Effect of Moisture Absorption on Mechanical Properties of Natural Fibre Hybrid Composite

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Abstract: The study on the effect of environmental conditions on the mechanical properties of composites is much important. Natural fibre reinforced composites have been widely used in the variety of applications. Natural fibre composites may suffer when the material is exposed to adverse environments for long periods of time. Natural fibre-synthetic of kenaf-Kevlar and jute-Kevlar laminated with epoxy resin. The hybrid composites were subjected to water immersion in order to study the effect of water absorption on the mechanical properties of samples containing about 30% by weight of fibre content. The diffusion coefficient of water absorption and maximum moisture content were calculated by measuring water uptake of specimen at regular time interval. Tensile and impact properties of the composites were determined. A decrease in tensile properties of the composites was demonstrated, showing a great loss in mechanical properties of the humid samples compared to the dry samples. The percentage of moisture uptake increased as the weight percentage of fibre is increased due to the high cellulose content. The water absorption pattern of these composites was found to follow Fickian behaviour.

Key-Words: Hybrid composite; Environment; Water absorption; Natural fibre; Laminates; Mechanical properties.

1 Introduction
Natural fibres are widely used for reinforcement in polymer composites. The advantages of natural fibres such as renewable, environmental friendly, low cost and many more are well known. Besides that, there are also disadvantages in term of mechanical properties [1]. Natural fibres are used in many applications such as aerospace industry, marine sector, automotive industry, sporting segments, and construction industries [2]. In order to improve the mechanical properties of natural fibres composites, researcher enhanced their effort in hybridisation with synthetic fibres. Fibres such as aramid (Kevlar, Twaron), Ultra-high-molecular-weight polyethylene (UHMPE) and Dyneema are widely used for example in ballistic composites. Synthetic fibres normally are expensive and in some instances controlled items. The synthetic fibres such as aramid, glass etc. is classified as high performance fibres and used in various fields including automotive, aerospace, marine etc. The research on natural fibre hybrid composites are reported in…..The advantages of hybridisation is among others will reduce the use of synthetic fibres which mostly produced from petroleum based resources. The durability of hybrid composites
has attracted the attention of engineers and scientist. Sustainable to the environmental effect is one of the criteria in evaluating its durability.

The environmental effects on the mechanical properties of natural fibre composites are well researched and described in the literatures. Costa et al. [3] studied the effect of water absorption on the mechanical properties of sisal and jute fiber composites. The jute epoxy composite showed the best properties over all the immersion times analysed. The experimental results showed that the sisal fibres are much more strongly affected by moisture than jute fibres. The jute-epoxy composites showed the best mechanical properties and were the least affected by the exposure of the composites to distilled water. Rashdi et al. [4] effects of water absorption due to water immersion, soil buried and natural weather on mechanical properties of kenaf fibre unsaturated polyester composites (KFUPC). They observed the reduction in tensile strength and modulus of the composites in the humid samples compared to the dry samples. The percentage of moisture uptake increased as the weight percentage of fibre is increased due to the high cellulose content. The water absorption pattern of these composites was found to follow Fickian behavior. Seki et al. [5] studied the effects of water absorption on the interlaminar shear strength of jute-reinforced polyester in distilled water and salt water. The results showed that all the solutions marginally degraded the interlaminar shear strength values of the composites. The ILSS of the composites was reduced by more than 53% by the distilled water and the salt water after immersion time of 2736 h.

In the present study, kenaf/Kevlar hybrid composites were prepared, and their water absorption and thickness swelling behaviours were studied. After 4 months, the mechanical properties of these samples were tested to determine the effect of water ageing.

2. Experimental details

2.1 Materials

The specimens tested were manufactured from sheets of woven kenaf, recycled jute and aramid (Kevlar) fabric. Kevlar fabric used in this study is a plain weaved structure Kevlar 29. The density of Kevlar is 1.44g/cm³, which is taken from the supplier’s data sheet. Kenaf in the form of non-woven mat was used and the density of kenaf is 1.40g/m³. The resin used in this study is D.E.R. ™ 331 liquid epoxy with a density of 1.08g/m³. The resin was cured using joint amine type (905-3S), cycloaliphatic amines. Non-silicone mould release agent formula 700-A supplied by Aerosol Specialist Sdn. Bhd. Penang, Malaysia, was used prior to fabrication processes.

2.2 Fabrication of composites laminates and samples configuration

Hand-lay-up method was adopted to fabricate laminates of Kevlar 29 and kenaf in epoxy resin. The specimen consists of layers of Kevlar and kenaf fibres in the sample configuration as shown in Figure 1. Kenaf and Kevlar fabric were hand laid-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 were used as a mould (20cm x 20cm) in the fabrication process. All the mould surface was 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 consolidated material had an average fibres content of about 30% weight. The properties of samples are shown in Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Kenaf (vol. %)</th>
<th>Kevlar (vol. %)</th>
<th>Thickness (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenaf</td>
<td>18.64</td>
<td>0.00</td>
<td>2.30</td>
</tr>
<tr>
<td>20%kenaf/Kevlar</td>
<td>8.27</td>
<td>21.30</td>
<td>4.89</td>
</tr>
<tr>
<td>50%kenaf/Kevlar</td>
<td>12.96</td>
<td>16.70</td>
<td>3.53</td>
</tr>
</tbody>
</table>

2.3 Experimental procedure
2.3.1 Water absorption test and thickness swelling

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 was measured. The percentage of water absorption was calculated by the weight difference using the following equation:

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

(1)

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

The thickness swelling of kenaf/Kevlar hybrid composites was calculated using the following equation:

\[ t_e(t) = 100 \times \left( \frac{t_t - t_0}{t_0} \right) \]  

(2)

where \( t_e \) is the relative thickness percentage, \( t_t \) is the thickness at the time \( t \), and \( t_0 \) is the initial thickness at \( t=0 \), and \( t \) is the water immersion time.

2.3.2 Tensile test

Tensile test was conducted to determine the stress-strain behaviour of the Kevlar-kenaf hybrid laminated composite. The test was carried out using Instron 33R 4484 testing machine based on ASTM D 3039 on plates with a size of 200 mm x 25 mm x sample thickness for each composite. The samples were carefully cut from the laminate using wheel saw and finished to the accurate size. A standard head displacement at a speed of 5mm/min was applied. For each sample, three specimens were tested and average results were obtained.

2.3.3 Impact test

The test samples are prepared and tested according to the ASTM D256. The Charpy test was performed on five samples using a pendulum impact tester. Five un-notched samples of dimension 80mm×10mm x respective thickness from each composition were tested. The energy needed to break the samples and composite toughness can be analysed.

3. Results and discussion

3.1 Water absorption properties

The diffusion coefficient (D) is the most important parameter of Fick’s model, which shows the ability of the water molecules to penetrate inside the composites. For the initial part of the absorption phenomenon, the mass of water, \( M\% \), absorbed in a time \( t \) can be written as a percentage of the mass of water absorbed at saturation, \( M_\infty \). It was calculated using the following equation from the initial slope of the plot of \( M\% / M_\infty \) against \( (\text{time})^{1/2} \).

\[ \frac{M_t}{M_\infty} = \frac{4}{L} \left( \frac{Dt}{\pi} \right)^{1/2} \]  

(3)

\[ D = \pi \left( \frac{kL}{AM_\infty} \right)^2 \]  

(4)

where \( L \) is the thickness of the specimen. \( M_t \) is water absorbed in a time \( t \) and \( M_\infty \) are the mass of water absorbed at saturation, \( h \) is the slope of plot of \( M\% \) vs. \( \sqrt{t} \). The experimental data points, \( M_t \), versus \( \sqrt{t} \) were fitted to Eq. (3) and (4) in order to obtain the values of \( D \) and \( M_\infty \).

Table 1. Water absorption parameter

<table>
<thead>
<tr>
<th>Sample</th>
<th>D($10^{-9}$ mm$^2$/s)</th>
<th>( M_\infty ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenaf</td>
<td>3.58</td>
<td>5.68</td>
</tr>
<tr>
<td>20%Kenaf/Kevlar</td>
<td>0.87</td>
<td>3.15</td>
</tr>
<tr>
<td>50%Kenaf/Kevlar</td>
<td>12.9</td>
<td>6.01</td>
</tr>
</tbody>
</table>

In Table 1, diffusion coefficients of distilled water for their absorption are given. Sample of 50% kenaf/Kevlar hybrid composite shows higher diffusion coefficient, \( D \) and greater water uptake, \( M_\infty \) compared with sample of 50% jute/Kevlar hybrid composites. The overall diffusion of the tested composites could be described by the Fickian model as it shows an increasing trend before it reaches equilibrium. Maximum water absorption is higher in non-
hybrid composite except for 50% kenaf/Kevlar. An increased in natural fibre content lead to increasing to water absorption of the hybrid composites.

Table 2. Thickness swelling of kenaf/Kevlar hybrid composites

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thickness swelling (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenaf</td>
<td>2.54</td>
</tr>
<tr>
<td>20%kenaf/Kevlar</td>
<td>3.83</td>
</tr>
<tr>
<td>50%kenaf/Kevlar</td>
<td>5.59</td>
</tr>
</tbody>
</table>

Table 2 shows the thickness swelling behaviours of composites tested. 50% kenaf/Kevlar hybrid composites showed the highest rate of thickness swelling (5.59%) among all the composites. The 20% kenaf composite showed a moderate thickness swelling (3.83%).

3.3 Tensile tests

Figure 1-2 shows the measured tensile strengths of the hybrid composites. In Figure1, tensile strength of un-aged kenaf/epoxy is 23.24MPa and reduced to 17.55MPa after water ageing test. Samples with 50% kenaf/Kevlar recorded 137.71MPa before ageing and the tensile strength reduced 22.4% to 106.82MPa after 4 months water ageing test. Tensile strength of samples with 20% kenaf/Kevlar was reduced about 16.8% from the un-aged samples. The experimental results showed that the kenaf fibres are much more strongly affected by moisture. When the natural fibre/kevlar composites are immersed in the water, water uptake would happen as the results of capillarity of the materials and the water absorption of the hydrophilic groups in the aramid fibre and the epoxy. The weight uptake would increase with prolonged immersion time until the composite is unsaturated. The reaction between the water molecules and the matrix would deteriorate the interphase resulting in a weaker material.

3.4 Charpy impact tests

Figure 5 shows the measured impact strength of hybrid composite before and after water ageing. The results indicate that impact strength of hybrid composites are slightly increased after 4 month water ageing. The impact strength of samples of 50% kenaf/Kevlar and 20% kenaf/Kevlar increased 12.17% and 7.94% compared with un-aged samples respectively. This may be explained by the effect of water ageing improves the strength due to the increasing ductility caused by the water in the matrix.
4. Conclusions

The effect of water ageing on the mechanical properties of kenaf/Kevlar composites was investigated. Based on the results, the following conclusions are made:

(1) With the water ageing test, the water absorption and thickness swelling increased with immersion time for all types of composites.
(2) Tensile strength of kenaf/Kevlar hybrid composites was significantly affected by water ageing.
(3) Impact strength of kenaf/Kevlar hybrid composites was not affected by the water ageing.

Acknowledgements

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

References


