Finite element modelling of AA6063T52 thin-walled tubes under quasi-static axial loading

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Abstract. The behavior of aluminum alloy 6063T52 thin walled tubes have been present in this paper to determine absorbed energy under quasi-static axial loading. The correlation and comparison have been implemented for each experimental and finite element analysis results, respectively. Wall-thickness of 1.6 and 1.9 mm were selected and all specimen tested under room temperature standard. The length of each specimen were fixed at 125 mm as well as diameter as well as a width and diameter of the tube at 50.8 mm. The two types of tubular cross-section were examined whereas a round and square thin-walled profiles. The specific absorbed energy (SEA) and crush force efficiency (CFE) were analyzed for each specimen and model to see the behavior induced to failure under progressive collapse. Result showed that a correlation less than 5% different between both of comparison experimental and finite element model. It has been found that the thin walled round tube absorbed more energy rather than square profile in term of specific energy with both of either 1.6 or 1.9 of 23.93% and 35.36%, respectively. Overall for crush force efficiency (CFE) of each tube profile around 0.42 to 0.58 value. Indicated that the all specimen profile fail under progressive damage. The calibration between deformed model and experimental specimen were examined and discussed. It was found that the similarity failure mechanism observed for each thin walled profiles.

1. Introduction

Thin walled structure such as tubular form have been used in many engineering application for easy of human being daily life. For crashworthy structure, thin walled tube have been applied as crush box element to protect the compartment occupant during collisions. Metallic material such as steel, mild-steel or aluminum predominantly used to design in structural element such as automotive compartment in order to absorb strain energy during collisions. The peak force would occurred when initial contact between platen and front-end specimen of structure cause by un-deformed of the body and suddenly sudden jerk observed [1-2]. This situation can avoid for applying triggering mechanism to prevent huge peak force induce to catastrophic failure mode [3]. The catastrophic failure is often occurred when the design configuration of tube designed cannot withstand the extreme force and the severity of its deformation [4]. The finite element model of thin walled structure have been more explore by previously by investigators, researchers and engineers [1-18]. This approach were often determine by axial force to develop folding process of the thin walled tubes as well as their properties of material.
The finite element software primary packages in the 21 century provide more option in order to implement develop model and coding to ensure that the numerical model is sufficiently accuracies compared to experimental result or existing analytical and numerical model previously done by investigators. The main objective and propose in this paper is to determine the load-displacement curve and the energy absorption of thin walled tube of AA6063T52 under axial quasi-static loading. Furthermore, the study aims to correlate and calibrate the result done by experimental and numerical model to observe deformation pattern and failure mechanism.

2. Experimental work and modelling technique

2.1 Materials modelling
Thin walled tube of aluminum alloy AA6063T52 were found from Kamco Aluminium Sdn Bhd, Malaysia with the varied cross-section and cut-off for each 120 mm length. The wall thickness of thin walled tube were 1.6 and 1.9 mm with 2 type of cross-section, which is square, and round profile with diameter and width of 50.8 mm. Each of the thin walled tube were not created triggering mechanism in order to find original or actual deformation behavior of tube deformed from undeformed until total displacement onto compaction zone. The finite element software of ls-dyna package was used in this study to model and analyzed results from numerical modeling. The Belytschko–Tsay quadrilateral shell elements was used to model aluminum in the single tube. The element size was 2.0 x 2.0 mm. The following contact algorithms [5] were used between the aluminum shell elements and the rigid top platen solid elements to simulate interaction between them and to prevent interpenetration, contact “automatic surface to surface” to model the interaction between the aluminum tube and rigid top solid element. Contact “automatic single surface” is an option to prevent interpenetration among successive folds as well as to simulate interaction between the aluminum walls and the rigid solid element. The coefficient of friction was assumed equal to 0.3. The loading velocity was assume to be 5.0 mm/minutes. The bottom end of the tube was considered fixed. To carry out the quasi-static analysis condition, some criteria should be implement. In order to reduce the time steps, the mass density of aluminum was scaled up 1000 times the original density. Since the ls-dyna is an explicit finite element code, scaling up the density and the relatively low loading velocity of 5.0 mm/minutes were used to ensure a quasi-static simulation. The interface contact between the loading plate and the tube was plotted as a function of displacement, from which the folding initiation force and energy were obtained. The mean crush force was calculated by dividing the energy with the end displacement.

Table 1. Dimensions of the aluminum.

| Specimen/model type | No. Series | Mass (kg) – (1.6, 1.9 mm) | Profiles | Wall Thickness Jute/polyester + AA6063 t (mm) | Length |
|---------------------|-----------|--------------------------|----------|---------------------------------------------|--------|
| ALR                 | 0.0667, 0.07882 | Round                    | 1.6, 1.9 | 125                                         |
| ALS                 | 0.085, 0.100   | Square                   | 1.6, 1.9 | 125                                         |

The MAT24 of ls-dyna was used to model aluminum alloy 6063T52 thin walled tube was used, which is based on piecewise linear isotropic plasticity and uses von Mises flow rule. Fig. 1 shows the stress–strain responses of aluminum under static tensile test. The material has Young’s modulus E=68 GPa; Poisson’s ratio ν=0.3; yielding stress σy=0.117 MPa; plastic modulus E_p=280 MPa; and density ρ=2.7×10³ kg/m³. The tension test conducted in accordance with the ASTM: E8M.
2.2. Crashworthiness perimeter
The determination of crashworthiness mechanism some of following aspect of crush phenomenon is measured during crushes event. The all data were recorded and calculated there are Peak force $P_{\text{max}}$: maximum compressive force. Mean force $P_{\text{avg}}$: 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

\[
\bar{P} = \frac{1}{\delta} \int_{0}^{\delta} Pd\delta
\]  

(1)

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

\[
E = \int_{0}^{\delta} Pd\delta
\]  

(2)

The units of $E$ are used to express the crashworthiness parameters, hence they are written in kJ. $P$ 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:

\[
\text{SEA} = \frac{E}{m}
\]  

(3)

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

\[
\text{CFE} = \frac{P_{\text{avg}}}{P_{\text{max}}}
\]  

(4)

3. Results and discussion

3.1. Axial loading characteristics
The result in Figure 2 show the load against displacement curve subjected to axial loading under quasi-static conditions. The response observed that the characteristic of fluctuation force roughly similar as displacement increased. The experimental test conducted on specimen of 1.6 and 1.9 mm with similar length found similar collapse modes. The collapse pattern of symmetric concertina mode observed for both wall-thickness thin-walled round tube seen in Figure 3 (b). The increasing thickness wall of tube increase absorbed energy when applying quasi-static loading also can be seen in Figure 2. Similar result also found on Othman [13, 16], stated that the when wall-thickness increase, absorbed
energy and specific absorbed energy also increase and enhanced the capability crashworthiness performance.

![Graph](image1.png)

**Figure 2.** Load-displacement relation for thin-walled AA6063T52 tubes.

The correlation have been studied within the result done by experimental and finite element analysis shown in Figure 3. The result showed that the good agreement between both of result. Similar result also found and reported by [16], showed that similar result observed analysis under finite element simulation. The mode pattern is similar either 1.6 or 1.9 mm wall-thickness as well as wrinkle for each tube for experimental and finite element results. Each results also observed similarity folded pattern for both results, which is 5-fold pattern of 1.6mm, and 5/6 fold pattern on 1.9 mm shown in Figure 3 (b).

![Graph](image2.png)

Aluminum alloy 6063T52 (wall-thickness – 1.6 mm)
Aluminum alloy 6063T52 (wall-thickness – 1.9 mm)

(a) Load against displacement curve of Aluminum alloy 6063T52 round tubes.
Figure 3. Crushing characteristic of Aluminum alloy 6063T52 thin walled round tubes.

The fluctuation force fluctuated with different gap between each result shown in Figure 3, this is because influence by noise and vibration during experimental done. The Figure 3 also showed the deformation pattern observe with simulation and experimental technique. The result indicated that the symmetric concertina mode pattern formed obtained either experimental and simulation results.
The square cross-section profile show efficient crushing mode seen in Figure 4. Definitely, the fluctuation force obtained in this result relatively not the same as a round tube. The initial contact strongly huge at the higher peak maximum one compared to round tube, but the squared formed the wrinkle mode started on the four corner edges. On the other hand, the progressive collapse occurred after the peak force begin and the force fluctuated throughout entirely the wrinkle process. The fluctuation force uniformly recorded during that process and the specimen and numerical model crumpled until compaction zone area. The mode of pattern wrinkled observed showed in Figure (b), and indicate that the similar lobe of failure found from the results.

Figure 5. Initial, mean and crush force efficiency relation for round and square of aluminum.

Figure 5 show a systematic comparison obtained by experimental and finite element results. The crush force efficiency obtained by both result around 0.42 to 0.57, it is indicate that the almost of specimen and model fail under progressive folding. For both round and square cross-section obtained increasing load when wall-thickness increase.

3.2. Specific Energy Absorption

To specify the energy absorbed for each profile, the sum of area under load against displacement curve was calculated. The result found that the round cross-section tube absorbed more energy compare to square tube profile; this is because the restriction for round tube to wrinkle on failure deformed than square tube profile. Result also indicate that the specific energy absorption (SEA) for 1.9 mm wall-
thickness, improvement around of 25.66 - 35.36% different between round and square thin walled profile and around a 23.93 - 30.43% for 1.6 mm. The result also supported from previous study found in literature [16-18] indicated that a round tube profile absorbed more energy compared to square tube profile. This is an evident for the result obtained and justification on how for a selection of material structure on better design in developing vehicle structure.

Figure 6. Energy absorption and specific absorbed energy relation for round and square of aluminum.

4. Conclusion
The crushing behavior on thin walled profile of round and square tubes have been understood for empty case. The concertina mode failure obtained on each tube of round given most predominantly absorbed more energy compared to square profile fail under wrinkle and crumpling on four round corners. The buckling mode of wrinkle found by round tube profile created a fluctuate force throughout crushing proses under quasi-static condition. The studies found that the good agreement obtained by of both result, which is a 5.0 to 10.0% different between result found by experimental and finite element analysis. The correlation have been discussed both of result tailored by existing analysis worked by previous researcher in literature.

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