre and matrix type as well as fabrication and test conditions [1]. Generally, two categories of energy absorbers are being used, low and high speed impacts depending on the impact loading conditions [2]. In recent years, the use of polymeric composites reinforced with natural fibre is increasing due to their economical and environmental advantages as well as high impact resistance during their service life [3]. Among the natural lignocellulosic fibres, kenaf fibres possess moderately high specific strength and stiffness that
could be utilized as reinforcing materials in polymeric resins to make useful structural composite material [4, 5].

Recent works on the impact resistance of curaua fibre reinforced either polyester [6] or epoxy [7] were investigated for continuous and aligned fibres. It has been reported that the toughness measured by the absorbed impact energy in Charpy test increases linearly up to volume fractions of 20-30% of fibres. In other studies, low impact tests were carried out on hemp reinforced unsaturated polyester composite specimens by Dhakal et al. [8, 9]. Likewise, Meredith et al. [10] investigated the unwoven hemp, flax and jute fibres reinforced composites and concluded that the unwoven hemp with its low embodied energy is a promising candidate for sustainable energy absorption structures. In an experimental study, Yan and Chouw [11] reported that flax fabric reinforced epoxy composite tube has the potential to be a useful energy absorber device. Similarly, Santulli and Caruso [12] carried out low velocity impact testing on the jute/epoxy and hemp/epoxy laminates. It has been concluded that the increase in fibre volume fraction results in an increased damage propagation phase thus increasing the impact resistance properties of the composite.

However, it is clear from the literature review that there are no reported works on the impact response of composites of plain woven kenaf reinforced PVB film. Hence, the objectives of the current study were to fabricate kenaf/PVB film and kenaf/epoxy composites and test using varying charpy hammer energy. Moreover, scanning electron microscopy (SEM) analysis of the fracture surface of the notched specimens was analyzed.

2. Materials and experimental procedure

To clarify the effect of the resin system with the energy absorption capability, kenaf/PVB film and kenaf/epoxy were fabricated and tested. Plain woven kenaf fibre is the main fibre that is used in this study with 2mm thickness, 1.2g/cm$^3$ density, and 100.64MPa average breaking strength [13]. PVB film (Polyvinyl butyral) is employed in a wide array of industrial and commercial applications as well as epoxy resin, which are commonly used in industry, were used to fabricate the composite samples. The epoxy used in this study is LY556 liquid with a density of 1.14 g/m$^3$, elongation at break 4.5%, and tensile strength 73.3MPa, with 1:2 HY951 hardener. While the tensile strength of the PVB film ≥ 20MPa and breaking elongation ≥ 200%, (manufacturer data sheet).

The composite samples were made with 35% kenaf fibre weight content by using a hot hydraulic press technique to reinforce PVB film, and cold hydraulic press-molded to reinforce epoxy resin. The plain woven kenaf fibre reinforced PVB film composite panels were prepared by compressing layers of kenaf fabric and PVB film stacking between the hot plates of a compression moulding press. The plates were electrically heated to a temperature of 170°C for 20 minutes, at a pressure of 8 MPa applied on the material. Same procedure was followed for the kenaf/epoxy composites but with cold hydraulic press. Plates of these composites with five layers of plain woven kenaf reinforced polymers were press-molded and allowed to complete inner cured for 4 hours. Twenty specimens were fabricated for each composite and energy, five replications were considered. Standard ASTM D 6110 Charpy notched specimens [14], 127 mm × 12.7 mm × 7 mm was cut from each composite plate and tested with different striking energy (0.5, 2.7, 5.4, 21.6) Joule. By using a wheel saw machine, the specimens were carefully cut and finished from the composite to the accurate size. They were notched with the radius of curvature 0.25R mm to 2.54 mm by motorised notch vis in the middle, according to the standard. The charpy impact tests were conducted by using a universal testing machine INSTRON, MECOMB in the Laboratory of Bio-Composites Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia. A detail flow chart for processing method is explained in figure 1, which includes the fibre preparation, mold preparation (two stainless steel plates), fabricating process (different resins systems), composite sample preparation (notched) and charpy impact testing progress. While figure 2 shows the specimens after breaking.
Figure 1. Drawing of the plain woven kenaf/PVB film and kenaf/epoxy composite laminates, by using hot press and hand lay-up techniques.

Figure 2. The composite specimens after Charpy impact tests.
3. Morphological Observation
The influence of the resin system on the fractured surface of the three types of composites after charpy impact tests were observed by using the scanning electron microscope (SEM) instrument model ZEISS SUPRA 35VP. All the fractured specimens were coated with a thin layer of gold to avoid electron charge accumulation, and subjected to a voltage of 10–15 kv.

4. Results and discussion
The variation of the charpy impact energy with the two types of kenaf/PVB film and kenaf/epoxy composites is shown in figure 3. In this Figure, a highly increment in the absorbed energy can be seen for kenaf/PVB film composite. While much less energy is absorbed by kenaf/epoxy composite at different energy levels. Furthermore, the charpy impact energy of kenaf/PVB film and kenaf/epoxy composites showed almost same behavior when tested with a low energy level, (0.5 J). The level of maximum impact energy for the kenaf/epoxy composite is significantly lower than the corresponding for kenaf/PVB composite, reached of the order of 0.895% and 3.995% at 21.6 J, respectively.

![Figure 3. Charpy impact energy of the composites.](image)

A similar finding was also observed in the average impact strength of the two types of composites, as shown in figure 4. It was clear that for the composite specimens fabricated using plain woven kenaf/PVB composite recorded the higher values of impact strength compared with the composite specimens fabricated using epoxy resin, at different energy levels. This may be explained by that PVB film has higher elongation properties compared to epoxy resin due to its low viscosity which help in penetrating fabrics easily. High strength and viscosity of the epoxy resin have increased the specimen stiffness and decreased from its ability to absorb impacts. Furthermore, using a hot press technique to fabricate the kenaf/PVB composite has affected the impact properties of the composites which lead to good resin/fabrics penetration. As research studies have reported, the type of polymer is a critical factor which has an important influence on the impact strength of the natural fibres composites [15-17]. A similar trend has been reported in the study done by Rassmann et al. [18] on kenaf fibres reinforced three different resins; namely polyester, vinyl ester and epoxy. The three different resins affect the impact strength differently depending on the fibre volume fraction. It was evident that the impact strength of the epoxy laminates is slightly lower than that of the polyester and vinyl ester laminates for each of the three fibre volume fractions. Generally, it can be seen that the impact energy strongly depends on the resin system. Another mechanism that may contribute to the increase in composite strength is the low interface shear stress between a hydrophilic lignocellulosic fiber and a hydrophobic polymeric matrix [19]. As reported for curaua fibers [7, 20], ramie fibers [21] and coir fibers [22] reinforced epoxy composites. The incorporation of lignocellulosic fibres offers an obstacle to the propagation of an initial crack at the specimen notch, then cause others cracks at the weak fibre/matrix interface propagate longitudinally through the interface following the specimen length.
direction. Consequently, this mechanism is associated with a higher absorbed impact energy resulting in corresponding higher notch strength of the composite. Ultimately, it is worth mentioning that among the literature review results, the present results on plain woven kenaf fibers reinforcing PVB composites are the ones with the highest impact properties.

Figure 4. Charpy impact strength of the composites.

Similarly, the charpy impact toughness seems to have same impact energy and impact strength behaviors at different energy levels, as represented in the figure 5. It is clearly seen that the kenaf/PVB composite has greater impact toughness than the impact toughness of the kenaf/epoxy composite, especially at high energy levels. This means that the kenaf/PVB composite absorb the most energy before failure while the kenaf/epoxy composite absorb the least. The average impact toughness of two composites exhibited high difference when tested at high energy levels, approximately six times of the kenaf/epoxy composite value at both 5.4J and 21.6 J. While the average impact toughness of the two composites showed almost same behavior when tested at low energy levels. As stated by others [23, 24], the properties of the polymer were accountable for deciding the impact toughness of composites. This implies that both the effect of interlaminar delimitation and interfacial strength between fibre and matrix highly decide impact properties, especially in the case of weaving pattern as stated by researchers [25-27].

Figure 5. Charpy impact toughness of the composites.

5. Morphological Properties
SEM examinations of the charpy impact fractured surface of the kenaf/PVB film and kenaf/epoxy composites specimens are presented in figures 6 and 7. It was observed that for the two composites, there is no delamination between layers and the interfacial bonding between kenaf fiber and PVB film
was the best. Similar failure modes have been reported for bamboo and coconut fibres reinforced epoxy composites [28]. Based on the morphology achieved, kenaf/PVB composite failed by fibre fracture while kenaf/epoxy composite failed by a combination of fibre pull-out and fibre fracture as well as crack propagations through the matrix. A tortuous path in crack propagation through the fibre/matrix interface and many hollow portions after the fracture can be seen in the micrograph of the kenaf/epoxy composite, indicating that the phenomenon of fibre pull-out occurred to a large extent. In figure 7(b), the crack propagating through the epoxy matrix reaches a kenaf fiber causing decohesion and separation of fibrils and consequently reduced its strength. These failure mechanisms agree very well the impact damage observed by Aly et al. [25] for flax fibre reinforced epoxy composite. Generally, the strength of the composite is governed by the initiation and propagation of microscopic cracks through the matrix. This indicates that PVB film bonds better with the kenaf fibres (disorderly distributed in the matrix) than epoxy resin. The appearance of transverse cross sections of the kenaf fibre end reflects the absence of kenaf fibre pullout and ensures enhanced interfacial adhesion which leads to good impact resistance for the kenaf/PVB composite. Furthermore, both crosslinking of kenaf fibre and PVB film properties could create the complex load sharing behavior between the kenaf fibre and PVB film, as shown in figure 6(a) and (b).

![Figure 6](image1.png)  
**Figure 6.** The SEM micrographs of the charpy impact failure surfaces of kenaf/PVB film composite.

![Figure 7](image2.png)  
**Figure 7.** The SEM micrographs of the charpy impact failure surfaces of kenaf/epoxy composite.
6. Conclusion
Results of this study reveal that significant increases in energy absorption, strength and toughness of the kenaf/PVB composite were found at different energy levels. The impact strength and toughness of the kenaf/PVB film was six times of kenaf/epoxy composite, especially at high energy levels. SEM examinations of charpy impact test specimens show that there is no delamination between layers and the interfacial bonding between kenaf fiber and the two resins, but PVB film was the highest. In addition, kenaf/PVB composite failed by fibre fracture while kenaf/epoxy composite failed by a combination of fibre pull-out and fibre fracture as well as crack propagations through the matrix.

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