Impact Properties of Natural Jute Fabric/Jute Mat Fiber Reinforced Polymer Matrix Hybrid Composites

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Received: March 22, 2012 / Accepted: April 11, 2012 / Published: June 25, 2012.

Abstract: Recycled needle punched jute fiber mats as a first natural fiber reinforcement system and these jute mats used as a core needle punched with recycled jute fabric cloths as skin layers as a second natural fiber reinforcement system were used for unsaturated polyester matrix composites via modifying the hand lay-up technique with resin pre-impregnation into the jute fiber in vacuum. Two types of impact tests, swing pendulum (Izod) and drop weight (impulse) were carried out to evaluate the effect of fiber contents on the impact properties of above-mentioned composites. The results showed that as the fiber weight content increased, the Izod impact strength and total impact energy of jute mat composites increased and the improvement had occurred at 11 wt% compared to those of the neat resin. Moreover, by adding the jute cloth as skin layers to jute mat composites, the Izod impact strength was significantly enhanced, while there is slightly effect on the total impact energy by adding the jute cloth as skin layers compared to the jute mat composites. Additionally, the fracture surface of the composites yielded from the Izod impact and drop weight impact tests was also investigated.

Key words: Jute mat, jute fabric, unsaturated polyester, hybrid, impact properties.

1. Introduction

Recently, the strict environmental regulations have forced the composite industry to find alternatively eco-friendly reinforcements and resin systems to produce environmentally friendly composite materials. These natural composites could be used in automotive industry as interior parts and in constructions sector as walls and roofs. Natural fibers reinforced composite materials have been subject of many intensive studies due to the considerable characteristics of the natural fibers, such as biodegradability, abundance, renewability, low cost, low specific gravity, and high specific strength, etc. However certain drawbacks, such as incompatibility with the hydrophobic polymer matrices, the tendency to form aggregates during processing, and poor resistance to moisture absorption, reduce significantly the mechanical properties of the natural fibers reinforced composite materials [1-3].

Amongst the natural fibers used as composite reinforcements, jute fiber constitutes large area of investigation. This is because the good mechanical properties of jute fibers when compared with other natural fiber, such as sisal, coir, and ramie [1]. Several authors have studied the continuous jute fiber composites from different aspects, e.g., mechanical properties [4-9], the effect of fiber treatments on mechanical properties [6-9], dynamic mechanical properties [10], physical properties [5], processing and microstructures [11]. Moreover, some authors have studied the mechanical properties, dynamic properties and the effect of fiber treatments for short jute fiber reinforced thermoplastics matrices composite materials manufactured by injection molding technique [12-14].
as well as by continuous extrusion compounding [15].

As well known, the jute bags at the end of their longevity will be as waste materials, moreover the remaining short slivers of jute fibers yielded from the jute cloth fabrication aren’t yet reused efficiently. Therefore, in this research, the used jute bags were recycled by mincing them and mingled with short jute slivers to produce jute mats. These jute mats were produced by applying slightly compressive load on short jute fibers to be packed together in the form of mat and then needle punched. These jute mats can also be used as a core which is needle punched with recycled jute woven fabric cloths as skin layers (natural hybrid reinforcements) which can be called as jute fabric/jute mat. These two types of reinforcements can be used later as natural reinforcements for valuable polymeric composite structures with certain degree of green.

In this research, a modified hand lay-up technique was introduced to the composites with the same fabrication procedure of the conventional hand lay-up technique used after primary resin impregnation into the jute fabrics in vacuum conditions. The aim of the suggested simple modification is to improve the impregnation of resin throughout the jute mats targeting lower void content and better fiber/matrix interfacial properties in the final composites. The suggested method is called pre-impregnation hand lay-up technique.

Furthermore, various researchers carried out in depth investigation about the synthetic fiber/natural fiber based hybrid composite but natural fiber/natural fiber based hybrid composites are recent research phenomena [16] due to the ecological concerns and little research was carried out on the effect of hybridization of natural fiber/natural fiber based hybrid reinforcements on the impact properties. Therefore, the effect of skin jute fabric and fiber weight contents on the Izod and impulse impact properties was investigated, and the fracture behavior of the composites was also examined for determining the required fiber weight content for high performance composites.

2. Experimental

2.1 Preparation of the Composites

The Two systems of reinforcements were prepared by Yano Co., Ltd., Japan. The first one is needle punched jute fiber mats consisting of 50% jute slivers and 50% recycled and the second type of reinforcement is to use these jute mats as a core, which needle punched with recycled jute fabric cloths as skin layers. Unsaturated polyester, RigoracTM was obtained from Showa Denko K.K., Japan and the curing agent is Methyl ethyl ketone peroxide (PERMEK® N) obtained from NOF Corporation, Japan.

Time-temperature profile of the modified technique of fabrication the composites. The jute fabrics were dried for 6 h at 100 °C and were completely submerged in unsaturated polyester resin. The next step which differentiates the modified technique over the conventional technique is that the jute fabrics were degassed in a vacuum for 20 minutes at room temperature to remove the entrapped air bubbles. After that the jute fabrics were cured under a pressure of about 50 kg/cm² at room temperature for 24 h with the presence of a 6 mm spacer to produce the composite on the same thickness for different fiber contents.

The composite was then post-cured at 100 °C for 2 h and finally it was allowed to cool naturally to room temperature for about 30 minutes. Sheets of jute mat composite panels with 11, 22, 32 wt% and Jute fabric/jute mat composite panels with 26, 36, 46 wt% fiber weight contents were prepared and the specimens of the required dimensions were cut and used for testing. The abbreviations of the two composite systems are JMC for jute mat composites and JFJMC for jute fabric/jute mat composites.

2.2 Mechanical Characterization

Izod impact test on unnotched specimens with dimensions $62 \times 12.7 \times 6$ mm³ was done according to ASTM D 256-05 using an I5.5J digital pendulum impact tester, TOYOSEIKI, Japan. Impulse impact test
was done with sample dimension 102 × 102 mm² using 
intron dynatup 9250 HV. The fracture behavior of the 
composites was studied using scanning electron 
microscope (SEM) JEOL-5200. ImageJ (image 
processing software) has been used to measure the 
fractured area of the composites.

3. Results and Discussions

3.1 Izod Impact Properties of the Composites

The impact strength of the composites depends 
mainly on two factors: the toughening properties of the 
fibers, and the interface properties between the fibers 
and the matrix. And the more energy absorbed by the 
material, the more toughness the material will be. The 
impact strength is highly affected by the interface 
strength between the fibers and the matrix, and it is 
known that very strong interface between the fibers 
and the matrix has the negative effect on the impact 
strength [17-18].

The effect of the fiber content on Izod impact 
strength of JMC and JFJMC is shown in Fig. 1. It can 
be observed that as the fiber content increases the 
impact strength of JMC increases. The impact strength 
was slightly improved by 8% at 11 wt% fiber content 
compared to the value of the neat resin because the 
fiber content is very low and so the effect of the jute 
reinforcement in the matrix is low.

As the fiber content increases to 22 wt%, value of the 
impact strength was also slightly enhanced by 12% 
with respect to the value of neat resin. As the fiber 
content increases to 32 wt%, the impact strength was 
improved by 43% with regard to the value of the neat 
resin. The nature of the natural fiber is porous and can 
be considered as a composite of hollow cellulose fibrils 
held together by a lignin and hemicelluloses, this 
nature displays absorbing mechanism for the impact 
energy.

On the other hand, by adding the jute cloth as skin 
layers to the jute mat composites, the Izod impact 
strength increases for different fiber weight contents as 
shown in Fig. 1. The impact strength was improved by 
43, 71, 161% at 26, 36, 46 wt% fiber weight content, 
respectively compared to the value of the neat resin. Many researchers have studied the mechanical 
properties of hybrid composites. Park and Jang [19] 
found that the stacking pattern of the different 
components in hybrid laminated composite play an 
important role in influencing the mechanical properties 
of the hybrid composites. It was reported by Ref. 
[20-22] that natural fiber hybridization improved the 
mechanical properties of natural hybrid composites 
compared to individual fiber composites.

The Izod fracture behavior of JMC (22 wt%) and 
JFJMC (26 wt%) are indicated in Figs. 2a-2b, 
respectively as an example to explain the fracture 
behavior. It can be observed that the hammer side is the 
tension side which the fracture starts and propagates 
through the thickness until fracture occurs at the other 
side. The tensile strength the composites will be higher 
when the higher strength material is used as the skin 
[16]. It can also be observed that extensive fiber pull 
out in jute cloth skin compared to jute mat as a core as 
shown in Fig. 2b compared to Fig. 2a, indicating that 
skin layer withstands most of the tensile stresses at the 
hammer side.

As a result of that, the strength of the tension 
surface of JMC was increased by adding jute cloth as skin 
layers and so the impact strength of JFJMC was 
improved compared to that of JMC for different fiber 
weight contents. Moreover, there is no delamination 
occurred between the jute cloth skins and the jute mat.
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3.2 Drop Weight (Impulse) Impact Properties of the Composites

A typical load-deflection curve derived from drop impact test on the composites is shown in Fig. 3. The peak load \( F_m \) is the maximum load that the specimen can sustain on fracture, which indicates the beginning of significant damage. The associated energy absorbed up to this point is symbolized by \( E_m \) and it represents the energy to initiate crack. After \( F_m \), the dropping off in force indicates crack propagation and \( E_p \) represents the energy absorption in this phase. The total energy absorption \( E_t \) is

\[
E_t = E_m + E_p
\]

where \( E_t \) is the area under the load-deflection curve.

To represent the ability of material plastic deformation during fracture propagation process, ductile ratio (D.R.), which is the percentage of energy absorption \( E_p \) divided by total energy absorption \( E_t \) is defined as

\[
D.R. = \frac{E_p}{E_t}
\]

Load-deflection curves of JMC and JFJMC composites for different fiber weight contents compared to that of neat resin are indicated in Figs. 4a-4b, respectively.

Load-deflection curve of neat resin indicates the linear increase in force to the peak force \( (F_m) \) where some damage is initiated and after damage initiation, shows a sharp drop in the load and this implies that little energy was absorbed in the damage propagation process as shown in Tables 1-2. However, the traces of JMC and JFJMC for different fiber weight contents show almost the same linear increase in force to the peak force \( (F_m) \) where some damage is initiated and after damage initiation, shows a dropping off in several stages after the specimen reaches \( F_m \). Hence, the gradual dropping off leads to a much higher deflection value associated with much more energy absorption.

This implies that little energy of JMC and JFJMC with different fiber weight contents was absorbed in the initiation process and most of the energy was absorbed in the damage propagation process as shown in Tables 1-2 and therefore the total energy absorbed of JMC and JFJMC with different fiber weight contents is much higher compared to that of neat resin.

Moreover, the effect of fiber weight content on the ductility ratio of JMC and JFJMC is indicated in Fig. 5, it can be observed that, by the addition the jute cloth skin layers to the jute mat composites the ductility ratio
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Fig. 4 Load-displacement of impulse impact test of (a) JMC and (b) JFJMC for different fiber weight content compared to the neat resin.

Table 1 Summary of drop weight impact results of JMC.

<table>
<thead>
<tr>
<th>Fiber weight content (wt%)</th>
<th>Initiation energy to max. load (J)</th>
<th>Propagation energy after max. load (J)</th>
<th>Total absorbed energy (J)</th>
<th>Ductile ratio (D.R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>7.58</td>
<td>5.27</td>
<td>12.85</td>
<td>0.41</td>
</tr>
<tr>
<td>22</td>
<td>4.76</td>
<td>8.45</td>
<td>13.21</td>
<td>0.53</td>
</tr>
<tr>
<td>11</td>
<td>3.40</td>
<td>11.64</td>
<td>15.04</td>
<td>0.71</td>
</tr>
<tr>
<td>Neat resin</td>
<td>1.44</td>
<td>2.42</td>
<td>3.86</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Table 2 Summary of drop weight impact results of JFJMC.

<table>
<thead>
<tr>
<th>Fiber weight content (wt%)</th>
<th>Initiation energy to max. load (J)</th>
<th>Propagation energy after max. load (J)</th>
<th>Total absorbed energy (J)</th>
<th>Ductile ratio (D.R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>7</td>
<td>6.37</td>
<td>13.37</td>
<td>0.48</td>
</tr>
<tr>
<td>36</td>
<td>4.34</td>
<td>8.45</td>
<td>12.89</td>
<td>0.66</td>
</tr>
<tr>
<td>26</td>
<td>5.47</td>
<td>6.37</td>
<td>11.84</td>
<td>0.54</td>
</tr>
<tr>
<td>Neat resin</td>
<td>1.44</td>
<td>2.42</td>
<td>3.86</td>
<td>0.40</td>
</tr>
</tbody>
</table>

was decreased compared to that of jute mat composites and therefore the capability of plastic deformation in crack propagation process decreases.

This can be validated by measuring the fractured area by using ImageJ by measuring the total area around the impacter hole and subtracting this area from the impacter hole area for different fiber weight contents for JMC and JFJMC as shown in Figs. 6-7. The fractured area at low fiber weight content cannot be measured because the specimens were fully fractured in all direction with very large fracture area. The effect of fractured area on the total impact energy for JMC and JFJMC for different fiber weight content is shown in Fig. 8, it can be observed that the impact energy was increased by increasing the fractured area and the fractured area for JFJMC is lower than that of JMC and so the capability of plastic deformation in crack propagation process decreases by adding the jute cloth as skin layers to the jute mat composites.

This also validates the finding from characteristic distance principle that the sensitivity of tensile strength of jute mat composites to the notch was increased by adding the jute cloth as skin layers as validated experimentally in previous work in details [23]. As a result of the previous explanations, the addition of the jute fiber to the unsaturated polyester resin enhanced significantly the total impulse impact energy of the jute fiber mat reinforced unsaturated polyester matrix composites as shown in Fig. 9, which indicates the effect of fiber contents on the total impulse impact energy of JMC and JFJMC. It can be observed that the total energy was increased with the addition of 11 wt % and 22 wt % fiber weight contents to about three times, while the total energy was increased at 32 wt % fiber weight content to about four times compared to the value of the neat resin.
Moreover, it can be observed that the jute cloths as skin layers have a slightly effect on the total impulse impact energy because the properties of plain woven jute is weak in the transverse direction and the drop load is perpendicular or in the transverse direction to the jute plain woven.

The fracture surface of the composites under drop weight impact load for the impact side and the opposite side for JMC and JFJMC is shown in Figs. 6-7, respectively. It can be observed by comparing Fig. 6 and Fig. 7 that the fracture surface of JMC was completely broken from the opposite side. However, by adding the jute cloth as skin layers to JMC, the fracture surface was not fully fractured and the fracture like pyramid shape fracture due to the effect of the jute cloth as skin layers and so the fractured area was decreased as was revealed from Fig. 8.

Finally, it can be concluded from this study that the effect of the jute fiber has more effect on the improvement of the impulse total impact energy than that of Izod impact strength and the jute cloth as skin layers has more effect on the Izod impact strength than that of the total impulse impact energy compared to JMC.

4. Conclusions

Recycled needle punched jute fiber mats were used as natural fiber reinforcements for unsaturated polyester matrix composites via modifying the hand lay-up technique with resin pre-impregnation into the jute fiber in vacuum. The effect of fiber weight content
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and the effect of adding the jute cloth as skin layers to the jute mat composites on the Izod impact strength and drop weight impact energy were investigated compared to those of neat resin. The results showed that as the fiber weight content increased, the Izod impact strength and total impact energy of jute mat composites increased and the improvement had occurred at 11 wt% compared to those of the neat resin. Moreover, by adding the jute cloth as skin layers to jute mat composites, the Izod impact strength was significantly enhanced, while there is slightly effect on the total impact energy by adding the jute cloth as skin layers compared to the jute mat composites. The fracture surface of Izod impact surface investigated by SEM demonstrated that fiber pull out mechanism is the failure mode. Moreover, the fracture surface of JMC under the impulse load was completely broken from the opposite side. However, by adding the jute cloth as skin layers to JMC, the fracture surface was not fully fractured and the fracture like pyramid shape fracture due to the effect of the jute cloth as skin layers. This study showed that the effect of the jute fiber has more effect on the improvement of the impulse total impact energy than that of Izod impact strength and the jute cloth as skin layers has more effect on the Izod impact strength than that of the total impulse impact energy compared to JMC.

References


