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AXIAL ENERGY ABSORPTION OF WOVEN KENAF FIBER REINFORCED COMPOSITES

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ABSTRACT

This paper presents the energy absorption of woven kenaf fiber reinforced composite tubes subjected to axial compressive force. As-received kenaf yarn is plain-weaved to form a woven kenaf mat. Then, it is oriented and wraped around the circular steel mould. Different fiber orientations and number of layers are used to fabricate the tubes and it is then quasi-statically compressed to obtain the force-displacement curves. Two important crashworthiness parameters are extracted from the curves such as peak forces and energy absorptions. The roles of these parameters are discussed with the relation of fiber orientations and number of layers. From the experimental works, it is found that fiber orientation and number of layer played an important role in determining the crushing performances. It is also found that maximum specific energy absorption is obtained for the fiber arrangement of [$0^0/0^0$] and [$0^0/0^0/0^0$]. Whereas, the minimum value is occurred when 15^0 fiber orientation is included. Local buckling failure mechanism is responsible in producing lower specific energy absorptions.

Keywords: kenaf natural fiber, crushing behaviour, composites, woven fiber.

INTRODUCTION

Nowadays, natural fiber is increasingly used to replace the synthetic fiber especially for non-load bearing applications. Natural fiber such as jute is used as a rope in marine engineering. This is due to the role of corrosion resitance offers by the fibers. Some automotive companies used natural fiber in fabricating the parts mainly for the decorations. The review of the natural fiber on the aspect of mechanical performances can be found in (Akil *et al*., 2011; Khalid *et al*., 2015 and Hassan & Ismail, 2015).

Davoodi *et al*. (2010) investigated the mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam. They found the advantages in term of mechanical properties compared with other common bumper beam material. However, the impact property is still less than the desirable level. Eshkoor *et al*. (2013) conducted a comparative research on the crashworthiness characteritics of woven natural silk/epoxy composite tubes. There are 12 layer of silk fabric are used and 3 tube length are considered. They found that the values of energy absorptions have decreased with increasing the tube length regardless of their triggering mechanisms.

Yan and Chouw (2013) characterized the crashworthiness aspects of flax fibre reinforced epoxy tube for energy absorption application. They tested the samples under uniaxial compression. The samples are fabricated using three inner diameters (36, 54 and 82 mm), three numbers of plies (1, 2 and 3) and three length-to-diameter ratios (1, 1.5 and 2). Based on the experimental works, the sample with diameter of 36mm and number of plies of 3 and length-to-diamter ration of 2 has the largest specific energy absorption compared with other type of composites.

While, Alkbir *et al*. (2014) studied the effect of geometry on crashworthiness parameters of natural kenaf fiber reinforced composite hexagonal tubes. Different hexagonal angles are used ranging between 40-60^0. Kenaf fiber mat was used and fabricate to form a hexagonal shape. Based on the experimental works, the tubes with the angle of 60^0 produced the highest energy absorption performance due to local buckling failure mode.

According to the previous work found, there are lack of research finding on the characterization of crashworthiness performances of the composite tubes fabricated using kenaf yarn. Recently, several research works have been conducted by author on the use of woven kenaf fiber for the crashworthiness applications. Ismail & Sahrom (2015) investigated the lateral crushing energy absorption of cylindrical kenaf fiber composites. Two important parameters are considered in preparing the composites suc as fiber orientations and number of layers. Then, the composites are quasi-statically crushed laterally. It is found that fiber orientations are not the key factor in increasing the specific energy absorptions and the force ratios.

Ismail (2014) investigated the crushing performances of square kenaf fiber reinforced composite tubes. The yarn kenaf fiber is submerged firstly into the polyester resin before it is wound around the square mould. The composites are axially crushed to obtain the force-displacement curves. It is reported that Varying fiber orientations for a single layer of fiber has no significant effect on the energy absorption performances. As expected, if the number of layer is increased, the absorbed energy is also increased. Kenaf yarn fiber is also hybridized with steel tubes and the work can be found in Ismail (2015).

Based on the literature survey, it is found that kenaf fiber especially in the form of yarn is used to fabricate the composites using the winding technique. However, there are lack number of works available in

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investigating the crashworthiness performances when the tubes are fabricated using the woven kenaf mat.

Therefore, this work presents the fabrications of kenaf woven tube reinforced composites. Two number of layers are used where the woven mats are oriented using different angles. The tubes are quasi-statically crushed to obtain the force-displacement curves. Then, the crashworthiness parameters are extracted, discussed and analysed.

EXPERIMENTAL PROGRAM

Materials

The as-received kenaf fiber in the form of yarn of 1mm in diameter is weaved to produce a plain woven fiber mat using in-house weaving machnine. Figure-1(a) shows the bundle of kenaf yarns used in this study while Figure-1(b) reveals the process of making the woven mats. Figure-1(c) shows the complete woven mats.

Cylindrical tube composites

The woven mats are submerged into a resin bath and at the same time roller is used to squeeze the resin uniformly into the mats. Then the wet woven mats are wound around the cylindrical mould before they are circumferentially compressed to expel the excessive resin. After 24 hours, the composites are fully hardened and removed from the mould as shown in Figure 2. Both ends of the composite tubes are trimmed in order to remove the unnecessary fibers and hardened resin. In this work, the total height of the tube is 70mm and the thickness is depend on the number of layers. Two main types of composite tubes are produced namely 2 and 3 layers producing 5 and 7 mm in thicknesses, respectively. The detail of these composites are tabulated in Tables-1 and -2.

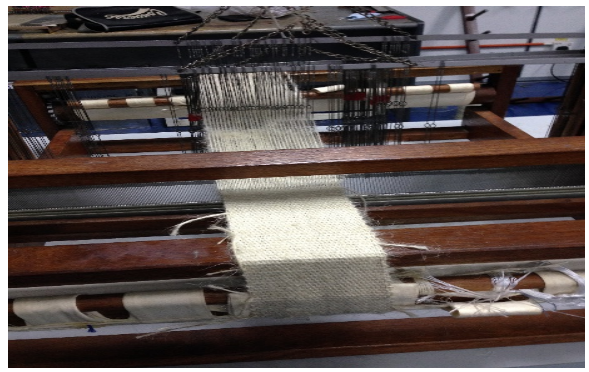
Table-1. Two layers of composite tubes.

Samples	Fiber Orientations, θ°	Internal Diameter, mm
A1	[0°/0°]	70
A2	[0°/15°]	70
A3	[0°/30°]	70
A4	[0°/45°]	70

Table-2. Three layers of composite tubes.

Samples	Fiber Orientations, θ°	Internal Diameter, mm
B1	[0°/0°/0°]	70
B2	[0°/15°/0°]	70
B3	[0°/30°/0°]	70
B4	[0°/45°/0°]	70

(a)



(b)

(c)

Figure-1. (a) Kenaf yarns in the form of rolls, (b) The process of making the woven mat and (c) The finish product of plain kenaf woven.

Quasi-static compression tests

The tubes are positioned vertically and compressed quasi-statically under constant cross-head displacement of 5.0mm/min. The tubes are crushed approximately 80% of its height. The force versus displacement curve for each composite conditions is recorded automatically where the area under the curve represents the energy absorption performances. Other important crashworthiness parameters are investigated such as peak and mean forces, P_i and P_m, respectively.

The peak force is defined as the maximum force of an elastic deformation before the composite shows the

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initial sign of failure. Mean force is obtained by averaging the maximum and minimum forces around the fluctuated region. The energy absorption, E is defined as the area under the curve of force versus displacement expressed as:

$$E = \int_0^L P\,ds$$

where, P is a crushing force and ds is a small element of crushed distance and L is the total crushed length.

(a)

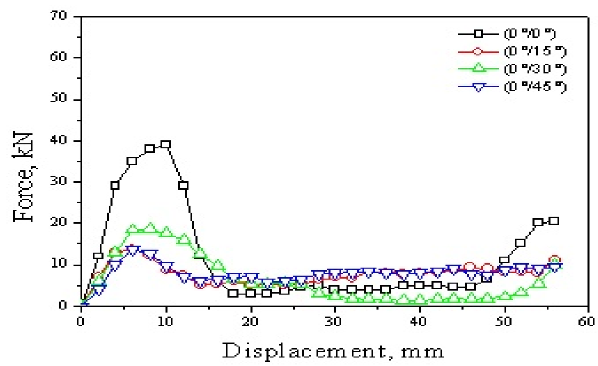
(b)

Figure-2. (a) Wet and warpped woven kenaf around the mould and (b) The hardened cylindrical woven kenaf composites.

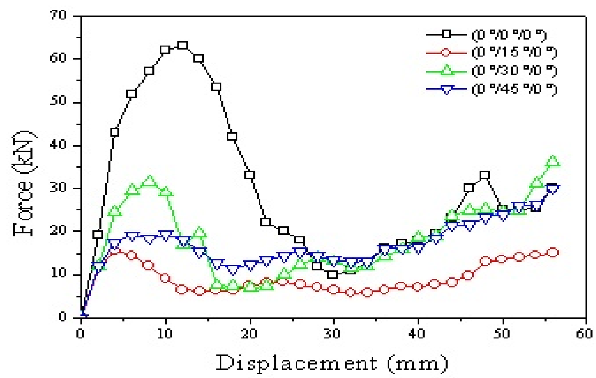
RESULTS AND DISCUSSIONS

Figure-3 shows the force-displacement curves for two and three-layered composite tubes under quasi-static compressive forces. The curves show the typical force-displacement diagram where they can be divided into three main regions. The first region is the linear elastic deformation where the force is linear proportional to displacement. Once the tube disintegrated, the composite experienced sudden drop. If the force is continued, the forces are fluctuated where the composite progressively collapsed. When the crushed length is approximately 50mm, the force is increased again however there is insignificant displacement. This is due to the fact that the crushed composites are densely accumulated.

Figure-3(a) reveals the force-displacement curves for two-layered composites. It is indicated that the composite fabricated using [0º/0º] produced higher force responses compared with other types of tubes. The tubes fabricated using [0º/15º] and [0º/45º] have an identical force-displacement curve. This mean that if 15^0 and 45^0 fiber orientations are used they tend to produce similar results. If 30^0 fiber orientation is adapted, the force is relatively higher than 15^0 and 45^0. However the composite is observed to experience catastrophic failure especially at the second stage.



(a)



(b)

Figure-3. Force-displacement curves for (a) two- and (b) three-layered composite tubes.

As-expected when the number of layers are increased, the responses of force-displacement curves seem to increase. However, the effect of fiber orientations are obvious especially in the first region. According to Figure-3(b), the composites fabricated using 15º fiber orientation revealed the lowest force-displacement curve. As a result lower crashworthiness performances are obtained. Additionally, 15º fiber orientation also revealed that there is no significant different between two and three number of layers in term of force-displacement responses.

Table-3 tabulates two important crushing performances such as peak force and the specific energy absorption. On the other hand, Figure-4 shows the similar results plotted against fiber orientations. It is indicated that there is no direct relationship between fiber orientations and the specific energy absorption for both cases considered. It is seemed that for two layered composites, 0º and 45º capable to resist crushing deformations compared with other type of composites as shown in

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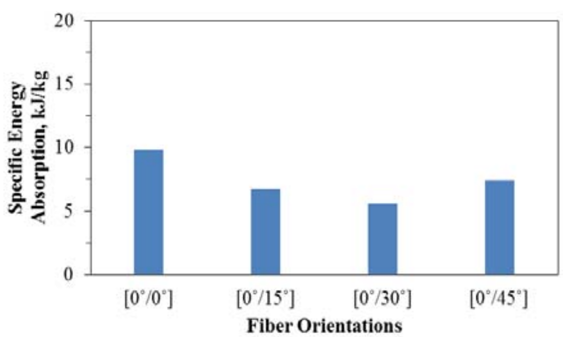
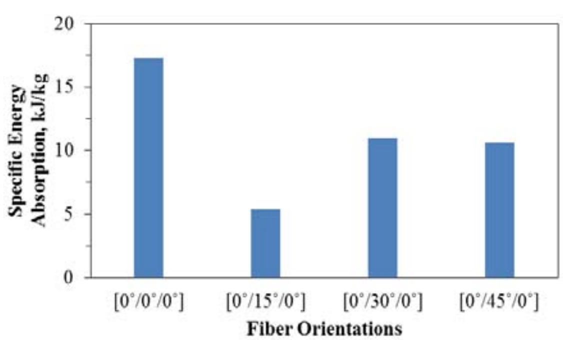
Figure-4(a). Similar trend is observed for three layered composite tubes as revealed in Figure-4(b).

Table-3. List of peak forces and the specific energy absorptions for different fiber orientations.

Fiber Orientations, θ°	Peak Forces, kN	Specific Energy Absorptions, kJ/kg
[0°/0°]	39	9.83
[0°/15°]	14	6.76
[0°/30°]	19	5.57
[0°/45°]	14	7.43
[0°/0°/0°]	63	17.27
[0°/15°/0°]	16	5.38
[0°/30°/0°]	32	10.98
[0°/45°/0°]	19	10.63



(a)

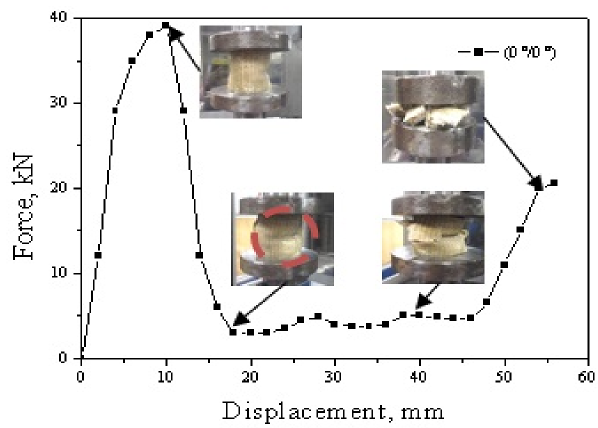


(b)

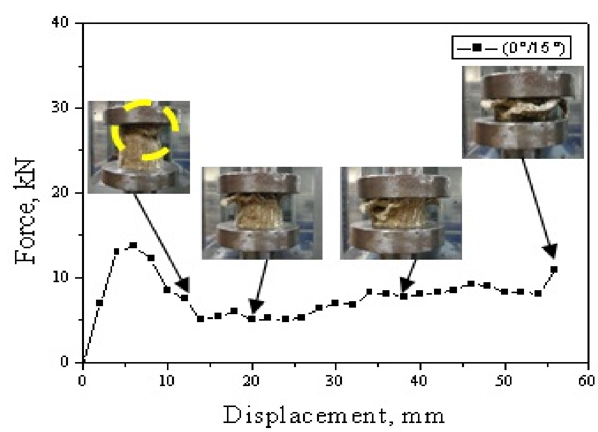
Figure-4. The effect of fiber orientations on the specific energy absorptions of (a) two- and (b) three-layered composite tubes.

Figure-5 shows the crushing mechanisms of two type of fiber orientations [0°/0°] and [0°/15°]. Figure-5(a) reveals the force-displacement curve for the composite tube fabricated using [0°/0°]. It is clearly showed that the peak force is higher compared with the composite shown in Figure-5(b). Although, the peak force is high but the force drop is significantly large. This is due to the formation of local buckling at the middle height of the tube however the upper and bottom composite portions are still intact. If the force is continued, the remaining composite wall is deformed and crushed catastrophically without showing a mechanisms of progressive collapses.

Figure-5(b) shows the crushing mechanisms of the composite fabricated using [0°/15°]. The peak force for this type of composite is relatively lower than the composite as revealed in Figure-5(a). Local buckling occurred at the upper end of the tube and the disintegrated wall began to fold progressively downward. This behaviour is shown by the plateau stage of force-displacement curves where the curve is almost flattened. The force seemed to increase when the crushed wall accumulated and there is no more composite wall to be crushed.



(a)



(b)

Figure-5. Crushing mechanisms of the composite tubes fabricated using different fiber orientations (a) [0°/0°] and (b) [0°/15°].

CONCLUSIONS

This paper present the crushing performances of the woven kenaf fiber reinforced composite tubes under axial loading. The composites are fabricated using different fiber orientations and two type of number of layers. According to the experimental observations, several conclusion can be drawn:

- Force-displacement curves for both type of composites (2 and 3 layers) revealed that fiber orientations have played an important role and the effect is more obvious if the thicker tubes are used.
- Higher specific energy absorptions are obtained when the fibers are aligned using [0°/0°] and [0°/0°/0°] compared with other type of composites.
- Different curshing modes are responsible to determine the crushing performances.
- Even though the composites with [0°/0°] offered better force-dsiplacement response but the sudden force drop is large due to local buckling in the middle height of the tubes.
- For the composites contained fiber orientations of 15°, 30° and 45°, no local buckling is observed. The failure mechanisms started with the wall disintegration before it is crumpled downward therefore producing lower force drop.

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