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QUASI STATIC AXIAL CRUSHING OF KENAF FIBRE REINFORCED EPOXY COMPOSITE FABRICATED BY VARTM METHOD

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ABSTRACT

Fibre reinforced plastic (FRP) composites have been increasing put into daily life application such as in transportation and sport industries due to its lightweight and good mechanical properties. However, less work has been done on using natural fibre reinforced plastic composites as energy absorbing device. Therefore in the current study, it is aimed to investigate the potential application of kenaf fibre reinfoced epoxy (KFRE) composite as energy absorber. In the study, two types of KFRE have been used namely random orientated KFRE (R-KFRE) and unidirectional orientated KFRE (U-KFRE). These composites have been fabricated into square hollow section (SHS) by using vacuum assisted resin transfer molding (VARTM). For the test, R-KFRE and U-KFRE were compared with neat epoxy (NE) SHS by mean of quasi static axial crushing at speed of 2mm/min. From the test, U-KFRE exhibited the best result which has the highest energy absorbed at 1453.77J. Moreover, it crushed progressively compared to the other two which failed catastrophically.

Keywords: kenaf fibre, axial crushing, energy absorption, fibre reinforced plastic.

INTRODUCTION

Synthetic fibre such as glass and carbon fibre reinforced plastics (FRP) composites have been widely used in industry and in transportation due to their low weight and having good in mechanical properties [1], [2]. However due to increase in environment awareness, these fibres neither naturally decomposed nor recycled [1]. Therefore, fibres based on natural resources have been highly studied in the recent years. Kenaf, hemp, jute, and flax to name a few, have been known for its mechanical properties [3]. From literatures [4], [5], these natural fibres reinforced plastics are having competitive results compare to the synthetic ones. A part from that, natural fibre itself has higher specific strength, lower density, and most of all it is abundant availability [6].

In composite axial crushing, less works have done on using natural fibre reinforced plastics. In the review of composite axial crushing [7], glass and carbon fibre reinforced plastics are heavily studied. Different shapes, structure geometries, as well as type of fracture modes which contributed the best energy absorption were reviewed. Abosbaia *et al.* [8] conducted axial crushing on cotton fabric. In the test, filament winding fabrication has been used and stacking sequence concept was adopted. From the test, cotton was crushed progressively. Furthermore, folding formation was observed after peak load at 5.43kN. On the other hand, Mahdi *et al.* [9] tested on solid cones made of oil palm fibre and coir fibre reinforced polyester composites. In their study, it was revealed that cone vertex angle influenced peak load. A part from that, type of fibre used in the test affected on the crashworthiness parameters. Although all the specimens crushed progressively, specific energy absorption (SEA) of natural fibre reinforced composites were relatively low compare to carbon and glass fibre reinforced plastics which for cotton, oil palm and coir reinforced plastics composite are at 2.501kJ/kg, 0.633kJ/kg and 0.577kJ/kg, respectively. Hence, it is a huge room to improvise crashworthiness of natural fibre reinforced plastic composites. Besides the work done by [10] found that non-woven kenaf fibre prone to crush catastrophically and absorbed less energy despite using thick wall for hexagonal shape.

In a work compiled by Ramakrishna [11], a part from fibre materials and its constituent, fibre architecture and fibre content affect to the SEA. Due to this, crashworthy of composite materials can be customised by mixing the effect of the fibre lay-up. Hadavinia and Ghasemnejad (2009) reported on a work regarding on the effect of different layers of fibre architecture used. In the work, it is found that composite with layer $[0/45]_2$ have higher SEA compare to composite with layer $[0]_4$. However, crush force efficiency for composite with layer $[0]_4$ is the highest due to initial maximum collapse force of the composite. In another work [13], two types of tubes with 4 and 6 combination of fibre lay-up have been studied. From the work, fibre reinforced composite with combination of the most unidirectional fibre (along the composite tube) close to inner diameter gave the better energy absorption characteristics due to its resistance of bending and smaller radius of curvature inside the tube.

From the above literature, natural fibre reinforced composite should be further investigated for its crushing capability. In the current work, square hollow section (SHS) made of kenaf fibre reinforced epoxy (KFRE) composite have been fabricated. Crushing characteristics under quasi-static condition was studied. The test parameters such as fibre orientations, SEA, peak load, mean crushed load and crushing process are presented.

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MATERIALS AND COMPOSITES PREPARATION

Raw fibre

Raw bulk kenaf fibres were received from Lembaga Kenafdan Tembakau Negara, Malaysia and it is being separated into short (length between 10mm to 20mm) and long (at 350mm length) fibres. In this study, the fibres were washed with plain water. Then, short and long fibres were arranged into random and unidirectional mats, respectively. Next, these fibres were dried in room temperature at 28±2 ◦C for 3 days.

Composite preparation

In the current work, alternate unidirection kenaf fibre has been used to support epoxy resin to form square hollow section (SHS). The arrangement of the fibre is such that the inner layer is perpendicular to outer layer which parallel to axial loading as shown in **Error! Reference source not found.**

For the fabrication of the square hollow section (SHS), Auto-Fix 1710A and its hardener Auto-Fix 1345B epoxy resin is used. The mixing ratio for the resin is 1:1 as specified by the supplier. By using vacuum assisted resin transfer molding (VARTM), KFRE SHS with size of 40mm × 40mm with length of 350mm was fabricated. In the process of fabrication, each mat was weighed in order to have equivalent weight in each layer. Then, it was cut into the size of mould length and specimen perimeter width. Before the mats were put into the mould, the thickness of the fibre mat used was estimated by placing them between vacuum bags and the measurement was done by using micrometer. For the current study, mats thickness of 5mm has been used. Two types of fibre orientation has been used namely unidirectional and random orientation KFRE. As the desire thickness has achieved, the mats were rolled on deformable madrel which made of the sequence of bagging film-nylon mats (uniform distributor)-peel ply film at its outer most.

In **Error! Reference source not found.** shows the vacuum assisted resin transfer molding (VARTM) process. In the process, the mould was placed vertically. VACUUM pressure of 100kPa was applied at the top of the mould to pull the resin up. After the resin reached its height, it was cured in vacuum pressure for 6 hours and left in the mould for the next 24 hours before the mould was dissembled. Then again the composite was undergoes another curing process in convection oven at 700C for 1 hour before it was cut into specimen in length of which described in **Error! Reference source not found.**.

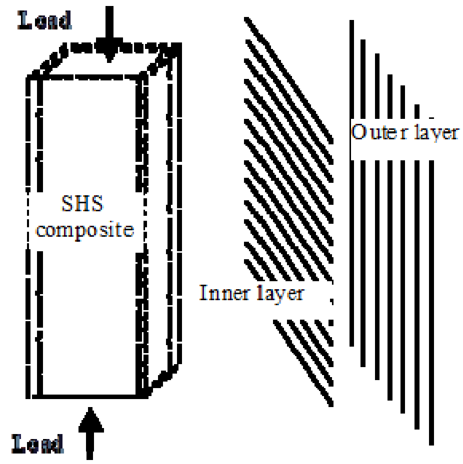

Figure-1. Arrangement of fibre.

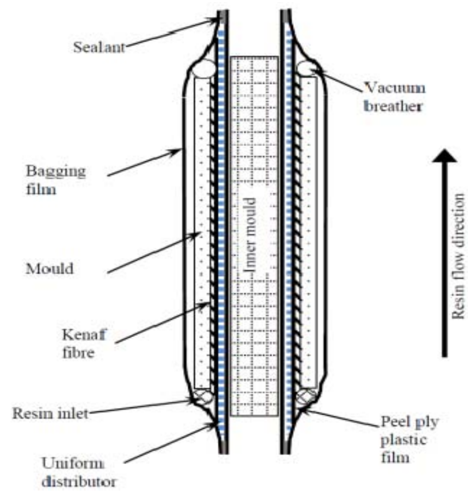

Figure-2. VARTM setup KFRE composite.

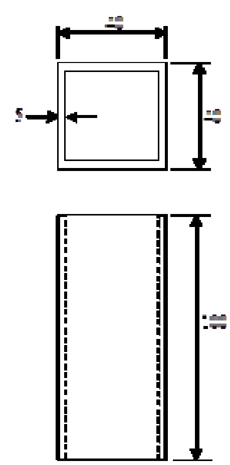

Figure-3. Specimen geometry.

Experimental methodology

In axial crushing, quasi-static crushing behaviour was studied. Three types of materials namely neat epoxy (NE), random oriented (R-KFRE) and alternate unidirectional kenaf fibre reinforced epoxy (U-KFRE) composite were compared with same 5mm wall thickness. For all of the tests, crushing speed of 2mm/min was used. Each test was repeated 3 times and the average of total energy absorbed, E_{total}, by the composite which calculated by using equation. 1.

$$E_{total} = \int P \, ds \quad (1)$$

Where P is instantaneous crushed load (N) and s is crushing displacement (mm). For the specific energy absorbed, E_s, it was calculated by using equation. 2

$$E_s = \frac{E_{total}}{m} \quad (2)$$

Where m is the mass of the crushed composite.

RESULTS AND DISCUSSION

Experimental result

Error! Reference source not found. shows the typical crush load versus displacement curves for 5mm wall thick SHS. From the figure, NE and R-KFRE were crushed catastrophically compared to U-KFRE which able to hold loads at longer distance. For the peak load, NE shows the highest peak load at 40425N compared to R-KFRE and U-KFRE by 53% and 13% lower, respectively. For U-KFRE at 5mm wall-thickness, it reached its peak load at about 4mm platen displacement. Then crushed load were dropped before it again increases after displacement of about 13mm. As the displacement increases, crushing load was gradually increases before its densification at 90% of its length.

Crushing characteristic of NE

Figure- shows the history of load-deformation curve of 5mm wall-thick neat epoxy (NE) SHS. In the curve, compression load for NE SHS reach its peak load at 40425N at displacement of 4.2mm. During peak load, the structure was having local buckling before it is plastically deformed and it failed catastrophically. Due to the behavior of epoxy which is brittle and it also has been reported by Mamalis *et al*. (2004), it caused the structure burst into pieces as the strain continues.

Crushing characteristic of R-KFRE

In **Error! Reference source not found.**, it shows the crushing history of 5mm wall-thick R-KFRE. From the figure, R-KFRE was able to withstand peak load of 29637N before it failed catastrophically. For the structure, it was deformed with local buckling when it reached peak load. Unlike NE structure, the failure of the structure failed due to axial crack at entire structure. Hence, it held no load due to this failed mode. Apart from that, it is also had composite fracture at one end of the structure.

Crushing characteristic of U-KFRE

Error! Reference source not found. shows the crushing history of 5mm wall-thick U-KFRE. In the figure, the structure reached its peak load at 32837N. At peak load, the sign of local buckling began to occurred (see Figure-7a). Thereafter in Figure-7b, axial crack was initiated at the top of the structure as the deformation increases. Thus, the load started to drop tremendously. At further deformation displacement, compress load gradually picking up. This happened due to the structure axial cracks was propagated to the side of the side of the structure. Thus, the structure revealed another surface to give resistance
to the crushing load.

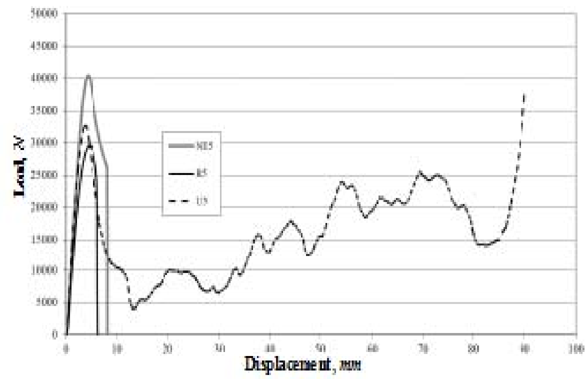

Figure-4. Typical crushed displacement curves of 5mm SHS.

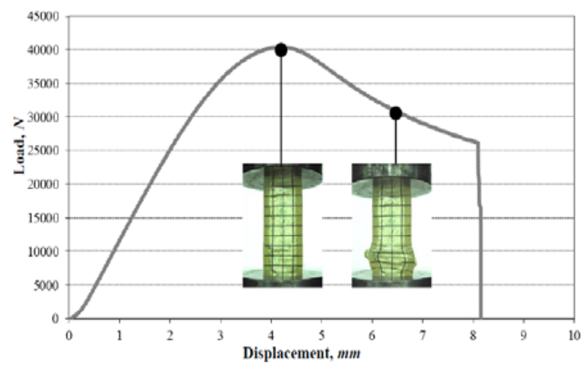

Figure-5. Load displacement curve of NE.

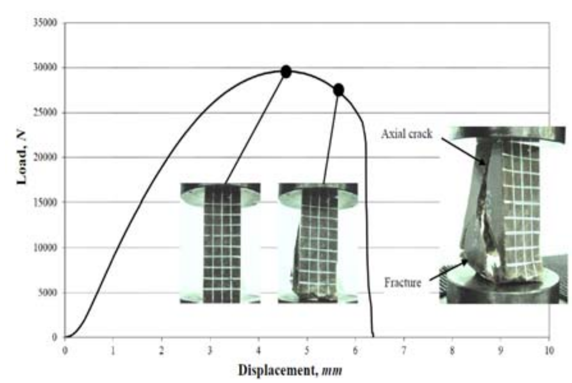

Figure-6. Load displacement curve of R-KFRE.

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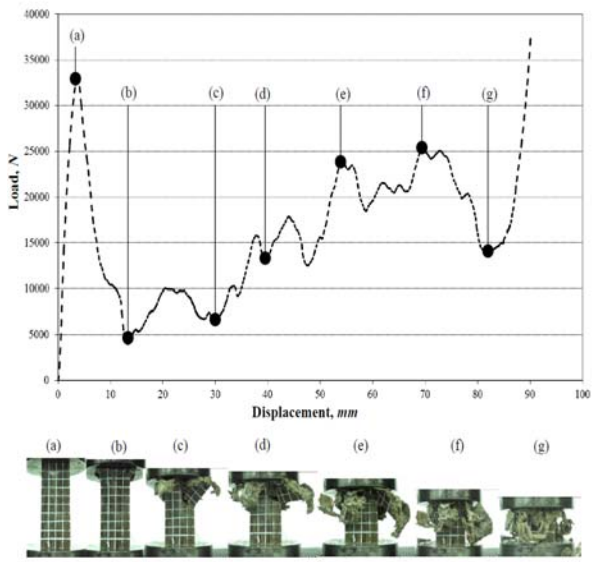

Figure-7. Load displacement curve of U-KFRE.

Table-1. Performance of ne &kfre 5mm wall-thick SHS.

	NE	R-KFRE	U-KFRE
Peak Load, P_{peak}(N)	40425	29637	32837
Energy Absorbed, E_{total}(J)	229.74	131.43	1453.77
Specific energy absorbed, E_s(kJ/kg)	-	-	22.4

DISCUSSION

Error! Reference source not found. summarized the performance of the NE & KFRE SHS. In the table, the highest total energy absorbed was obtained by U-KFRE which is 1453.77J. For the other two structures namely NE and R-KFRE failed to compete with U-KFRE due to the catastrophic failure that occurred, therefore only U-KFRE able to have SEA at 22.4 kJ/kg.

Energy dissipation of the structure

External energy that used to crush all the structures can be obtained by the external force which is the moving steel platen against the distance moved. On the other hand, the reaction from the structures are the dissipation of the energy that to absorb the external energy.

From the load displacement curve, there are 2 regions for energy dissipation namely, pre-crush and post-crush regions. For post crush region, it contains during the crushing period and densification period.

In pre-crush of the structure, the curve was increases with steep inclined with little displacement for the platen before the structure start to show it failure by cracking. At this point, the product of the force and displacement are comparative small. This result was significantly showed by the NE and R-KFRE structures.

For the post crush, it began after the pre-crush region. In this region, structures start to crack which can be seen in the crushing characteristics of R-KFRE structures, local buckling was occurred after peak load and axial cracking initiated along the structure thus it failed catastrophically.

Unlike R-KFRE, U-KFRE failed with progressive crushing which desirable characteristics that to have more energy absorption. During the crushing, splitting and splaying of the structure contributed to the energy absorption as can be seen in **Error! Reference source not found.**. Apart from that, frictional sliding due to bending of the structure as well as the contact at moving platen also contributed to crushed energy dissipated. Besides, in the densification stage, the load increases with high line gradient. This happens due to the compaction of the structures. However the consequences of the amount of the energy contributed is not significant in the second stage.

Upon to this, it is proposed that there are 3 stages of energy dissipation for the total crushed energy which is according to equation. (4)

$$E_{total} = E_{pre} + E_{crush} + E_{densification} \quad (3)$$

where,
E_{total} is total crushing energy,
E_{pre} is pre-crush energy,

E_{crush} is crushing energy after peak load and before densification,
$E_{densification}$ is energy absorbed in densification stage.

For E_{crush}, it can be determined by the following equation (4)

$$E_{crush} = E_{split} + E_{splay} + E_{bend} + E_{friction} \quad (4)$$

where,
E_{split} is energy to fracture or to split (crack) the structure,
$E_{splay}$is energy to separate interlaminar wall,
E_{bend} is energy to bend the structure wall,
$E_{friction}$ is work done by the friction wall between the structure wall and steel platen.

CONCLUSIONS

From the study, it can be concluded that:

1. Axial crushing of KFRE is depending on the orientation of the fibre. In the current study, U-KFRE able to crush progressively compared to R-KFRE.
2. Due to the progressive crushing of U-KFRE, it has highest total energy absorbed follow by NE and R-KFRE.

From the analysis of the crushing, the energy dissipated more effectively in the post crush which exhibit by U-KFRE. Most energy was dissipated in this section by means of splitting, splaying, bending and work done by the friction between the structure wall and moving steel platen.

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