Comparison Of Energy Absorption And Pattern Of Deformation Material Crash Box Of Three Segments With Bilinear And Johnson Cook Approach

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Abstract. The study aimed to find out the comparison of energy absorption and pattern of deformation material crash box of three segments using software simulation FEM-Based (finite element method) and bilinear and Johnson cook approach. The crash box made with a three-segment circle cross section using Al 6063-T5 material, 1.2 mm thick, 162 mm length and chamfer angle between 45° segments. Simulation on the crash box was done by frontal direction collision simulation using an impact factor of 200 kg and impact speed of 7.67 m / s. The findings showed that the value of energy absorption in the crash box material with bilinear approach was higher of 8954 J compared to the crash box with the Johnsoncook approach of 8859 J. The patterns of deformation of bilinear crash box tended to form concertina and mixed patterns (concertina + diamond).

Keywords: crash box, energy absorption, pattern of deformation, bilinear and Johnson cook

1. Introduction
Indonesia is a country with a large population and using private vehicles, especially cars, increasingly used by the community. Along with the increasing the number of vehicle users as supporting community mobility, the number of traffic accidents has increased quite high. World health organization (WHO) reports “the global report on road safety 2015”. It reports the traffic accidents in 180 countries. In this report, Indonesia is the third country in Asia on the number of deaths due to traffic accidents after China and India, with a total of 38,279 deaths [1].

With the increase in traffic accidents and a fairly high death number, this led to the policies that safety is the most important thing. The research attention in the field of vehicle safety engineering
makes it very popular, especially the design of impact resistance on cars. Cars are required to pass a crash test that allows saving the drivers and users. In the development of technology, there are many security systems implemented by vehicle manufacturers, especially four-wheeled vehicles, namely the crash box [2] [12] [13].

![Figure 1. Installation position of Crash Box on the car](image1)

The crash box is a passive safety system technology and many researchers give attention because its function is to absorb the kinetic energy when the car has collisions in an accident, both collisions from the front and from behind. The crash box components are designed to reduce the occurrence of forces occurring throughout the structure of the vehicle during a collision. Therefore, the crash box installed between the suspension and frame of the vehicle, because its function is a component to absorb energy [4] [5] [11]. The devices used in the absorption of kinetic energy in cars called crash box usually installed between the main structures of the bumper. Research on the crash box has been done to find out the value of absorbing energy. Zhang and friend conducted a simulation of square tube collisions with two patterns using pyramid elements and showed an energy absorption value of 92% when compared to conventional square-shaped tubes showed an energy absorption value of 22% [6] [8].

![Figure 2. Front Structure configuration(1) Undeformable cockpit, (2) upper front rails, (3) crash box, (4) bumper cross member, (5) main front rails, (6) mechanics frame](image2)

![Figure 3. Crash box model: 1 segments, 2 segments, 3 segments (Type 1), 3 segments (Type 2)](image3)
Velmurugan et al. in 2009 conducted a study on energy absorption in the crash box with a quasi-static test using a variety of shapes, such as circles, squares, and rectangles using the same material and thickness. Based on the simulation results, found out that the value of energy absorption in the circle crash box is the highest absorption value compared to the other crash box shape [6] [8]. The study on the crash box with circle section also was conducted by Moch. Agus Choiron, aiming to reduce the buckling phenomena by adding segments in order the value of absorption energy and the pattern of deformation of the crash box became better. The segment on the crash box wall tended to be symmetrical in concertina mode [7].

Based on several studies, the development of crash box research still leads to simulations using software simulation FEM-Based (finite element method) with multi-segment circle shape which is predicted to be stable and increase the energy absorption reaching 92.1% in optimal cases [9]. FEM-based software for crash box research is still considered very interesting because reducing costs and facilitating the control of the system as an alternative design structure. In this study, a further study was conducted relating to energy absorption and the pattern of deformation resulting from the simulation of the three-segment crash box using the bilinear and JohnsonCook approach.

2. Research Method
The research method was quasi-experimental, namely by computer simulation using software FEM-based (Finite Element Method) which aimed to predict the results of experiments to be used as references to conduct real experiments. The Crash Box in this study was the crash box of a three-segment circle cross section with the research variables as follows:

2.1 The independent variable was a material of crash box of three-segments using the Bilinear and JohnsonCook approach.

The research dimension of the crash box was presented in Figure 4.

2.2 Dependent variable: energy absorption, force reaction, deformation pattern

2.3 Controlled Variable:
- The speed of Impactor is 7.67 m/s
- The length of crash box is 162 mm.
- The thickness of crash box is ± 1.2 mm.
- The Chamfer angle between segments is ± 45°
The crash box material used Al 6063-T5 with the specifications presented in table 1. Impactor assumed as a rigid body that crashed the crash box with a speed of 7.67 m/s. Gravity acceleration set at 9.81 m/s² in the direction of the impactor. At the bottom of the crash box, it set as fixed support.

Testing on the crash box is conducted by the quasi-static test method which was a destructive test to determine the crash box's ability toward the value of energy absorption. The procedure for crash box testing was by installing in the base of the test machine with steel support and subjected to axial compression.

| Properties             | Score |
|------------------------|-------|
| Density (kg/m³)        | 2700  |
| Young’s Modulus (MPa)  | 69000 |
| PoissonRatio           | 0.33  |
| Yield Strength (MPa)   | 180   |
| Tangent Modulus (MPa)  | 580   |

Mesh is the division of objects into smaller or finite parts. The smaller the meshing used, the more accurate the calculation results, but it requires large computing power. In this study, using an automatic meshing with explicit elements type and an 8-node brick type size of 1.3 mm are used for crash boxes and hexahedron 300 mm solid elements for impactor.

Simulation and loading in this study were carried out with the impactor and the crash box attached. The impactor is modeled as a rigid body while the crash box as a flexible body and fixed support type is positioned at the bottom of the crash box. In the simulation, the impactor moves towards the axial crash box which results in a deformation in the crash box with a simulation time of $1 \times 10^{-2}$ seconds.
3. Results and Discussion

3.1 Force Reaction

Force reaction is the force given by the crash box as a reaction to hold the impact of the impactor on each material connection variation and presented in figure 7 and 8.

**Figure 7.** The graph of crash box deformation-reaction force with a bilinear approach

**Figure 8.** The graph of crash box deformation-reaction force with a jhonsoncook approach
Figure 7 and Figure 8 showed the relationship between force and displacement in the crash box which simulated using the bilinear and jhonsoncook approach. The score of crash box force reaction carried out by the simulation with the jhonsoncook approach is higher than the bilinear approach. Based on the simulation, the crash box bilinear has a maximum force reaction value of 50491 N and the jhonsoncook crash box connection has a maximum force reaction value of 74636 N.

3.2 Energy Absorption

When the impactor hits the crash box, the energy impact from the impactor will be converted into strain energy which results in changes in the shape of the crash box. The strain energy is obtained through the area under the curve in figure 9 and figure 10 as an effort of the impactor, and the strain energy is assumed as the result of the kinetic energy conversion from the impactor [10]. Apart from the area under the curve, strain energy can also be obtained directly from the simulation.

![Figure 9. The graph of crash box deformation-reaction force with a bilinear approach](image)

![Figure 10. The graph of crash box deformation-reaction force with a jhonsoncook approach](image)

Figure 9 and Figure 10 showed the amount of energy absorption on each crash box model at the same displacement. The highest score of energy absorption found in the crash box model with a bilinear approach with energy absorption score of 8954 J and then the crash box with the jhonsoncook approach with energy absorption score of 8859 J. The following equations used to calculate the energy absorption:

$$ U = W = \int_0^\delta P(\delta) \, d\delta $$

Where:
- $U$ = Strain Energy (J)
- $W$ = Work (J)
\[ P = \text{Load (N)} \]
\[ \delta = \text{Displacement (m)} \]

The equation is an equation to find the strain energy or work. From the equation, the value of energy is directly proportional to the value of the load; so, the greater the value of the load, the greater the value of the energy. [14]

3. Pattern of Deformation

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure11.png}
\caption{The graph of crash box deformation-reaction force with a bilinear approach}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure12.png}
\caption{The graph of crash box deformation-reaction force with a Jhonsoncook approach}
\end{figure}

Figures 9 and 10 are deformation changes during the impactor hitting the crash box on each model. Found out that the crash box connection model with the bilinear approach has a better deformation pattern compared to the crash box with the Jhonsoncook approach. In general, the value of energy absorption can affect the deformation pattern produced at each connection of the crash box. The results of the crash box deformation pattern with the bilinear approach according to Velmurugan and Muralikannan (2009) in the study axially loaded test of crash box deformation pattern might occur in two modes, namely axisymmetric or called concertina and diamond where transversal and longitudinal folds are formed [6] [13].

4. Conclusion and Suggestion

Based on the discussion, concluded that the value of energy absorption and deformation patterns generated in the three-segment crash box using the bilinear and jhonsoncook approach had almost the same values of 8954 J and 8859 J. The deformation patterns tend to form the concertina and mixed patterns (concertina + diamond). Further research might discuss in real experiments and compare with simulation results.
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