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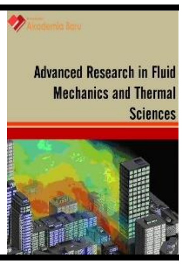

Energy Absorption and Deformation Pattern on Two Segment Crash Box with Rubber Connection Variation

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ABSTRACT

Crash box is known as passive safety devices used to reduce collision damage effect. This study aims to develop two-segment crash box design by utilizing rubber as inter-segment holder. Al 6063-T5 is used as crash box material with Butyl Rubber connection. The design parameter is the location of the segment connections: 1/4, 1/3, and 1/2 of the total length of the crash box. Energy absorption, and deformation patterns is observed as response variables. From the simulation result, it can be obtained that crash box with 1/3 segment connection has the highest energy absorption (1.326 kJ). The results showed that crushing force efficiency (CFE) of the crash box with 1/3 segment connection was highest, followed 1/4 segment connection and 1/2 segment connection, respectively. The deformation pattern of three models is diamond mode. The deformation pattern of the crash box with 1/3 segment connection is more stable due to more symmetrical deformation pattern.

1. Introduction

The increasing trend of car sales in Indonesia continues to increase every year, especially types of MPV cars. In 2014 passenger car vehicles amounted to 12,599,038 units and increased by 9.11% from the previous year. On the other hand, the number of traffic accidents also increased approximately 9.59% annually [1]. Most traffic accidents occur in frontal vehicles (64%), while the rest are oblique, side and roll over [2]. Based on these reviews, vehicle safety standard is required to be improved.

The crash box is a passive safety device and one part of the crashworthy system installed between the bumper and the frame (Figure 1) used to reduce the degree of accidents suffered by passengers and the vital part of the vehicle due to collision [3]. The kinetic energy at the time of the collision will be converted to strain energy in the crash box indicated by the deformation of the crash box itself.

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The shape of the crash box is a hollow structure and has a thin thickness with variations of the type of cross-section.

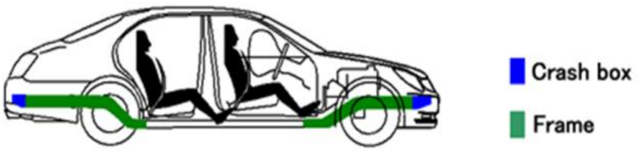

Fig. 1. Crash Box location in the car

Static and dynamic testing of crash box with variations of cross-sectional shape was performed. The energy absorption of crash boxes in the rectangular section is lower than circular-section crash box [4]. Choiron *et al.*, [5] examined the effects of tapered angles on crash box walls against energy absorption and deformation by frontal test model. The result of energy absorption increases with increasing tapered angle [5]. The hybrid crash box made of steel and aluminum was developed to decrease the total weight with weight saving of 17.5% [6]. The multi-segments crash box design has been studied to obtain energy absorption by using computer simulation [7]. In this study, a circular two segments crash box is developed. The connection between segments used a chamfer with 45^{o} angle and rubber is used as inter-segment holder. The location of the segment connections is varied from total length of the crash box. Energy absorption and crash deformation patterns are observed.

2. Methodology

Computer simulation using ANSYS software based on Finite Element Method (FEM) is used as method to provide the observed value [8]. The crash box used in this study is a two segment crash box and added rubber on the connection as inter-segment holder. The two segment crash box dimension can be seen in Figure 2. The design parameter is varied as location of the segment connections of crash box calculated from the end of segment 1 as shown in the Table 1.

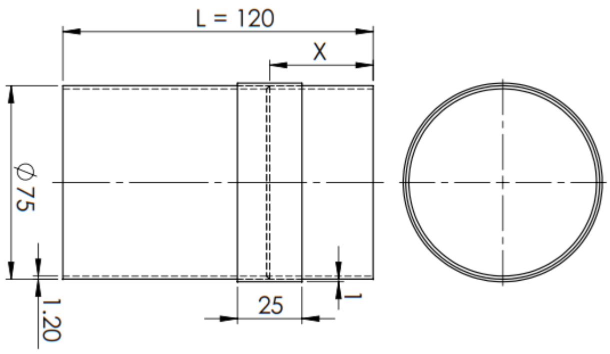

Fig. 2. Dimension of Crash Box

Table 1
Design Parameter

Model	Location (X)	Segment length (mm)
CB 1/4	1/4L	30
CB 1/3	1/3L	40
CB 1/2	1/2L	60

Energy absorption, and deformation patterns is observed as response variables. The assumptions are used as follows:

- Bilinear Isotropic Hardening is assumed as material model.
- Impactor speed is 7.67 m/s (based on study of Velmurugan).
- Crash Box length is 120 mm and thickness is 1.2 mm.
- Impactor modeled as rigid.

Both segments crash box uses material Al 6063-T5 and butyl rubber is used as inter-segment holder on the connection between the segments. Material properties of both materials can be seen in Table 2 and Table 3. The element size is 1.3 mm for crash box and 300 mm for impactor (Figure 3).

Table 2
Al 6063-T5 Material Properties [9]

Properties	Value
Density (kg/m^3)	2700
Young's Modulus (MPa)	69000
Poisson Ratio	0.33
Yield Strength (MPa)	180
Tangent Modulus (MPa)	580

Table 3
Butyl Rubber Material Properties [10-12]

Properties	Value
Density (kg/m^3)	1150
Young's Modulus (MPa)	4
Poisson Ratio	0.45
Yield Strength (MPa)	7
Tangent Modulus (MPa)	3

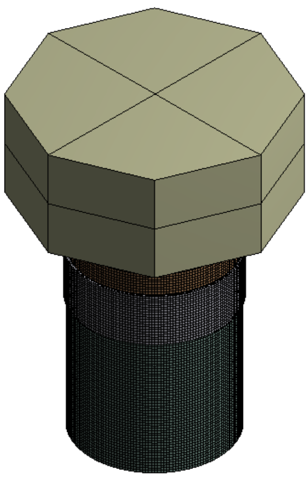

Fig. 3. Meshing on crash box model

Impactor with a mass of 103 kg is assumed as a rigid body that pushes the crash box with a speed of 7.67 m/s. The gravity acceleration is set as 9.81 m/s^2 in the impactor direction. The bottom of crash box was set as fixed support (Figure 4).

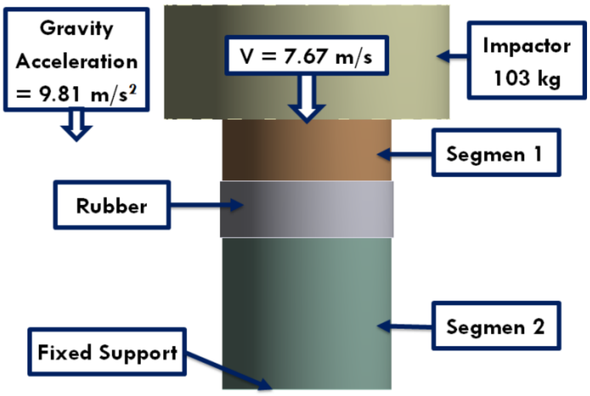

Fig. 4. Crash box setting model

The verification is done to ensure the FEA simulation procedure by comparing with the experimental results. Figure 5 shows the comparison between simulations results and experimental result by using Velmurugan crash box data. Table 4 show the result of comparison between simulation and experimental.

(a) FEA Software (b) Experimental

Fig. 5. Verification

Table 4
Comparison between Simulation and Experimental Results

Variable	FEM Simulation	Experimental
Diameter	75 mm	75 mm
Length	150 mm	150 mm
Thickness	1,6 mm	1,6 mm
Deformation	37,2002 mm	37,2 mm
Energy Absorption	2527,7 J	2395,3 J

$$\text{Error EA} = \left| \frac{2527{,}7 - 2395{,}3}{2527{,}7} \right| \text{ x } 100\% = 5{,}237\%$$

From the verification result, it can be obtained that comparison between experimental and FEM simulation produce a small error value, therefore FEA simulation can be used for this crash box study.

3. Results

In the frontal test mechanism, impactor push the crash box, the impact energy from the impactor will be converted into strain energy resulting in a change of shape in the crash box. The strain energy is obtained through the area under the curve of load and displacement with strain energy is assumed similar with kinetic energy result conversion from the impactor. Energy absorption is one of criteria to measure the performance of crashworthiness of the crash box. Figure 6 shows the energy absorption of each crash box model on the 99.71 mm deformation. The largest energy absorption value is occurred in the 1/3 segment connection crash box model (1326.5 J).

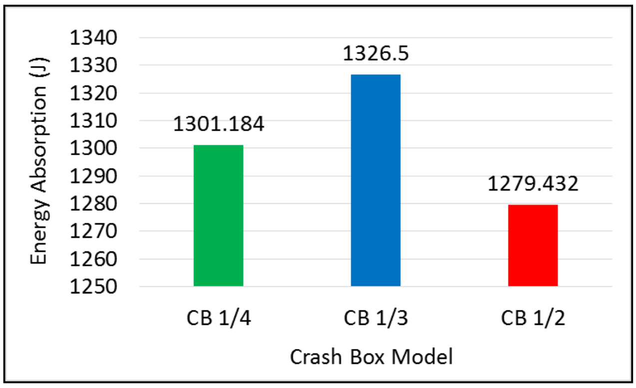

Fig. 6. Energy absorption of each crash box model

Specific energy absorption (SEA) is calculated as energy absorbed by the crash box per unit mass from Eq.1 [13] and summarize in Table 5.

$$SEA = \frac{E_a}{m} \tag{1}$$

where,
SEA = Specific Energy Absorption (J/kg)
Ea = Energy Absorption (J)
m = Mass (kg)

Table 5
Specific Energy Absorption on crash box models

Model	Energy (J)	Massa (kg)	SEA (J/kg)
CB 1/4	1301.184	0.0995	13082.7
CB 1/3	1326.5	0.0995	13337.3
CB 1/2	1279.432	0.0995	12864.0

Figure 7 shows the specific energy absorption of each crash box model. It can be seen that the crash box with 1/3 segment connection has the highest specific energy absorption value (13337.3 J/kg). In the similar mass, it can be denoted that greater the energy absorption provides greater the specific energy absorption.

Figure 8 shows force reaction and deformation curve of each crash box model. It can be seen that the crash box with 1/2 segment connection has the highest of first peak load (55807 N), followed by the 1/4 segment connection (54848 N), and the lowest on the crash box with of 1/3 segment connection (52534 N). This phenomenon is occurred due to the crash box with 1/2 segment connection has the same segment length, it means does not have long segment. The segment length connected as inversely proportional to the critical load. Based on critical load equation, crash box with 1/2 segment connection provide higher critical load.

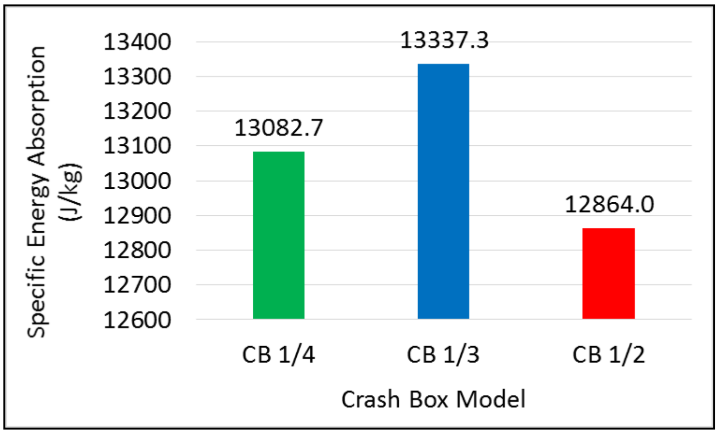

Fig. 7. Specific Energy absorption of each crash box model

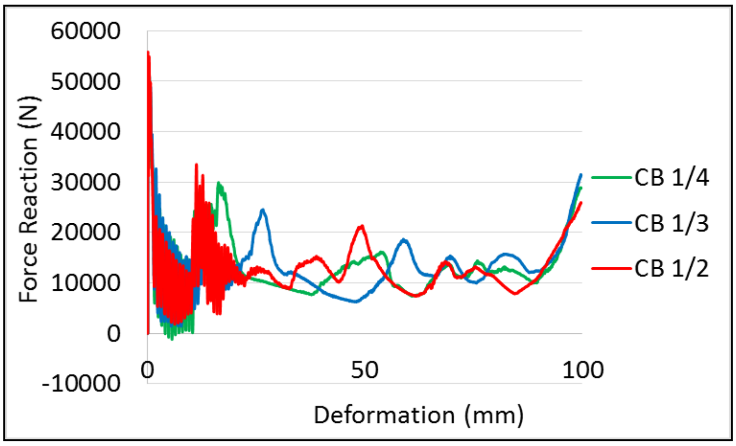

Fig. 8. Force Reaction and Deformation of Each Crash Box Model

Figure 9 shows the average force of each crash box model. Based on this result, it can be denoted that crash box with 1/3 segment connection has the highest average force (Pm = 13403.27 N) than other models. High average force cause high energy absorption. The higher the CFE value, the better the load uniformity for an energy absorber [14]. It can be seen from Crushing Force Efficiency (CFE) Eq. 2 as follows [15]:

$$CFE = \frac{P_m}{P_{max}} \tag{2}$$

where,
CFE = Crushing Force Efficiency
P_m = Average Force (N)
P_{max} = Maximum Peak Force (N)

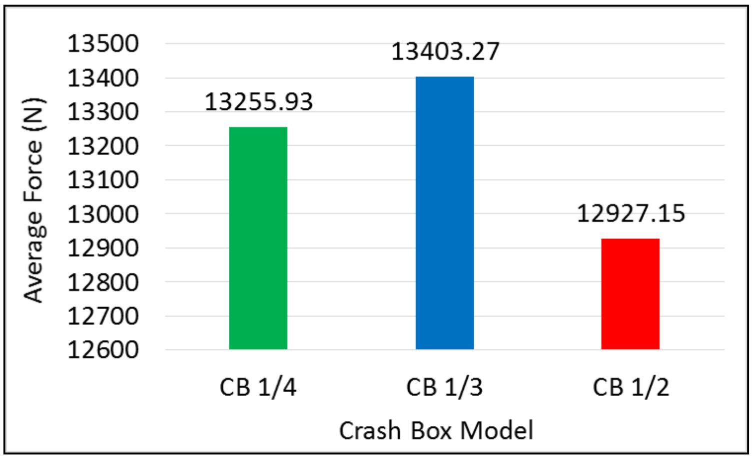

Fig. 9. Average Force of each crash box model

Table 6 represents the CFE value of each crash box model. From the table it is found that the highest value of CFE is crash box with 1/3 segment connection (CFE=25.51%), followed by crash box with 1/4 segment connection (CFE=24.17%), and the lowest is crash box with 1/2 segment connection (CFE=23.16%). CFE value is connected directly as proportional to the energy absorption value of the crash box. It can be found that the greater the CFE, the greater the energy absorption.

Table 6
CFE on Crash Box Models

Model	Peak Force (N)	Average Force (N)	CFE (%)
CB 1/4	54848	13255.93	24.17
CB 1/3	52534	13403.27	25.51
CB 1/2	55807	12927.15	23.16

Figure 10 denotes the deformation patterns of each crash box model. It can be shown that the crash box with 1/3 segment connection provide more symmetrical deformation patterns than two other models. This condition connected with the high average force of the crash box with 1/3 segment connection, therefore the load more uniform to absorb more energy than other models. Velmurugan and Muralikannan [4] revealed that the deformation pattern of the crash box can occur in two modes: asymmetries mode or called as concertina mode and diamond mode which the transverse and longitudinal folds are formed. In this study, the deformation pattern of the three models is diamond mode as shown in the Figure 10.

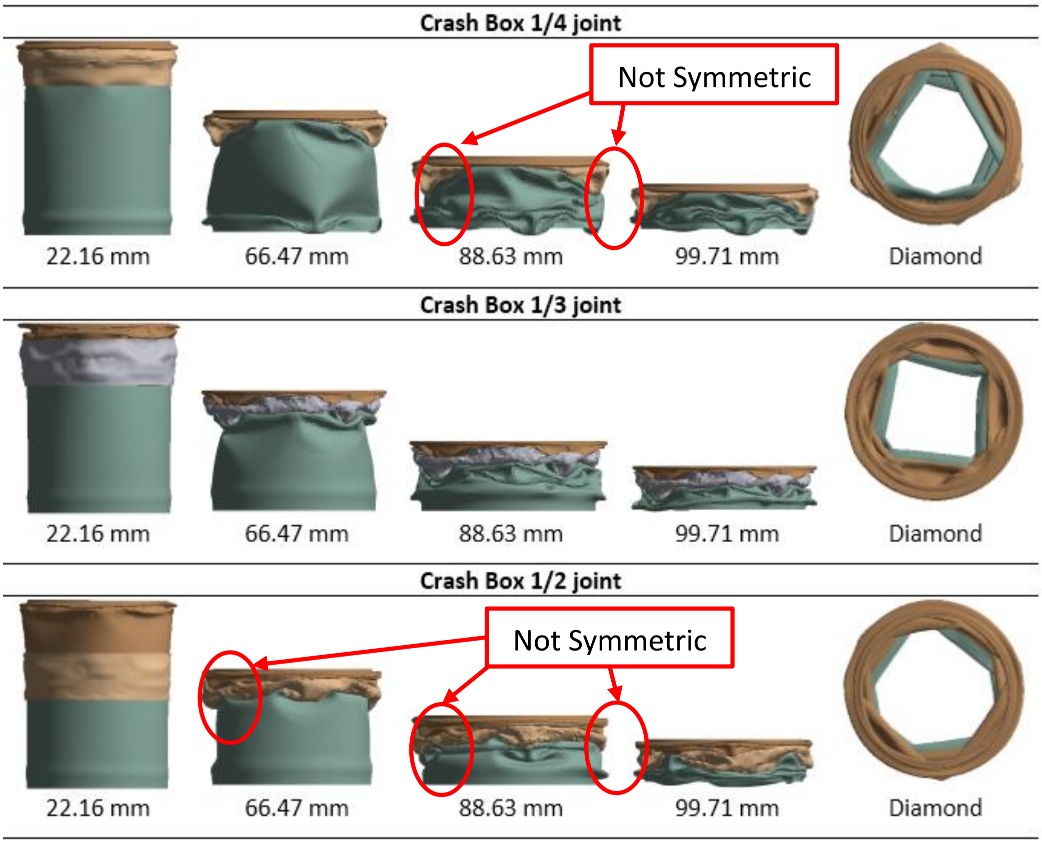

Fig. 10. Deformation pattern on each crash box model

4. Conclusions

This paper presented the two segment crash box model under frontal load by considering added rubber on the connection as inter-segment holder.

- The highest energy absorption and specific energy absorption occurred in the crash box with 1/3 segment connection (13337.3 J/kg and 1326.5 J, respectively).
- Deformation pattern of crash box with 1/3 segment connection produce more stable than other models and all models formed as diamond mode.
- The best model is the crash box with 1/3 segment connection due to the highest energy absorption, energy absorption, and crushing force efficiency (CFE), and a more stable deformation pattern than other models.

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