Crushing Performances of Winding Square Kenaf Fiber Reinforced Composites

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***Abstract*—This paper presents the crushing performances of winding kenaf square composite tubes under axial compression. As-received kenaf yarn is firstly wetted with polymeric resin and wound around the square mould. Two important parameters are used such as number of layers and fiber orientations. The composite tubes are quasi-statically compressed to obtain their force versus displacement responses. Then, the energy absorption performances and other crashworthiness parameters are determined and analyzed. It is found that both parameters have insignificant effect on the force ratios. However, wall thickness has played an important role in increasing the specific energy absorption performances. It is observed that single layered composite tubes collapsed in stable manner. On the other hand, for three layered composites, the tubes failed catastrophically through of global buckling.**

I. INTRODUCTION

Composite materials generally offer higher specific strength such as tension strength and energy absorption performances when compared with the metallic materials. It is also widely used in automotive industries due to higher ratio of strength to weight. Considering the environmental impact of the synthetic fiber, natural fibers are increasingly utilized in replacing such fibers.

Natural fibers are also offered low production cost, lower in density and higher specific strength. However, it has a lower resistance in humidity [1]. Natural fiber reinforced composites have a great potential to be used as a energy absorbing device. For example unwoven hemp exhibited specific energy about 54.3J/g whereas carbon fiber gained about 55.7J/g. On the other hand, woven flax and jute capable to sustain 48.5J/g and 32.6J/g, respectively [2].

Geometries and materials played an important role in determining the capabilities in absorbing the impact energies. Mahdi et al. [3] experimentally investigated the crushing behavior filament winding cone-cone intersection composite shell. They suggested that both structural geometry and vertex angles exhibited the important parameters to produce better energy absorption performances.

Eshkoor et al. [4] studied the crashworthiness of woven natural silk/epoxy composite square tubes. They focused on the effect of different triggering mechanisms on the energy absorption capability. It is found that the external triggering mechanisms produced insignificant results in term of failure modes as compared with non-triggered tubes.

Yan and Chouw [5] characterized the flax fiber reinforced composite tubes for energy absorption application. It is found that the optimal tube design capable to produce the specific energy absorption about 41J/g which is as good as conventional metal and close to that of glass/carbon fiber reinforced composites.

Alkbir et al. [6] conducted an investigation to study the effect of hexagonal kenaf fiber composite tubes on the crashworthiness parameters. They concluded that the change in the hexagonal tube angle affects the crashworthiness parameters where the angle of 60o exhibited better energy absorption performances compared with other types of composites.

Lateral crushing of winding kenaf fiber cylindrical tubes can be found in [7]. Different number of layers and fiber orientations are used. The tubes are compressed laterally. It is found that fiber orientations are not the key factor in increasing the energy absorption performances. However, it is increased when numbers of layers are increased. Another work on the crushing of natural fiber composite tubes can also be found in [8-10].

This paper therefore presents the crushing performances of winding kenaf yarn square tubes under axial compression. There are important parameters used to fabricate the composite tubes such as number of layers and fiber orientations. The tubes are quasi-statically compressed to obtain their force-displacement responses. Then, the areas under the curves represent the energy absorption capability.

II. ENERGY ABSORPTIONS CHARACTERISTICS

Crashworthiness characteristic defined as the capability of a vehicle to protect occupants from structure response by dynamic crush load with probability of injury. Therefore, it is an important parameter for vehicle design and it has been a hot topic of engineering study and researches for engineers and scientists over the years. The circular high – strength steel tubes are modelled as an absorber device to absorb several energy absorptions when collapsible impact applied in eccentric loading condition.

The load-carrying capability can be evaluated for the following two force levels [7]. Maximum force which is generally defined as peak force, P_{peak}. The peak force of a component is the highest load required to cause significant permanent deformation or distortion. The value of peak load was concerned by two factors, it's because of low – speed and low – energy impact. It also peaks load was occurring when the maximum load observed in the useful stroke of the energy absorbing device [2]. Absorbed crush energy which refers to the area under the force – deformation curve and it can be determined using Eq. (1):

$$E = \int_{o}^{d\max} P d\partial \qquad (1)$$

Specific absorbed energy, E_S is defined as the absorbed crush energy per unit of the crushed specimen mass as in Eq. (2):

$$E_S = \frac{E}{m} \qquad (2)$$

Fig. 1. (a) As-received kenaf yarn; (b) Weaving process; (c) Finished woven mats.

Average crushing force, P_m obtained by the following equation, when the load and post – crush deformation was defined as δ and P_m respectively as in Eq. (3):

$$P_m = \frac{1}{\partial} \int_{0}^{\partial} P d\partial \qquad (3)$$

Crush force efficiency, η is the ratio of the average crushing force, P_m to the peak force, P_{peak}. The information from the force-deformation curve got the average and peak force is important parameters to be determined the deceleration that will be experienced by the crashworthiness impact. It also as the ratio to determine the crush force efficiency and in general their value approaches unity, the better is the performance of the energy absorbing structure.

III. EXPERIMENTAL PROGRAM

The as-received yarn kenaf fiber of 1 mm in diameter is used as revealed in Fig. 1. In order to produce composite tubes, filament winding technique is used. The yarn is firstly wetted with polyester resin before it is wound around the square mould. During the process, the tension of the yarn is kept as constant as possible to ensure the residual stress is minimized. Proper observation is conducted to make sure the resin is uniformly penetrated into the fibers. Fig. 2 shows a schematic diagram of the filament winding process conducted in this work.

After 24 hours, the composites are fully hardened and removed from the mould. Both ends of the composite tubes are trimmed in order to remove the unnecessary fibers and hardened resin as shown in Fig. 3. In this work, the total height of the tube is 50mm and the thickness is depend on the number of layers. While, the internal cross-section is 55x55 mm. There are three fiber orientations are selected such as 0^o, 5^o and 10^o. For each orientation, there are three numbers of layers such as single, double and three layers as shown in Fig. 4. The tubes are positioned vertically and compressed quasi-statically under the constant cross-head displacement of 5.0mm/min. The tubes are crushed approximately 80% of its height as revealed in Fig. 5.

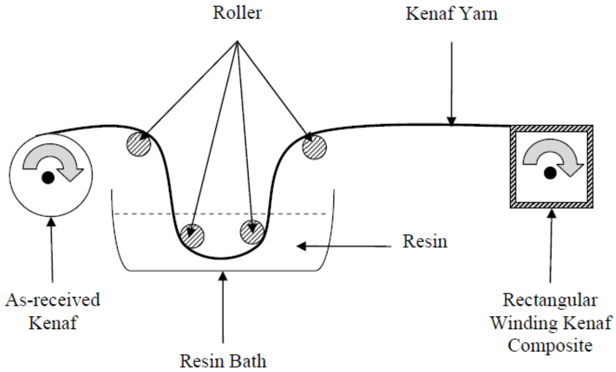
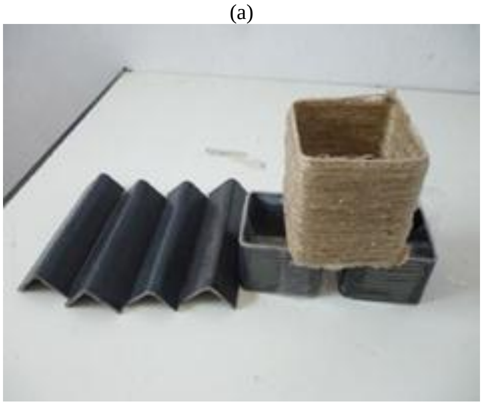


Fig. 2. Schematic diagram of a filament winding process.

(a)



(b)

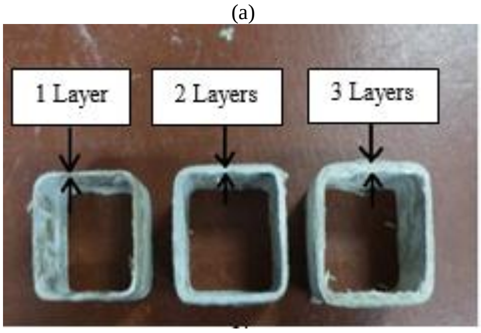
Fig. 3. (a) Wet and wrapped woven kenaf around the mold; (b) The hardened square woven kenaf composites.

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 initial sign of failure. Mean force is obtained by averaging the maximum and minimum forces around the fluctuated region.

IV. RESULT AND DISCUSSIONS

The responses of force-displacement curves of the winding square kenaf fiber reinforced composites are presented in Figure 5. These curves reveal a typical force-displacement for a progressive collapse under compression. There are three type of layers are used where they are affected the wall thickness of the tubes. For an identical number of layer, the force-displacement curves have insignificant responses where the curves are almost similar. The curves can be divided into three stages where the first stage is the linear deformation. In this region, the force and displacement is linearly proportioned. Once the tube wall disintegrated, the peak force drops before the force fluctuations are observed during the stable crushing processes. This is called the second stage. Lastly, the third stage starts when the compression force is gradually increased for a small displacement.

(a)



(b)

Fig. 4. (a) Wet and wrapped woven kenaf around the mold; (b) The hardened square woven kenaf composites.

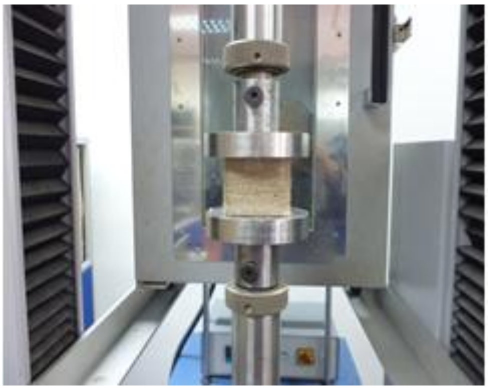
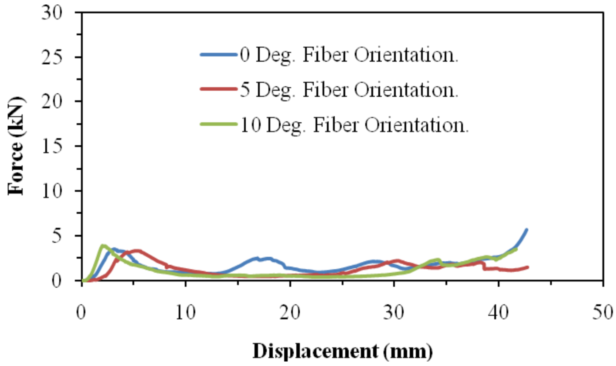


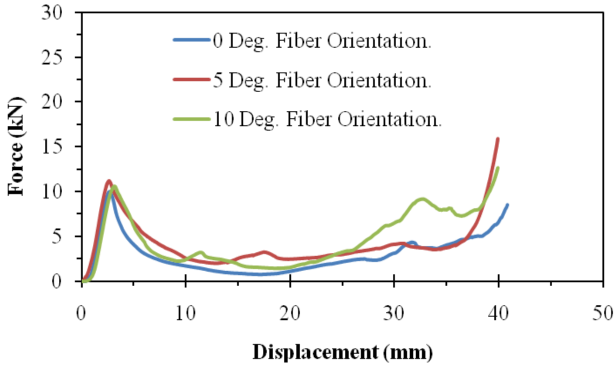
Fig. 5. Square composite tube under compression.

Figures 6(a) indicates the force-displacement curves for a single layered composite tubes fabricated using different fiber orientations. The curves are almost similar except for the cases of linear elastic deformation stage. It is revealed that 10^o fiber orientation capable to sustain displacement compared with other type of orientations. The composites fabricated using 0^o and 5^o fiber orientations indicated that they are lack of stiffness where the deformation of tube wall is insufficient to resist the compression loading.

When the numbers of layers are greater than two, the effect of fiber orientation is diminished as shown in Figures 6(b) and 6(c). However, fiber orientations played an important role in the second stage where the differences in peak and mean forces are significant. The force drop of 0^o fiber orientation is significant. This is due to the fact that for the laterally aligned fiber, the cracks between two yarns are easily triggered and propagated and therefore weakening the composite wall.



(a)



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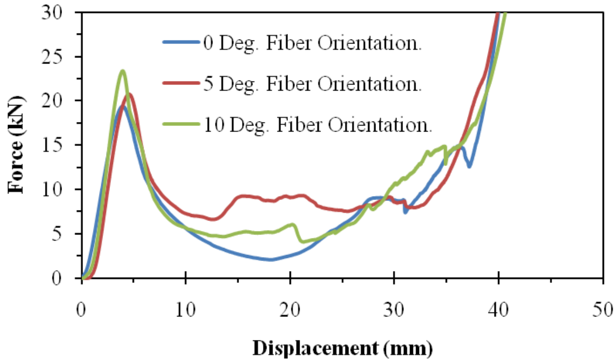
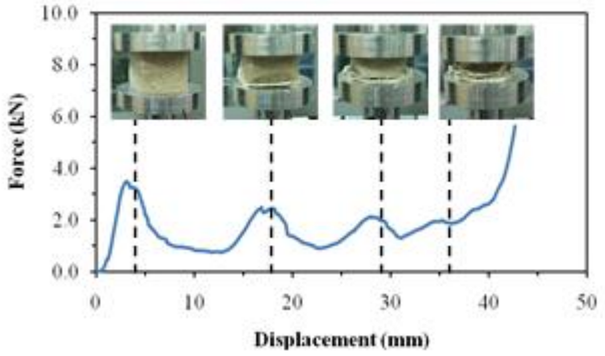


(c)

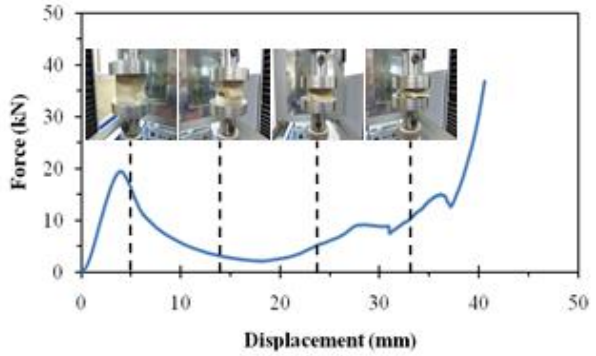
Fig. 6. Force versus displacement curves for (a) single , (b) two and (c) three layers woven kenaf fiber reinforced composites.

Figure 7 shows the crushing mechanisms of single and three layers of composite tubes wound with 0^o fiber alignment. For a single layer composite as reveal in Figure 7(a), the composite damages initiated at the bottom edge where the wall folded inward for all sides. Once the progressive collapse is continued, another folding mechanism is observed. It is continued until most of the composite walls are crushed and therefore increasing the compressive force gradually.

Figure 7(b) indicated the crushing mechanism of three layers square composite. Distinct disintegration behavior is observed where the damages occurred at the middle height due to the global buckling. It is occurred when there is a large drop of peak force. The damages also started at all sides caused the tube splits into two separated segments. There is only a small fraction of compression force is required to compress the tube as a result lower mean force is obtained.

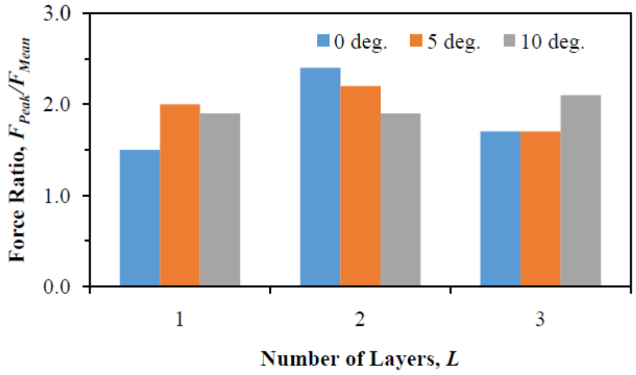


(a)

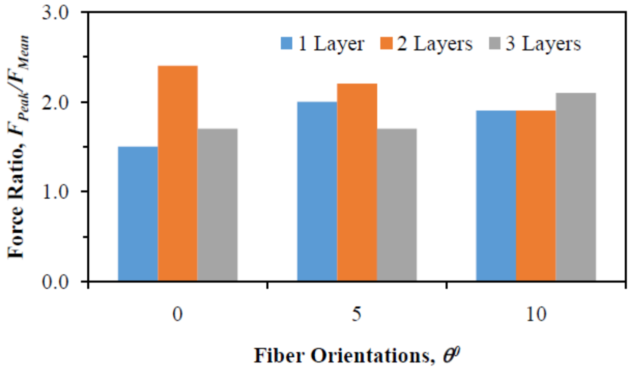


(b)

Fig. 7. Crushing mechanisms of (a) single and (b) three layers woven kenaf fiber reinforced composites.



(a)



(b)

Fig. 8. Force ratio of winding square kenaf fiber reinforced composites, on the effect of (a) number of layers and (b) fiber orientations.

Peak and mean forces are extracted from the curves of force-displacement and the ratio between peak and mean forces are then determined and plotted against number of layers and fiber orientations as presented in Figure 8. The role of number of layers on the force ratio is presented in Figure 8(a). It is revealed that there is no strong relationship between number of layers and the force ratio. It is seemed that in general, thicker the wall thickness, the variation of force ratio is considerably small.

The effects of fiber orientations on the force ratio are similar with the effect of number of layers. However, for 10^{o} fiber orientation, the force ratio is almost flattened where thickness is insignificantly played an important role in determining the force ratio. This is due to the fact that for three layered composites, most of the failure mechanism is global buckling leading to produce a single value of force ratio.

The energy absorption performance is determined based on the area under the curves of force-displacement. In order to eliminate the different in geometries, the values of energy absorption capabilities are normalized with their corresponding mass. Then, it is called specific energy absorption performances.

Both number of layers and fiber orientations played a significant role in determining the specific energy absorptions are revealed in Figure 9, respectively. According to Figure 9(a), the effect of number of layers on the specific energy absorptions. As expected, increasing the number of layers capable to increase the performances of specific energy absorptions. For an identical fiber orientation, no significant effects on the energy absorptions are observed.

The effect of fiber orientations on the specific energy absorptions are presented in Figure 9(b). Obviously, again the influence of number of layers are paramount important. However, 5^{o} fiber orientation composite tubes capable to produced relatively higher specific energy absorption compared with other orientations. It is also observed that 0o and 10^{o} fiber orientations have no significant effect where their values of energy absorptions are almost similar.

V.CONCLUSION

In this work, yarn kenaf fiber is wound around the square mould to produce composite tubes. Three type of fiber orientations are used 0^{o}, 5^{o} and 10^{o}. For each orientation, three numbers of layers for example single, double and triple layers are utilized. Quasi-static axial crushing tests are conducted experimentally and several conclusions can be drawn:

1. There is insignificant effect of the fiber orientations on the force-displacement curves. However, 5^{o} fiber orientation shows better mean force compared with other type of composites.
2. As-expected thicker the tube wall thickness higher the force-displacement curves.
3. Both fiber orientations and number of layers do not have strong relation with the force ratios. However in term of specific energy absorption, it is increased as both parameters increased.
4. Failure mechanisms are observed to be strongly depending on the number of layers. For a single layer tube, the wall is progressively collapsed while for triple layered composite tubes, the wall collapsed catastrophically resulting lower force ratio but maintaining higher specific energy absorptions.

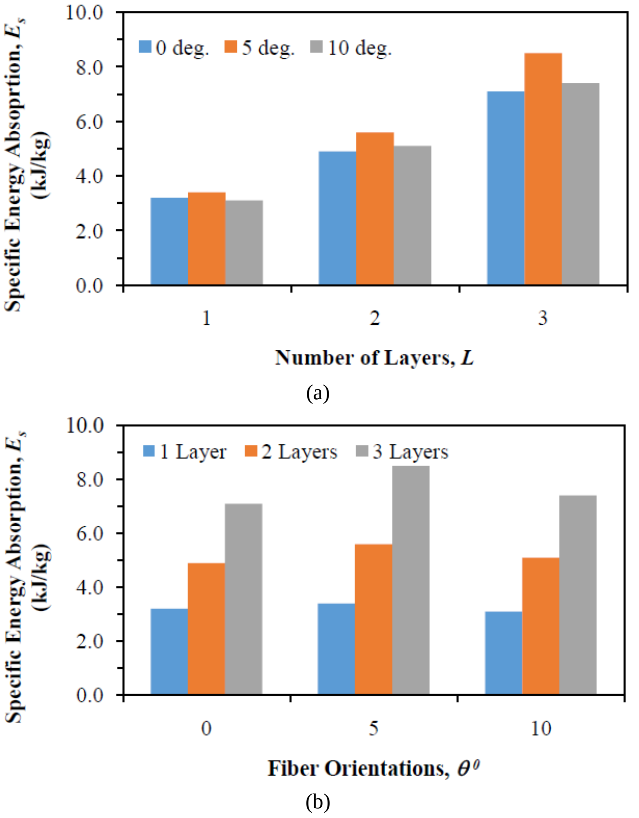


Fig. 9. Specific energy absorption of winding square kenaf fiber reinforced composites, on the effect of (a) number of layers and (b) fiber orientations.

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