The Effect Of Material Exposure Variations On Energy Absorption Capability And pattern Of Deformation Material Of Crash Box Of Three Segments

Willy Artha Wirawan, Akbar Zulkarnain, Hari Boedi Wahjono, Jamaludin, Ajeng Tyas Damayanti,
Indonesian Railway Academy

Email: willy@pengajar.api.ac.id;

Abstrak. Crash box is part of the supporting components on vehicle safety, especially cars. The crash box is designed to reduce the occurrence of driver’s injuries due to collisions. This study aimed to determine the capability of energy absorption and deformation patterns in the crash box using a three-segment circle cross-section. The research method was quasi-experimental with a simulation using Finite Element Method software. The crash box simulation carried out with a 200 kg impactor on a speed of 7.67 m/s. The independent variable in this study is the material exposure variation in the crash box using steel-aluminum-steel and aluminum-steel-aluminum. The dependent variables were energy absorption, force reaction and deformation patterns occurring in the crash box. Based on the simulation results, the values of energy absorption was 82452 J and force reaction was 1127700 N in the crash box of steel-aluminum-steel material. Meanwhile, the crash box material of aluminum-steel-aluminum has an energy absorption value of 236210 N, force reaction of 12432 J and a better and more stable on deformation pattern.

Keywords: multi-segment crash box, energy absorption, force reaction, computer simulation

1. Introduction
Indonesia is a country with a large population; so, it is increasing the use of private vehicles, especially cars. Along with the increasing number of vehicle users as supporting community mobility, the number of traffic accidents has increased quite high. World Health organization (WHO) provides a report with a title of the global report on road safety 2015, containing reports of traffic accidents in 180 countries. In this report, Indonesia is the third-ranked country in Asia in the death numbers due to traffic accidents after China and India which amounted to 38,279 [1].

By the increase in traffic accidents and high rates of death, this has led to policies of safety become the most important thing. The attention of the research in the field of vehicle safety engineering makes it very popular, especially the design of the car’s resistance. Cars are required to pass a crash test that allows the drivers to survive. In technological developments, many security systems are implemented by vehicle manufacturers, especially four-wheeled vehicles, namely crash boxes [2] [9].
The crash box is a passive safety system technology which has been studied lately because its function aims to absorb the kinetic energy when the car has collisions of 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 [3]. 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% [4].

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 compare the other crash box shape [5] [8] [7]. Based on various studies of crash boxes with predetermined impact velocities, there changes on plastic deformation. This shows the energy absorption in the crash box. However, the phenomenon indicates; the faster the plastic deformation changes in the crash box, the remaining speed of impact is still high which can endanger the main body of the vehicle. In this case, the safety of the driver and passengers are considered low. Therefore, research is carried out by adding segments to the crash box and material variations on the crash box. The addition of segment and material variations in each crash box segment are hopefullyable to reduce the buckling and increase the absorption of energy [6]. This particular study carried out by quasi-experimental testing through computer simulations using software based on the Finite Element Method.

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 material of crash box of three-segments using materials of aluminum-steel-aluminum and steel-aluminum-steel with the dimension presented in figure 2.
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.

| **Table 1. Material Properties Al 6063-T5** |
|------------------------------------------|
| **Properties** | **Score** |
| Density (kg/m³) | 2700 |
| Young’s Modulus (MPa) | 69000 |
| PoissonRatio | 0.33 |
| Yield Strength (MPa) | 180 |
| Tangent Modulus (MPa) | 580 |

| **Table 2. Material Properties AISI 1340** |
|------------------------------------------|
| **Properties** | **Score** |
| Density (kg/m³) | 8077 |
| Young’s Modulus (GPa) | 205 |
| PoissonRatio | 0.29 |
| Yield Strength (MPa) | 266.94 |
| Shear Modulus (GPa) | 76 |

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.

![Figure 3. Meshing Crash Box Results](image)

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.

![Figure 4. Software modeling (Finite Element Method)](image)

### 3. Result 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 5 and 6.
Figure 5. The graph of crash box deformation-reaction force with a material of steel-aluminum-steel

Figure 6. The graph of crash box deformation-reaction force with a material of aluminum-steel-aluminum

Figure 5 and Figure 6 showed the relationship between force and displacement in the crash box. It obtained model of crash box with material of steel-aluminum-steel which has the maximum highest score of force reaction of 1127700 N and material of aluminum-steel-aluminum of 236210 N. It based on the formula, as follows;

\[ P_{cr} = \frac{\pi^2 EI}{4L^2} \]

Where:
- \( P_{cr} \) = Critical Load (N)
- \( E \) = Modulus of Elasticity (MPa)
- \( I \) = Moment of the Section Inertia (m^4)
- \( L \) = Column Length (m)

The equation is an equation aiming to find the critical load of a structure. The critical load is the minimum load needed for a deformed structure. Based on the equation, the column length is inversely proportional to the critical load. The longer the structure, the smaller the critical load. In the crash box exposure with steel-aluminum-steel material has the highest score compared to the crash box using the material of aluminum-steel-aluminum exposure due to the differences in the hardness score of a material used by the crash box. Crash boxes that have an aluminum-steel-aluminum composition tend to occur buckling when impact factor entering each segment resulting in a low score.

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 7 and figure 8 as an effort of the impactor, and the strain energy is assumed as the result of the kinetic energy conversion from the impactor. Apart from the area under the curve, strain energy can also be obtained directly from the simulation.
Figure 7. The graph of crash box deformation-reaction force with a material of steel-aluminium-steel

Figure 8. The graph of crash box deformation-reaction force with a material of aluminium-steel-aluminium

Figure 7 and Figure 8 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 material of steel-aluminium-steel with energy absorption score of 82452 J and then the crash box with material of aluminium-steel-aluminium with energy absorption score of 12432 J. It because the model of exposure crash boxes with material of steel-aluminium-steel is able to distribute the high load in the next segment. 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)
- \( P \) = Load (N)
- \( \delta \) = 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.
3.3 Pattern of Deformation

Figure 9. The graph of crash box deformation-reaction force with a material of steel-aluminum-steel

Figure 10. The graph of crash box deformation-reaction force with a material of aluminum-steel-alumunium

Figure 9 and 10 are deformation changes during the impactor hitting the crash box of each model. Found out that the crash box connection model with the steel-aluminum-steel material has an imperfect form of deformation compared to the crash box with aluminum-steel-aluminum material because the crash box of steel-aluminum-steel material has an assembly point between segments which make a high factor impact and a hard deformation pattern.

4. Conclusion and Suggestion

Based on the discussion, concluded that the most optimal design was a multisegment crash box with a steel-aluminum-steel exposure that had a better impact value, but when viewed in a deformation pattern, a crash box could be used with an aluminum-steel-aluminum material. This research might suggest; (1) might carry out real experimental research about the circle crossing crash box aiming to compare the data, and (2) research on the cross-sectional crash box might be done with other variables.
5. References

[1] World health organization (WHO), 2015, the global report on road safety 2015, WHO/NMH/NMH/NVI/15.6.

[2] L. Morello, L.R. Rossini, G. Pia, A. Tonoli, 2011, The Automotive Body: Volume II: System Design, Springer Science & Business Media, Berlin.

[3] Rusinek A., R. Zaera, P. Forquin and J.R. Klepaczko, 2008, Effect of plastic deformation and boundary conditions combined with elastic wave propagation on the collapse site of a crash box. Laboratory of physics and mechanics of materials, France.

[4] X. Zhang, and You, Z., (2014), Energy absorption of thin-walled square tubes with a prefolded origami pattern-part I: geometry and numerical simulation. Journal of applied mechanics vol. 81..

[5] Velmurugan., dan Muralikanan. (2009): Energy Absorption Characteristics of Annealed Steel Tubes Of various Cross Sections in Static And Dynamic Loading. Latin American Journal Of Solids And Structures, Volume. 6, 2009 : 385 – 412.

[6] X. Zhang, G. Cheng, Z. You, H. Zhang, (2007), Energy absorption of axially compressed thinwalled square tubes with patterns, Thin-Walled Struct. 45. 737-746.

[7] M.A. Choiron, A. Purnowidodo, E. Siswanto, N.A. Hidayati, (2016), Crash Energy Absorption of MultiSegments Crash Box Under Frontal Load. Jurnal Teknologi. 347.

[8] J.Tanaskovic., dkk. (2014): Experimental Investigations Of The Shrinking – Splitting Tube Collision Energy Absorber, Journal Thin – Walled Structures. University of Belgrade, faculty of Mechanical Engineering, kralije, marije 16, belgrade, Serbia.

[9] Sumitomo. (2005): Sumitomo Metals and Toyota Iron Works Co. Ltd : New Mazda Incorporates High – Efficiency Crash Box from Sumitomo Metals. Japan : Azom.