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Lateral Crushing Energy Absorption of Cylindrical Kenaf Fiber Reinforced Composites

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Abstract

This paper presents the crushing behavior of kenaf fiber reinforced composite tubes subjected to lateral compressive loading. As-received kenaf yarn is firstly submerged into a resin bath before it was wrapped around the cylindrical mould. Two important parameters were considered during the composite preparation stage which were fiber orientations (0^0, 5^0 and 10^0) and number of layers (1, 2 and 3 layers). Then, the hardened composite tubes were positioned horizontally prior to quasi-static compression. Lateral crushing resistances of the composite tubes are compared in term of specific energy absorptions, force ratios and deformation modes. Lastly, these crashworthiness parameters are discussed relating with fiber orientations and number of layers.

Keywords: Lateral crushing, Specific energy absorption, Kenaf fiber, Composites.

1. Introduction

In the past, natural fiber is used to produce traditional goods such as ropes and other non-load bearing applications. Due to environmental and sustainability concerns, natural fibers are now given special attentions especially in replacing synthetic fibers [1-6]. Additionally, natural fibers offer cost effective, have low density with high specific strength and stiffness and also readily available [1-6]. Thin-walled structures normally used in automotive industries are made of synthetic fibers. The main concern is their strength-to-weight ratio, corrosion resistance and higher energy absorption performances compared with metallic structures. However lack of information available on the study of crashworthiness capabilities of the composite made of natural fibers [7-12].

Yan et al. [9] used flax fiber composite to study its energy absorption performances. Two types of tubes are used such as empty and foam-filled tubes. The results indicated that the energy absorption of flax fiber has the potential to be used as energy absorber. Alkbir et al. [10] utilized non-woven kenaf fiber to reinforce the composites. They concentrated the effect of geometries on the energy absorption performances. Various kinds of failure modes and energy absorptions can be obtained if different geometries are used. Animal based natural fiber is also researched by Oshkovr et al. [11]. They used silk/epoxy composite square tubes and quasi-statically compressed to analyze its crashworthiness performances. The results indicated geometry and material conditions played an important role in determining the energy absorption and the crushing modes.

As supported Yan and Chouw [12], a lot of studies on the energy absorptions compressed axially regardless whether the composites are made from synthetic or natural fibers can be easily found. However, there is lack of information available when the composites are compressed laterally especially for natural fiber reinforced composites. Therefore, this paper investigates the crushing behavior of kenaf yarn wrapped cylindrical composite tubes. Two parameters are studies; fiber orientations and number of layers. Then, the composites are horizontally compressed and the crushing collapses are observed. The effect of fiber orientations and number of layers are investigated in term of specific energy absorptions and force ratios.

2. Methodology

Kenaf fiber is used in this present study. It is in the form of as-received yarn as shown in Figure 1. An average diameter of the kenaf yarn is 1 mm. The fabrication process of the composite is shown in Figure 2 where the kenaf yarn bundle is firstly wetted with the polyester resin. A special attention is paid in order to ensure the wetting process is uniformly distributed on the whole kenaf surfaces. Then, the process is continued where the fiber is properly warped around the square steel mould assuming that the fiber tension is constant. The cylindrical steel mould is specially designed so that it can be easily removed once the composite is fully hardened as shown in Figure 3. Two important parameters are considered when fabricating the cylindrical composites (50x50mm) such as fiber orientations (θ = 0, 5 and 10^0) and number of layers (L = 1, 2 and 3 layers). Once the composites are removed from the mould, both ends of the composites are trimmed to remove any excessive resin and fibers. In order to investigate the crushing behavior, the composites are horizontally aligned and then they are quasi-statically compressed using a constant cross-head displacement 1.5 mm/min as revealed in Figure 4. Force-displacement curve for each sample is recorded automatically and the area under the curve represented the energy absorption performances. During the progressive collapses, the crushing mechanisms are observed for different crushed distances. Several important crashworthiness parameters such as peak and mean forces and specific energy absorptions are studied on the effect of fiber orientations and number of fiber layers.

Fig. 1. A bundle of an as-received kenaf yarn fiber.

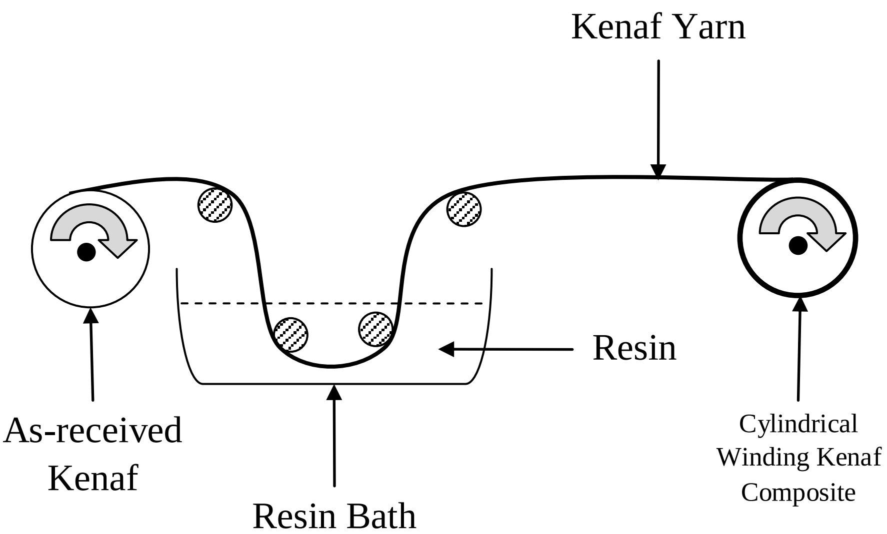
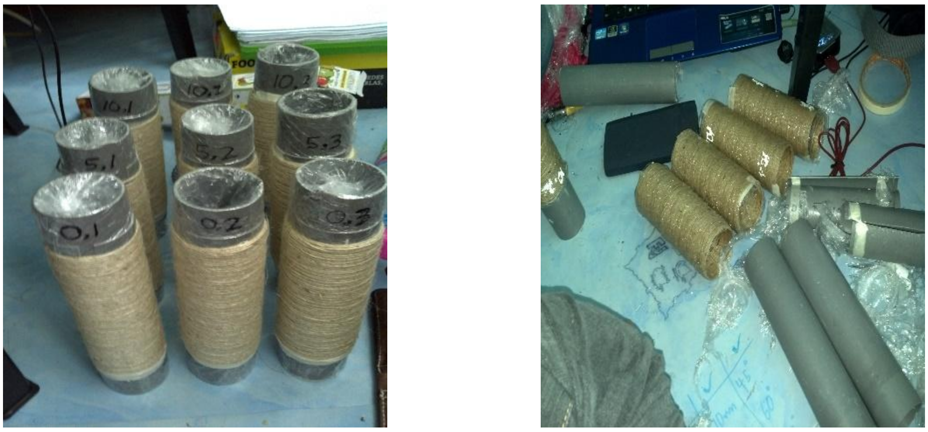


Fig. 2. Schematic diagram of the winding process of the kenaf yarn fiber.

(a)

(b)



(c) (d)

Fig. 3. (a) Plastic mould, (b) Mould assembly, (c) Kenaf yarn wrapped around the mould and (d) Final composite tubes.

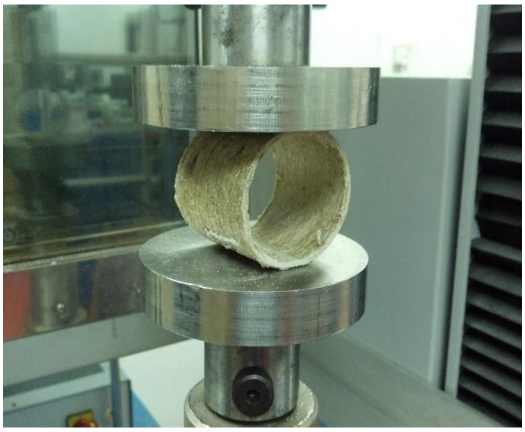


Fig. 4. Composite is laterally positioned before quasi-static compression loading.

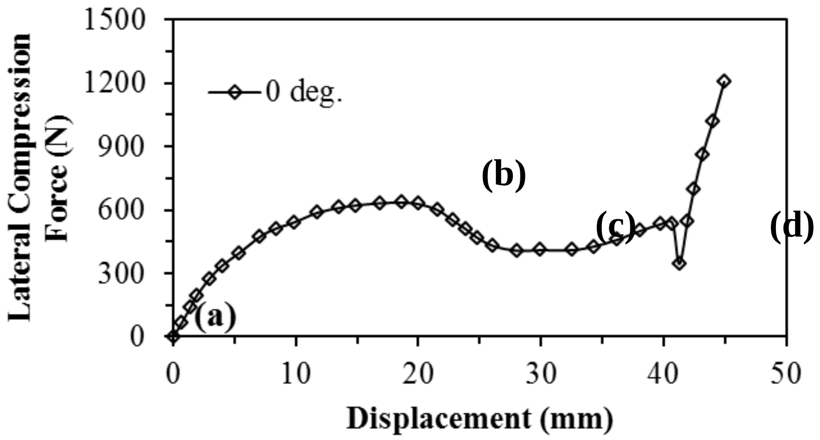
3. Results and Discussion

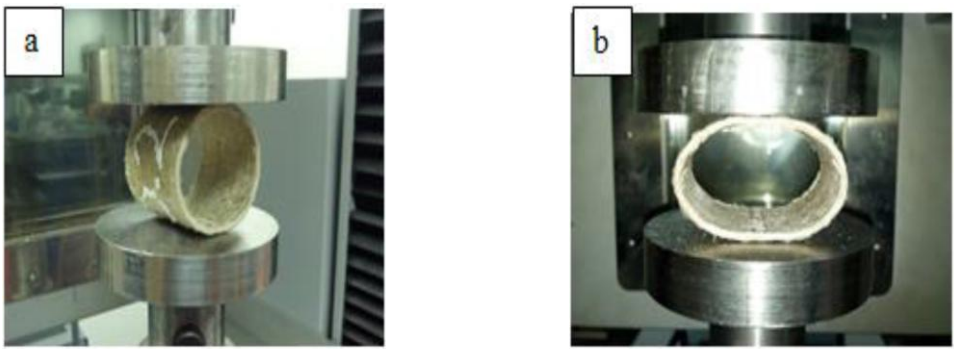
3.1 Progressive Collapse of the Composite Tubes

Figure 5 shows the force against lateral displacement of two layers of 0^0 fiber orientations reinforced composite tubes. It is also revealed the collapse stages during the lateral deformations. There is an obvious typical force versus displacement generally occurred when the composites are crushed. It is mainly composed of three main stages; (1) linear elastic deformation, (2) plateau deformation and (3) densification stages. The transition between stages (1) and (2) are not clearly defined where there is no abrupt force dropped. Stage (a) shows the initial condition of laterally compressed tube. Point (b) occurred when the curve has showed some force dropped where the both upper and lower sides of the tubes have experienced plastic hinges. Once the force increased another plastic hinge sites initiated at the left and right sides of the tubes. In this condition (point (c)), the tube is slightly supported the force showing the plateau stage. When the internal faces of the tube contacted, the densification stage started to increase as in point (d).

3.2 Effect of Fiber Orientations on the Crushing Responses

Figure 6 shows the force versus displacement diagrams of three different numbers of layers composites; one, two and three layers, respectively. It is revealed that the number of layers played an important role in determining the crushing responses. For identical type of composites, fiber orientations have no significant effect on the force-displacement curves. When the fiber orientations are increased from 0^0 to 10^0, the response is slightly increased especially for a single layer composite. However, when the number of layers increased, the curves are independent on the fiber orientations. Figures 6(b) and 6(c) showed that 5^0 fiber orientations seemed to result higher crushing response compared with other orientations especially at the initial stages.





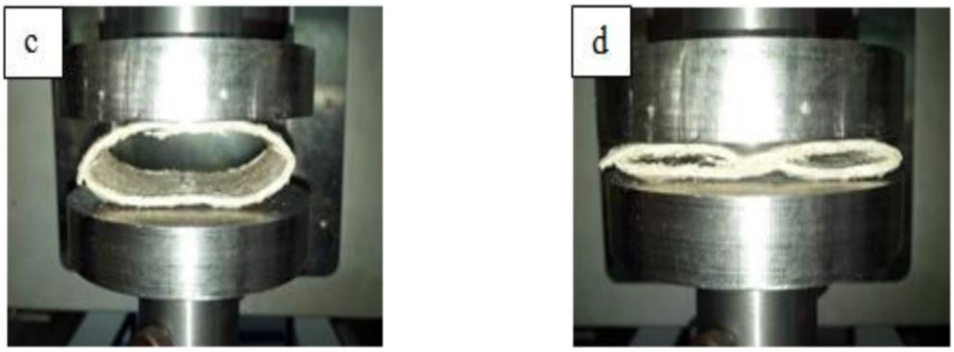
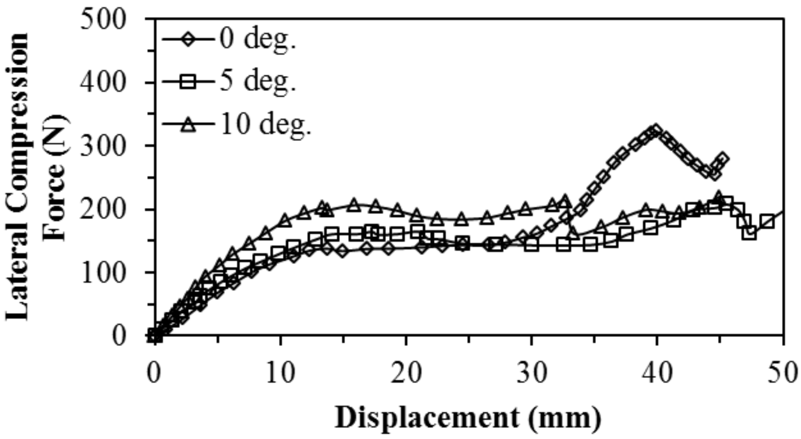
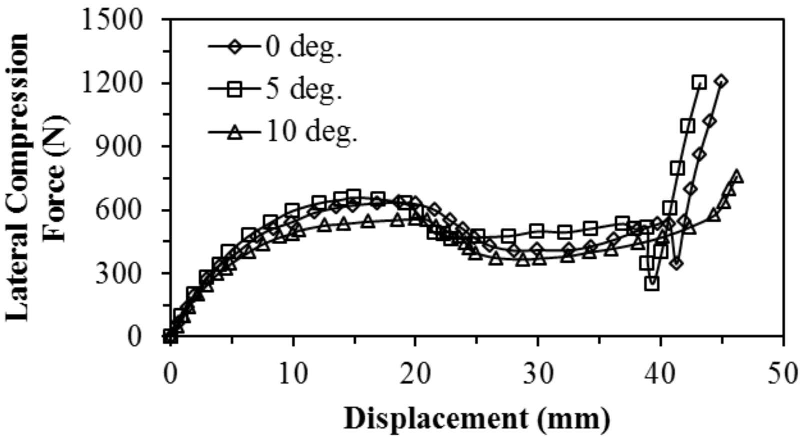


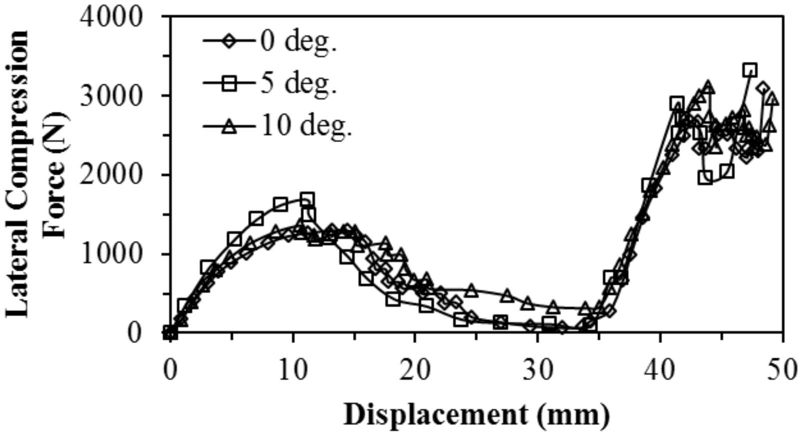
Figure 5. Progressive collapse of different displacement of 2 layers and 0^0 orientation fibers.



(a)



(b)



(c)

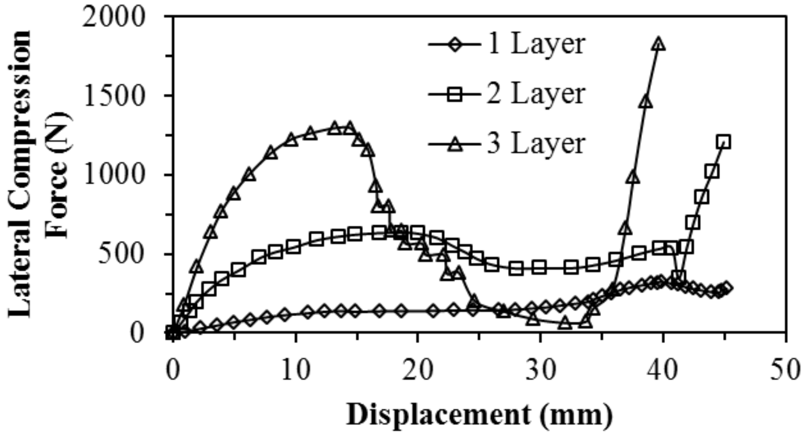
Figure 6. Force versus displacement of (a) 1 layer, (b) 2 layers and (3) 3 layers of different fiber orientations composite tubes.

3.2 Effect of Number of Fiber Layers on the Crushing Responses

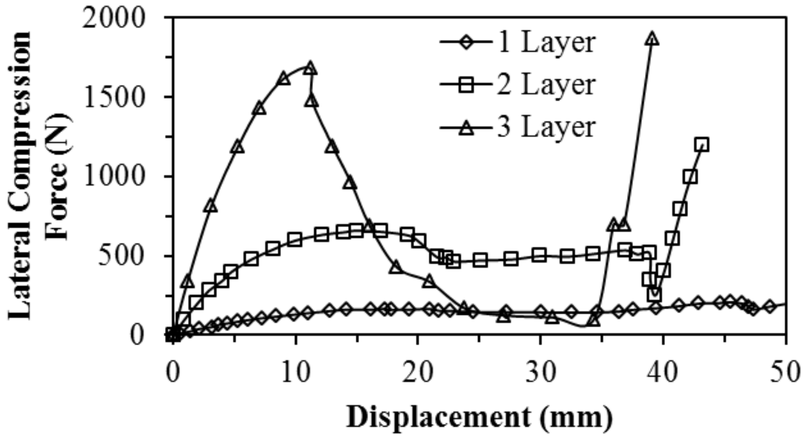
It is more obvious when the forces versus displacement curves are plotted in term of fiber orientations as in Figure 6. As expected, the number of layers played an important role in increasing the crushing responses. Even though the crushing responses are higher than others, the thicker composites revealed the catastrophic deformations. This effect is pronounced where the sudden peak force drops are significant. However, when 10^0 fiber orientations are used, the sudden peak force drop is slightly improved. This is indicated that when the inclined angle is used, it is capable to overcome the shear force around the tubes as a result reducing the degree of sudden drop forces.

3.3 The effects of number of layers and fiber orientations on the specific energy absorptions

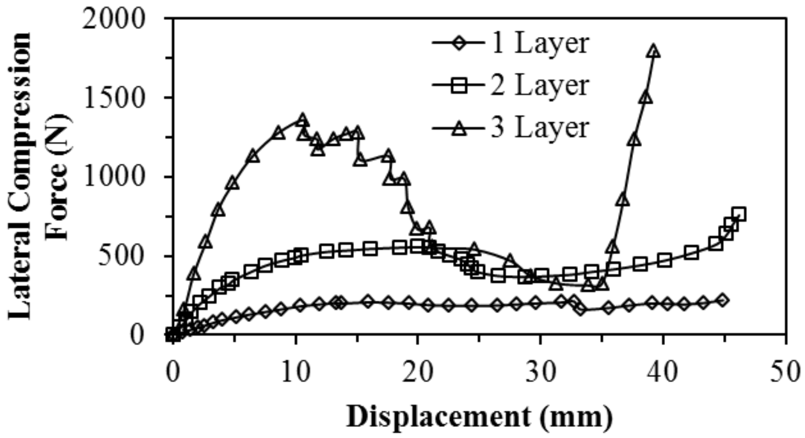
In this paper, specific energy absorption is used instead of energy absorption alone in order to normalize them. The energy absorption determined from the area under the curve is then divided by mass of the composites. Figure 7 shows that obviously the specific energy absorptions increased when the numbers of layers are increased. This is due to the fact that the numbers of layers are related with the amount of fibers used. Once the fiber contents increased, it is affected the material stiffness however the materials become brittle. The brittleness effect on the other hand produced several toughening mechanisms compared with the composites collapse ductile-like manner. For single or double layer composites, 0^0 fiber orientations capable to support the circumferential stress effectively. However, when three layer fibers are used, 5^0 and 10^0 orientations produced better energy absorption performances.



(a)

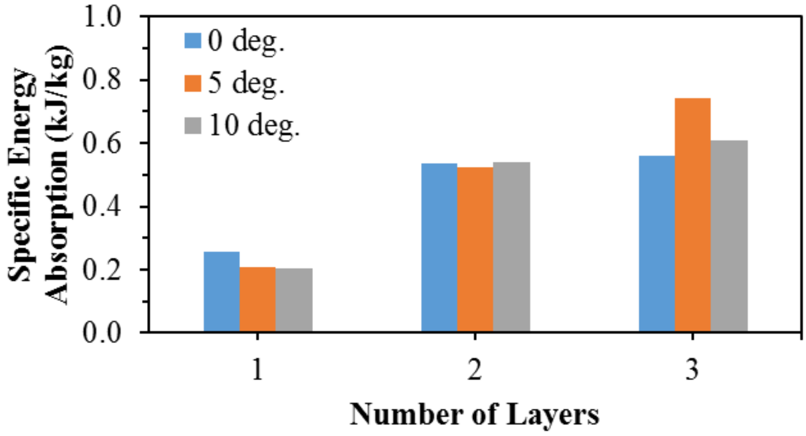


(b)

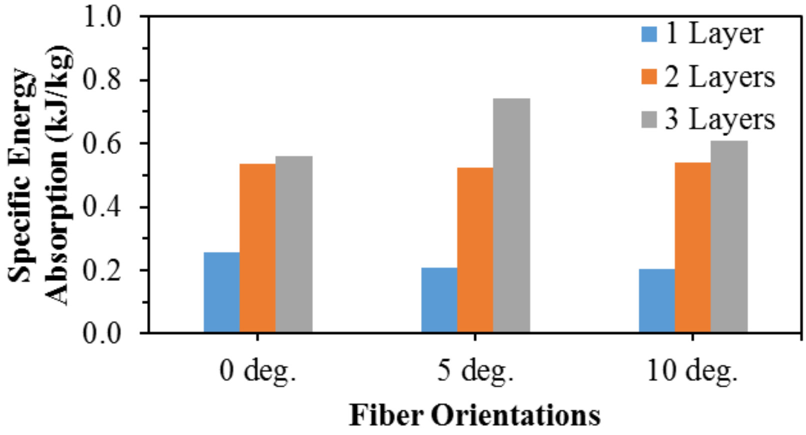


(c)

Figure 6. Force versus displacement of (a) 0^0, (b) 5^0 and (3) 10^0 for different number of layers composite tubes.



(a)

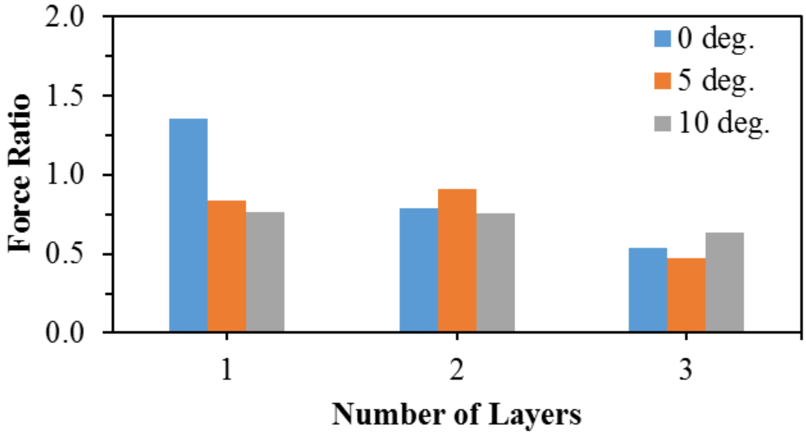


(b)

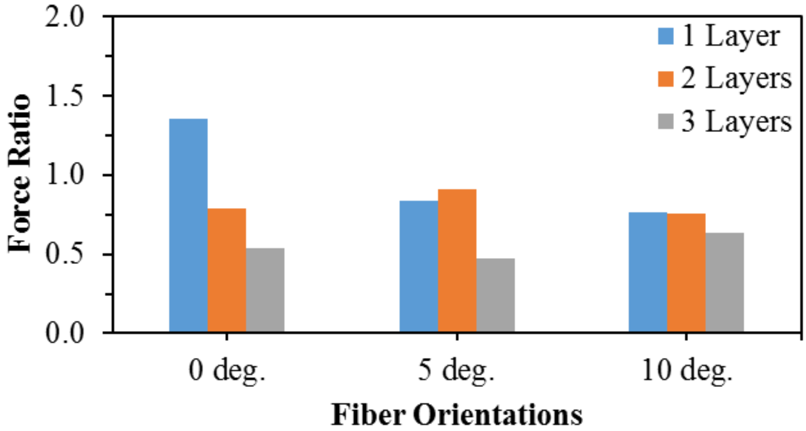
Figure 7. The effect of (a) number of layers and (b) fiber orientations on the specific energy absorptions

3.4 The effects of number of layers and fiber orientations on the force ratio

Figure 8 shows the influence of number of layers and fiber orientations on the force ratios. It is an indication factor in crashworthiness to show the severity of the catastrophic collapses or buckling. If the ratio is high, the both peak and mean forces are almost identical and it is appropriate for energy absorbing structures. If the ratio is low, it is probably the tubes collapse in buckling manners and it has lower value of energy absorption performances. According to Figure 8(a) when the numbers of layers are increased, the force ratio decreased. It meant that there is higher tendency for the tube collapses catastrophically. However in contrast, it is still sustained higher specific energy absorption capabilities as depicted in Figure 7(a). In term of the effect of fiber orientations on the force ratio, Figure 8(b) describes that 0^0 orientation results better force ratio especially for single layer composite. However, for other orientations (5^0 and 10^0) including 0^0, there is no significant effect on the force ratio when more than two layers of composites are considered.



(a)



(b)

Figure 8. The effect of (a) number of layers and (b) fiber orientations on the force ratio

4. Conclusion

In this paper, lateral compression force against displacement of the kenaf yarn reinforced composite tubes are studied and analyzed. There are three types of layers are used to reinforce the composite tubes (one, two and three layers). Each layer fabricated using three different fiber orientations such as 0^0, 5^0 and 10^0. From the experimental results, specific energy absorption performances and force ratios are calculated and related with the composite parameters. It can be concluded that:

i. Specific energy absorption performances increased when the numbers of layers are increased.

ii. Fiber orientations are not played an important role in increasing the capabilities of specific energy absorptions.
iii. Force ratios decreased when the numbers of layers are increased but it is significantly not affected the energy absorption performances.
iv. Fiber orientations seemed not to affect the force ratios. However when fiber orientations increased, force ratios are slightly decreased.

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