International Journal of Integrated Engineering, Vol. 10 No. 1 (2018) p. 189-195
© Penerbit UTHM
DOI: https://doi.org/10.30880/ijie.2018.10.01.029

Crushing Performances of Axially Compressed Woven Kenaf Fiber Reinforced Cylindrical Composites

Al Emran Ismail[*1], Azmahani Sadikin[1], Mohd Nasrull Abdol Rahman[1], Shahruddin Mahzan[1], Salihatun Md. Salleh[1], Sufizar Ahmad[1], Mohd Baharudin Ridzuan[2]

[1]Mechanical Failure Prevention and Reliability (MPROVE) Center of Research, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Johor, Malaysia.
[2]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Johor, Malaysia.

Received 30 January 2018; accepted 21 February 2018; available online 26 April 2018

Abstract: This paper presents experimental investigations on the crushing performances of axially compressed woven kenaf fiber reinforced cylindrical composites. Based on the literature survey, there are tremendous amount of work are available on the crushing performances regardless whether the composite contained synthetic or natural fibers. However, lack number of work found in discussing the crushing capability for the composite tubes fabricated using woven kenaf mat reinforced composites. Kenaf fiber in the form of yarn is weaved into a woven mat before it is submerged into a resin bath prior the mats are shaped to form a cylindrical tube. There are two important parameters are used such as number of layers and fiber orientations. The composite tubes are then quasi-statically compressed to obtain the force-displacement curves. Energy absorption capability and other crashworthiness parameters are calculated and discussed in term of number of layers and fiber orientations. According to the results, it is found that both number of layer and fiber orientations played an important role in an elastic region or the first region. On the other hand, in the second stage, it is insignificantly affected the plateau stage where the curves seemed not much different.

Keywords: Kenaf fiber, woven kenaf mat, crushing performance, specific energy absorption, composites.

1. Introduction

Natural fiber reinforced polymer composites have raised great interests among material scientists and engineers in recent years due to the need for developing an environmentally friendly material, and partly replacing currently used glass for composite reinforcement [1]. In addition, natural fibers are also more affordable than synthetic fibers and can be replaced in many applications for which its cost saving feature outweighs the high composite performance requirements [2]. In the past, composite materials such as coconut fiber and natural rubber latex were extensively used by the automotive industry. Over the past few years, there has been a renewed interest in using these fibers as reinforcement materials to some extent in the plastic industry. This resurgence of interest is due to the increasing cost of plastics, and also because of the environmental aspects of using renewable and biodegradable materials.

Kenaf (Hibiscus cannabinus, L. family Malvaceae) is seen as an herbaceous annual plant that can be grown under a wide range of weather condition, for example, it grows to more than 3 m within 3 months even in moderate ambient conditions with stem diameter of 25-51 mm. It is also a dicotyledonous plant meaning that the stalk has three layers; an outer cortical also referred to as ("bast") tissue layer called phloem, an inner woody ("core") tissue layer xylem, and a thin central pith layer which consist of sponge-like tissue with mostly non-ferrous cells [3, 4].

The core and bast fibers from kenaf have been used to make composites for car components, furniture, and building industries [5]. The long Kenaf's bast fibers have potential to become reinforced polymers due to the high content of cellulose, ranging up to 70% compared to the kenaf core fiber and the other types of natural fibers in Malaysia such as banana fiber, coir fiber and others [6]. Kenaf quite well known economically. The idea of using cellulose fibers as reinforcement in composite materials is not a new or recent one. Mankind had used this idea for a long time, since the beginning of our civilization when grass and straws were used to reinforce mud bricks.

Ismail et al. [7] investigated woven kenaf reinforced composite tubes under axial compression. In this work, woven mat is submerged into a resin bath before it is rolled to form cylindrical tubes. According to the experimental results, the composites produced using $[0^0/0^0]$ and $[0^0/0^0/0^0]$ fiber orientations, better force-displacement curves are observed compared with other

*Corresponding author: emran@uthm.edu.my / al_emran@hotmail.com
2011 UTHM Publisher. All right reserved.

type of composites. However as expected, the [$0^0/0^0$] is lower that the [$0^0/0^0/0^0$] composites due to different in tube thicknesses. When the composites contained 15^0 fiber orientations in their configurations, there is no significant specific energy absorption found for both two and three layer composites. During progressive collapses, global buckling is observed especially for the composites contained 45^0 fiber orientations. Similar crushing pattern is observed for three layered composites.

Ismail [8] then used the filament winding method to fabricate kenaf fiber reinforced composite tubes. Kenaf yarn is firstly submerged into the resin bath before they are wounded around the cylindrical mold. The tubes are them compressed quasi-statically to obtain their force-displacement responses. It is found experimentally that when the number of layers are increased, as expected the responses of force-displacement curves are higher than single layered composite tubes. Higher energy absorption performances can be obtained using thicker composite tubes. On the other hand, increasing the fiber orientations from 0 to 10^0 are also increased the energy absorption significantly. Thicker the tube thicknesses, higher force ratios can be obtained. Consequently, better energy absorption capabilities are produced. A localized wall buckling dominated the failure mechanisms. Large wall fragmentations are observed during the progressive collapses therefore responsible for large sudden force drop. Others related works can be found in [9-18].

Ismail and Che Abdul Aziz [17] worked to investigate the tensile strength of woven yarn kenaf fiber reinforced polyester composites. As-received kenaf yarn is arranged into specific orientations before it is hardened with polyester resin. The composites are shaped according to the ASTM standard and then stressed uni-axially to obtain the stress and strain curves. According to the results, it is shown that fiber orientations greatly affected the ultimate tensile strength but it is not for modulus of elasticity for both types of layers. It is estimated that the reductions of both ultimate tensile strength and Young's modulus are in the range of 27.7-30.9% and 2.4-3.7% respectively, if the inclined fibers are used with respect to the principal axis. Fatigue strength is also investigated and can be found in [18].

This paper presents the investigation of crushing performances of axially compressed woven kenaf fiber reinforced cylindrical composite tubes. There are two important parameters are used such as number of layers and fiber orientations. Several important crashworthiness indicators are extracted and discussed in relation with number of layers and fiber orientations.

2. Experimental Program

The aim of this research is to study the capability of energy absorption of Kenaf fiber reinforced polyester composites. It is consisted firstly the method of producing the samples. The size of tube is 50 mm of external diameter and 70 mm of height. The outer diameter and thickness are fixed regardless of the number of layers Polyvinyl chloride pipes (PVC) are used as a mould in order to produce the cylindrical tubes. Woven kenaf mats is firstly submerged into a resin bath and light pressure is applied to ensure the uniformity of resin before it is radially compressed to squeeze out the excessive resin. The composites are then cured for 24 hours before the mould is removed.

Figure 1 shows the kenaf yarn before the weaving process and the size is 1 mm in diameter. Figure 2 shows the weaving process conducted using in-house weaving equipment while Figure 3 shows the finished woven kenaf mat. On the other hand, Figure 4 reveals a schematic diagram of plain weaving pattern used in this paper.

Table 1 reveals number of layers and fiber orientations used in this work. It is showed that the thickness is strongly related with number of layers. Once the cylindrical tubes hardened, both ends are trimmed and flattened before they are placed vertically between two rigid flat plates. Tubes are then compressed quasi-statically at a constant cross-head displacement of 5 mm/min. Force and displacement are recorded automatically and then force-displacement curves are plotted as in Figure 5. Several crushing parameters can be calculated such as:

i. Initial Peak Load (P_i) is the initial crushing load that can be obtained directly from the load displacement response.
ii. Mean-crushing load (P_m) is the average crushing load that can be obtained by averaging the crushing load values over the crush displacement through the post-rush region.
iii. Crush Force Efficiency (CFE). It is the ratio between mean crush load and initial crush load. It is calculated as in Eq. (3.1) where P_i and P_m represent the initial and mean crush failure loads respectively:

$$CFE = \frac{P_i}{P_m} \quad (1)$$

iv. Initial Failure Indictor (IFI). It is the ratio between initial crush load and critical crush load, which can be calculated as in Eq. (3.2) where P_i is the initial crushing load and P_{cr} is the critical crushing load:

$$IFI = \frac{P_i}{P_{cr}} \quad (2)$$

v. Specific energy absorption (E_S) is defined as the energy absorbed per unit mass of material. Figure 5 is a typical load displacement curve obtained from progressive crushing of a composite tube specimen. The total work done or energy absorbed, W, in crushing of composite specimens is the area under the load–displacement curve as in Eq. (3.3) and m is a crushed mass:

$$E_s = \frac{W}{m} = \int \frac{P}{m} ds \quad (3)$$

3. Results and Discussion

Figure 5 shows the responses of force-displacement curves of woven kenaf fiber reinforced cylindrical tubes under axial compression. It is revealed that the curve exhibited a typical force-displacement pattern where in general there are three important regions occurred during the axial compression. The first region is an elastic deformation where the force is linearly related to the displacement. Once the force reached the peak force, it is experienced sudden force drop indicating of the first wall disintegration. Second stage is called a plateau region where the force experienced some fluctuations indicating the wall experienced subsequent wall damages. Last region is a densification stage where all crushed wall accumulated until no more displacement can be observed.

Fig. 1 Kenaf yarn

Fig. 2 Weaving process.

Fig. 3 Completed woven kenaf mat.

According to the Figure 6, it is revealed that the force-displacement curves are significantly related to the thickness, thicker the wall higher the curves. Based on the experimental observations, the wall is firstly experienced a localized buckling mainly around the contact between the rigid plate and the composite. After that, the wall showed a large wall deformation without showing any fragmentations or wall disintegration. On the other hand, many researchers have reported especially for composites fabricated using synthetic fiber that significant wall fragmentations are also observed [18].

Table 1 Experimental setup for fibre orientations and number of layers of cylindrical tubes.

Typ e	Orientations	Thicknes s (mm)	Inner Dia. (mm)	Heigh t (mm)
C1	[0°/0°]	5	50	70
C2	[0°/15°]	5	50	70
C3	[0°/30°]	5	50	70
C4	[0°/45°]	5	50	70
C5	[0°/0°/0°]	7	50	70
C6	[0°/15°/0°]	7	50	70
C7	[0°/30°/0°]	7	50	70
C8	[0°/45°/0°]	7	50	70
C9	[+15°/0°/-15°]	7	50	70
C10	[+30°/0°/-30°]	7	50	70
C11	[+45°/0°/-45°]	7	50	70
C12	[0°/0°/0°/0°]	10	50	70
C13	[0°/+15°/-15°/0°]	10	50	70
C14	[0°/+30°/-30°/0°]	10	50	70
C15	[0°/+45°/-45°/0°]	10	50	70

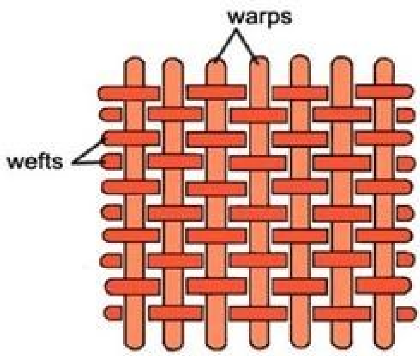


Fig. 4 A schematic diagram of woven pattern.

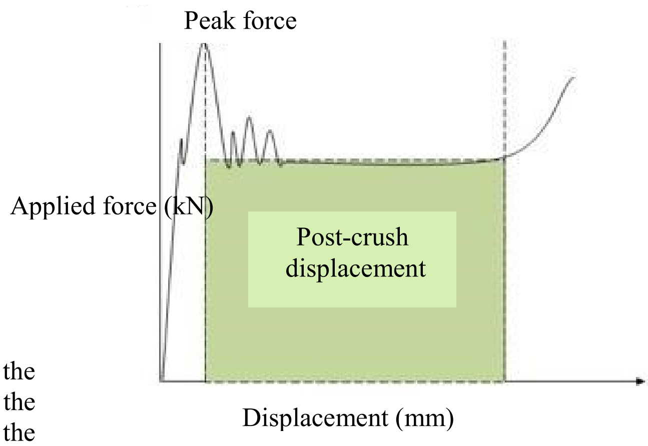
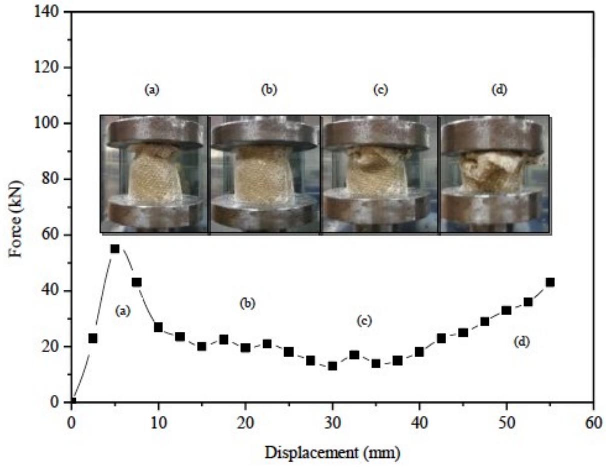


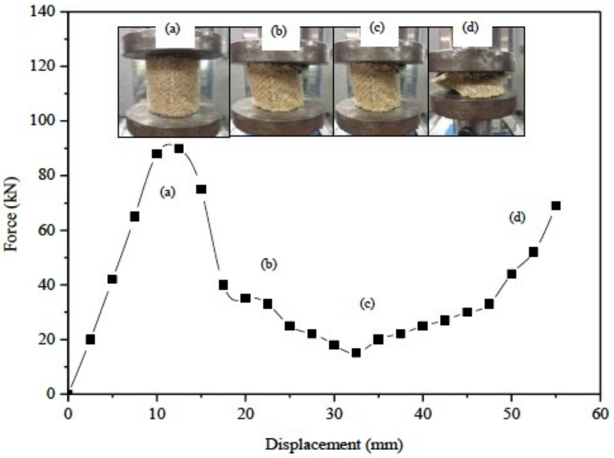
Fig. 5 Force-displacement curve.

Published by UTHM Publisher
http://www.uthm.publisher.edu.my/ojs/ijie

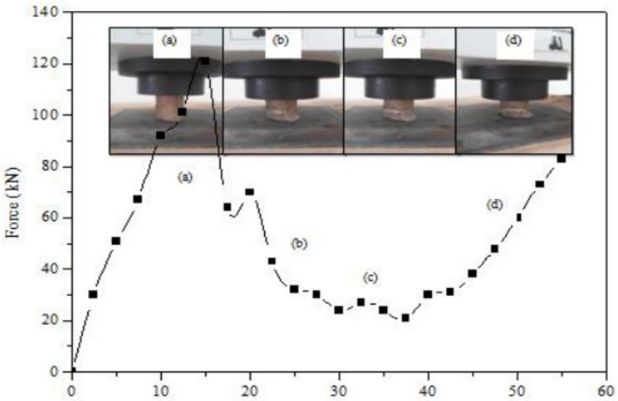
Figure 7 shows a comparison between the responses of force-displacement curves. Most of tubes contained 0° fibre orientations. However the only difference is Figures 7(a) until 7(c) contained 15°, 30° and 45° fibre orientations.



(a)

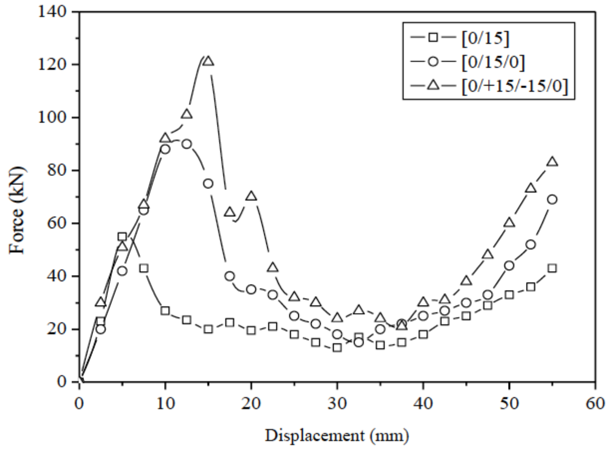


(b)

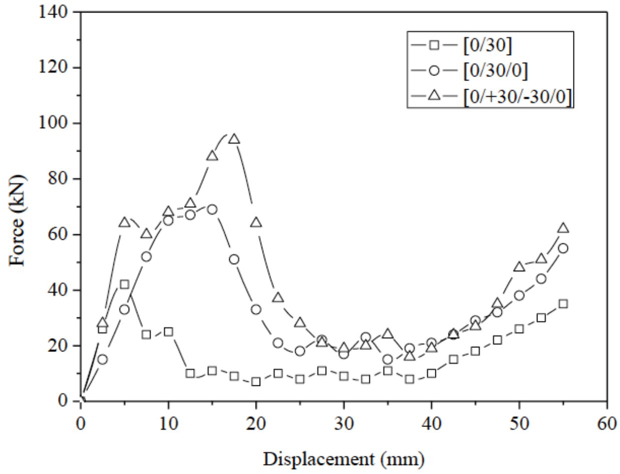


(c)

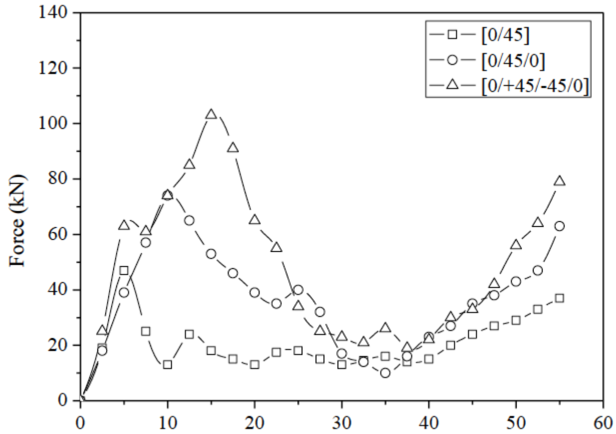
Fig. 6 Crushing mechanisms of cylindrical composite tubes (a) 2 layers, (b) 3 layers and (c) 4 layers.



(a)



(b)



(c)

Fig. 7 Effect of number of layers and fibre orientations on the responses of force-displacement, (a) 15°, (b) 30° and 45°.

In general, higher number of layers produced higher force-displacement curves. This behaviour is already reported elsewhere [18] for all kind of materials and configurations. It is also observed that varying number of layers contributed to higher peak forces. However, it is insignificantly affected the plateau stage where the curves seemed not much different. This is indicated that after peak force dropped, failure mode is not significantly controlled by wall thickness and fibre orientation except the elastic region and similar wall collapses are observed. This is to confirm that both number of layers and fibre orientations are not played an important role determining the responses of force-displacement curves especially in the second stage.

Figure 8 shows the comparison between number of layer when fibre orientations are varied. It is indicated that the composites contained 15º fibre orientations which is capable to produce slightly higher force-displacement curves. However, based on the observation, it is revealed that the composites experienced large force drop when compared with other type of composites. In this work, 0º fibre orientation are aligned in the tranverse direction relative to the tube axis. Therefore, it is capable to resist the tube deformation radially. On the other hand, higher fibre orientation contributed to the prevention of large peak force droped and then produced higher crushing performances.

Figures 9(a) shows the effect of number of layers and fibre orientations on the crushing force efficiency (CFE). It is defined as the ratio between mean and peak forces. When the force is low, it is indicated that there is a large difference between both force or in other word, the peak force dropped significantly. This behaviour contributed to the lower crushing performances. According to the Figure 9(a) the effect of number of layers on the CFE is significant where higher number of layers resulted lower CFE indicating the tube exerienced large peak force drop.

Figure 9(b) shows the effect of fibre orientations on the CFE. It is observed that fibre orientation is not the key factor in affecting the CFE. Based on Figures 7 and 8, fibre orientation is only affected in the elastic region while in the second region it is not.

Figure 9(c) shows the effect of fibre orientations on the initial failure indicator (IFI) when number of layer is varied. It is defined as the ratio between the peak and critical bukling forces. If the IFI approached 1.0, it is indicated that the initial and critical buckling forces is almost similar and the tube tendency to experience a global buckling is higher. According to the experimental observation, for all cases of fibre orientations, thinner the tube wall higher IFI vaues. This is indicated the tubes with 3 layers and above produced almost a single value of IFI. On the other hand, this is also indicated that 3 layers and above capable to prevent a catastropic failure when compared with 2 layers composite tubes.

Figure 10 shows the effect of fibre orientations on the specific energy absorption performances when number of layers are varied. As expected, higher number of layers produced higher specific energy absorptions (SEA) as reported elsewhere [8]. It is observed that the tubes contained 0º dominated fibre orientations resulted higher SEA. This is due to the fact that 0º orientation capable to resist the deformation of tube wall radially. When, fibre orientation is increased, SEA seemed to decrease almost linearly eventhough higher number of layers are used.

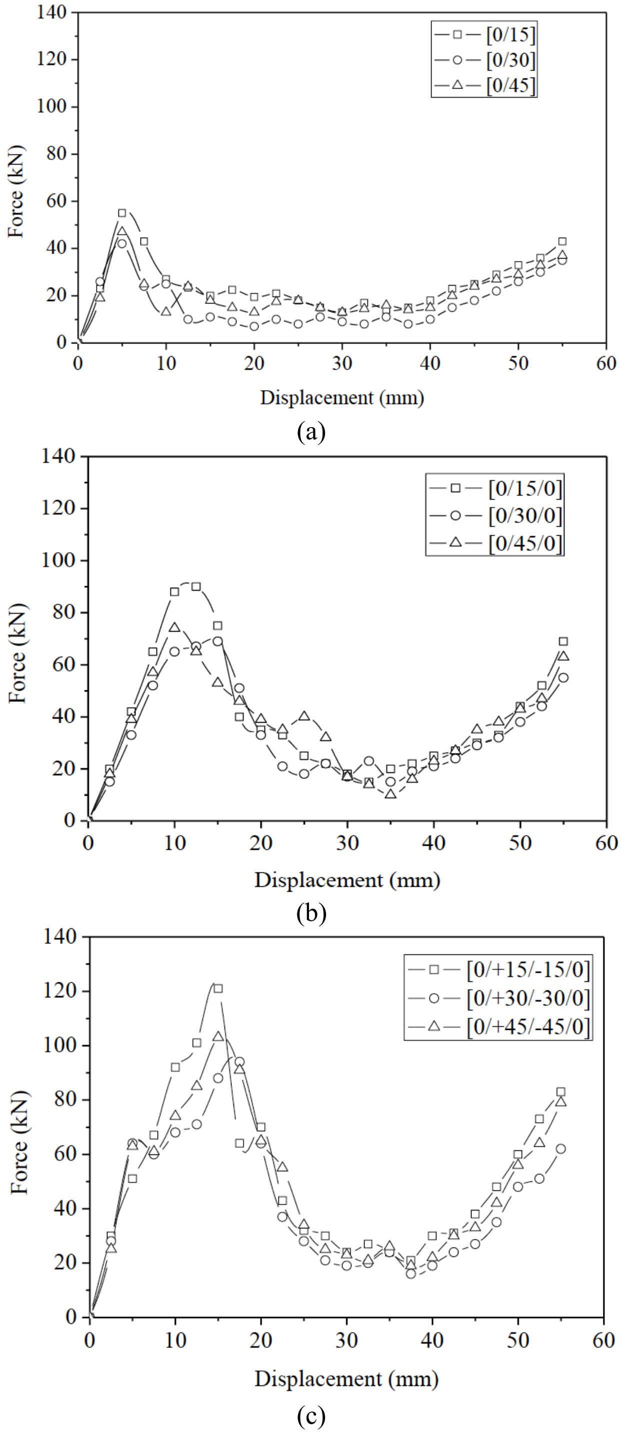


Fig. 8 Effect of number of layers on the crushing performances, (a) 2, (b) 3 and (c) 4 layers.

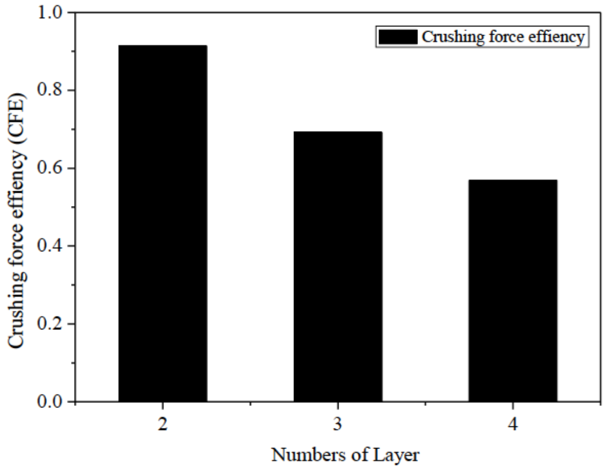
4. Summary

From experimental works, several conclusions can be drawn such as:

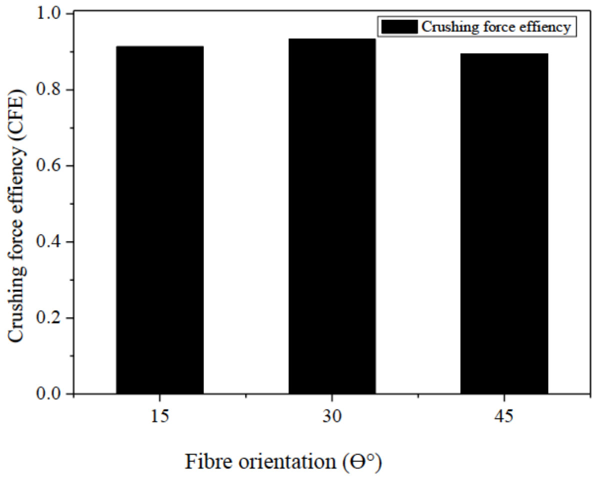
a) Both fiber orientations and number of layers played an important role in increasing the crushing performances. However, it is not for the second region of deformation.
b) Higher peak force is produced when all fibers are aligned in 0° due to the fact that these fibres capable to resist the deformation radially.
c) Crushing force efficiency (CFE) decreased gradually when the number of layers are increased indicating that the tube wall collapsed catastrophically.
d) Specific energy absorption (SEA) capability increased when number of layer is increased. On the other hand, changing fiber orientations from 0° to 45° decreased the SEA.

Table 2 Summary of results obtained experimentally of woven kenaf fibre reinforced cylindrical tubes

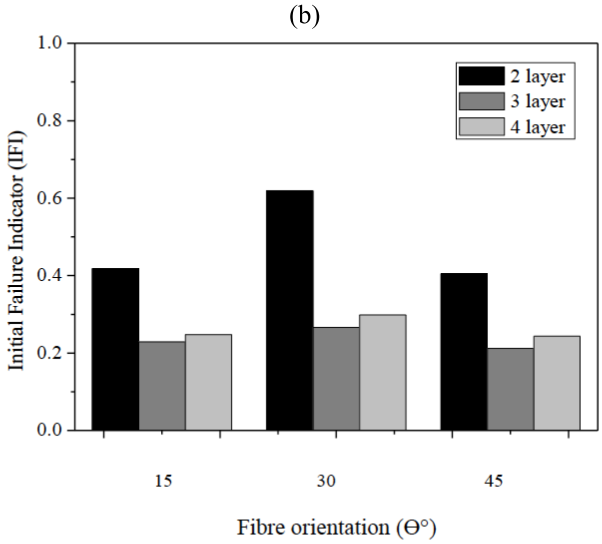
Type	Orientations	Peak force (kN)	Mean force (kN)	SEA (kJ/kg)
C1	[0°/0°]	62.4	20.7	15.530
C2	[0°/15°]	55.0	18.0	11.781
C3	[0°/30°]	42.1	11.2	10.905
C4	[0°/45°]	46.7	14.3	9.350
C5	[0°/0°/0°]	101.0	32.1	22.567
C6	[0°/15°/0°]	91.8	28.4	14.581
C7	[0°/30°/0°]	69.2	21.6	12.748
C8	[0°/45°/0°]	73.4	25.2	10.638
C9	[+15°/0°/-15°]	71.2	25.9	12.442
C10	[+30°/0°/-30°]	65.4	18.5	11.153
C11	[+45°/0°/-45°]	69.7	21.7	10.180
C12	[0°/0°/0°/0°]	123.7	24.2	53.450
C13	[0°/+15°/-15°/0°]	121.0	22.5	47.280
C14	[0°/+30°/-30°/0°]	93.1	19.5	33.489
C15	[0°/+45°/-45°/0°]	105.6	20.4	21.2111



(a)



(b)



(c)

Fig. 9 Crushing performances, (a) Crushing force efficiency (effect of number of layer), (b) Crushing force efficiency (effect of fibre orientation) and (c) Initial failure indicator.

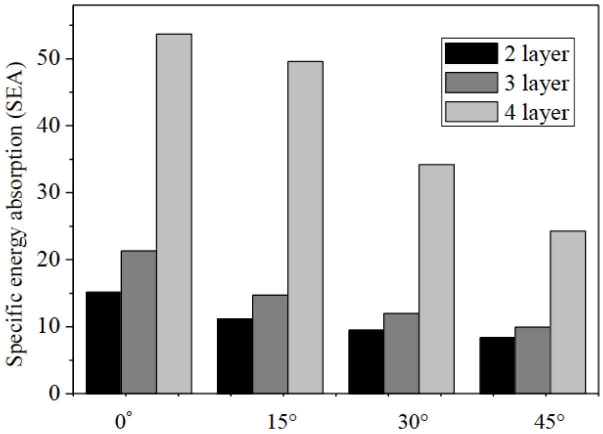


Fig. 10 Specific energy absorption capabilities of woven kenaf fibre reinforced cylindrical tubes

References

[1] Pickering K.L., Aruan Efendy, M.G., Le, T.M., A review of recent developments in natural fibre composites and their mechanical performance, *Composite Part A: Applied Science and Manufacturing*, Volume 83, (2016), pp. 98-112.

[2] Kristiina Oksman, Mikael Skrifvars J.F Selin, Natural fibres as reinforcement in polylactic acis (PLA) composites, *Composites Science and Technology*, Volume 63, Number 9, (2003), pp. 1317-1324.

[3] Lee, C.H., Mohd Sapuan Salit, Hassan, M.R., A review of the flammability factors of kenaf and allied fibre reinforced polymer composites, *Advances in Materials Science and Engineering*, Volume 2014, (2014), 514036.

[4] Mohd Hadi Akber Basri, Ariffin Abdu, Nasima Junejo, Hazandy Abdul Hamid, Khalil Ahmed, *Journey of kenaf in Malaysia: A review, Scientific Research and Essays*, Volume 9, Number 11, pp. 458-470.

[5] Akil, H.M., Omar, M.F., Mazuki, A.A.M., Safiee, S., Ishak, Z.A.M., and Bakar, A., Kenaf fiber reinforced composites: A review. *Material and Design*, Volume 32, Number 9, (2011), pp. 4107-4121.

[6] Aji, I.S., Sapuan, S.M. Zainudin, E.S., and Abdan, K., Kenaf fibres as reinforcement for polymeric composites: A review, International Journal of Mechanical and Materials Engineering, Volume 8, Number 4, (2009), pp. 239-248.

[7] Ismail, A.E. and Mohd Tobi, A.L., Axial energy absorption of woven kenaf fiber reinforced composites, *ARPN Journal of Engineering and Applied Sciences*, Volume 11, Number 14 (2016) pp. 8668-8672.

[8] Ismail, A.E., Crushing mechanisms of cylindrical winding kenaf fiber reinforced composites, *Jurnal Teknologi*, Volume 78, Issue 6 (2016) pp. 45-50.

[9] Ismail, A.E., Ariffin, A.K., Abdullah, S. and Ghazali, M.J. Finite element analysis of J-integral for surface cracks in round bars under combined mode I loading, International Journal of Integrated Engineering, Volume 19, Number 2, (2017), pp. 1-8.

[10] Abdullah, N. and Ismail, A.E., Axial quasi-static crushing behavior of cylindrical woven kenaf fiber reinforced composites, IOP Conf. Series: Materials Science and Engineering, Volume 165 (2017) 012004.

[11] Khalid, S.N.A, Ismail, A.E. and Zainulabidin, M.H., Optimization on impact strength of woven kenaf reinforced polyester composites using Taguchi Method, *IOP Conf. Series: Materials Science and Engineering*, Volume 165 (2017) 012010.

[12] Khalid, S.N.A, Ismail, A.E. and Zainulabidin, M.H., Impact strength of different weaving patterns of woven kenaf reinforced polyester composites, *IOP Conf. Series: Materials Science and Engineering*, Volume 165 (2017) 012011.

[13] Ismail, A.E. and Nezere, N., Numerical simulation of hybrid composite tubes under oblique compression, *World Journal of Engineering*, Volume 14, Issue 2 (2017) pp. 173-177.

[14] Ismail, A.E., Mode I stress intensity factors of sickle-shaped surface crack in round bars, *International Journal of Integrated Engineering*, Volume 8, Number 2 (2016) pp. 1-8.

[15] Ismail, A.E., Masran, S.H., Jamian, S., Kamarudin, K.A., Mohd Nor, M.K., Muhd Nor, N.H., Mohd Tobi, A.L. and Awang, M.K., Fracture toughness of woven kenaf fiber reinforced composites, *IOP Conf. Series: Materials Science and Engineering*, Volume 160 (2016) 012020.

[16] Ismail, A.E., Kenaf fiber reinforced composites tubes as energy absorbing structures, *International Journal of Mechanical and Mechatronics Engineering*, Volume 16, Number 1 (2016), pp. 49-53.

[17] Ismail, A.E. and Che Abdul Aziz M.A., Tensile strength of woven yarn kenaf fiber reinforced polyester composites, *Journal of Mechanical Engineering and Science*, Volume 9 (2015) pp. 1695-1704.

[18] Ismail, A.E. and Che Abdul Aziz M.A., Fatigue strength of woven kenaf fiber reinforced composites, *IOP Conf. Series: Materials Science and Engineering*, Volume 100 (2015) 012037.