



Simulation Study of Elliptical Thin-Walled Structure Crash Box with Holed Initiator Through Axial Impact

Jeffery Jep Brown¹, Al Emran Ismail^{1*}, Dave Kidau anak Willie Chiak Mong¹

¹Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, MALAYSIA

*Corresponding Author Designation

DOI: <https://doi.org/10.30880/rpmme.2022.03.01.110>

Received 01 Dec 2021; Accepted 01 April 2022; Available online 30 July 2022

Abstract: Crash box is a thin-walled structure which is used as a medium for energy absorption to increase crashworthiness of vehicles during accidents by reducing impact or energy received by passengers in the passenger compartment of a vehicle. This study is to analyse the energy absorption performance of A36 steel elliptical shaped crash box with holed initiators. Using ANSYS simulation software, the effects of holes on elliptical shaped crash box by subjecting it to axial impact are analysed. Each designed elliptical crash box with holed initiator is analysed using performance indicators such as energy absorption value, crush force efficiency and specific energy absorption as to understand effects of holes on elliptical shaped crash box. It was found that energy absorption of the crash box is significantly increased but CFE values are also significantly decreased.

Keywords: Elliptical Crash Box, Crashworthiness, Holed Initiator, ANSYS, Axial Impact.

1. Introduction

To increase crashworthiness or energy absorption of vehicles, the introduction of thin-walled structures such as crash boxes have been introduced in automobile industry as a medium to reduce impact energy. The advantage of thin-walled structures is that they are lightweight and could reduce fabrication cost while having excellent energy absorption characteristics [1]. Thin walled structures reduce impact energy due to the fact that it deforms plastically during impact thus dissipates impact energy and reduces the amount of energy which could be felt by the passengers [2]. Thin-walled structures such as crash box is touted as a viable alternative due to its high energy absorption characteristics, being lightweight, and low cost. Although, the energy absorption characteristics is highly dependent on many factors such as its geometrical shape, material and other characteristics [3], [4]. There is a plethora of research that has been carried out in improving the energy absorption of a thin walled structures such as crash box due to direct axial impact [4]. Such as experiment done upon thin walled kenaf fibre structure subjected to axial loading in order to investigate the crushing responses of that structure.[5,6]. However, during vehicle collision or car accidents energy absorbers such as crash

*Corresponding author: emran@uthm.edu.my

2022 UTHM Publisher. All right reserved.

penerbit.uthm.edu.my/periodicals/index.php/rpmme

box are subjected to both axial and oblique impact. Not to mention that each thin walled structure systems performs differently in terms of energy absorption performance [1].

The analysis of hexagonal tubes, square tubes, rectangular, triangular and pyramidal systems and found that circular tubes have the highest energy absorption capabilities and mean crushing force while also produced a progressive folding mode which would increase energy absorption performances. Although, they neglected testing elliptical shaped thin walled structures in which might have a better energy absorption performance due to its surface area or through different deformation modes [7]. Foam-filled elliptical tubes under oblique loading using aluminium A6060 T4 and discovered that energy absorption performance of foam filled elliptical thin walled structure is the highest of all structures tested [2]. In addition, the elliptical thin walled structure is also shown to have the highest performance in specific energy absorption than circular, square and rectangular [7,8].

Thin-walled structures usually have an ideal energy absorption performance after optimization design although its crushing behaviour is sensitive to imperfections. Such that researchers have investigated ways in decrease peak initial crush force and desired deformation modes through imperfections. the introduction of holes in thin walled structure as a way of increasing performance of thin walled structures as they conclude that holed thin wall structures have an increased in energy absorption performance and a decrease in peak crushing force both in axial and oblique loading [9]. Too few holes in each row in the thin walled structure would create a non-uniform deformation during folding process while too many holes decreases energy absorption performance of the structure which is not ideal and would negate to objective of creating thin walled structure [10].

Recent advancements in technology has shifted researchers from experimental to computer aided engineering (CAE) simulations (finite element analysis-FEA) based studies [11,12]. CAE such as ANSYS is a technique widely used globally in design, analysis and optimization. The CAE simulations reduce the need to manufacture expensive prototypes for physical testing and aid in comparison and improvement of different concepts [1,13].

Thus, in this paper, the effect of holed initiators on the energy absorbing ability is studied. This is to determine the most efficient number of holes and the positions of the holes on the crashworthiness. The purpose of this paper is to investigate the value of energy absorption of the thin-walled structures. Apart from that, this paper also studied the crush force efficiency. Last but not least, the specific energy absorption is also to be determined.

2. Methodology

The elliptical thin-walled structure crash box was modelled using A36 steel. The length and thickness of the structure was chosen following study done by Tarlochan et al to be 350mm and 2mm respectively while major and minor axis is set at 62mm and 31mm respectively [3], while the radius of the hole initiator set to be 3mm.

2.1 Simulation

The simulation is conducted with impact weightage set at 275kg and initial impact velocity 15.6m/s. It was chosen due to the recommended guidelines from New Car Assessment Program (NCAP). The angle of 30 degrees and 5 degrees is chosen due to it being said as the highest load enhancement without a major reduction in mean force and the minimum difference between axial impact [3,11]. In addition, due to it being a nonlinear dynamic to solve a dynamic equilibrium equation problem, the simulation is done using ANSYS explicit dynamics since in explicit dynamic the total time is divided into a smaller time steps or increments in which data of n+1 is obtained from previous time step (n) and has no dependence on current time step [14]. Duration of simulation was set at 0.008 seconds with time step safety factor at 0.9 and automatic mass scaling off. Furthermore, erosion controls were used on

geometric strain limit and was set at 1.5 in order to avoid problems due to time step errors being too small. Result number of points on output controls were set at 100.

2.2 Finite Element Modeling

The entire structure is comprised of the thin-walled structure or crash box and its fixed support base. The thin-walled structure was modelled using element sizes of 2mm with a surface mesh method of uniform and a mapped mesh method of prism as to avoid time step too small errors which could abruptly end simulation before the required duration. The contact between all bodies was modelled as finite sliding penalty based with the crash box and fixed support bonded together while coefficient of friction is set at 0.2 [14], [15]. The top part and fixed support region were modelled as rigid structure as to prevent deformation. In addition, the top part having one allowable displacement which is until 200mm and other displacement either transitional or rotational is fixed. Figure 1 and Figure 2 shows the modelled elliptical thin-walled structure crash box while Table 1 shows the specifications of the designed elliptical thin-walled structure crash box with holed initiator which will be tested with the original non-holed model.

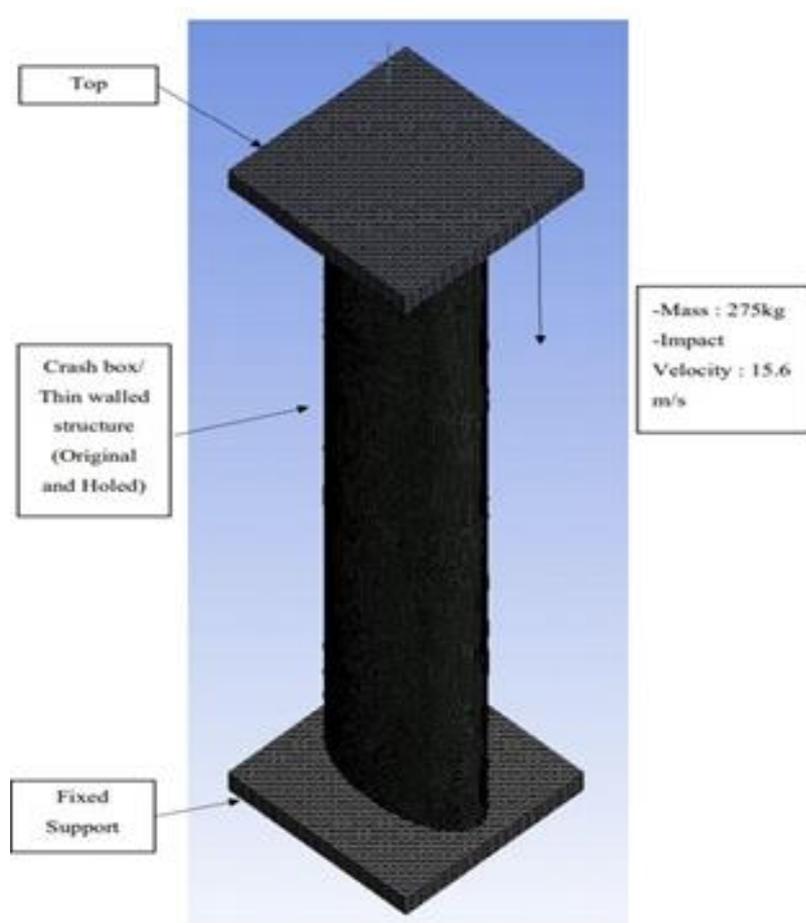


Figure 1: Axial Crash Test

Table 1: Characterization of the models

Model	Original	1st (3x3)	2nd (5x5)	3rd (10x 10)	4th (3x5)	5th (5x3)
Holes in X-axis	0	3	5	10	3	5
Holes in Y-axis	0	3	5	10	5	3
No. of Holes (Front Face)	0	9	25	100	15	15
Total No. of Holes	0	18	50	200	30	30
Spacing between holes (X-axis)	-	50 mm	24 mm	10.5mm	45 mm	25 mm
Spacing between Holes (Y-axis)	-	165 mm	75 mm	35 mm	80 mm	150 mm

2.3 Equations

Performance of crash box will be evaluated by crash response of each crash box design, which are obtained through peak force (Fmax), energy absorption (Ea), crush force efficiency (CFE) and specific energy absorption (SEA). Energy absorption or energy absorbed, Ea, of the structure is equivalent to the area under the load-displacement curve or graph. Which can be calculated using (1),

$$Ea = \int_0^{d_{max}} F dS \quad \text{Eq. 1}$$

Crush force efficiency (CFE) is the ratio of average force to peak force. A ratio of which when close to 1 is desired for an ideal energy absorber or crash box can be determined using the equation (2)

$$CFE = \frac{F_{average}}{F_{max}} \quad \text{Eq. 2}$$

Specific energy absorption, SEA is the energy absorbed by the structure per unit mass of the structure, where it could be calculated using the equation (3),

$$SEA = \frac{\text{Energy Absorbed}}{\text{Mass of crash box}} \quad \text{Eq. 3}$$

2.4 Validation of data

A validation of data was done with recreation of the design and settings used during the analysis process done by them so that it could be recreated on the simulation of all holed elliptical shaped crash box or thin-walled structure. Besides that, this is also as to get a validation on the effects of the holes on the structure as to get a definitive analysis on its performance when holes are introduced to the structure in terms of energy absorption, average force, crush force efficiency and graph of load-displacement curve.

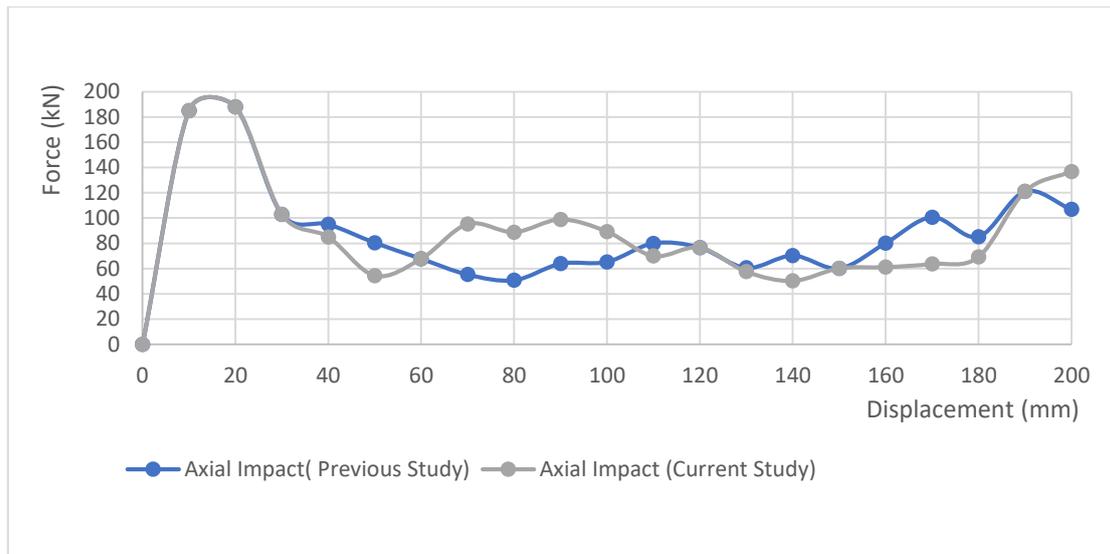


Figure 2: Comparison between previous study graph vs current study graph

Table 2: Comparison table between previous study graph vs current study graph

Indicators	Axial/Direct Impact	
	Previous study	Current study
Energy Absorbed (kJ)	17.29	17.50
F_{max} (kN)	187.16	188.00
$F_{average}$ (kN)	85.87	86.78
Crushing Force Efficiency, CFE	0.46	0.46
Specific Energy Absorption, SEA	10.60	10.94

While the graph of axial and oblique impact is nearly similar although axial graphs have slight difference in several displacement points but should not be a big factor since the error calculations for energy absorption, peak force and crushing force efficiency is less than 5%. Thus, it can be concluded that data recreation and validation is a success thus the next step of studying the effects of holed initiator on crash box or elliptical structure could then be carried.

3. Results and Discussion

The results and discussion part were divided in to two parts. The first part was the results obtained through simulation using ANSYS explicit dynamics while the second part will be the discussion of the results obtained.

Table 3: Axial crash test

Model	Original	1 st (3x3)	2 nd (5x5)	3 rd (10x 10)	4 th (3x5)	5 th (5x3)
EA (kJ)	17.5	77.2	70.2	65.6	80.2	51.9
Fmax (kN)	188	1110	1460	1540	1540	1110
Faverage (kN)	86.78	370.04	339.14	317.63	391.47	250.33
CFE	0.46	0.33	0.23	0.21	0.25	0.23
SEA (kJ/kg)	10.94	48.25	44.51	43.73	50.36	32.70

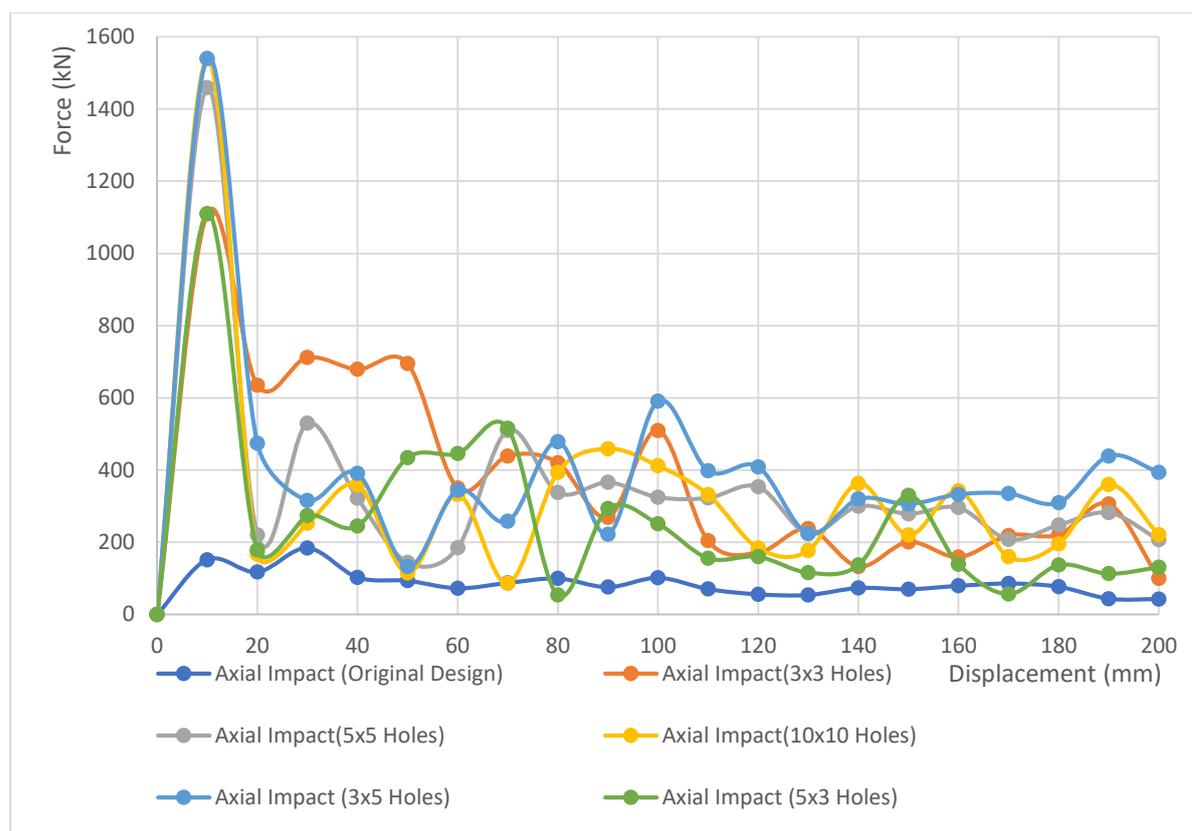


Figure 3: Graph of force vs displacement

From Table 3 and Figure 3, it is evident that, introducing holes into elliptical crash box does increase energy absorption and specific energy absorption value of the crash box significantly through axial impact while also increasing its peak force before deformation. Although, the negative effect of it is the crushing force efficiency of the crash box does suffer. A low CFE value of all of the models simply is not viable for a good design crash box. Thus, introducing holes on elliptical crash box according to the results is simply not a viable option if CFE value is at the most important. If CFE value is not an important aspect, then introducing holes on the crash box is a great option as to increase the energy absorption of the crash box. The matter of which decrease the CFE value of the elliptical crash box is the peak force which the crash box generates and the rapid decrease in forces after the peak force is achieved. A reason why probably the peak force increase is due to the force being distributed along the crash box. This is seen when vertical holes are introduced in the crash box in which by example of 3x5 holes where more holes are introduced vertically did increase the peak force generated. Thus, holes in the vertical direction do affect heavily on the peak force of the crash box. Another reason is due to the moment of inertia of the crash box. When evaluating each designed model, it is observed that the moment of inertia is increased in proportional fashion with the increase in the number of holes introduced to the crash box. All the designed elliptical crash box with holed initiator was found to have an increased moment of inertia value than the original elliptical crash box of the previous study.

4. Conclusion

In a nutshell, when holes are introduced on elliptical crash box, energy absorption of the crash box is significantly increased but CFE values are also significantly decreased. Secondly, when peak force has been achieved for elliptical crash box with holed initiator, there is a rapid decrease in force in which decreases CFE value of the structure. Next, when peak force has been achieved, rapid deceleration than stabilization of forces could be observed. If peak force could be decreased, thus CFE value of elliptical holed crash box could increase significantly. Introducing only holes to the design of the crash box is undesirable for crashworthiness since CFE value of the elliptical crash box is low, although decreasing

peak force value while maintaining forces at a slow decrease rate would make the elliptical crash box with holed initiator a viable design for crashworthiness application. Holes in the vertical direction effects energy absorption performance of elliptical crash box more than horizontal holes. Furthermore, increasing number of holes decreases axial impact energy absorption of elliptical crash box with holed initiator while increasing energy absorption performance of elliptical crash box when crash box undergoes oblique impact.

Acknowledgement

This research was made possible by funding from research grant number E15501 provided by the Ministry of Higher Education, Malaysia. The authors would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

- [1] S. E. Alkhatib, M. S. Matar, F. Tarlochan, O. Laban, A. S. Mohamed, and N. Alqwasm, "Deformation modes and crashworthiness energy absorption of sinusoidally corrugated tubes manufactured by direct metal laser sintering," *Eng. Struct.*, vol. 201, no. December, p. 109838, 2019.
- [2] Q. Gao, L. Wang, Y. Wang, and C. Wang, "Crushing analysis and multiobjective crashworthiness optimization of foam-filled ellipse tubes under oblique impact loading," *Thin-Walled Struct.*, 2016.
- [3] F. Tarlochan, F. Samer, A. M. S. Hamouda, S. Ramesh, and K. Khalid, "Design of thin wall structures for energy absorption applications: Enhancement of crashworthiness due to axial and oblique impact forces," *Thin-Walled Struct.*, vol. 71, pp. 7–17, 2013.
- [4] Z. Fan, G. Lu, and K. Liu, "Quasi-static axial compression of thin-walled tubes with different cross-sectional shapes," *Eng. Struct.*, vol. 55, pp. 80–89, 2013.
- [5] A. E. Ismail and M. F. Sahrom, "Lateral crushing energy absorption of cylindrical kenaf fiber reinforced composites," *Int. J. Appl. Eng. Res.*, vol. 10, no. 8, pp. 19277–19288, 2015.
- [6] A. E. Ismail and M. A. Che Abdul Aziz, "Tensile strength of woven yarn kenaf fiber reinforced polyester composites," *J. Mech. Eng. Sci.*, vol. 9, pp. 1695–1704, 2015.
- [7] O. H. Mete, M. Yalcin, and K. Genel, "Experimental and numerical studies on the folding response of annular-rolled Al tube," *Thin-Walled Struct.*, 2018.
- [8] J. Marzbanrad, M. Mehdikhanlo, and A. S. Pour, "An energy absorption comparison of square, circular, and elliptic steel and aluminum tubes under impact loading," *Turkish J. Eng. Environ. Sci.*, vol. 33, no. 3, pp. 159–166, 2010.
- [9] H. Nikkhah, F. Guo, Y. Chew, J. Bai, J. Song, and P. Wang, "The effect of different shapes of holes on the crushing characteristics of aluminum square windowed tubes under dynamic axial loading," *Thin-Walled Struct.*, vol. 119, pp. 412–420, 2017.
- [10] A. Moradpour, M. Elyasi, and S. Montazeri, "Developing a new thin-walled tube structure and analyzing its crushing performance for aa 60601 and mild steel under axial loading," *Trans. Indian Inst. Met.*, vol. 69, no. 5, pp. 1107–1117, 2016.
- [11] M. Bulik, M. Liefvendahl, R. Stocki, and C. Wauquiez, "Stochastic simulation for crashworthiness," *Adv. Eng. Softw.*, vol. 35, no. 12, pp. 791–803, 2004.
- [12] H. Wang, G. Y. Li, and E. Li, "Time-based metamodeling technique for vehicle crashworthiness optimization," *Comput. Methods Appl. Mech. Eng.*, vol. 199, no. 37–40, pp. 2497–2509, 2010.
- [13] R.-Y. Yao, B. Zhang, G.-S. Yin, and Z.-Y. Zhao, "Energy absorption behaviors of foam-filled

holed tube subjected to axial crushing: Experimental and theoretical investigations,” *Mech. Adv. Mater. Struct.*, pp. 1–14, 2020.

- [14] G. Lu and T. X. Yu, *Energy absorption of structures and materials*. Elsevier, 2003.
- [15] B. Dehghan-Manshadi, H. Mahmudi, A. Abedian, and R. Mahmudi, “A novel method for materials selection in mechanical design: combination of non-linear normalization and a modified digital logic method,” *Mater. Des.*, vol. 28, no. 1, pp. 8–15, 2007.