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# Energy Absorption and Deformation Pattern Analysis of Initial Folded Crash Box Subjected to Frontal Test

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## Abstract

*Crash box design as one of the passive safety components in a vehicle had been developed to enhance energy absorption. Initial fold on the crash box is set to facilitate folding during the crash. The aims of this study is to investigate the initial folded crash box with length to thickness ratio subjected to frontal test. The frontal test is modelled by using finite element analysis. Through computer simulation using 9 models, the obtained result was used to provide the better design of crash box. The variations in this study were length to thickness ratio of crash box with length of tube (L) = 115; 132.5; 150 mm and the thickness of tube (t) = 1.6; 2.0; 2.5 mm. The crash box material was assumed as bilinear isotropic hardening material. The velocity used in the simulations was 7.67 m/s with impact mass of 103 kg. Based on the results, it can be shown that 1<sup>st</sup> model to 8<sup>th</sup> model produce deformation pattern as concertina mode and 9<sup>th</sup> model has diamond mode. The 3<sup>rd</sup> model has the largest energy absorption with value of 18.29 kJ.*

**Keywords:** *Initial folded crash box; energy absorption; deformation pattern; frontal test*

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## 1. INTRODUCTION

The development of modern society is increasing human demand for transportation. Based on the end of 2016 data, the number of car sales in Indonesia reached 1,062,729 units [1]. Unfortunately, as increasing the number of vehicles, the number of traffic accident has also increased significantly. Only two months (January – March 2017), traffic accident reported is 24,268 cases and the car was the second causes of this accident after motorcycle [2].

The crash box is one of the passive safety components in vehicle located at the front and rear between bumper and frame. It's function as energy absorber due to collisions result in plastic deformation. In the crash box mechanism, the kinetic energy is dissipated by progressive deformation at collision and the minimum amount of force is transferred to the occupants. The study of deformation modes and energy absorption performance had been done for various section geometries of crash box and compared both experimentally and numerically [3]. In the next study, many researches carried out on initial folding sections technique to produce more folding by adding grooves, corrugations and patterns [4][5]. Initial folded produce more folding and exhibits good impact resistance. In other technique, the crash box with holes is designed to create as pre-folding corresponding to the peak of crush force reducing [6]. In the multi-segments crash box, variation on segment combinations of crash box was intended to obtain the better performance in

crash energy absorbing [7]. The four-segmented aluminum tubes with circular cross sections were investigated with the length, thickness and mechanical properties of each tube segment varies along the length [8]. Based on these reasons, effects of changing the wall thickness and length of each segment are important parameter design. In this study, initial fold crash box is investigated to evaluate the deformation pattern and energy absorption with various length to thickness ratio.

## 2. METHODOLOGY

The computer simulation was done by the ANSYS 14.5 academic software based on Finite Element Analysis. Figure 1 shows the geometry of crash box design. The details of variations of Length (L) to Thickness (t) ratio can be seen in Table 1. The angle of initial fold crash box is set as 90° with 1:1 of fold ratio. The crash box material is Mild Steel ASTM E-04 based on the previous study [9] and the material is assumed as Bilinear Isotropic Hardening as shown in the Table 2.1.

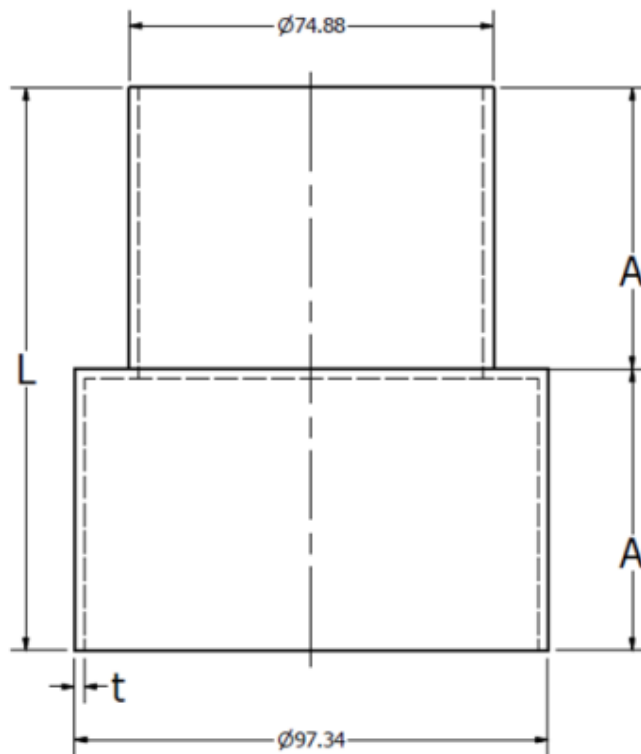


Figure 2.1 Geometry of crash box design

Table 2.1 Initial fold crash box model with various length to thickness ratio

No.	Crash box	L (mm)	t (mm)	Ratio L/t
1	Model 1	115	1.6	71.8
2	Model 2	115	2.0	57.5
3	Model 3	115	2.5	46
4	Model 4	132.5	1.6	82.8
5	Model 5	132.5	2.0	66.2
6	Model 6	132.5	2.5	53
7	Model 7	150	1.6	93.7
8	Model 8	150	2.0	75
9	Model 9	150	2.5	60

The diameter of circular tube was set as constant of 97.34 mm. Shell element has been used to mesh crash box model with element size of 1.3 mm. The velocity of impactor used in the simulations was 7.67 m/s with impact mass 103 kg. Impactor was modeled as a rigid body. Contact between the crash box, impactor and fixed support were set as bounded contact. The boundary conditions of model can be seen in Figure 2. In term of the crash box performance indicators, deformation pattern and energy absorption are observed.

*Table 2.2 Material properties of crash box*

Density (kg/m <sup>3</sup> )	8,077 x 10 <sup>3</sup>
Modulus Young (MPa)	2,05 x 10 <sup>5</sup>
Poisson's Ratio	2,9 x 10 <sup>-1</sup>
Yield Strength (MPa)	2,6694 x 10 <sup>2</sup>
Tangent Modulus (MPa)	2,6667 x 10 <sup>3</sup>

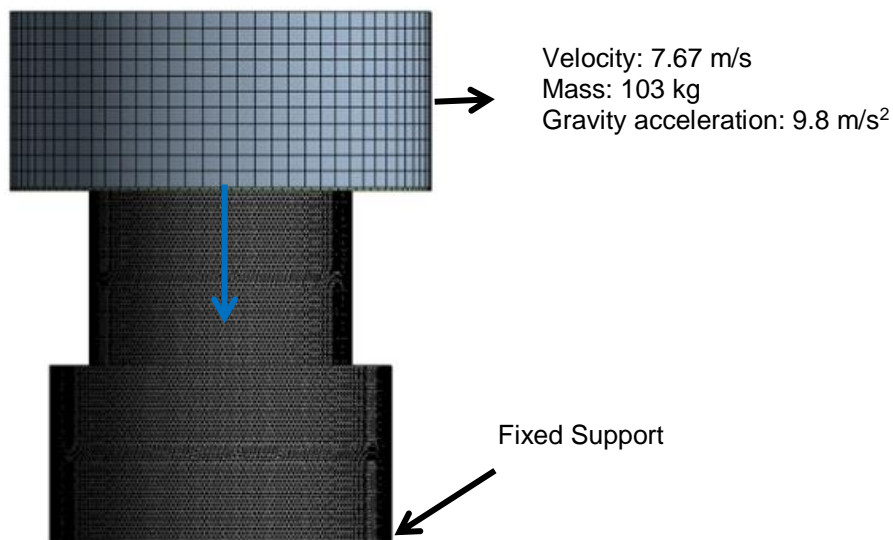


Figure 2.2 Meshing and boundary conditions of model

### 3. RESULT AND DISCUSSION

From the computer simulation results, it can be obtained the energy absorption results on all models as shown in the Table 3.1. Based on the table, it can be shown that the 3<sup>rd</sup> model with length of 115 mm and thickness of 2.5 mm has the largest energy absorption.

Table 3.1 Summary of Energy absorption for all models

Crash box	Energy Absorption (J)
Model 1	8376.54
Model 2	12222.63
Model 3	18294.06
Model 4	6775.44
Model 5	8602.44
Model 6	13518.13
Model 7	5991.03
Model 8	8405.36
Model 9	11904.93

In the frontal test on crash box, deformation pattern can occur as concertina (axisymmetric), diamond or mixed mode [10]. The deformation pattern occurred in each models can be seen in Table 3.2. Visual analysis on these result shows each models has similar deformation pattern in the initial loading. First folding occurred in the inside of initial fold. After the wall crash the fixed support, folding of upper and bottom of crash box is occurred (Figure 3.1). Based on the table, it can be shown that 1<sup>st</sup> - 8<sup>th</sup> models produce deformation pattern as concertina mode, and 9<sup>th</sup> model has diamond mode.

Table 3.2 Deformation Pattern on Models

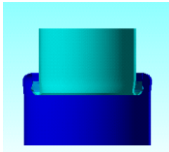
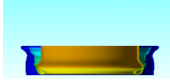

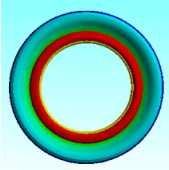
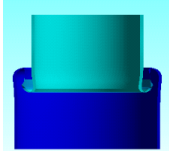
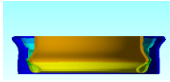

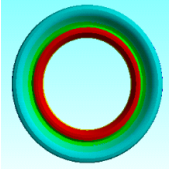
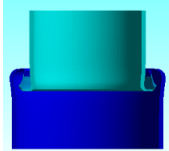
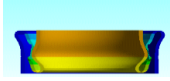

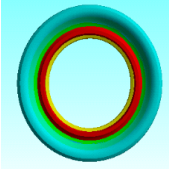
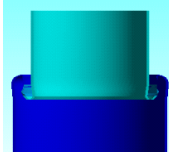
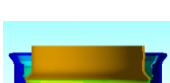

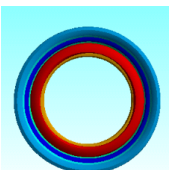
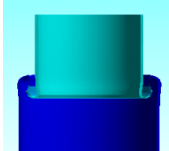
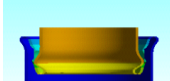

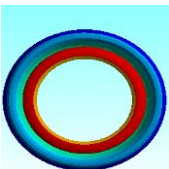
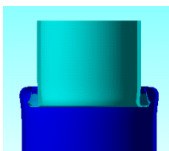
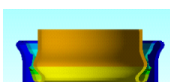

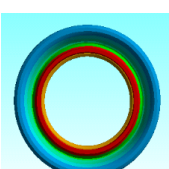
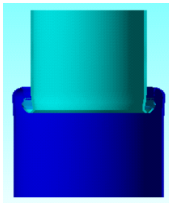
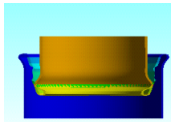
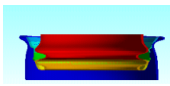
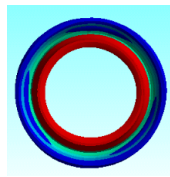
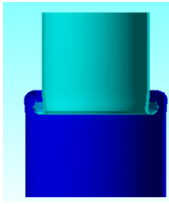
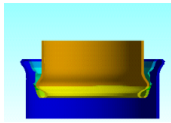
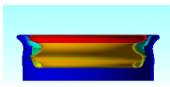
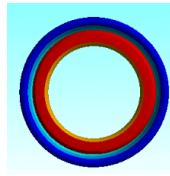
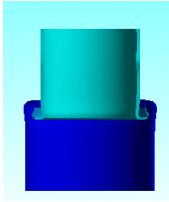
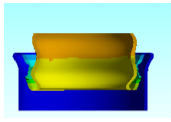
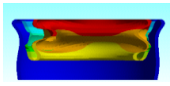
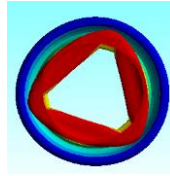
No	Deformation (mm)			Top View	Deformation Mode
	29.31	78.17	91.71		
1					Concertina
2					Concertina
3					Concertina
4					Concertina
5					Concertina
6					Concertina

Table 3.2 Deformation Pattern on Models (continued)

7					Concertina
8					Concertina
9					Diamond

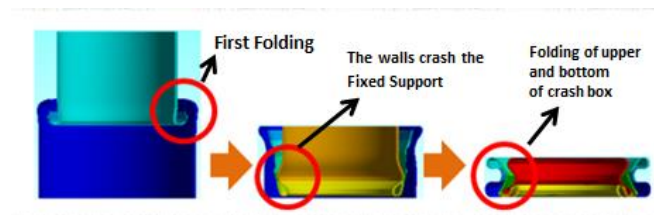


Figure 3.1 Folding Process of 3<sup>rd</sup> Model

Figure 3.2 shows the deformation pattern connected with energy absorption on 3<sup>rd</sup> Model. At the beginning deformation, the energy absorption curve tends in the straight line, and the first folding is occurred caused by the first peak of loading connected with increasing of energy absorption. In the next folding, energy absorption curve perform increase as the fact that this design exhibits good impact resistance due to collisions result in plastic deformation with number of folding occurred [3, 10].

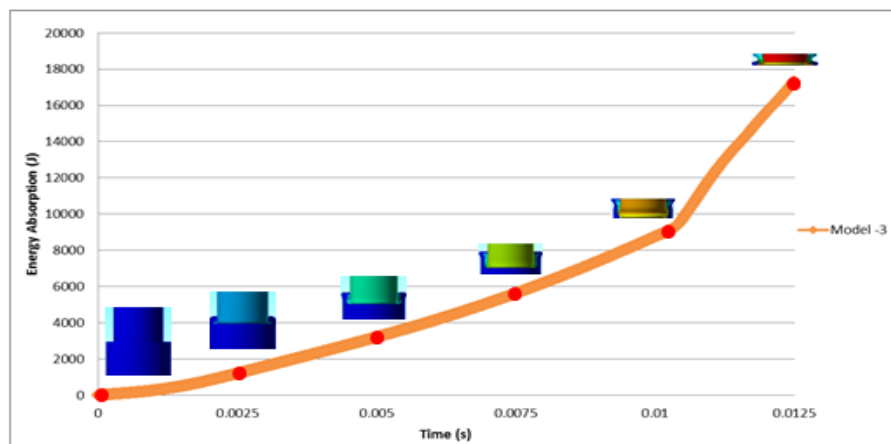


Figure 3.2 Deformation Pattern and Energy Absorption on 3<sup>rd</sup> Model

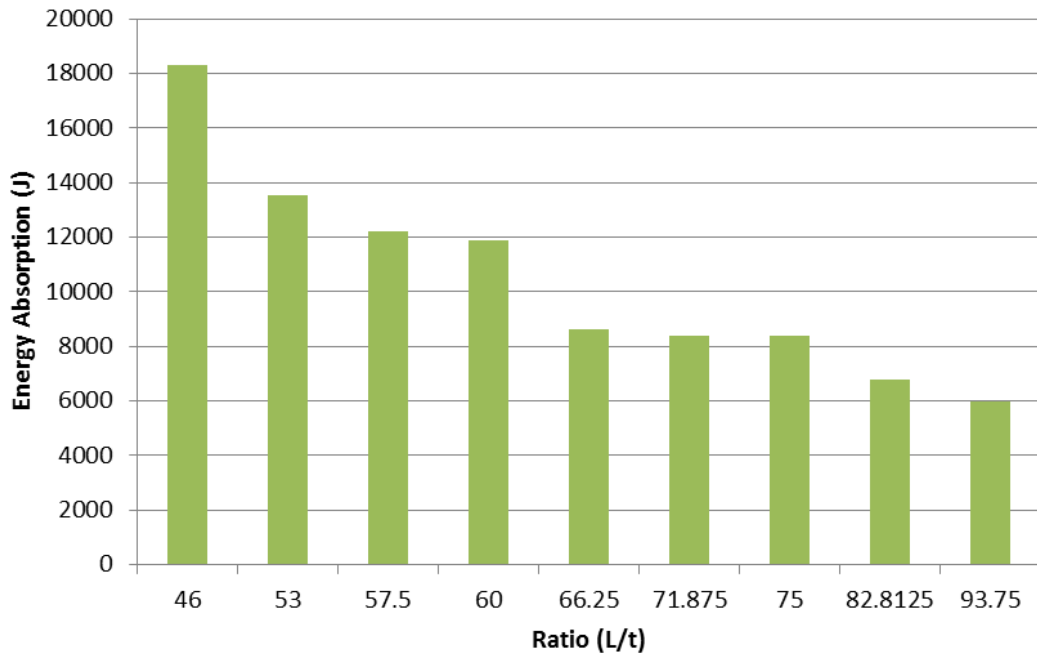


Figure 3.3 Energy absorption on length-thickness ratio variation

As shown in the Figure 3.3, high value of energy absorption is obtained by decreasing the length to thickness ratio of crash box. In other analysis, specific energy absorption is defined as the energy absorbed per unit of mass. This magnitude is considered due to increasing of length to thickness ratio connected with increasing of crash box mass. The mass and the specific energy absorption can be seen in Figure 3.4 and Table 3.3.

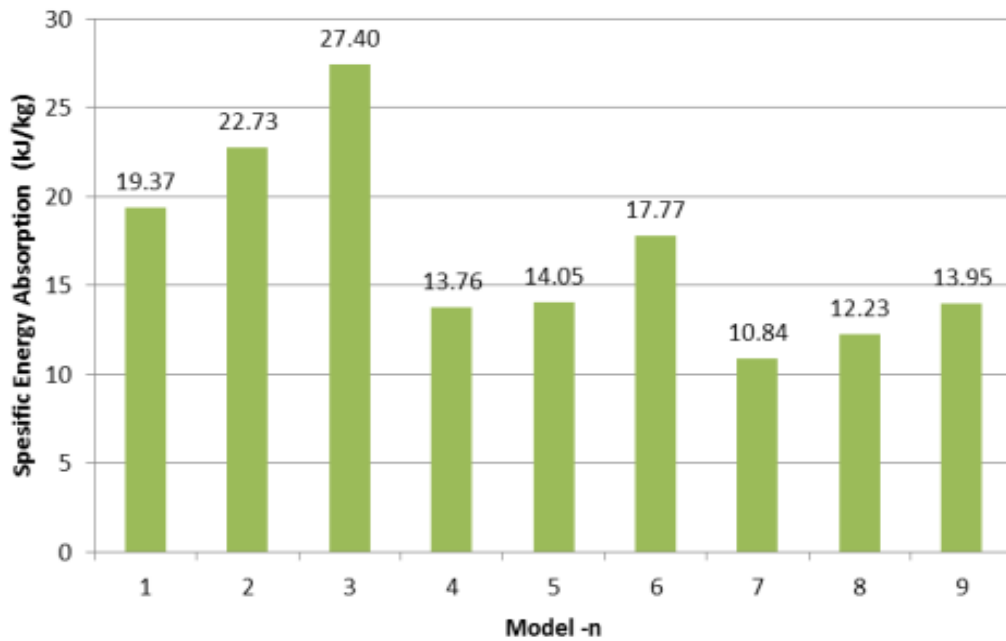


Figure 6. Specific energy absorption on all models

Crash box length of 115 mm and thickness of 2.5 mm produce largest specific energy of absorption with 27.39 kJ/kg. It can be concluded that increasing of thickness will increasing the value of specific energy absorption. Meanwhile, as increasing the number of length, the value of specific energy absorption has decreasing. High value of specific energy absorption is determined by decreasing the ratio length and thickness of crash box.

Table 3.3 Mass and specific energy absorption of models

Crash box	Mass (kg)	Energy (kJ)	Specific Energy (kJ/kg)
1	0.43237	8.37	19.37
2	0.53768	12.22	22.73
3	0.66773	18.29	27.39
4	0.49242	6.77	13.75
5	0.61237	8.60	14.04
6	0.76055	13.52	17.77
7	0.55246	5.99	10.84
8	0.68707	8.40	12.23
9	0.85337	11.90	13.95

#### 4. CONCLUSION

Crash simulation under frontal load was carried out on initial fold crash box design to obtain better performance in crash energy absorbing. From the results of this study, it can be concluded that 1<sup>st</sup> - 8<sup>th</sup> models produce deformation pattern as concertina mode, and 9<sup>th</sup> model has diamond mode. The 3<sup>rd</sup> model has the largest energy absorption with value 18,29 kJ.

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