Experimental Quasi-Static Test for the Energy Absorber Tube in High-Speed Train (HST)

Willy Artha Wirawan[1(✉)], Moch. Agus Choiron[2], Hari Boedi Wahjono[1], Fadli Rozaq[1], Natriya Faisal Rachman[1], and Maulana Jihan Alfana[1]

[1] Indonesian Railway Polytechnic, Tirta Raya Street, Manguharjo, Madiun 63161, Indonesia
willy@pengajar.ppi.ac.id

[2] Mechanical Engineering Department, Brawijaya University, Mayjen Haryono Street 165, Malang 65145, Indonesia

Abstract. A crash box is a passive device normally used to absorb impact energy during high-speed train accidents. Therefore, the focus of this study is to determine the ability of a circular crash box to absorb energy and its deformation pattern. The sample used was designed to have an outer diameter of 50 mm and a thickness of 1.5 mm while the length was varied at 100 and 200 mm. The experiment was conducted in the frontal collision direction using a quasi-static test approach with a UTM engine moving at a speed of 10 mm/s. The results showed that the crash box designed with 200 mm length had a lower energy absorption value of 2,414 J due to the buckling mechanism.

Keywords: Energy absorption · Crashworthiness · Passive safety · Quasi-Static

1 Introduction

There is currently a quite high increase in the operating high-speed of trains, thereby, making it important to implement several safety policies [1]. Different studies have been conducted on the feasibility of colliding train structures but the main challenge is the limited dimensions of their front end which mostly limits their energy absorption capacity. This signifies it is necessary to have several design considerations to ensure a more efficient energy absorption capacity [2]. It is important to note that conventional designs have provided opportunities for the development of new devices with high energy absorption capacity in a limited space at the end of the train (Figs. 1, 2 and 3).

Several designs of passive safety systems for trains have been widely examined in the last decade and multilevel tube design was proven very effective in absorbing energy in high-speed trains. Moreover, the tubes with circular cross-sections were reported to have the highest energy absorption value compared to those with square or rectangular shapes [4]. Another study by Hosseini Tehrani et al. studied the crashworthiness design at the end of a high-speed train and found that a longer and slimmer nose can absorb energy better [5]. It was further reported that a crash box device can prevent fatal damage to the end of the train in a situation of frontal collision [6, 7]. It also has the ability to

W. A. Wirawan et al. (Eds.): ICORT 2022, AER 220, pp. 96–103, 2023.
https://doi.org/10.2991/978-94-6463-126-5_11

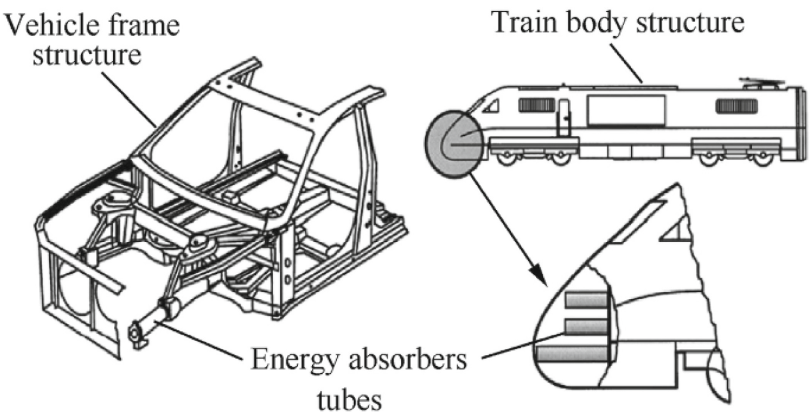

Fig. 1. Impact energy absorbing device [3]

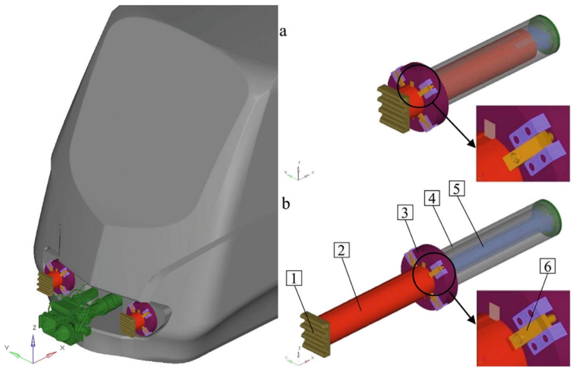

Fig. 2. The absorber (1 anti-climber gear 2. crush tube, 3. support tool, 4. Guide tube, 5. reversible actuator 6. die) [2]

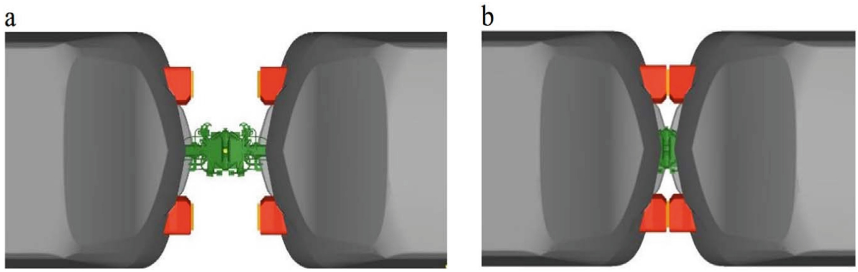

Fig. 3. Working principle of the typical thin-walled energy-absorbing structure: (a) railway vehicle coupling, (b) railway vehicle collision.

absorb as much as possible kinetic energy during the collision to be controlled by the deformation elements to reduce the force on the entire frame or structure [8, 9].

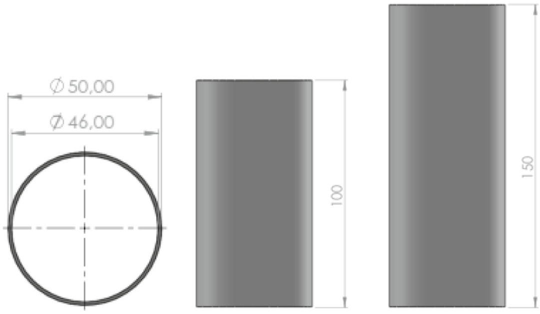

Fig. 4. Crash Box Design

Table 1. Properties of Al 6063 Material

Density	Melting point	Poisson Ratio	Modulus of elasticity	Tensile Strength	Shear Strength
2700	600 °C	0.3	70 GPa	195 MPa	160 Mpa

The studies showed the importance of using a crash box as a passive safety system device. Therefore, this study focuses on the experimental energy absorption capacity of tubes for high-speed trains. The purpose is to determine the effect of varying the tube length on the energy absorption capacity and the deformation pattern produced.

2 Research Method

This is an experimental study conducted through a direct test using a UTM (universal testing machine) machine. The goal was to obtain data on the force reactions and deformation patterns. The crash box used was designed in the form of a circular tube with the independent variable stated to be the length varied at 100 mm and 200 mm while the dependent variables were the energy absorption and deformation pattern. Meanwhile, the controlled variables include 10 mm/s crash speed, 1.5 mm tube thickness, and the 50 mm outer diameter. The design of the energy-absorbing crash box tube used in this study is presented in Fig. 4.

The material used to design the crash box was aluminum type 6063 and the properties are listed in the Table 1. Moreover, the quasi-static test was conducted using a UTM machine with the impactor and pedestal observed to be in the form of rigid objects and was used to press the crash box tube at a speed of 10 mm/s and gravity of 9.8 m/s (Fig. 5).

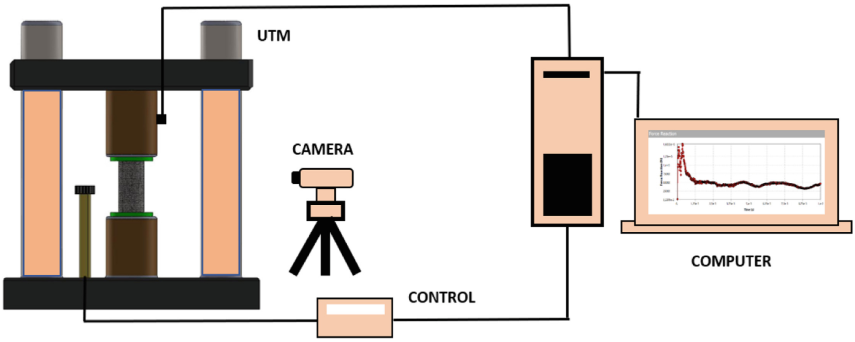

Fig. 5. Schematic Diagram of the Experimental Quasi-Static Test

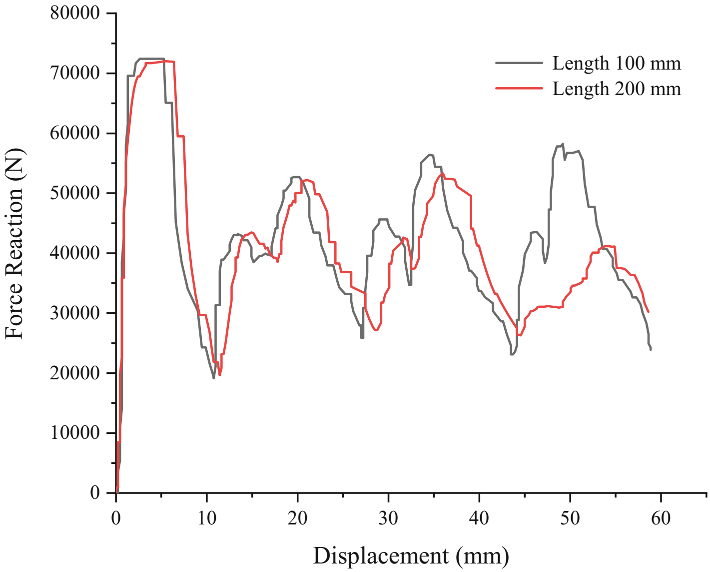

Fig. 6. Force Reaction

3 Result and Discussion

Several characteristics were identified in studying the application of crash box as a passive security device and these include IPFC (Initial Peak force), MF (Mean Force), SEA (Specific Energy Absorption), and EA (Energy Absorption) while the experimental quasi-static test showed the deformation patterns. Moreover, the force reaction was generated when the crash box resisted the impact of the impactor on the length at different variations of 100 mm and 200 mm as indicated in Fig. 6.

Figure 7 shows the relationship between force and displacement on the crash box tested as a function of its resistance to quasi-static compressive loading. It was discovered that the force reaction at 100 mm length has an average MF value of 37,271 N which is

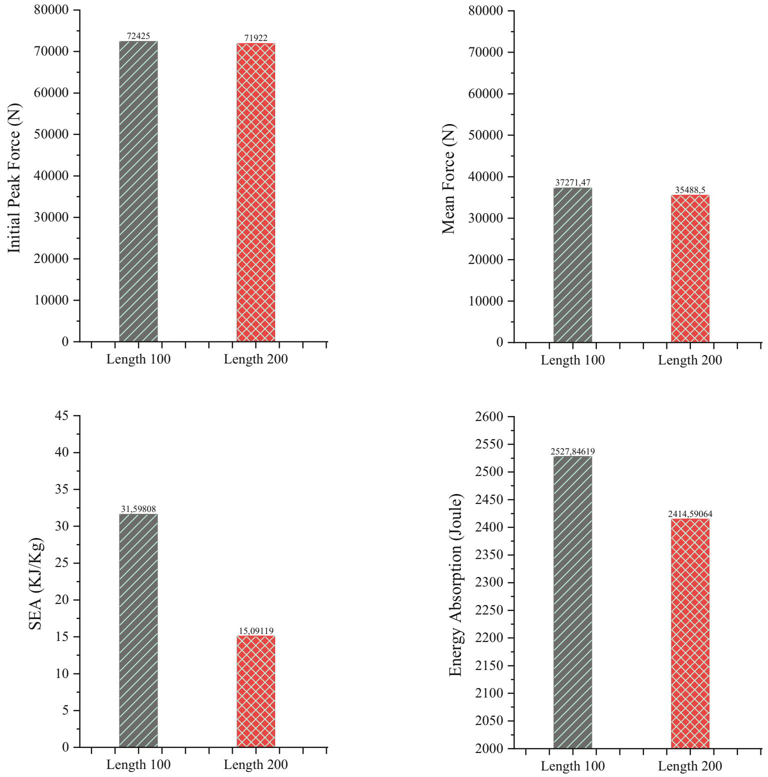

Fig. 7. (a) Initial Peak Force (b) Mean Force (c) Specific Energy Absorption (d) Energy Absorption

higher than the 35,488 N recorded for 200 mm. This implies the reaction force of the impactor in the shorter design was evenly distributed and more stable while the longer size was unstable and allowed a buckling mechanism.

The IPFC is the initial peak point for the formation of the folding mechanism due to the collision force. It was discovered at the beginning of the loading that the 100 mm tube has a higher IPFC value of 72,427 N and this can lead to bad impacts leaving injury and very severe damage because the energy cannot be directly absorbed by the crash box. Meanwhile, the longer size with 200 mm has a better value of 71,922 N.

The impact energy of the impactor when it hits the crash box tube was converted into strain energy which subsequently caused a change in the deformation shape. The strain energy was determined based on the area under the curve of the force reaction graph as the work accomplished by the impactor. This is the reason it is assumed to be the result of the conversion of the kinetic energy produced by the collision [6]. It was observed from the experimental results that the 100 mm tube has an absorption value of 2,527 J which is higher than the 2,414 J recorded for the 200 mm tube. The low energy absorption value in the long tube dimension is caused by an uneven or stable load distribution which led to buckling.

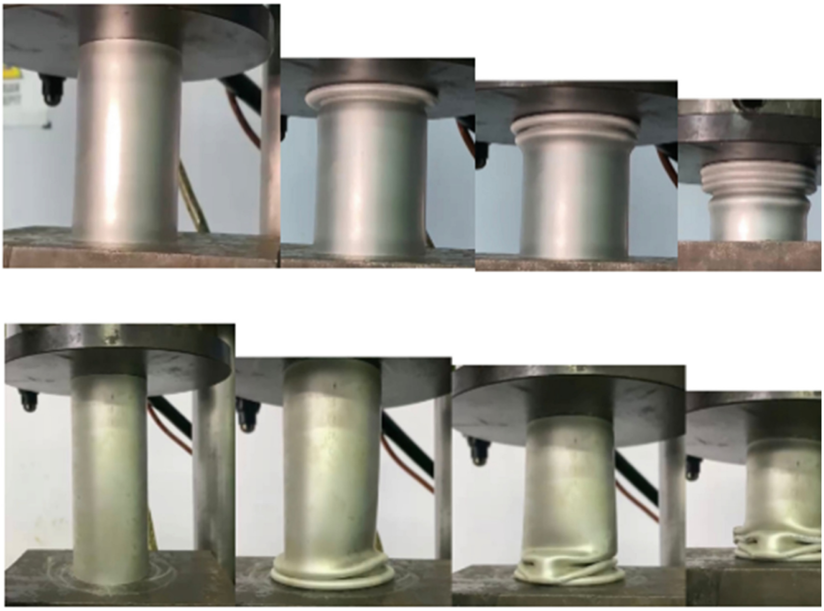

Fig. 8. Folding Mechanism (a) 100 mm tube (b) 200 mm tube

This shows the tube with longer dimensions has a good IPFC as indicated by the small value, therefore, it is possible to apply a long nose shape to the end of the train [2]. However, the selected option has the potential to experience a buckling mechanism which further leads to low energy absorption capacity [5].

4 Deformation Pattern

The deformation pattern was formed when the impactor hits the crash box. It was discovered that the 100 mm crash box has an imperfect pattern compared to the 200 mm dimension. However, the 200 mm specimen tends to experience buckling because the deformation process occurs when the impactor hits the tube first at the bottom, thereby, forming a mix-mode pattern in the form of concertina and diamond [10]. An increase in the load was observed to have caused the top tube to experience diamond deformation which led to buckling and a reduction in energy absorption [11] (Fig. 8).

Figure 9 shows that the crash box with the shorter size experienced better deformation, hence the load was distributed evenly and stably when the impactor hits the tube. The tube subsequently formed a ring or concertina deformation pattern from the top end to the bottom end and this has been proven in a previous study to have the best absorption capacity compared to the other patterns [4].

Fig. 9. Final deformation pattern

5 Conclusion

The experimental results showed that the crash box with short dimensions of 100 mm has a superior value in terms of IPFC (Initial Peak force) with 72,425 N, MF (Mean Force) of 37,271 N, SEA (Specific Energy absorption) of 31.59 kJ/Kg, and EA (Energy Absorption) with 2,527 J. Moreover, its deformation formed a Concertina pattern while the long dimension experienced a buckling mechanism. This implies the train nose should be designed with a longer tube as a passive safety technology due to its lower IPFC value which indicates it is safer during the initial collision. It is, however, important to note that this choice has the potential for a buckling mechanism that can reduce its energy absorption capacity.

Acknowledgement. This is part of the research collaboration between cadets and lecturers that received funding support through the research center and community service of Indonesian Railway Polytechnic of Madiun.

References

1. M. A. Choiron, "Characteristics of deformation pattern and energy absorption in honeycomb filler crash box due to frontal load and oblique load test," *Eastern-European J. Enterp. Technol.*, vol. 2, no. 7–104, pp. 6–11, 2020, doi: https://doi.org/10.15587/1729-4061.2020.200020.

2. G. Gao, W. Guan, J. Li, H. Dong, X. Zou, and W. Chen, "Experimental investigation of an active–passive integration energy absorber for railway vehicles," *Thin-Walled Struct.*, vol. 117, no. March, pp. 89–97, 2017, doi: https://doi.org/10.1016/j.tws.2017.03.029.
3. A. B. M. Supian, S. M. Sapuan, M. Y. M. Zuhri, E. S. Zainudin, and H. H. Ya, "Hybrid reinforced thermoset polymer composite in energy absorption tube application: A review," *Def. Technol.*, vol. 14, no. 4, pp. 291–305, 2018, doi: https://doi.org/10.1016/j.dt.2018.04.004.
4. R. Velmurugan and R. Muralikannan, "Energy absorption characteristics of annealed steel tubes of various cross sections in static and dynamic loading," *Lat. Am. J. Solids Struct.*, vol. 6, no. 4, pp. 385–412, 2009.
5. P. Hosseini-Tehrani and A. Nankali, "Study on characteristics of a crashworthy high-speed train nose," *Int. J. Crashworthiness*, vol. 15, no. 2, pp. 161–173, 2010, doi: https://doi.org/10.1080/13588260903094418.
6. M. A. Choiron, A. Purnowidodo, E. S. Siswanto, and N. A. Hidayati, "Crash energy absorption of multi-segments crash box under frontal load," *J. Teknol.*, vol. 78, no. 5, pp. 347–350, 2016, doi: https://doi.org/10.11113/jt.v78.8334.
7. S. Widi Astuti, W. Artha Wirawan, A. Zulkarnain, and D. Tri Istiantara, "Comparison of Energy Absorption and Pattern of Deformation Material Crash Box of Three Segments with Bilinear and Johnson Cook Approach," *J. Phys. Conf. Ser.*, vol. 1273, no. 1, 2019, doi: https://doi.org/10.1088/1742-6596/1273/1/012078.
8. S. Reddy, M. Abbasi, and M. Fard, "Multi-cornered thin-walled sheet metal members for enhanced crashworthiness and occupant protection," *Thin-Walled Struct.*, vol. 94, pp. 56–66, 2015, doi: https://doi.org/10.1016/j.tws.2015.03.029.
9. W. Artha Wirawan, A. Zulkarnain, H. Boedi Wahjono, Jamaludin, and A. Tyas Damayanti, "The Effect of Material Exposure Variations on Energy Absorption Capability and pattern of Deformation Material of Crash Box of Three Segments," *J. Phys. Conf. Ser.*, vol. 1273, no. 1, 2019, doi: https://doi.org/10.1088/1742-6596/1273/1/012081.
10. F. Djamaluddin, S. Abdullah, A. K. Ariffin, and Z. M. Nopiah, "Optimization of foam-filled double circular tubes under axial and oblique impact loading conditions," *Thin-Walled Struct.*, vol. 87, pp. 1–11, 2015, doi: https://doi.org/10.1016/j.tws.2014.10.015.
11. A. A. A. Alghamdi, "Collapsible impact energy absorbers: An overview," *Thin-Walled Struct.*, vol. 39, no. 2, pp. 189–213, 2001, doi: https://doi.org/10.1016/S0263-8231(00)00048-3.