Quasi-static axial crushes on woven jute/polyester AA6063T52 composite tubes

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Abstract. Quasi-static axial loading have been studied in this paper to determine the behaviour of jute/polyester wrapped on aluminium alloy 6063T52. The filler material also was include into crush box specimen, which is polyurethane (PU) and polystyrene (PE) rigid foam at ranging 40 and 45 kg/m\textsuperscript{3} densities. All specimen profile was fabricated using hand layup techniques and the length of each specimen were fixed at 100 mm as well as diameter and width of the tube at 50.8 mm. The two types of tubular cross-section were studied of round and square thin-walled profiles and the angle of fibre at 45\textdegree were analysed for four layers. Thin walled of aluminium was 1.9 mm and end frontal of each specimen of composite were chamfered at 45\textdegree to prevent catastrophic failure mode. The specific absorbed energy (SEA) and crush force efficiency (CFE) were analyses for each specimen to see the behaviour on jute/polyester wrapped on metallic structure can give influence the energy management for automotive application. Result show that the four layers' jute/polyester with filler material show significant value in term of specific absorbed energy compared empty and polyurethane profiles higher 26.66\% for empty and 15.19\% compared to polyurethane profiles. It has been found that the thin walled square profile of the jute/polyester tubes with polystyrene foam-filled is found higher respectively 27.42\% to 13.13\% than empty and polyurethane (PU) foam tubes. An introduce filler material onto thin walled composite profiles gave major advantage increases the mean axial load of 31.87\% from 32.94 kN to 48.35 kN from empty to polystyrene thin walled round jute/polyester profiles and 31.7\% from 23.11 KN to 33.84 kN from empty to polystyrene thin walled square jute/polyester profiles. Failure mechanisms of the axially loaded composite tubes were also observed and discussed.

1. Introduction
The tubular cross-section profile of composite have been used to replace the metallic tube as an energy absorber device in automotive application [1]. The type of conventional material of composite such as carbon, kevlar and glass has a major concern for researcher to study the capability of crashworthy structure under dynamic impact and quasi-static loading condition [1-5]. The natural fiber of composite have been popularized in the late of 20 century for do research to improve the capability of their properties under various applied loading condition on benefit for automotive application [1-15]. The mechanical properties of natural fiber reinforced composites highly depend on the interface adhesion property between the fibers and the polymer matrix as have been reported by many
researchers [5–9]. Natural fibers contain cellulose, hemicelluloses, pectin’s and lignin and are rich in hydroxyl groups, natural fibers tend to be strong polar and hydrophilic materials whilst polymer materials are a polar and exhibit significant hydrophobicity [7]. The problem happen with this phenomenon was the interface between debonding matrix and fiber each layers. The used of thin-walled alloy aluminum 6063-T52 would enhanced and improve the capability of crush box structure as a hybrid material wrapped together with jute/polyester woven composites. On the other hand, surface debonding between interfaces have been modified and cured as well as to reduce air bubble to strengthen material under quasi-static loading condition. The energy management of material have been studied previously with various aspect such as combination of two or more material mentioned in [10-18]. Othman et al. conducted pultruded square cross-section with rigid foam filler material under quasi-static loading condition, they found that an influence cellular material improve the specific absorbed energy with additional density of filler material as well as wall-thickness tube. Owing to the aforementioned observation, this study utilises of using cellular material applied on jute reinforced polyester composite and added filler material to stabilized the energy absorption performance during quasi-static regimes.

The focus on this study is to determine the load-displacement curve and the energy absorption of jute/polyester composite tubes wrapped AA6063T52 under axial quasi-static loading. Furthermore, the study aims to investigate the effect of filler material such as polyurethane and polystyrene rigid foam of the composite tubes.

2. Experimental work

2.1 Materials and fabrication

The natural woven roving jute/polyester composite were fabricated using hand lay-up technique wrapped on aluminium thin walled tube fix with four layers jute of [±45°]. The aluminium alloy 6063T52 was selected as a core material with total length of 500 mm and then cut off for an each 100 mm length for both of round and square cross-section. The diameter and width tube was constant 50.8 mm and front end of each tube were chamfered end of 45° when composite hybrid finished. Each of composite tube were curing with room temperature in order to specimen profile were good enough cure. Table 1 shows the dimensions of the fabricated composite. Samples of the fabricated specimens are shown in figure 1. The terms AL, R, S, L, PE, and PU are respectively aluminium, round, square, layer, polystyrene and polyurethane. The number 4 referred to the number of layers of the composite laminate structures. The inner diameter and width of all specimen tube were fixed at 50.8

| Specimen type | Mass (kg) | Profiles | Foam Filler | Wall Thickness Jute/polyester + AA6063 t (mm) | Length |
|---------------|-----------|----------|-------------|-----------------------------------------------|--------|
| ALR-4L        | 0.223     | Round    | -           | 4.00+1.9                                      | 100    |
| ALR-4L-PU     | 0.230     | Round    | Polyurethane| 4.02+1.9                                      | 100    |
| ALR-4L-PE     | 0.231     | Round    | Polystyrene | 4.02+1.9                                      | 100    |
| ALS-4L        | 0.284     | Square   | -           | 4.01+1.9                                      | 100    |
| ALS-4L-PU     | 0.293     | Square   | Polyurethane| 3.98+1.9                                      | 100    |
| ALS-4L-PE     | 0.294     | Square   | Polystyrene | 4.04+1.9                                      | 100    |
2.2. Testing procedure

The testing procedure of quasi-static loading condition were tested on all specimens with constant speed of 5 mm/m compression using a computer-controlled servo-hydraulic Instron machine type GT instruments. The cross-section tube crushed between two parallel steel flat platens, one fix and one moving. The fixed platen was fitted with a load cell from which the load signal is taken directly to the computer. For each test, the axial loading was plotted on the Y-axis and the crosshead displacement on the X-axis. The end front of each specimens were chamfered at 45° to ensure that the load fluctuation characteristic were avoided [15].

Some of following aspect of crush phenomenon was measure during crushes event. The all data were recorded and calculated there are Peak force $P_{max}$: maximum compressive force. Mean force $P_{avg}$: average compressive force obtained by the following equation where force and deformation are defined as $P$ and $d$, respectively and the area of cross section, $A$, and the density of the material, $\rho$ defined as

$$\bar{P} = \frac{1}{\delta} \int_0^\delta P d\delta$$  

(1)

Energy absorption $E$: area under the load–displacement curve up to the compaction zone.

$$E = \int_0^\delta P d\delta$$  

(2)

The units of $E$ are used to express the crashworthiness parameters, hence they are written in $kJ$ here $P$ is the load acting on the composite specimens. Therefore, the specific energy absorption per unit mass $kJ/kg$ (SEA) where $m$ the crushed mass of the composite is recognized as:

$$SEA = \frac{E}{m}$$  

(3)

Crash force efficiency (CFE): ratio of the average crushing load $P_{avg}$ to peak load $P_{max}$.

$$CFE = \frac{P_{avg}}{P_{max}}$$  

(4)

3. Results and discussion
3.1. Axial loading characteristics
The result of each specimen profile have been shown in figure 2 until 5 below. The letter of AL, R, S, 4L, PE and PU were referred to the aluminium, round, square, four layers, polystyrene and polyurethane, respectively. In figures 2 and 3 indicated that the different between empty and rigid foam-filled both of polystyrene and polyurethane rigid foam filler under quasi-static loading against displacement curves. The behaviour of the quasi-static condition observed that the influence of filler material improved significantly specific energy absorption when introduce foam filler material of the tubes.

![Graph showing load-displacement relation](image1)

(a) Load against displacement curve of four layers jute/polyester composite tubes.

![Profiles of tubes](image2)

(b) Profile of jute/polyester of four layers without foam.

(c) Profile of jute/polyester of four layers with polyurethane foam.

**Figure 2.** Load-displacement relation for jute/polyester tubes for four layers.

The filler material strengthen and sustain force quasi-statically during crush regimes also reported previously done by Othman et al. [10-15]. They observed that the influence of polyurethane with different density of rigid foam bring more additional value on crashworthy structures. The fluctuation curve load against displacement can be seen an increasing force from empty to foam filled profiles. It also can be seen in figure 2 and 3 that the configuration of each behaviour curve and deformation pattern recorded from empty and foam filled tubes.
(a) Load against displacement curve of four layer jute/polyester composite tubes.

(b) Profile of jute/polyester of four layers with polystyrene foam.

(c) Profile of jute/polyester of four layers without foam.

**Figure 3.** Load-displacement relation for jute/polyester tubes for four layers.

Obviously, each curve seen deformed progressively under quasi-static loading condition. The influence of jute/polyester wrapped on aluminium tube has seen less effect when the actual contact occurred, the formation of crack formed and continuously propagated until reach compaction zone (total length deformed). Almost of each specimen of the composite tube fail with the same criteria as well as round and square profiles. Square profile fails with crack formation on the fourth edges estimate around 2 mm of fillet. Different with a round tube profile fail at the front end of the tube with crack formation around eight cracks formed and propagated until final failure.

3.2. Quasi-static loading characteristics

The increasing fluctuation force occurred on the foam-filled profile observed on both round and square composite tubes profiles it can be seen on figure 2 and 3 above. The significant influence of foam-filled as a filler material tremendously attract more advantage when applying on automotive structure.
However, in this study, the main focusing and motivation on how jute/polyester given an impact on increasing specific energy absorption. The crush force efficiency (CFE) of each tube profile have been calculated to determine the mode failure whether specimen fail either under progressive or under catastrophic failure regime. Jimenez et al. [4] state that, either the criteria of failure mode under 0.5 value was fail under catastrophic failure or reach to 1.0 is safe and fail progressively.

Figure 4. Initial, mean and crush force efficiency relation for jute/polyester tubes for each layers.

Figure 4 below showed all the results that is initial peak, mean load and crush force efficiency (CFE). Result showed that almost specimen profiles value above of 0.5, indicated each specimen profile fail with progressive condition. It also can be seen the value of initial peak load increase when tube profile introduce foam-filled either polyurethane or polystyrene. The mean or average load of each tube have been showed significant increase also, empty than foam-filled profiles. The failure pattern occurred during first contact between platen and specimen, however the crack formation formed on specimen influence the load fluctuation curve and thin walled aluminum tube formed with diamond mode of failure for round tubes. The square tube aluminum formed lobe of 2 stage with total length of 100 mm.

3.3. Specific Energy Absorption
Energy absorption is defined the total area under of load versus displacement curve. Figure 5 showed the different value of square and round tube profile. An increase of energy absorption observed part of foam-filled profiles. The specific energy absorption have been calculated total energy during absorbed quasi-statically divided by weight of each specimen profile. Results showed that the specimen absorbed more energy compared to square profile for value of energy absorption and specific absorbed energy, respectively. This is cause by the easily be fail and deformed by square tube during load compressed. The fourth edge corner of square tube formed crumpled until final deformed. For the square tube deformed with at least two lube and hinge. In addition, the diamond mode failure observed for each specimen of round tube profiles. The specific absorbed energy is a measure to calculate and
making comparison to the other tubular profile to evaluate their performance. The capability of the structures and the comparison between each specimen analysis are using equation 1, 2 and 3. The polystyrene foam showed better performance compared to polyurethane foam 15.19% comparison and enhancement for energy absorption. The SEA improve from empty 27.42% to polystyrene and 13.13% improvement compared to polyurethane.

![Figure 5](image_url)

**Figure 5.** Energy absorption and specific absorbed energy relation for jute/polyester tubes for each layers.

**4. Conclusion**
The present paper were determine the influence of jute/polyester composite wrapped on AA6063T52 thin walled tube of square and round tube profile under quasi-static loading. The hand layup method were used to fabricate for each specimen profile with fix four layered laminated of tube. Polyester resin and catalyst were used to composite made. The rigid polyurethane and polystyrene were cut off with same dimension cross-section profile as well as inner dimension of both tubes. The rigid polyurethane and polystyrene were provided locally company with estimate of 40 kg/m$^3$ for polyurethane and 45 kg/m$^3$ for polystyrene foam. The results of load fluctuation against displacement curve indicate that the 4 layers laminate jute/polyester composite tube bring less improvement compare to foam filler material. Comparison between square and round tube profile in term of quasi-static loading estimate about 15.87 to 26.33% different for initial load contact. The loading average between round and square also estimate between 29.84% to 30%. The polystyrene foam showed better performance compared to polyurethane foam 15.19% comparison and enhancement for energy absorption. The SEA improve from empty 27.42% to polystyrene and 13.13% improvement compared to polyurethane.

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