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Crush analysis of the foam-filled bitubal circular tube under oblique impact

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Abstract. This paper presents crashworthiness analysis of bitubal cylindrical tubes under different impact angular. The numerical solution of double cylindrical tubes are determined by finite element analysis (FEA). Moreover, the structure was impacted by mass block as impactor respect to longitudinal direction of the tubes. The model of structure was developed by non-linear ABAQUS sofware with variations of load angle and dimensions of tube. The outcome of this study is the respons parameters such as the peak crusing force (PCF), energy absorption (EA) and specific energy absorption (SEA), thus it can be expected this tube as the great energy absorber.

1. Introduction
To increase the crushing ability of thin walled and to decrease vehicle weight for fuel safety are the targets of automobile industry nowadays. These are some ways for these targets such as finding new materials and redesign play. In addition, the experiment test namely physical vehicle test more costly and for this reason, simulation is the best choice. With considering variables of tubes namely the geometry, size, and cross-section, some researchers study the behavior of thin-walled tubes to improve the energy absorption of material. Alexander et al. [1] was the pioneer studied the behavior of tubes under axial loading. Therefore, some scholars continued his work for instance, Reid et al. [2] studied the inversion and bending of tubes and Jones et al [3] compared the circular and square tubes subjected to axial loading of impact. The collapsible energy absorbers in different cross-sections, in particular circular and square tubes were studied by Alghamdi et al. [4]. To increase the energy absorption, the thin-walled tubes were filled by cellular material such as foams and honeycombs. Seitzberger et al. [5] was the first researcher studied empty and filled aluminum tubes. Meanwhile, the experimental and numerical solutions of tubes under axial and three-point bending were investigated by Guo et al. [6-7]. Then thin-walled aluminum subjected to oblique impact loading was analyzed by Reyes et al. [8-9]. The aluminum foam thin-walled tubes for beams had been investigated by several researchers. Li et al [10] performed experiment tests to study aluminum foam double tubes subjected to oblique loading.

2. Methodology

2.1. Crashworthiness indicator of structures
Several parameters were used to evaluate the crushing performance for instance, energy absorption (EA), specific energy absorption (SEA) and peak crushing force (PCF). EA is indicated as the total strain energy absorbed during deformation from the curve of crushing force-deflection. EA is defined in Eq. 1.

$$EA(d) = \int_0^d F(x)\, dx \tag{1}$$

where d is the effective stroke length and F(x) is the the instantaneous crushing load.

SEA is represented as the absorbed energy ratio (EA) to the structure mass (Mt) and is given by the formula in Eq. 2.

$$SEA = EA \,/\, M_t \tag{2}$$

2.2 Finite element models of tube under oblique impact

Figure 1 showed the models of the bitubal tube with dimensions, boundary and loading conditions. The tube was placed between two rigid wall that all of the tubes fixed at the bottom and at the other end impacted by a moving mass block with constant speed of 15 m/s. Aluminum foam filled thin – walled double circular tubes of the parameters design variable of tubes are the length (*L*) of 250 mm, the inner diameter tubes (*di*), outer diameter tubes (*do*), wall inner (*ti*) and thickness (*to*) can be seen in table 1. Seven angles of loading were considered ($\theta_1 = 0^\circ$, $\theta_2 = 5^\circ$, $\theta_3 = 10^\circ$, $\theta_4 = 15^\circ$ $\theta_5 = 20^\circ$, $\theta_6 = 25^\circ$, and $\theta_7 = 30^\circ$).

Table 1. Dimensions of bitubal circular tubes

do (mm)	*di* (mm)	*to* (mm)	*ti* (mm)
54	27 ; 25 ; 23	2 ; 1.8 ; 1.6	2 ; 1.8 ; 1.6

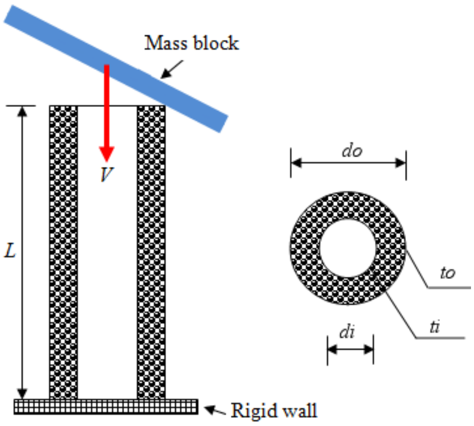


Figure 1. Schematic of aluminum foam filled double cylindrical tubes

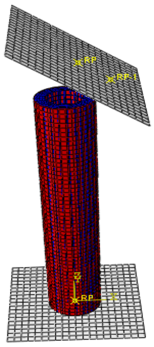


Figure 2. Finite element model of cylindrical double

3. Result and Discussion

Figure 3 shows the crushing behaviour under angular loading. Energy absorption influenced the deformation pattern of the structure. It can be seen that tubes under pure axial loading caused progresive deformation behaviour, on the other side oblique impact switched from deformation mode to the bending mode.

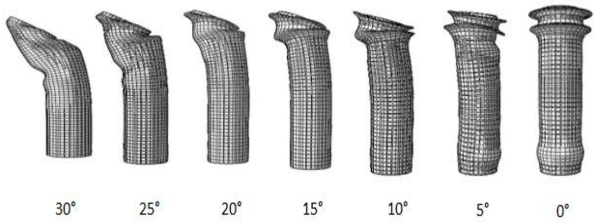
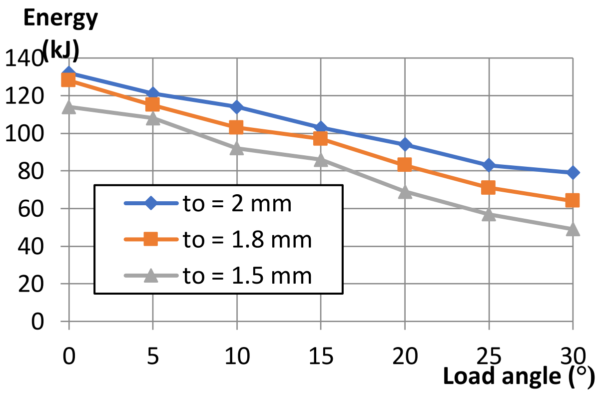
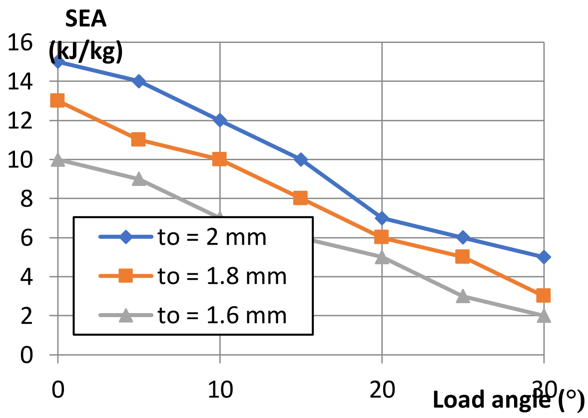


Figure 3. Crushing behaviour of aluminum foam tube under angular impact

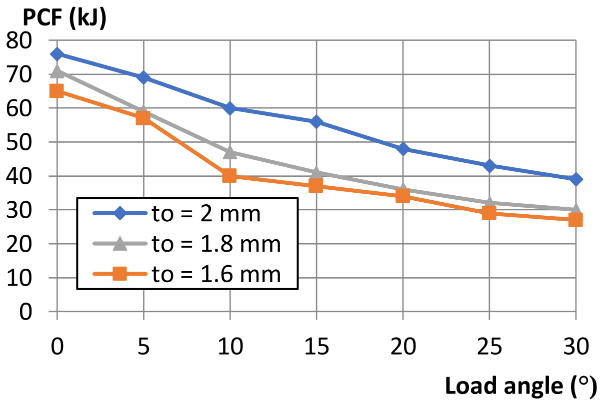
The structures were simulated to observe the inner and outer thickness of foam-filled bitubal tubes on the impact responses. The energy (*E*), specific energy absorption (*SEA*) and peak crushing force (*PCF*) versus different variation of thickness outer wall and angle loads are plotted in F\figure 5. It shows that the effect of the outer wall thickness of tubes with different angle loads. Furthermore, the load carrying capacity decrease with the increase outer thickness of wall.



(a)



(b)



(c)

Figure 4. (a) Energy, (b) specific energy absorption and (c) peak crushing force versus variation of thickness outer wall and angle loads.

Figure 5 displays the influence of the different thickness of inner wall for double foam-filled tube. It can be seen that the energy absorption has not significant effect with three kinds of inner tube in different thicknesses. However, SEA and PCF increased value slightly with increasing inner thicknesses.

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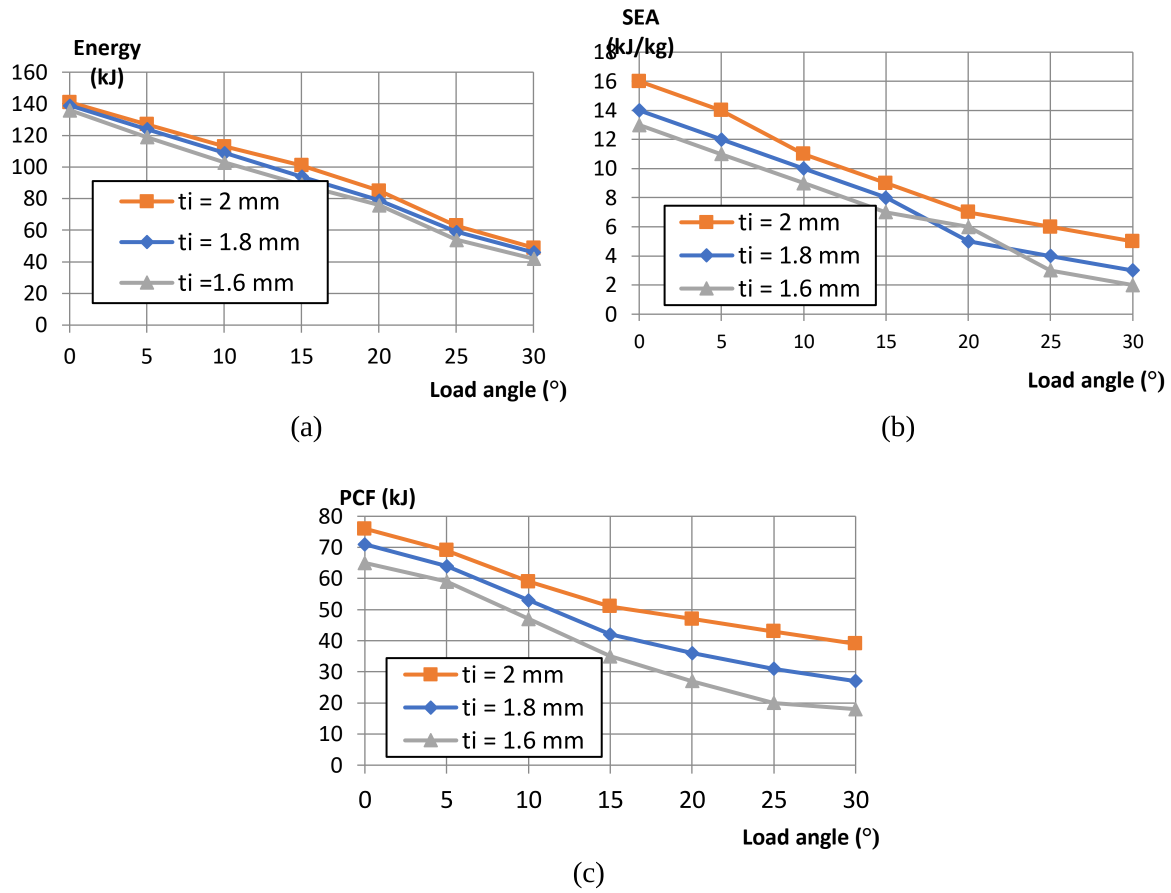
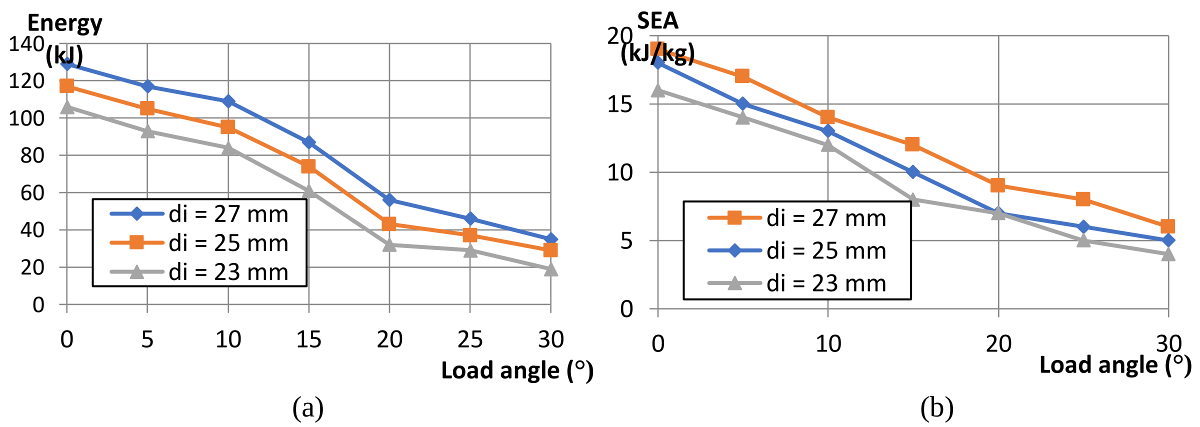
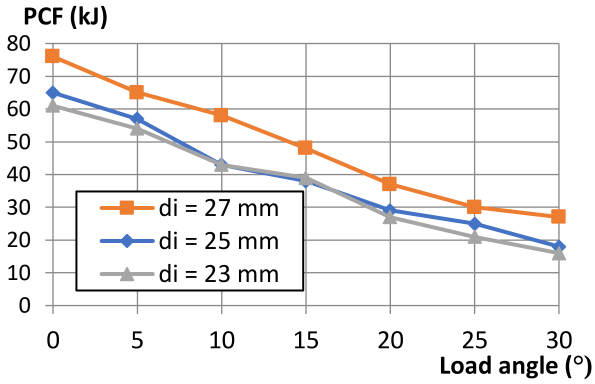


Figure 5. (a) energy, (b) specific energy absorption and (c) peak crushing force versus variation of thickness inner wall and angle loads.

The effect of the inner tube diameter of the foam-filled double tube was also studied on the energy absorption capacity and the results are shown in figure 6. It can be found that increasing diameter of the inner tube, therefore decreasing of the total energy and specific energy absorption and peak crushing force.





(c)

Figure 6. (a) The energy, (b) specific energy absorption (SEA) and peak (c) crushing force (PCF) versus variation of diameter inner wall and angle loads.

4. Conclusion

This paper presented the optimum conditions of aluminum foam cylindrical double tubes under oblique impact by considering various angles of loading and dimension tubes. Variation of geometrical dimensions such as inner and outer wall thickness, and inner diameters foam were observed to study the crash behaviour of bitubal circular tube. Finally, we found that the aluminum foam-filled double tubes are impacted by variation of angular loading. With increasing impact angle cause effects on the SEA and PCF which are decline of the value.

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