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Energy Absorption and Deformation Pattern Analysis of Crash Box with Tapered Wall Angle and Trigger Circles under Quasi-Static Loading

M. Sabri*[1], Otniel W. C. Simanjuntak*[2]
[1,2,3] *Department of Mechanical Engineering, Faculty of Engineering, University of North Sumatra, Medan, 20155, Indonesia*
*Corresponding Author: sabrimesin@gmail.com, nielchristian.7manjuntak@gmail.com

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ABSTRACT
Crash box is a passive safety system that is used to reduce the severity of accidents experienced by passengers or vital vehicle parts due to collisions. This study examines the effect of variations in the tapered wall angle and trigger ci rcles in a circular crash box on energy absorption and deformation patterns in a quasi-static loading simulation test. The research was conducted using software based on the Finite Element Method (FEM). The variations used in this study are crash boxes with tapered angles of 1° and 5.7° and the location of trigger circles A, B, C and D with Aluminum 6061-T4 crash box material. From the research results it was found that the deformation pattern formed was an axial pattern with a mixed mode (concertina + diamond). Mixed mode deformation occurs in the crash box tapered angle of 1° and 5.7°. The absorption with the greatest ability to absorb energy is in a crash box with a tapered angle (α) of 5.7° of 3124.0 J.
Keyword: Crash Box, Angle Tapered, Trigger Circles, Deformation Pattern, Energy Absorption

ABSTRAK
Crash box merupakan sistem keselamatan pasif yang digunakan untuk mengurangi tingkat keparahan kecelakaan yang dialami penumpang atau bagian kendaraan yang vital akibat tabrakan. Penelitian ini meninjau pengaruh variasi sudut tirus dinding dan *trigger circles* pada *crash box* berpenampang lingkaran (*circular*) terhadap penyerapan energi dan pola deformasi pada uji simulasi pembebanan *quasi-static*. Penelitian dilakukan dengan software berbasis *Finite Element Method* (FEM). Variasi yang digunakan dalam penelitian ini yaitu *crash box* dengan sudut tirus 1° dan 5,7° dan letak *trigger circles* A, B, C dan D dengan material *crash box* Aluminium 6061-T4. Dari hasil penelitian diperoleh bahwa pola deformasi yang terbentuk adalah pola aksial dengan mode campuran (*concertina* + *diamond*). Deformasi mode campuran terjadi pada *crash box* sudut tirus 1° dan 5,7°. Penyerapan dengan kemampuan menyerap energi terbesar pada *crash box* dengan sudut tirus (α) 5,7° sebesar 3124,0 J.
Keyword: *Crash Box*, Sudut Tirus, *Trigger Circles*, Pola Deformasi, Penyerapan Energi

1. Introduction

World health organization (WHO) provides a report with a title of the global report on road safety 2018, containing reports of traffic accidents in 175 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 31,726 [6]. Increasing traffic density, which results in high traffic accidents, encourages decision makers to consider and use safety as a major research topic in the field of vehicle technology.

In the production process, car components go through a more complex and complicated process which has implications for quite high costs. This also applies to the repair process if the car is damaged in an accident. Therefore, a safety tool is used that can reduce damage in the event of an accident, where this tool is included in a passive safety system.

Crash box is a passive safety system technology that has been studied a lot lately, because its function is to absorb kinetic energy when a car collides in the event of an accident, both front and rear collisions. Crash boxes are designed to reduce the occurrence of forces acting on the entire vehicle structure during a collision. Therefore, a crash box device is installed between the support and the vehicle frame because it functions as an energy absorbing component.

Velmurugan et al. (2009) conducted a study on the specific energy absorption characteristics of tubes with circular, square and rectangular sections. The energy absorption results for tubes with circular cross-sections were higher than for tubes with square and rectangular cross-sections [5]. Choiron M.A. et al. (2015) conducted a study on circular cross-section crash boxes by varying the tapered wall angle (α) 0.2°; 0.4°; 0.6°; 0.8°; and 1.0° for energy absorption and deformation patterns by obtaining the greatest energy absorption results found in the crash box model with a tapered wall angle of α 1.0° of 10823 J [4]. Nasution A. Y. et al. (2023) also conducted research on the energy absorption of crash boxes with a combination of frustrated shapes, cross sections and trigger circles. The energy absorption results were 142.66 kJ at 0.005 s, load 5728 kN and displacement 57 mm [2].

It is from this background that further research is needed to obtain better energy absorption capabilities in the event of an accident. In addition, it can be determined that the optimal deformation behavior of the crash box in greater energy absorption. The development of increasingly advanced technology, numerical simulations can be used to predict the amount of energy absorption and deformation pattern of the crash box before conducting experimental research. With a circular cross section model combined with tapered wall angles and trigger circles in the hope of getting optimal energy absorption to reduce the impact of the collision.

2. Methods

The research method was quasi-experimental, namely by computer simulation using 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 tapered wall angle and trigger circles circular cross section as follows;

2.1. Geometric speciment

In this study, a crash box model was used with circular tubes which had trigger circles with tapered angle variations on the wall. Geometry has diameter = 100 mm, thickness = 2 mm and length = 100 mm as shown in the Figure1.

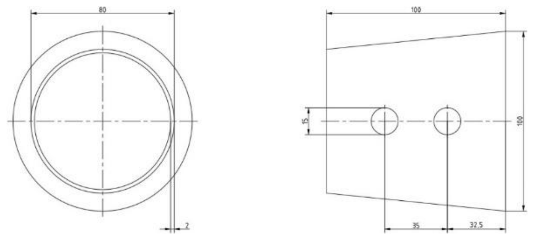


Figure 1. Crash box design

The parameter design of this study are the crash box circular geometry with variation tapered angle and location of trigger circles. All model specifications are shown in Table 1

Table 1. Parameter design

Model	Tapered Angle	Trigger Circles Location
1	5.7°	1 Face (A)
2	5.7°	2 Face (B)
3	5.7°	3 Face (C)
4	5.7°	4 Face (D)
5	1°	1 Face (A)
6	1°	2 Face (B)
7	1°	3 Face (C)
8	1°	4 Face (D)

2.2. Material model

The crash box and impactor materials used in this study are Aluminum 6061-T4 with a bilinear isotropic hardening plasticity model and Structural Steel. The material properties taken from data by Choiron M A [3].

Table 2. Parameters for Aluminium 6061-T4 and Structural Steel

Properties Material	**Al 6061-T4**	**Structural Steel**
Density ($\mathbf{kg/m^3}$)	2790	$5{,}2436 \times 10^5$
Modulus Elasticity (MPa)	70000	2×10^5
Poisson's Ratio	0,33	0,3
Yield Strength (Mpa)	145	240
Tangent Modulus (MPa)	450	1450
Specific Heat ($\mathbf{J\ kg^{-1}C^{-1}}$)	896	434

2.3. Finite element model

The finite element analysis software MSC Patran 2022 is used to carry out the numerical simulation analysis. Crash box model consists of three parts: the impacting rigid plate, the flexible crash box and fix support condotion, as shown in figure 2. In this modeling, the impactor position has no distance from the crash box and the impactor load velocity of 5 mm/s until 64 mm final deformation is obtained. In this study are 2 mm and automatic mesh was used to mesh crash box and impactor sequentially.

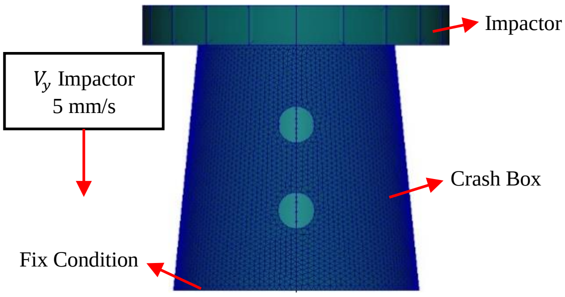


Figure 2. Meshing and testing model

3. Results and Discussion

The amount of energy absorption from each model due to load can be seen in Table 3 and the deformation patterns are shown in Figure 4-6.

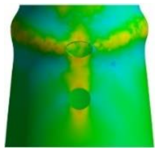
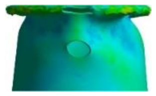
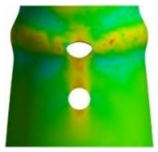
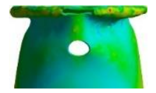
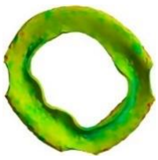
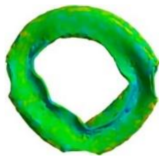
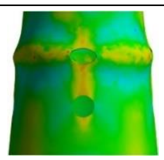
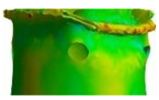
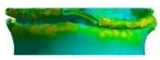
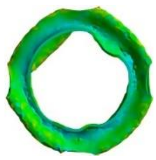
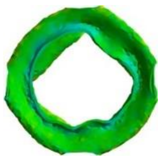
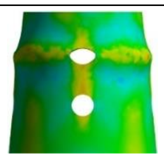
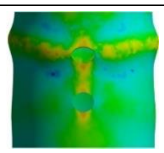
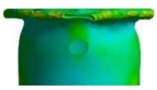
Table 3. Energy absorption value due to load

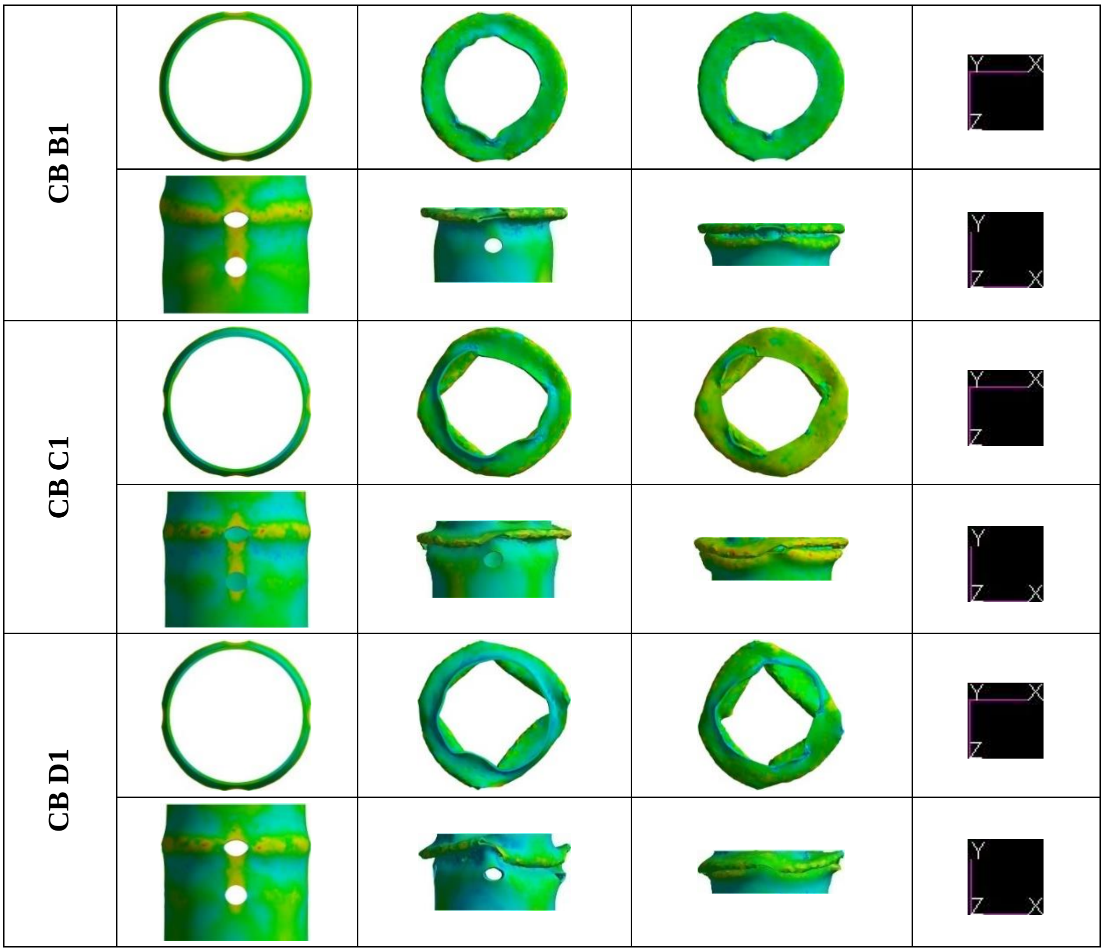
Model ke-n	$\boldsymbol{\delta}$ **(mm)**	$\boldsymbol{P_{max}}$ **(N)**	$\boldsymbol{P_{mean}}$ **(N)**	$\boldsymbol{E_a}$ **(J)**
1	63,995	75222	48236,39	**3124.0**
2	63,994	74656	43105,29	2793.1
3	63,994	71165	41898,76	2709.7
4	63,997	68131	39640,88	2567.8
5	63,996	**88559**	47807,22	**3101.7**
6	63,992	**85054**	45986,34	2984.7
7	63,994	**81136**	47505,05	**3072.8**
8	63,991	78176	47048,56	3025.9

The energy absorption E_a value based on Table 3 can be sorted into 3 models from the largest, namely models 1, 5, and 7. The energy absorption values of the three models sequentially can be written as follows 3124.0 J, 3101.7 J and 3072.8 J. The magnitude of the energy absorption value is influenced by the P_{mean} value and changes in the length of the specimen. The P_{mean} values for the three models are 48236.39 N, 47807.22 N, and 47505.05 N respectively, indicating that the order of magnitude of energy absorption corresponds to the order of the P_{mean} values. The value of the change in length also affects the value of energy absorption, but because there is no significant difference in the value of the change in length in the three models, the change in length can be assumed to be the same.

Thin-walled tubes or crash boxes have four possible deformation patterns when subjected to quasi-static loading, namely concertina (axisymetric), diamond (non-axisymetric), mixed mode, and Euler buckling. Deformation pattern is analyzed based on visual observations on the simulation results. The deformation pattern on the simulated crash box is set as 64 mm final displacement.

Table 4. Deformation pattern of crash box

Crash Box	**Displacement**			**Sumbu**
	4,8 mm	**32 mm**	**64 mm**	
CB A5.7				
				
CB B5.7				
				
CB C5.7				
				
CB D5.7				
				
CB A1				
				



4. Conclusion

In this study, effect of placement trigger circles and tapered angle on crash box subjected to quasi-static loading is determined. The highest energy absorption is achieved in the model-1 design with tapered angle 5.7° and 1 face of trigger circles as 3124.0 J. Deformation pattern formed in the crash box which has a larger tapered angle will dominantly form a diamond pattern and the influence of the location of the trigger circles that are not opposite each other will produce the same deformation pattern diamond too.

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