Effect of fibre orientations on the mechanical properties of kenaf–aramid hybrid composites for spall-liner application

R. YAHAYA a,b, S.M. SAPUAN a,c,d,*, M. JAWAID c,e, Z. LEMAN a, E.S. ZAINUDIN a,c

a Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
b Science and Technology Research Institute for Defence (STRIDE), 43000 Kajang, Selangor, Malaysia
c Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
d Aerospace Manufacturing Research Centre (AMRC), Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
e Department of Chemical Engineering, College of Engineering, King Saud University, Riyadh, Saudi Arabia

Received 18 April 2015; revised 20 August 2015; accepted 20 August 2015
Available online 14 September 2015

Abstract
This paper presents the effect of kenaf fibre orientation on the mechanical properties of kenaf–aramid hybrid composites for military vehicle’s spall liner application. It was observed that the tensile strength of woven kenaf hybrid composite is almost 20.78% and 43.55% higher than that of UD and mat samples respectively. Charpy impact strength of woven kenaf composites is 19.78% and 52.07% higher than that of UD and mat kenaf hybrid composites respectively. Morphological examinations were carried out using scanning electron microscopy. The results of this study indicate that using kenaf in the form of woven structure could produce a hybrid composite material with high tensile strength and impact resistance properties.

Keywords: Hybrid composites; Spall-liner; Aramid fibre; Porosity; Mechanical testing

1. Introduction

The search for alternative fibres as a replacement for man-made fibres has had continued. The well-known advantages of natural fibres are low density, low cost, its availability, renewability, ease of production, low process energy, non-abrasive, good acoustic property, acceptable specific strength and modulus, low cost, easily available, and easy recyclability [1–5]. However, there are some limitations which required further improvement such as its moisture absorption due to hydrophobicity, dimensional stability and poor wettability, low thermal stability during processing and its poor adhesion with synthetic fibres [5,6]. The combination of two or more natural and synthetic fibres into a single matrix has led to the development of hybrid composites [7]. Natural–synthetic fibre hybrid composites are increasingly used in a wide range of applications [8]. The advantages of hybridisation are fully utilised to reduce the use of synthetic fibres which are generally non-environmentally friendly. Hybrid composites can be made from artificial fibres, natural fibres and with a combination of both artificial and natural fibres [9].

Kenaf fibres (Hibiscus cannabinus L.) have a potential as an alternative for partial replacement of conventional materials or synthetic fibres as reinforcement in composites [10]. It is reported in the literature that kenaf are already being used in hybrid form with synthetic materials such as glass [8,11–13], carbon [14], and polyethylene terephthalate (PET) [15]. Aramid is one of the synthetic fibres used in hybrid composites. Aramid fibres are a class of heat-resistant and strong synthetic fibres which are widely used in aerospace and military applications, for ballistic rated body armour fabric and ballistic composites. Para-aramid fibre (Kevlar) is one of the commercially available aramid fibres and provides a unique combination of toughness, extra high tenacity and modulus, and thermal stability [16]. Kenaf–Kevlar hybridisation for defence application was reported in Refs. [17,18].

There are factors that influence the properties of kenaf hybrid composites. One of the factors is the hybrid types
Karahan et al. [21] studied the influence of woven structure and random orientation on the mechanical properties of the hybrid composites. Pothan et al. [22] studied composites of woven sisal and polyester using three different weave architectures (plain, twill and matt) with special reference to resin viscosity, applied pressure, weave architecture, and fibre surface modification. This study provided detailed information on the effect of weaving, architecture and fibre content on the mechanical properties of the hybrid composites. Karahan et al. [24] observed the decrease in the mechanical properties of carbon–epoxy composites as a result of weaving structure. Karahan et al. [25] determined the effect of weaving structure and hybridisation on the low velocity impact properties of carbon–epoxy composites. It was reported that the best result obtained from twill woven composite with the energy absorption capacity was improved by around 9–10% with hybridisation. Alavudeen et al. [26] studied the effect of weaving patterns and random orientation on the mechanical properties of banana, kenaf, and banana/kenaf fibre-reinforced hybrid polyester composites. They found that the plain type showed improved tensile properties compared to the twill type in all the fabricated composites.

Based on the literature studies, it was found that mechanical properties of kenaf–aramid hybrid composites were not reported. The present study aimed to evaluate the mechanical performance of kenaf–aramid hybrid composites for spall-liner application. Since the properties of a composite are often determined by the properties of the components and the fraction of inclusions [27], there is a requirement to study the effect of fibre properties in hybrid composite. In this study, the effects of kenaf fibre orientation on the physical and mechanical properties of kenaf–Kevlar hybrid laminate composites were studied. The kenaf fibres and Kevlar were arranged in similar sequences to prepare the hybrid laminated composites. The kenaf tested are in the form of woven and non-woven structures. The effects of the fibre content and its morphology were also analysed.

2. Materials and methods

2.1. Materials

Aramid fabric used in this study is the plain weaved structure Kevlar 129. Three types of kenaf fibres were used in this study: woven, unidirectional and mat. The woven kenaf was produced by the interlacement of warp and weft yarns by using table loom. The yarns were obtained from local suppliers, Innovative Pultrusion Sdn Bhd. The unidirectional samples consist of kenaf yarn (800 tex) cross plied at 0°/90°. No chemical treatment was conducted on the kenaf fibres prior to this study. The resin used in this study is DER 331 liquid epoxy with a density of 1.08 g/m³. The resin was cured using joint mine type (905-35), cycloaliphatic amines.

2.2. Fabrication of composite laminates

Hand lay-up method was adopted to fabricate laminates of Kevlar 129 and kenaf in epoxy resin. The specimen consists of six layers of Kevlar with the kenaf fibres in the middle as shown in Fig. 1. Kenaf and Kevlar fabric were hand lay-up with the epoxy matrix by mixing epoxy resin (DER 331) and amine hardener in the ratio of 2:1. Two thick mild steel plates are used as a mould (20 × 20 cm) in the fabrication process. All the mould surfaces were sprayed with a mould release agent to prevent adhesion of composites to the mould after curing and also to ensure smooth sample surface. Composites were cured by applying compression pressure using dead weights on the top of the mould and cured at room temperature for 24 hours. The specimens were also post-cured at 70 °C for 2 hours after removing from the mould. The composition of hybrid composites is shown in Table 1.

2.3. Density and void contents

The density of the hybrid laminates was measured according to the ASTM D792 standards. Rectangular samples with size of 10 mm × 10 mm were used. Distilled water at room temperature was used as the immersion fluid and the mass was measured using a digital balance with a 10⁻³ g resolution. Five specimens were tested and an average was taken. To analyse the void percentage in the composite laminates, the ASTM D2734 standard was used. The void content was determined from the

---

<table>
<thead>
<tr>
<th>Designation</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woven (W)</td>
<td>One layer of woven kenaf (10.46 vol %) + woven Kevlar (21.2 vol %) + Epoxy</td>
</tr>
<tr>
<td>Unidirectional (UD)</td>
<td>One layer of 0°/90° kenaf yarn (16.51 vol %) + woven Kevlar (16.78 vol %) + Epoxy</td>
</tr>
<tr>
<td>Mat (M)</td>
<td>One layer of non-woven kenaf mat (9.57 vol %) + woven Kevlar (21.39 vol %) + Epoxy</td>
</tr>
</tbody>
</table>
theoretical and the experimental density of the composites by using Eqs. (1) and (2):

\[ \text{Void (\%)} = \left( \frac{\rho_{\text{theoretical}} - \rho_{\text{experimental}}}{\rho_{\text{theoretical}}} \right) \times 100 \]  
(1)

where \( \rho_{\text{theoretical}} = \frac{1}{\left( \frac{w_f}{\rho_f} + \frac{w_m}{\rho_m} \right)} \)  
(2)

\( w_f \) is the fibre weight fraction, \( w_m \) is the matrix weight fraction, \( \rho_f \) is the fibre density, and \( \rho_m \) is the resin density.

2.4. Dimensional stability and water absorption test

The dimensional stability of kenaf–Kevlar hybrid composites was determined by water absorption and thickness swelling test. Three samples of each composite were immersed in distilled water at room temperature. After a certain period of time, the samples were removed from the water, wiped with a clean tissue paper before the weight and thickness value was measured. The percentage of water absorption was calculated by the weight difference using the following equation:

\[ w_e(t) = 100 \times \left( \frac{w_t - w_0}{w_0} \right) \]  
(3)

where \( w_e \) is the relative weight change or water absorption percentage, \( w_t \) is the weight at time \( t \), and \( w_0 \) is the initial weight at \( t = 0 \), and \( t \) is the soaking time.

The percentage of thickness swelling was estimated by

\[ T_e(t) = 100 \times \left( \frac{T_t - T_0}{T_0} \right) \]  
(4)

where \( T_e \) is the percentage of thickness swelling, \( T_t \) is the thickness at time \( t \), and \( T_0 \) is the initial thickness at \( t = 0 \).

2.5. Mechanical testing of composites

Tensile test was conducted to determine the stress–strain behaviour of Kevlar–kenaf hybrid laminated composites. The test was carried out using Instron 33R 4484 testing machine based on ASTM D 3039 on samples with a size of 200 mm × 25 mm × actual thickness. A standard head displacement at a speed of 5 mm/min was applied. Flexural test was conducted by using 3-point loading using Instron 33R 4484 testing machine according to the ASTM D 790-03. The rectangular samples with dimensions of 100 mm × 20 mm were cut using a circular saw. The tests were conducted at a crosshead displacement rate of 5 mm/minute. For each test, three samples were tested at room temperature and average data were taken as a final result. For Charpy impact, the test samples are prepared and tested according to the ASTM D256. Five un-notched samples with dimensions of 80 mm × 10 mm × respective thickness from each composition were tested. The composite toughness was analysed and reported.

2.6. Scanning electron microscopy (SEM)

Kenaf–Kevlar hybrid composite samples were observed using a scanning electron microscope Leo 1430VP. The cross-sectional surfaces of the samples were cut and the scanning electron micrographs were taken to observe the interface adhesion of fibre layers and the matrix of the hybrid composites. Prior to the analysis, the hybrid composite samples were coated with palladium using a sputter coater.

3. Results and discussion

3.1. Density and void

The measured density composites are listed in Table 2. It was observed that the density of samples W and UD are higher (1.10 g/cm³) than other composites. At the same time, the density of sample M is 0.87 g/cm³, which is lower than other composites. The presence of voids inside the samples was calculated by comparing the measured density with the theoretical density. It was found that the contents of the void in samples W, UD and M are 7.32%, 8.39% and 26.70% respectively. The result may be due to less air entrapment in the hybrid composites with woven kenaf structure, which led to lower void content. Measurement of void content is important as it is a critical imperfection in fibre reinforced composite materials [28].

3.2. Thickness swelling test

The result of thickness swelling test was shown in Fig. 2. Sample UD shows the highest thickness swelling (3.03%) among all the samples. The woven sample shows moderate (2.20%) thickness swelling and the mat sample is lower (2.04%). The figure also showed that the increase in immersion time will allow water absorption, thus increases the thickness swelling of the hybrid composites until a constant thickness was obtained. According to Jawaid et al. [29] the hydrophilic properties of lignocellulose materials and the capillary action will cause the intake of water when the samples were soaked in water and thus increase the dimension of the composite. The presence

![Fig. 2. Thickness swelling of hybrid composites.](image-url)
of voids also related to the thickness swelling of as the higher the void contents increase the thickness swelling of composites [29]. However, the result in swelling thickness is contradictory to this statement. This may be the effect of the hybridisation of kenaf with Kevlar, synthetic fibres. According to Ray and Rout [30], water molecules attract the hydrophilic groups of natural fibres and react with the hydroxyl groups (—OH) of the cellulose molecules to form hydrogen bonds. Thickness swelling occurred as the water molecules penetrate the natural fibre-reinforced composite through micro-cracks and reduce the interfacial adhesion of fibre with the matrix. Higher Kevlar content in sample M resulted in higher fibre–matrix interfacial adhesion, thus lower thickness swelling. Khalil et al. [31] reported that the water absorption and the thickness swelling of natural fibre reinforced with polyester composites are improved by the incorporation of synthetic fibres. The contradiction of water absorption and thickness swelling in this study may also be due to the exposure of the lignocellulosic fibre on the surface of the composite [32].

3.3. Water absorption test

The water absorption test was used to determine the amount of water absorbed by hybrid composite which consists of woven, UD and mat kenaf layers under specified conditions. Fig. 3 shows the behaviour of water absorption in the woven, mat and unidirectional (UD) samples. Initially, all samples had a sharp linear increase in moisture absorption and reached their saturation state with maximum moisture content of 8.07 % for W and UD samples and 26.84 % in sample M after 320 h of water immersion respectively. It was found that samples with woven and UD kenaf absorb less water before it reached a saturation state and the samples with kenaf mat recorded the highest water absorption before reaching the saturated state. Similar in thickness swelling, water absorption was also influenced by the void content of the composite; the weight of the composite will increase by trapping the water inside the voids [29]. In general, moisture diffusion in a composite depends on factors such as the volume fraction of fibre, fibre orientation, fibre type, area of exposed surfaces, surface protection voids, viscosity of the matrix, humidity and temperature [33].

3.4. Effect of kenaf fibre orientations on the tensile properties of the hybrid composites

Tensile strength of hybrid composites determined its ability to resist breaking under tensile stress. The tensile properties of kenaf–Kevlar hybrid composites are compared with various kenaf structures. Fig. 4 shows the tensile stress–strain curves of the tested samples. The curves show the brittleness and ductile nature of the composites. For woven and UD samples, the samples elongated with the increased stress level up to certain values where the kenaf layer failure occurred. The curve is continuous until total failure of the samples occurred as the outer layers of the Kevlar fabric break. No such observation was reported in the mat samples. Based on the curves, it was observed that the elongation at the break of woven samples is lesser than the other samples. The tensile properties of samples are compared and given in Fig. 5. The tensile strength and tensile modulus are found to be higher, 145.8 MPa and 3336.71 MPa, respectively, for composites with woven kenaf. The tensile strength and modulus of sample UD were recorded in intermediate with the values of 115.36 MPa and 2368.48 MPa. The lowest tensile properties are observed in non-woven kenaf sample M with the strength and modulus of
101.56 MPa and 1888.39 MPa respectively. The properties of the samples with woven kenaf are improved from the previous report [34]. It was found that the use of table looms weaved kenaf fabric compared with hand-weaved in earlier produced kenaf fabric. The result shows that the kenaf fibre orientation has an influential effect on the tensile properties of the composites. The advantages of woven fibre structure were observed in a previous work [26]. There are many other advantages of using woven composite such as stated in the published works [35,36].

### 3.5. Effect of kenaf orientations on the flexural properties of the hybrid composites

The flexural test is useful in quantifying the properties of composite mainly in structural applications. The flexural load-extension curves of woven, UD and mat kenaf–Kevlar hybrid composites are shown in Fig. 6. The curves indicate the failure mode of the composites. According to Pothan et al. [23] the abrupt failure of the composite can be related to flexural failure and the gradual decrease in loading indicates shear failure as the predominant mode. In this study, the failure mode can be classified as a mixed failure mode. Fig. 7 shows the variation in the flexural properties of kenaf–Kevlar hybrid composites. It is observed that the flexural strength of sample UD is the highest (100.3 MPa), followed by weaved structure and mat structure: 94.21 MPa and 35.82 MPa respectively. In terms of flexural modulus the woven samples are found to be the highest compared with other samples. From the works of earlier researchers it was found that the fibre orientation influences the properties of the composites [37]. The positive effect of woven structure was also observed by Alavudeen et al. [26].

Multiple factors can influence the flexural strength and modulus of hybrid composites. One factor might be the interfacial bonding between the fibres and epoxy matrix that facilitates load transfer. Fibre volume fraction and fibre orientation were determined as important factors in the mechanical properties of the composites [38]. Higher percentage of voids has also a negative effect on the flexural modulus and strength of the composites [39].

### 3.6. Effect of kenaf orientations on the Charpy impact strength of the hybrid composites

The Charpy impact test was conducted to determine the amount of energy absorbed by the hybrid composites during fracture. The results of the Charpy impact test are presented in Fig. 8. It is observed that the value of Charpy impact strength is higher in woven samples (51.41 kJ/m²) compared with the UD samples (41.24 kJ/m²) and mat samples (24.64 kJ/m²). The impact properties of composites depend on the interlaminar and interfacial adhesion between the fibre and the matrix. In this study it was found that the impact strength of kenaf–Kevlar hybrid composites is in similar trend as the tensile properties. This is in contrast with the observation of Van der Oever et al. [40] that the Charpy impact strength decreases with increasing fibre internal bonding and enhanced fibre–matrix adhesion, which is opposite to the trend for the tensile and flexural properties. The impact toughness of kenaf/glass hybrid composites was found to be influenced by the fibre orientation [41]. It was found to be affected by fibre orientation in glass fibre reinforced polymer matrix composites [42]. In determining the influences of weaving architectures on the impact resistance of multi-layer fabrics, Yang et al. [43] found that the weaving architectures and fabric firmness are less influential on the overall ballistic protection of multi-ply systems compared to the single-ply cases.

Generally, based on the above discussion, it was found that the effect of fibre orientations is important to the mechanical properties of hybrid composites as well as for ballistic resistant application [44]. Kenaf–Kevlar hybrid...
composites may find applications as alternatives to current spall-liners which are aimed at protection from impact by small fragments.

3.7. Scanning electron microscope

Figs. 9–11 show the SEM surface morphology of kenaf–Kevlar hybrid composites. The cross-sectional observation of untested samples was focused on the fibre–matrix interfacial and void content in the matrix. The interstitial regions which serve as crack initiators are observed in woven and UD samples. Fig. 11 reveals a weak fibre/matrix interface with voids and cracks. This could be responsible for the deterioration of the stress transfer from the matrix to the fibres, thus affecting the mechanical properties of the composites [11].

4. Conclusions

The outcomes of the present work are the effect of kenaf fibre orientation on the mechanical properties of hybrid composites. The effect of kenaf structure (woven, non-woven UD and non-woven mat) was investigated along with the tensile, flexural and impact performance of the prepared composites. The following conclusions are made based on the extensive experimental study:

1) The experiments show that a non-woven mat kenaf–Kevlar hybrid composite has low density as there are high void contents. Hybrid composites with woven and UD kenaf are almost similar in density and void content.

2) The addition of kenaf affects the water absorption behaviour of the composites. The hydrophilic nature of kenaf fibres and void content are responsible for the water absorption and this adversely affects the fibre swelling and dimensional stability.

3) The tensile and Charpy impact strength properties of woven kenaf–Kevlar composite are higher than other hybrid composites. On the contrary, the flexural strength of the hybrid composites with UD kenaf is slightly higher compared with a hybrid with woven kenaf.

4) The scanning electron micrograph of the hybrid composite exhibited higher void content in the mat kenaf composites compared with the UD and woven kenaf.

Acknowledgments

The authors would like to show their appreciation to Universiti Putra Malaysia and Science and Technology Research Institute for Defence (STRIDE) for supporting the research activity.

References


[4] Rashdi AAA, Sapuan SM, Ahmad MMHM, Khalina A. Combined effects of water absorption due to water immersion, soil buried and natural


