Energy Absorption Analysis of Composite Crash box by Finite Element Method

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Abstract. Safety in driving is certainly an important aspect. One of the efforts to maintain safety in driving is to have a solid vehicle structure, including a crash box. The crash box is thin-walled tube used as an energy absorber during the impact. The structure requires strong and lightweight materials; thus, the application of composite is often considered. This study investigated the energy absorption of the crash box made of carbon Pyrofil-HR40. The quasi-static analysis was performed by using the finite element software of LS-DYNA. The effects of the geometry and thickness of the crash box on the specific energy absorption were studied. It was found that the same diameter and thickness circular tubes had larger specific energy absorption with value 30.842 kJ/kg than that of the square with value 20.342 kJ/kg.

Keywords: Energy absorption, composite, crash box, quasi-static, finite element method.

1 Introduction

Vehicles are used to transport humans to ease the daily activities. Safety in driving is certainly an important aspect for the vehicle occupants. One of the efforts to maintain safety in driving is to have a solidvehicle body structure. According to Miyanishi [1], the weight of the vehicle is dominated by the body component by 30%. So the body structure of the vehicle has an important role in safety, and performance. The selection of lightweight and strong materials becomes a solution to suppressing 30% of that weight. It is also expected to improve the safety of the drivers. Based on the Insurance Institute for Highway Safety (IIHS) data, the number of driving accidents is quite high, especially the case of crashes from the front, which is around 52% [2]. The purpose of developing good structural conditions is to protect people in case of accidents or collisions. Crashworthiness analysis has been carried out in all the important structures found in vehicles,such as vehicle frames [3].

Crashworthiness has several aspects that must be met, including economic, strength, and load. Some vehicle components are classified as accident energy absorbent structures. Energy

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absorbent structures, such as bumpers and crash boxes on the front and rear of the vehicles are important components in the crash studies. The structure of the crash box serves as an energy-absorbing component of the vehicle's structure in the event of a collision. As a passive safety system in the vehicle, the structure of the crash box is expected to be able to absorb the energy resulting from the front and rear hit accidents. The crash box is designed to reduce the impact of an accident within safe limits according to its capacity. So it may minimize the possibility of injury to vehicle passengers during collisions. The use of aluminum and composite materials in crash boxes has been widely researched. The characteristics of both materials are well known to be light and strong, to realize the strong characteristic of a crash box, of course it takes an efficient crash box geometry, the most familiar strong crash box material between square geometry and circular geometry, beside strong, they are also known to be easy to make. The crash box experiments with composites have been reported to have an advantage over energy absorption values greater than metals [5].

This paper presents the analysis of the largest of the energy absorption of the crash box made between aluminum 6061-T6 and carbon Pyrofil-HR40. The quasi-static analysis is carried out by using the finite element software of LS-DYNA. The effects of geometry especially square and circular, with various thicknesses of the crash box on the specific energy absorption are studied.

2 Crash box

Some structures of automobiles are classified as accident energy absorbent limb structures. Energy absorbent structures, such as bumpers and crash boxes, are both major subjects in any crashworthiness study. Crash boxes installed in the front and rear areas of vehicles (between the bumper and front rail) have thin wall structures made of metal or composite materials. The crash box serves as an absorber of crash energy and reduces the impact that occurs against the vehicle frame during an accident. Crash boxes have general criteria that must be fulfilled for vehicle safety. The crash box has also an economic point of view for the repairing cost, namely minimizing the impact of damage to the vehicle frame structure. The crash box is a disposable component that shall meet the cost requirements. The crash box models are illustrated in **Figure 1**.

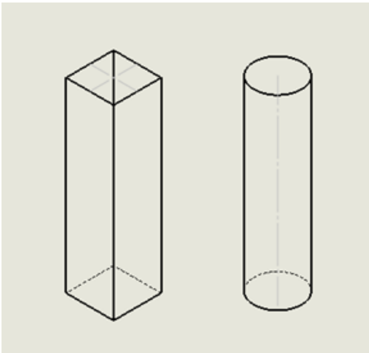

Fig 1. Crash box models.

Crashworthiness simulations shall consider the importance of efficient analysis in representing the models. Crashworthiness isthe ability of a structure to absorb energy in the event of an accident or impact to protect passengers on the vehicle. In addition to being a passenger safety, crashworthiness also serves to minimize the impact of accidents on vehicle structures. Crashworthiness has an important role in determining the exact location of the crash box point so that the damping of the impact of the accident can be maximal during the accident that is an unpredictable danger [3]. The criteria of effective crashworthiness in the event of an accident are as follows:

- The passenger compartment of the vehicle shall have minimal deformation.
- The vehicle shall have sufficient space for t h e passengers to be safely protected.

This present study uses crash box models (see **Figure 1**) that have circular and square geometries for different cross-sectional areas and thicknesses as presented in Table 1.

Table 1. Geometry parameters of the crash box models.

Code	Diameter (mm)	Thickness Inward (mm)
Al. 6061-T6	45.9	1.05
45.9 Sq. (1.05)	45.9	1.05
45.9 Cyl. (1.05)	45.9	1.05
46.3 Cyl(.0525)	46.3	0.525
46.3 Cyl. (1.05)	46.3	1.05
46.3 Cyl. (1.57)	46.3	1.575

3 Mechanical properties

Aluminum alloy 6061-T6 and carbon Pyrofil-HR40 are used in the simulations. The properties of both materials are shown in **Tables 2** and **3**.

Table 2. Mechanical properties of Al 6061-T6.

Aluminum Alloy 6061-T6	
Density (gr/mm³)	0.0027
Poisson’s Ratio	0.33
Modulus Elastisitas(Gpa)	69.8
Tensile Strenght, Ultimate (GPa)	0.310
Tensile Strength (GPa)	0.276

4 Finite element modelling

The ANSYS LS-DYNA software is suited toanalyze the large deformations and complex contact interactions in crash simulations. Low velocity impact-loading is predicted by using an explicit non-linear dynamic feature.The crash box is modeled using Belytschko-Lin-Tsay four-nodes thin shell element with a meshing size of 2 x 2 mm² [6]. The crash box model uses linear piecewise plasticity and enhanced composite damage type material. The crash box test is axially subjected to the impactor weight of 290 kg and has a velocity of 7.08 m/s as shown in Figure 2. According to (Jusuf, 2014), the assumption about the weight and speed of the impactor is influenced by the reference journal, which uses the Computational Solid Mechanics and Design Laboratory-Korea Advanced Institute of Science and Technology (CSMD Laboratory-KAIST), so the authors use the same conditions. The tester object is considered to be a rigid body that does not allow any deformation.

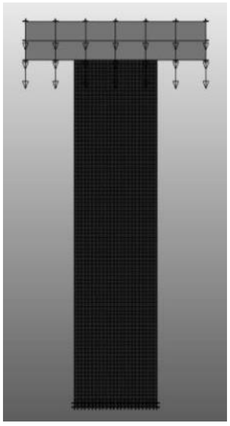

Fig 2. Modelling of axial crash test.

5 Validation of numerical simulation

The validations are made based on the experimental works (**Table 4** and **Figure 3** on the metal and **Table 5** on the composite). The results by the theoretical approach is shown in **Table 6**.

Table 4. Validation of the experimental results [7].

Crashworthiness Parameter	Experiment	Simulation	Error (%)
Deformation (mm)	70.3	70.571	0.38
Peak Load (kN)	106.5	101.215	5.21
Mean Load (kN)	52.86	51.91	1.82
SEA (kJ/kg)	17.5	16.651	5.09

Fig 3. ASTM A322 axial crush test [7].

Table 4 shows a validation to the experimental results [7] that was conducted on the crash box with ASTM A322 metal material as shown in **Figure 3**. It shows a maximum error of 5.21%. Meanwhile, **Table 4** shows a validation to the experimental results [8] that was conducted on the crash box with E-Glass composite as shown in **Figure 4**. It shows a maximum error of 2.6%.

Table 5. Validation to the experimental results [8].

Crashworthiness Parameter	Experiment	Simulation	Error (%)
Deformation (mm)	60	59.08	1.55
SEA (kJ/kg)	18.19	17.728	2.606

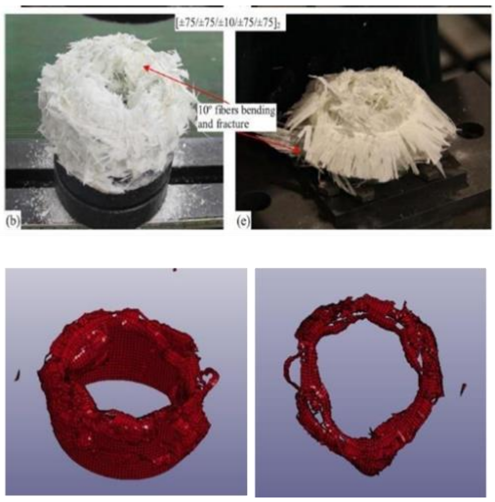

Fig 4. E-Glass /PET199 axial crush test [8].

Table 6. Validation to the theoretical calculations [9].

Model	SEA (Kj/kg)	Error(%)
Aluminum 6061-T6	15.95688	1.29
45.9 Sq (1.05)	20.94188	2.94
45.9 Cyl (1.05)	31.43127	1.91
46.3 Cyl (0.525)	25.2849	3.367
46.3 Cyl (1.05)	32.132	2.11
46.3 Cyl (1.575)	39.6029	3.37

Table 6 shows the results of theoretical calculation errors to the present simulations, The parameters of crashworthiness considered in the present study are energy absorption (EA), mean load, and specific energy absorption (SEA) [9]. Equations (1) – (3) are respectively used to calculate the energy absorption, mean load and specific energy absorption.

$$EA = \int_{0}^{S_b} PdS \quad (1)$$

$$P_{mean} = \frac{EA}{\delta_{max}} \quad (2)$$

$$SEA = \frac{EA}{mass} \quad (3)$$

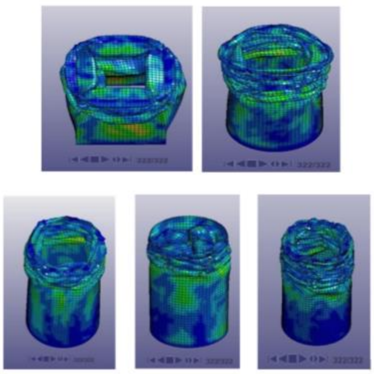

Fig 5. Carbon Pyrofil-HR40 and Aluminum 6061-T6 axial crush test simulation.

Figure 5 shows the deformations of aluminum alloy and Pyrofil-HR40 under the axial crush simulations, Aluminum 6061-T6 is shown to have linear deformation, while Pyrofil-HR40 has a form of the progressive folding deformation which is preferable in crashworthiness.

6 Result and discussion

The crash box simulation with aluminum alloy and carbon Pyrofil-HR40 materials presented in Table 7, it shows crashworthiness test modeling of simulations conducted, some of these models include variations in geometric geometries, the thickness of structure walls, and surface area.

Table 7. The simulation results.

Materials	Mass (kg)	Peak Load (kN)	Mean Load (kN)	*Energy Absorption*(J)	Deformation (mm)	Specific Energy Absorption (kJ/kg)
Al. 6061-T6	0.094	52.896	13.87	1475.89	106.38	15.753
45.9 SQ (1.05)	0.0543	61.082	10.2	1104.60	108.47	20.342
45.9 CYL (1.05)	0.0419	71.137	12.1	1293.949	107.29	30.842
45.9 CYL (1.05)	0.0211	31.37	4.66	517.638	111	24.461
45.9 CYL (1.05)	0.0423	71.706	12.4	1331.08	107.68	31.467
45.9 CYL (1.05)	0.0634	109.184	25.6	2601.77	101.67	40.984

Figure 6 shows that the largest axial force value is found in the Pyrofil-HR40 carbon with a diameter of 46.3 mm, a thickness of 1.575 mm, and a length of 180 mm. The larger diameter and thickness are desirable parameters for the carbon Pyrofil-HR40 with the circular geometry of the crash box having smaller deformations. The circle geometry has a larger axial force by 14.32% than that of the square geometry.

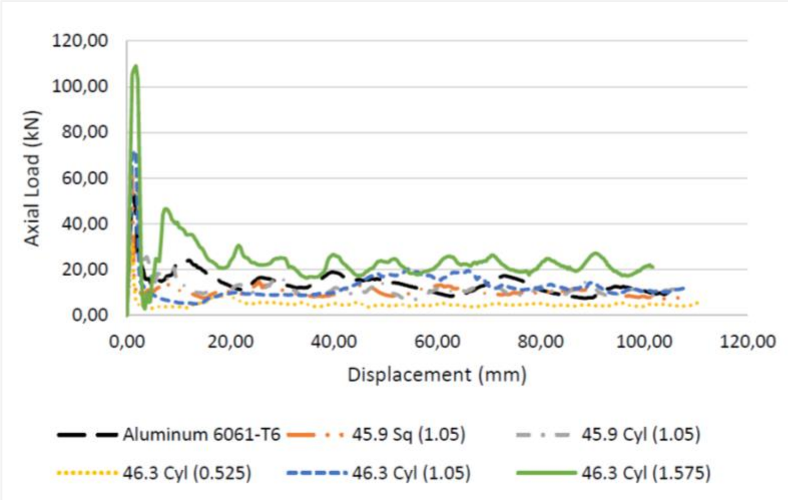

Fig 6. Crushing responses.

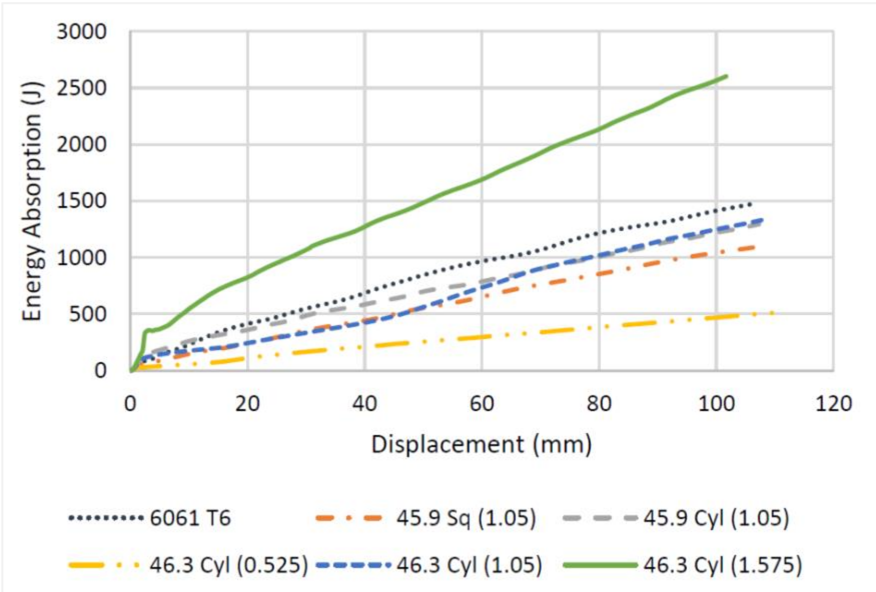

Fig 7. Energy absorption responses.

Figure 7 presents the energy absorption value of crash box models for different materials and geometry parameters. It can be seen from Figure 7, that the largest value of energy absorption is observed in the crash box of 46.3 Cyl (1.575),around 2601.77 J. It simply means that the axial force value is proportional to the energy absorption value. For a given geometry, the carbon 45.9 Sq (1.05) has the larger axial force and energy absorption than those of aluminum 6061-T6. Figure 8 shows the specific energy absorption of the crash box models.The largest specific energy absorption \value is found in the crash box made of carbon Pyrofil-HR40. The carbon Pyrofil-HR40 has a lighter weight than that of aluminum 6061-T6. Figures 9 and 10 show that the specific energy absorption increases as the diameter and wall thickness of the crash box increase. It can be seen from Figure 11 that the circular geometry possesses a larger specific energy absorption than that of the square geometry.

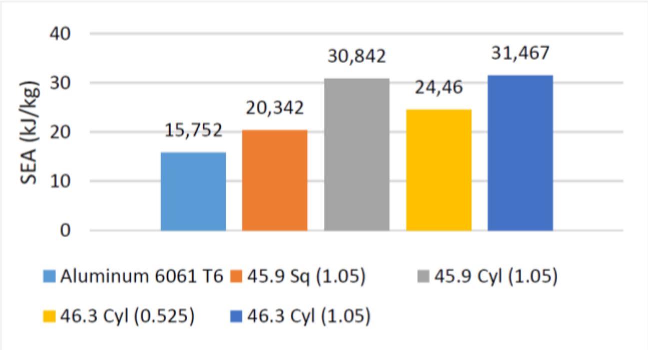

Fig 8. Specific energy absorption responses.

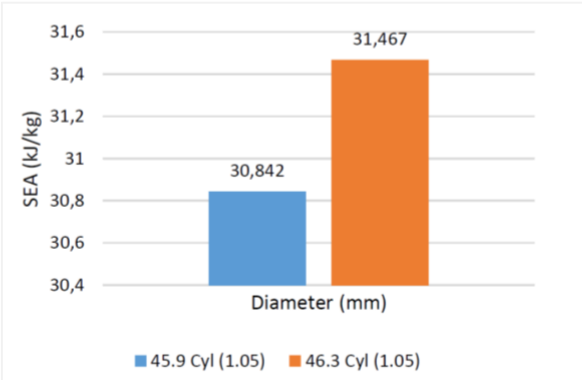

Fig 9. Surface area comparison.

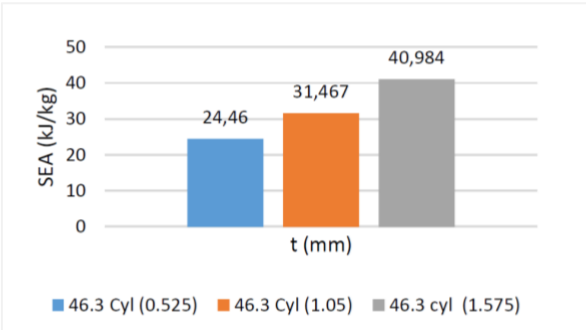

Fig 10. Thickness comparison.

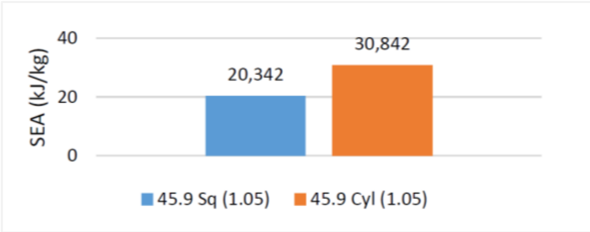

Fig 11. Geometries comparison.

7 Conclusion

Based on the crashworthiness simulation results by the finite element using the quasi-static testing method, drawn as follows :

- Al 6061-T6 had the smaller deformation or larger energy absorption larger than that of carbon fiber Pyrofil-HR40.
- In comparison to Al 6061-T6, the specific energy absorption of carbon fiber Pyrofil-HR40 is desirable in the crashworthiness. The Al 6061-T6 had a smaller specific emergy absorption (SEA) value than Pyrofil HR-40 with a difference in the value of 4.59 kJ/kg with square geometry and 1.05 mm thickness.
- The specific energy absorption increases as the diameter and wall thickness of the crash box increase.
- The circular geometry had larger specific energy absorption (SEA) than that of the square geometry.

So, the carbon Pyrofil-HR40 had more specific energy absorption (SEA) than Al 6061-T6 and the circular geometry had better specific energy absorption (SEA) value than that of the square geometry.

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