Energy Absorption Performances of Square Winding Kenaf Fiber Reinforced Composite Tubes

A.E Ismail
Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia,
Batu Pahat, 86400 Johor, Malaysia
emran@uthm.edu.my or al_emran@hotmail.com

Abstract—This paper investigates the energy absorption response of winding kenaf fiber composite tubes when subjected to an axial quasi-static crushing test. The square composites were prepared firstly by submerging the kenaf yarn into resin bath before it is warped around the mould for different number of layers and fiber orientations. The parameters measured were peak load, mean load and specific energy absorption. Collapse mechanisms during the progressive collapses were observed as a function of tube length. It is found that as-expected, number of layers played an important role in increasing the energy absorption performances. However, fiber alignments have insignificant effect on the absorbed energy. A surface bulge appeared on the one side of the tube walls responsible for premature failure of the composite prior to the progressive collapse.

Keyword-Energy Absorption, Natural Fiber, Kenaf Fiber, Composite Tubes, Collapse Mechanism

I. INTRODUCTION

Natural fiber is recently given an opportunity to replace a synthetic fiber to reinforce composite materials. Generally, this fiber is used as a reinforcing tool to strengthen the composites for non-load bearing applications [1]. The advantages of natural fibers such as low price, low density, unlimited and sustainability. Furthermore, natural fibers are recyclable and biodegradable [2]. A number of works have been carried out to investigate the potential use of natural fibers as reinforcement in polymers. Most of the results have shown that natural fiber can be used as reinforcing tool for plastics. However, their mechanical strength is relatively lower than the synthetic fiber composites [3].

Tremendous amount of works have been found on the investigations of mechanical strength of natural fiber composites. However, lack of information found study the crashworthiness aspects of natural fiber reinforced composites [4-7]. Most of the studies have been carried out to determine the effects of geometries [4], fiber orientations and types [2] and material hybridization [5] on the crashworthiness parameters. Mahdi et al. [5] studied the effect of fiber types and conical angles on their crushing behavior and performances. It is found that the crushing mechanisms are strongly dependent on the cone vertex angles and different fiber types altered the mode of failure. Warrior et al. [8] recently investigated the influence of tube geometry on the crashworthiness performances. In their study, randomly orientated non-woven kenaf fibers were hardened into hexagonal tubes. They found that the change in the hexagonal tube angle affects the crashworthiness parameter with various distinct failure modes.

Based on the literature survey [1-13], there are lack of works reported on the use of natural fiber especially for energy absorbing materials. Most of the reported works discussed more on the basic mechanical behavior such as tensile [11] and impact [2] behavior. Additionally, some works use natural fibers to reinforce plastics are available [2, 5, 6]. However, most of these papers implemented randomly oriented fiber reinforced composites to fabricate their materials. In this paper, an experimental work was conducted to study the response of winding kenaf yarn fiber composite tubes subjected to axial compression forces. Two important parameters are used such as fiber orientations and number of layers. Then, energy absorption and crushing mechanisms are discussed and analyzed in term of these two parameters.

II. 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 square 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 square composites 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 vertically 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.

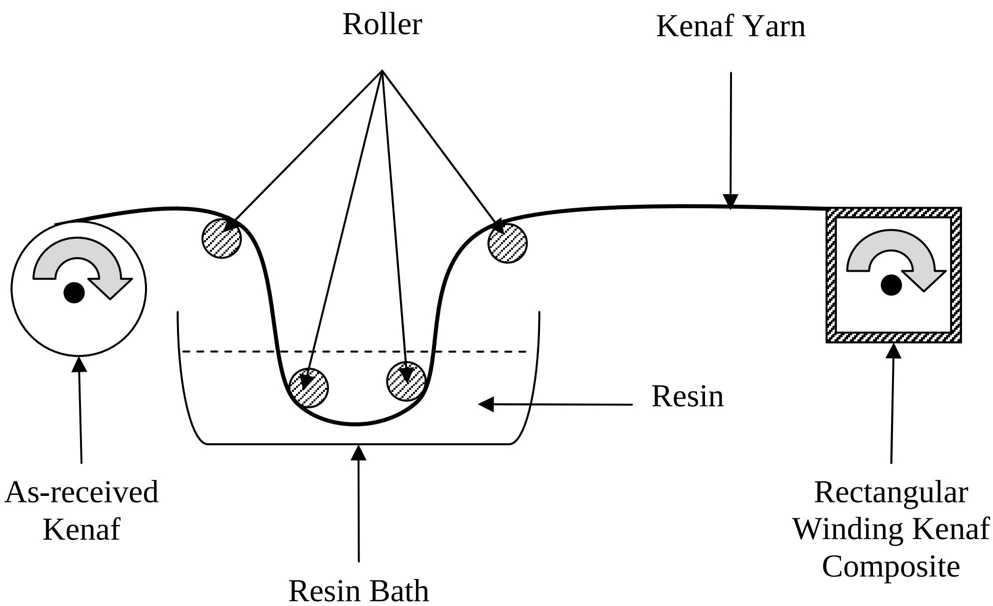
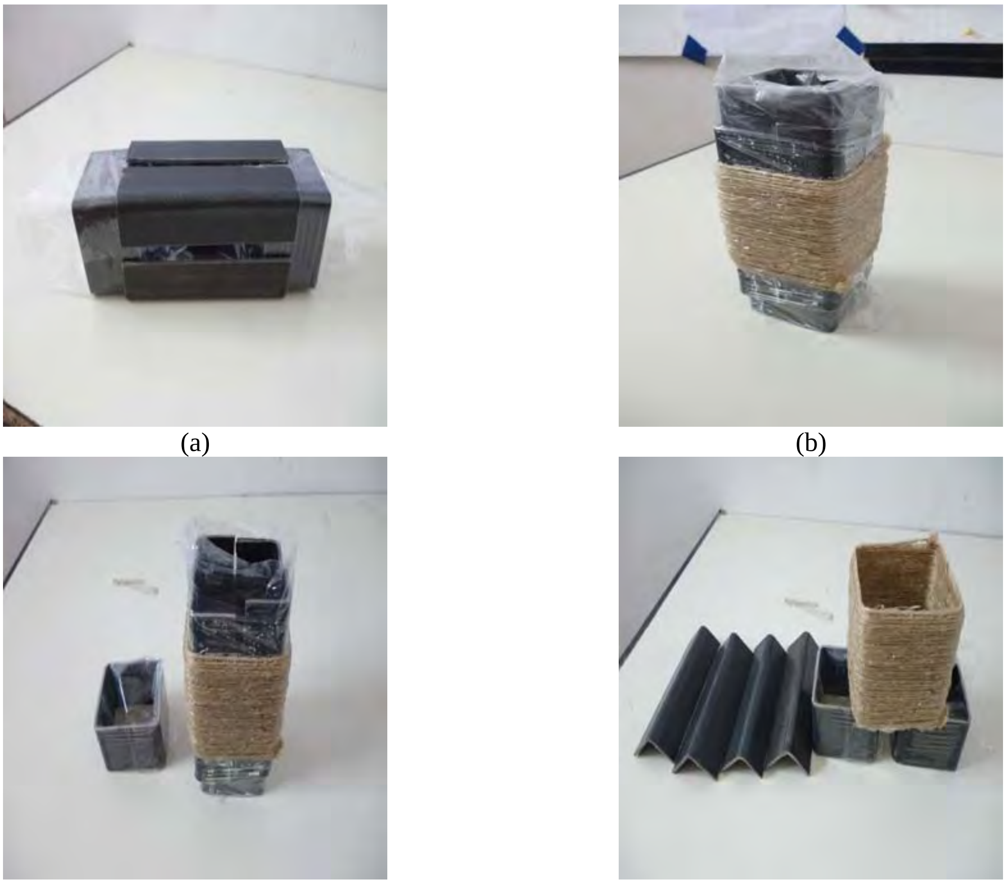


Fig. 2. Schematic diagram of the winding process of the kenaf yarn fiber.



(a) (b) (c) (d)

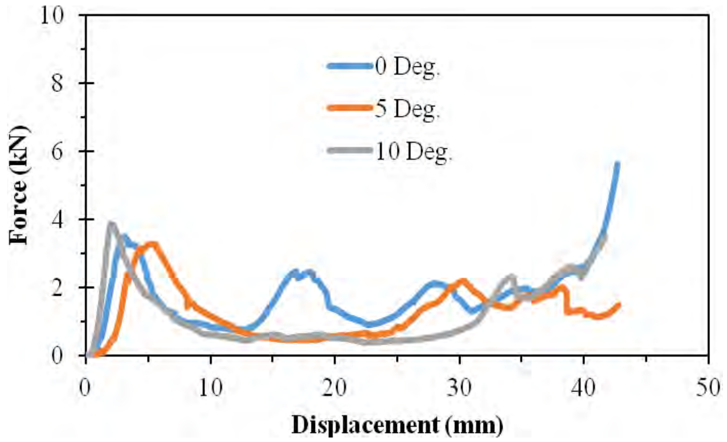
Fig. 3. (a) Design assembly, (b) Hardened composite, (c) End cap is removed and (d) Exploded assembly.

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

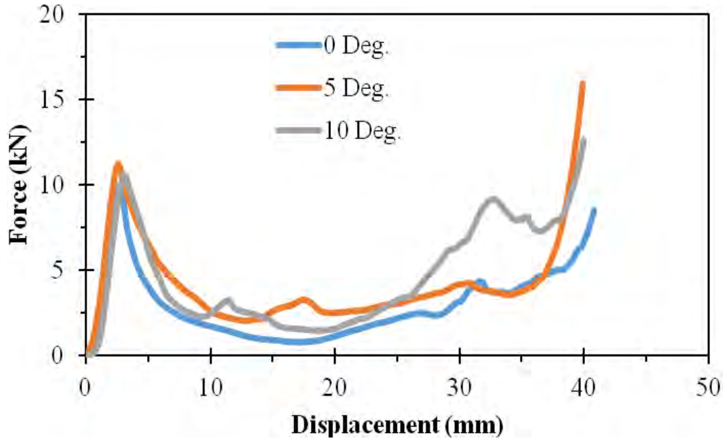
III.RESULTS AND DISCUSSION

A. Force-Displacement Diagram

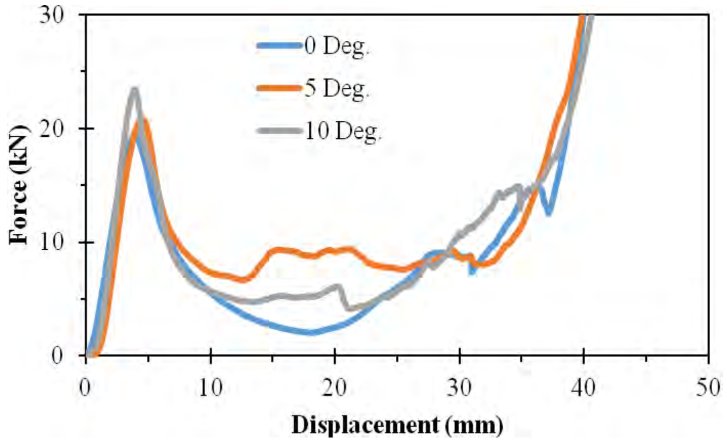
The force-displacement diagrams of the square composite tunes under quasi-static compressive loading is shown in Figure 5 for different number of layers. The force-displacement responses of the square tubes are almost similar to each other where it can be divided into three stages; linear elastic deformation, plateau stress and densification stages. For a linear stage, the displacement is linearly increased when the force is increased. Once, the damages initiated at the end or just below the tube upper edge line, the force started to have a sudden drop with insignificant force fluctuations indicating that the tubes are progressively collapses. At the end of the crushing process, the force increased again due to the collapsed composite densifications. Figure 5 also indicated that the effect of fiber orientations are not significantly affected the response of force-displacement curves. The role of fiber orientations can be clearly distinguished between three orientations used. When the numbers of layers are increased, the responses of force-displacement curves are also increased. However, the crushing distance is relatively shorter compared with the lower number of layers.



(a)



(b)



(c)

Fig. 5. Force-displacement curves of kenaf winding square composites for (a) 1 layer, (b) 2 layers and (c) 3 layers.

B. Effect of Number of Layers and Fiber Orientations on the Energy Absorption Performances

Figure 6 represents the effect of number of layers of winding fibers on the specific energy absorption for different fiber orientations. It is found that the absorbed energy increased when the numbers of fiber layers are increased. It is as expected where higher number of fibers capable to distribute the stresses across the tube wall and therefore toughening the composite materials. On the other hand, fiber orientations seem not to play an important role to increase the energy absorption capabilities. However when the fiber is slightly inclined to 50, higher absorbed energy can be seen compared with other type of fiber conditions. This is probably due to higher value of inclined angle capable to trigger the failure caused by shear stress.

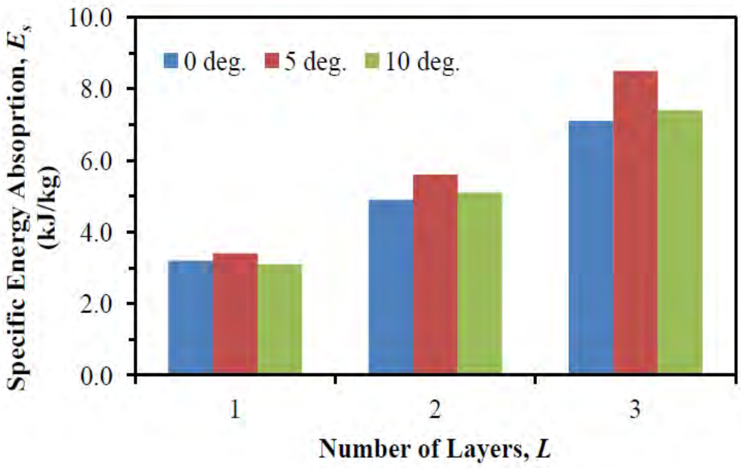


Fig. 6. Effect of number of layers on the specific energy absorption.

Figure 7 shows the effect of fiber orientations on the specific energy absorption for different number of fiber layers. As expected, number of layers played an important factor to increase the energy absorption performances. While, the fiber orientations affected insignificantly on the specific energy absorptions for each layer condition. However, energy absorption capability increased when the fiber alignment is increased from 0 to 5^0. It is then decreased when the fiber orientation up to 10^0. This is probably once the angle is greater than 5^0, the shear forces are triggered and therefore shearing the fiber and thus lowering the energy absorption performances.

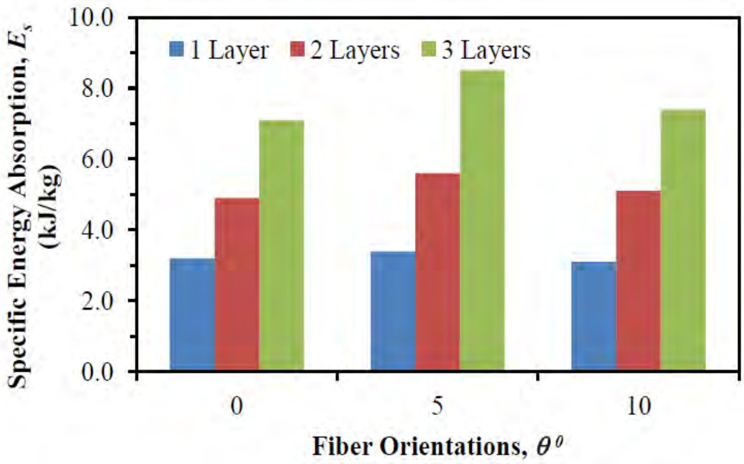


Fig. 7. Effect of fiber orientations on the specific energy absorption.

C. Collapse Mechanisms of the Composite Square Tubes

The force-displacement for 10^0 fiber orientation square composite tube under compressive loading is represented in Figure 8 for a different crushed length. It is an identical force-displacement curve where it can be divided into three stages; (1) linear elastic, (2) plateau stress and (c) densification stages. The area under the curve is therefore represented the energy absorption performance of the composite under compressive loading.

While, Figure 9 reveals the collapsing mechanisms of the square composite tubes. Figure 9(a) shows the initial condition of the tubes. Just after the peak load condition, a bulge appeared at one side of the composite (read arrow). Once the load increased, the bulge damage is more severe and a long crack started to propagate along the adjacent fibers as in Figure 9(c). Then, the composite wall is inward folded to represent the plateau stage as shown in Figure 9(d) until large wall fragmentation occurred (Figure 9(e)). Once, the wall totally collapse, the crushing force is again increased due to the fact that no more composite to be crushed as in Figure 9(f).

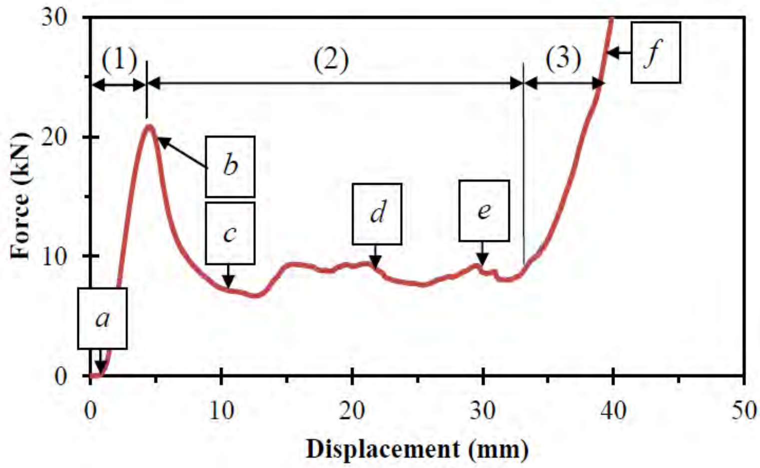
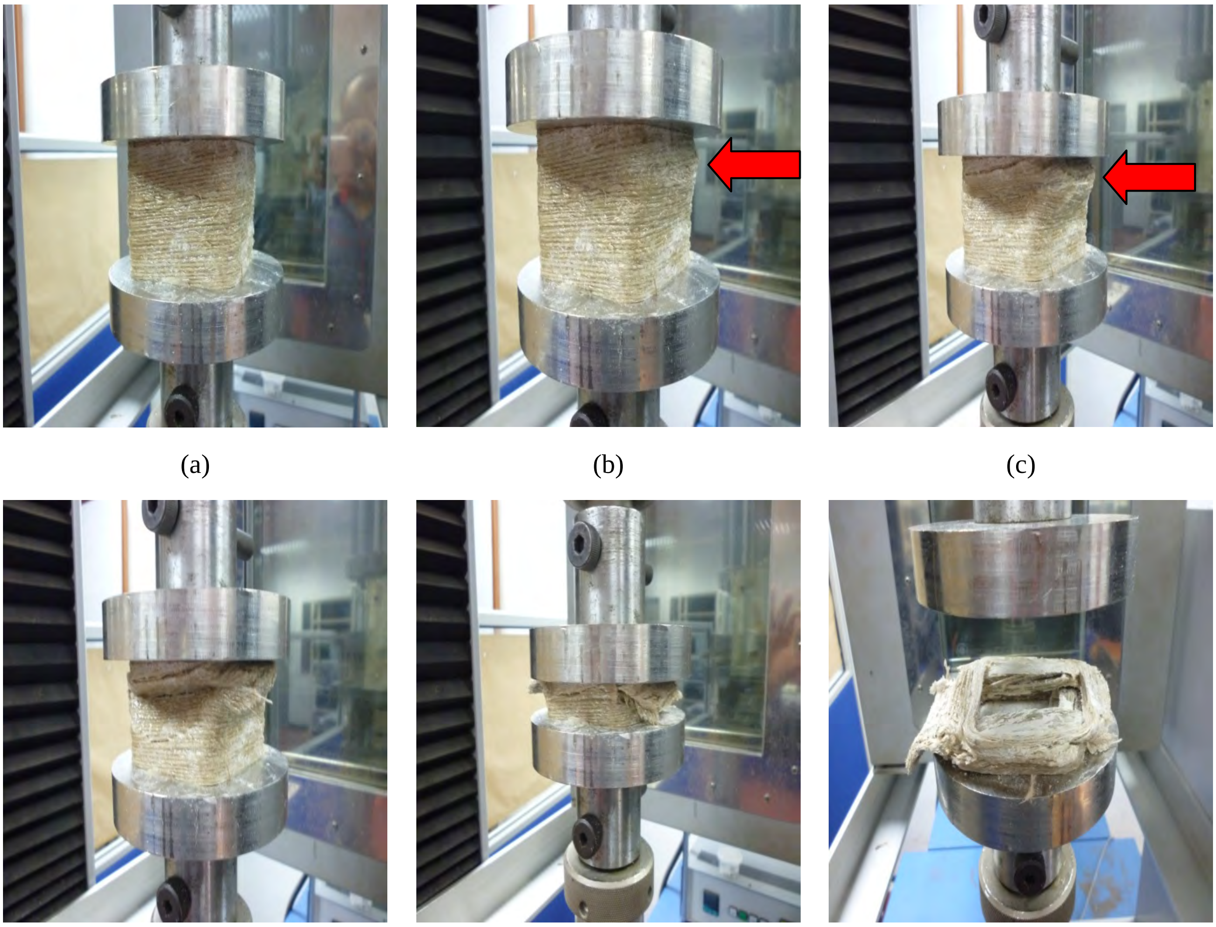


Fig. 8. The force-displacement curve of the 10^0 fiber alignment.



(a) (b) (c)

(d) (e) (f)

Fig. 9. Various stages of the crushed length of the composite square tubes.

IV. CONCLUSION

In this present paper, filament winding technique is used to fabricate the square composite tubes. During the process, two important parameters are used namely fiber alignment and number of fiber layers. These tubes are quasi-statically crushed until final stage. Then, the force-displacement diagram is obtained automatically and the area under the curve represents the energy absorption performances. There are several conclusions can be drawn:

i. 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.

ii. Just after the linear elastic displacement, one side of the tube walls bulged and then long crack along the adjacent fibers started to appear and propagate. Then, the crack wall folded several times before it is experienced totally collapsed.

iii. In the near future, several fiber alignments will be used and wound around the square mould. It is expected to increase the performances of energy absorption.

ACKNOWLEDGEMENT

Author acknowledges Universiti Tun Hussein Onn Malaysia (UTHM) and the Office of Research, Innovations, Consultancy and Commercialization (ORICC) for funding this work through Fundamental Research Grant Scheme (FRGS) 2/2013 Vot. 1424.

REFERENCES

[1] S. Palanivelu, W. Van Paepegem, J. Degrieck, D. Kakogiannis, J. Van Ackeren and D. Van Hemelrijck , “Comparative study of the quasi-static energy absorption of small-scale composite tubes with different geometrical shapes for use in sacrificial cladding structures”, Polymer Testing, vol. 29, pp. 381-477, 2010.

[2] A.E Ismail and M.A Hassan, “Low velocity impact on Woven Kenaf Fiber Reinforced Composites”, Applied Mechanics and Materials, vol. 629, pp. 503-506, 2014.

[3] A.E Ismail, M.K Awang and M.H Sa’at, “Tensile strength of natural fiber reinforced polyester composite”, AIP Conf. Proc., vol. 909, pp. 174-179, 2007.

[4] R.A Eshkoor, S.A Oshkovr, A.B Sulong, R. Zulkifli, A.K Ariffin and C.H Azhar, “Effect of trigger configuration on the crashworthiness characteristic of natural silk epoxy composite tubes”, Composites Part B, vol. 55, pp. 5–10, 2013.

[5] Mahdi E, Hamouda AMS, Sahari BB, Khalid YA, “Effect of hybridization on crushing behavior of carbon/glass fibre/epoxy circular–cylindrical shells”, Journal of Material Processing Technology, vol. 132, pp. 49–57, 2003.

[6] S.H Masran, A.E Ismail and M.F Marian, “A study of energy absorption performances of pultruded composites under quasi-static compressive loadings”, Applied Mechanics and Materials, vol. 465, pp. 662-666, 2014.

[7] A.E Ismail, M.H Zainulabidin, M.N Roslan, A.L.M Tobi and N.H.M Nor, “Effect of velocity on the impact resistance of woven jute fiber reinforced composites”, Applied Mechanics and Materials, vol. 465, pp. 1277-1281, 2014.

[8] Warrior TA, Turner E, Ribeaux Cooper M, “Effects of boundary conditions on the energy absorption of thin-walled polymer composite tubes under axial crushing”, Thin-Walled Structures, vol. 46, pp. 905–918, 2008.

[9] Ochelski Stanislaw, Gotowicki Pawel, “Experimental assessment of energy absorption capability of carbon–epoxy and glass–epoxy composites”, Composite and Structures, vol. 87, pp. 215–24, 2009.

[10] Solaimurugan S, Velmurugan R, “Influence of fibre orientation and stacking sequence on petalling of glass/polyester composite cylindrical shells under axial compression”, International Journal of Solids and Structures, vol. 44, pp. 6999–7020, 2007.

[11] Li Guoqiang, Maricherla Dinesh, Singh Kumar, Pang Su-Seng, John Manu, “Effect of fiber orientation on the structural behavior of FRP wrapped concrete cylinders”, Composite and Structures, vol. 74, pp. 475–83, 2006.

[12] Eksi Secil, Kapti Akin O, Genel Kenan, “Buckling behavior of fiber reinforced plastic–metal hybrid-composite beam”, Material and Design, 2013;49:130–8.

[13] A.E Ismail, “Effect of foam density and wall thickness interactions on the energy absorption performances”, Applied Mechanics and Materials, vol. 315, pp. 665-669, 2013.

AUTHOR PROFILE

Al Emran Ismail was born in 1977 and obtained his first and second degrees from Universiti Putra Malaysia (UPM) in 2000 and Universiti Teknologi MARA (UiTM) in 2003, respectively. After 5 years working in Universiti Tun Hussein Onn Malaysia (UTHM), he continued his studies in Universiti Kebangsaan Malaysia (UKM) for PhD degree and graduated in 2012. His expertise in the area of fracture mechanics. He is also interested in natural fiber reinforced composites for crashworthiness applications.