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# Analysis of multi-cell hexagonal crash box design with foam filled under frontal load model

M A Choiron \*

Department of Mechanical Engineering, Universitas Brawijaya, Indonesia

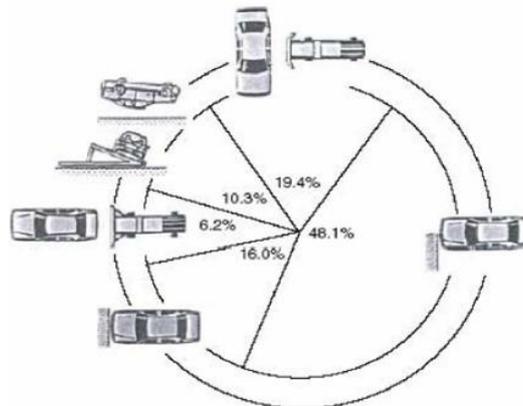
\*agus\_choiron@ub.ac.id

**Abstract.** This study aim is to determine the effect of Multi-Hexagonal crash box design variations on energy absorption. The research method used ANSYS Academic software version 18.1. The crash box model analysed consists of 3 models, namely the multi-cell hexagonal outer foam filled crash box, inner foam filled and without foam filled. Crash box testing refers to the instrumented drop mass setup test model, impactor with a mass of 103 kg crashing crash box with a speed of 7.67 m/s. Deformation pattern and energy absorption are observed as design criteria to determine the best crash box design specifications. The simulation results show that the highest energy absorption value is the multi-cell hexagonal outer foam filled crash box with that  $E_a$  is 30,606 kJ. There is a significant difference between the multi-cell hexagonal crash box model with foam filled and without foam filled. The addition of foam filled on the multi-cell hexagonal crash box has important effect to improve energy absorption performance. The deformation pattern that occurs in all three models is concertina mode. Based on the force reaction-displacement curve, it can be denoted the crash box that uses foam filled produces upward trend of curves in the end of the deformation. It can be connected to deformation pattern, folding increment is more identified compared to crash box without foam filled.

## 1. Introduction

The development of the vehicles marketing in Indonesia is very high, especially in the passenger car segment. Based on data from the Centre Statistics Department, passenger cars increased by 7.77% with a total of 15,493,068 units in 2017 [1]. Unfortunately, car sales increase is directly proportional to the high number of accidents in Indonesia (more than 100 thousand cases and increased by 0.77% annually). According to Kokkula [2], accidents from the frontal crash is 64% higher compared to the other crash direction (figure 1). Vehicle safety devices that have good safety performance during a collision are very required.



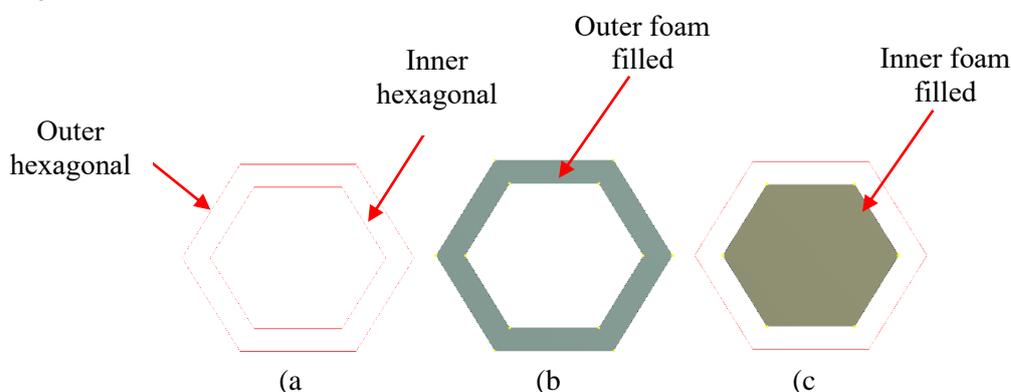


**Figure 1.** Percentage of collision of vehicles based on the crash direction [2]

Crash box is one of the safety devices on vehicles located between bumper and frame that serves as an energy absorber produced by collisions. In the previous study of crash box shape, various conventional cross-section shapes such as circular, rectangular and hexagonal shapes has been carried out [3]. The hexagonal crash box produces high performance crashworthiness capability due more folding in an appropriate manner [4]. In addition, hexagonal has a high absorption energy capability on the oblique load test [5]. In the next study, crash box consists of foam material is provide a significant increase absorption energy performance [6-7]. Another development of a crash box is a multi-segment crash box. Multi-segment crash boxes are crash boxes whose structure is composed of more than one segment [8]. Obtained from both studies, the two segment crash box has higher absorption energy performance compared to one segment crash box. Unfortunately, manufacturing process is still constrained by connections between segments. The next innovation is to create a multi-cell design model that is a combination of two conventional crashbox designs with two cells that complement the inside and outside section. In this study, a hexagonal multi-cell crash box model with foam filled and without foam filled were compared to find more feasible product as a prototype box crash.

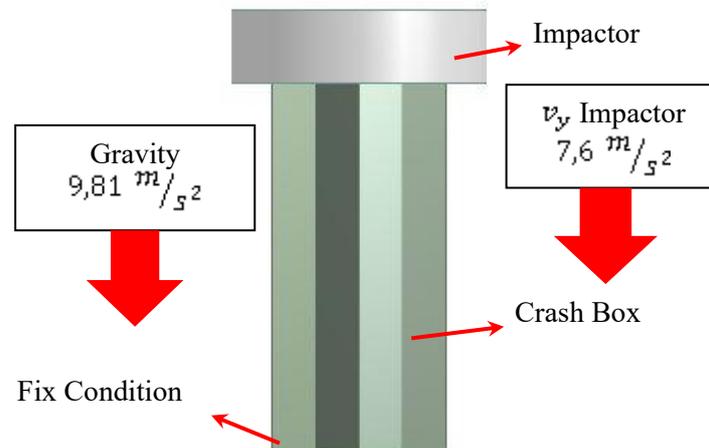
## 2. Methods

Figure 2 shows a multi-cell hexagonal crash box model that consists of two components namely the inner hexagonal and the outer hexagonal. Geometry of inner hexagonal diameter = 29.5 mm, outer hexagonal diameter = 39.0 mm, hexagonal thickness = 3,2 mm and crash Box length = 150 mm. Comparative design is done by varying three models, namely Multi-Cell Hexagonal Crash Box without Foam Filled, Multi-Cell Hexagonal Crash Box with Outer Foam Filled and Multi-Cell Hexagonal Crash Box with Inner Foam Filled.



**Figure 2.** Three models of multi-cell hexagonal crash box

The Finite element analysis software ANSYS Academic version 18.1 is used to carry out the numerical simulation analysis. Crash box Model consists of three parts: the impacting rigid plate, the crash box and the supporting rigid plate, as shown in figure 3. Crash box material using Aluminum 6061-T4 material and impactor using structural steel material properties are presented in table 1.



**Figure 3.** Modeling multi-cell hexagonal crash box

**Table 1.** Material properties crash box, impactor and foam

| Propertis Material                                | Crash Box | Impactor             | Foam  |
|---|-----------|----------------------|-------|
| Density ( $\text{kg/m}^3$ )                       | 2790      | $5,2436 \times 10^5$ | 627.3 |
| Modulus Elasticity (MPa)                          | 70000     | $2 \times 10^5$      | 60.75 |
| Poisson Ratio                                     | 0.33      | 0.3                  | 0.01  |
| Yield Strength (MPa)                              | 145       | 240                  | -     |
| Tangent Modulus (MPa)                             | 450       | 1450                 | -     |
| Specific Heat ( $\text{J kg}^{-1}\text{C}^{-1}$ ) | 896       | 434                  | -     |

The loading model based on Instrumented Drop Mass Setup. In this modeling, the impactor position has no distance from the Crash Box and the impactor impact the Crash Box with a velocity of 7.67 m/s until 100 mm final deformation is obtained. In this study a 2.0 mm mesh was used to mesh Crash Box.

### 3. Result and Discussion

The amount of energy absorption from each model due to frontal load can be seen in Table 2 and the deformation patterns are shown in Figure 4-6.

**Table 2.** Energy Absorption value due to frontal load

| Multi-Cell Hexagonal Crash Box Design                 | Energy Absorption (kJ) |
|---|------------------------|
| Multi-Cell Hexagonal Crash Box without Foam Filled    | 26.315                 |
| Multi-Cell Hexagonal Crash Box with Outer Foam Filled | 30.606                 |
| Multi-Cell Hexagonal Crash Box with Inner Foam Filled | 30.515                 |

The biggest energy absorption value is the hexagonal multi cell foam filled crash box model that is 30,606 kJ. There is a significant difference between the multi-cell hexagonal foam filled crash box model and the multi-cell hexagonal crash box model without foam filled. By adding foam filled to the hexagonal crash box, it can be denoted that energy absorption is increase. The energy absorption is influenced by the position of the foam filled in the crash box.

Deformation patterns in a crash box due to frontal loading can be categorized by three modes, which are concertina mode (axisymmetric), diamond mode and mixed mode (axisymmetric-diamond). Deformation pattern is analyzed based on visual observations on the simulation results. The deformation pattern on the simulated crash box is set as 100 mm final displacement. The deformation pattern on three hexagonal multi-cell crash box models is concertina.

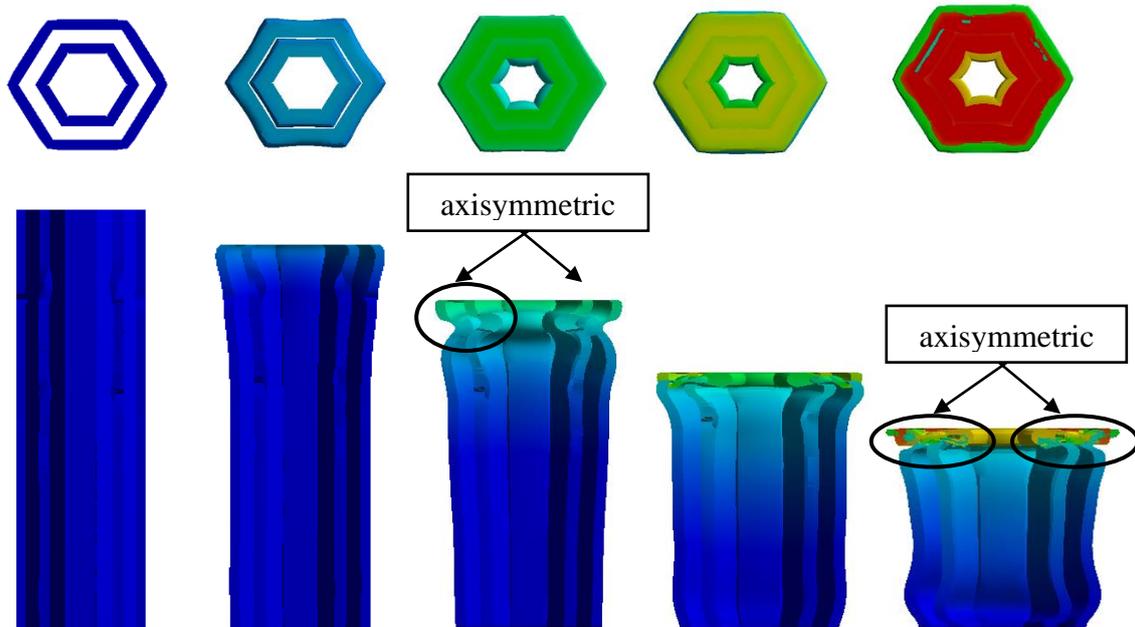


Figure 4. Deformation pattern on multi-cell hexagonal crash box without foam filled

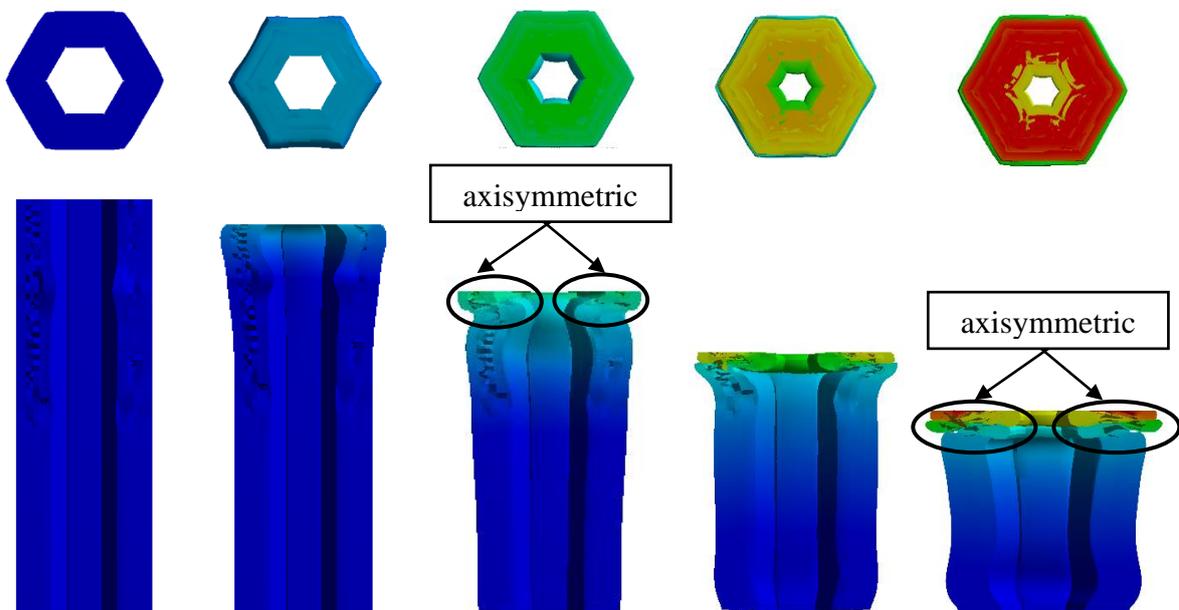
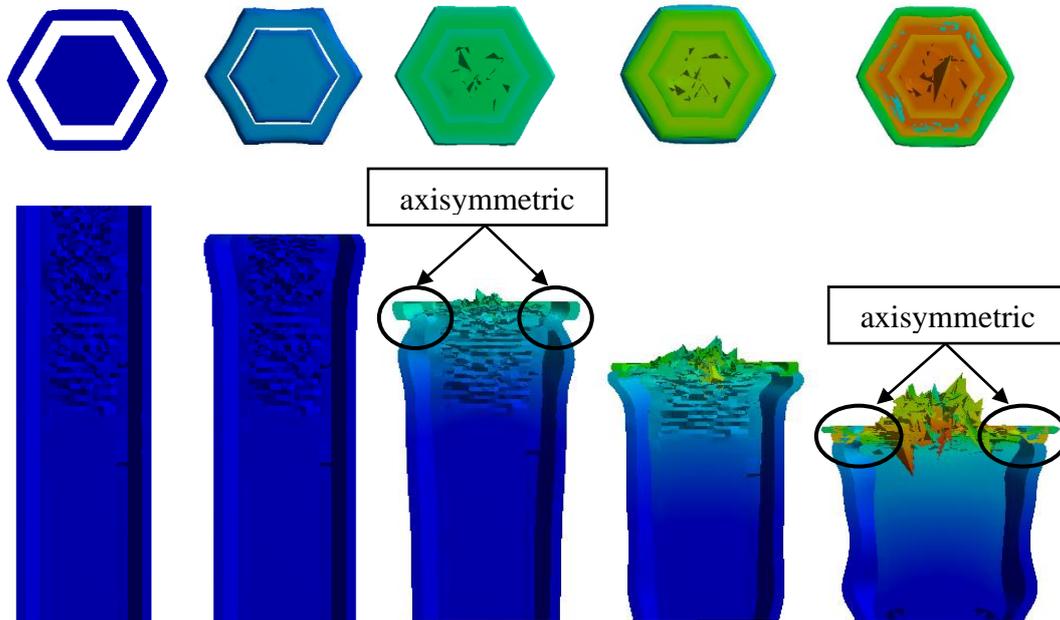


Figure 5. Deformation pattern on multi-cell hexagonal crash box with outer foam filled



**Figure 6.** Deformation pattern on multi-cell hexagonal crash box with inner foam filled

During frontal load applied on crash box, plastic deformation that occurs due to collisions between the impactor and crash box produces energy absorption called as kinetic energy. The energy absorption can be calculated from the area under the force reaction-displacement curve as shown in Figure 7.

At the beginning of folding, it can be connected with the appearance of the first peak on the force reaction and displacement curve. It indicates that the appearance of the peak will be marked by the occurrence of folding. In the next folding, the number and form of folding was formed again until the displacement and loading distances. On the loading time increases, the crash box will continue to deformed, therefore the absorption energy is increase by converted into strain energy. The deformation pattern on all multi-cell hexagonal crash box models with and without foam filled is concertina mode. Based on the force reaction - displacement curve, it can be denoted the crash box that uses foam filled produces upward trends of curves in the end of the deformation. It can be connected to deformation patterns, folding increments are more identified than crash boxes without foam filled (figure 8).

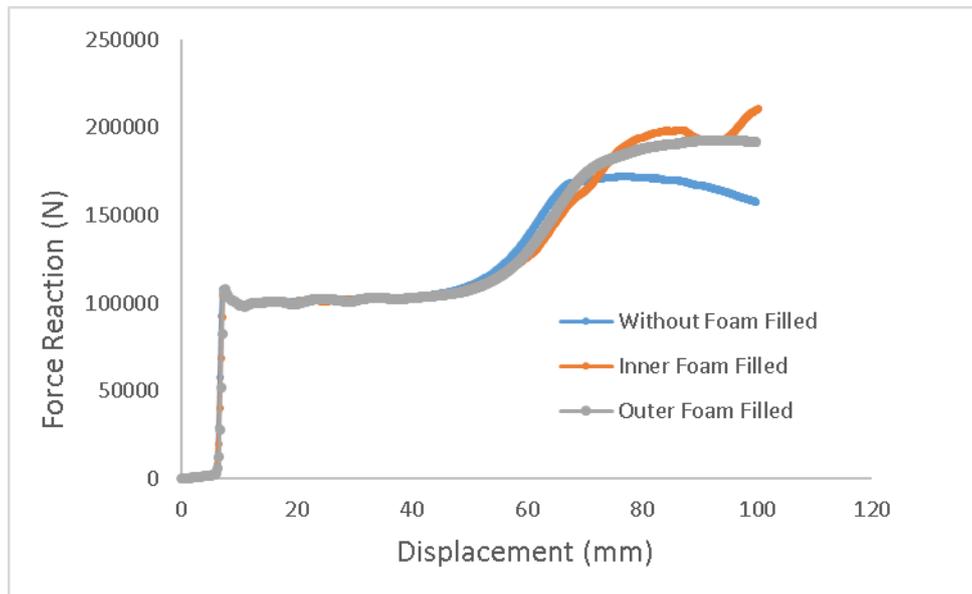


Figure 7. Curve force reaction-displacement in three crash box models due to frontal load

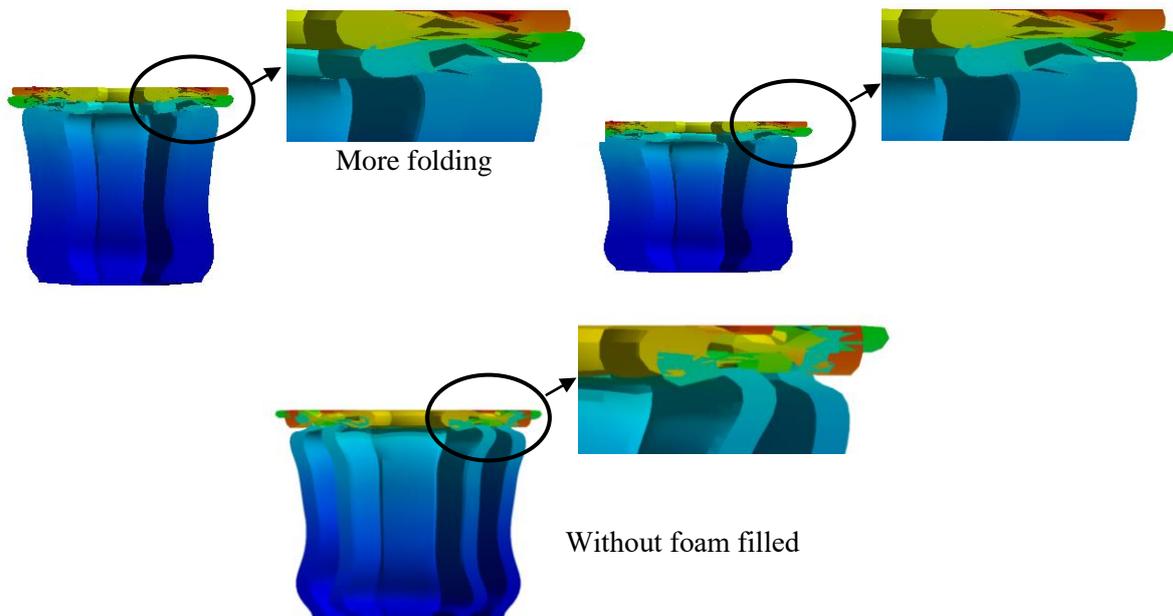


Figure 8. Comparison of folding at the end of the deformation on a crash box with foam filled and without foam filled models

4. Conclusion

The following conclusions can be made which is the highest energy absorption value is the multi-cell hexagonal outer foam filled crash box with that  $E_a$  is 30,606 kJ. The addition of foam filled on the multi-cell hexagonal crash box has important effect to improve energy absorption performance. The multi-cell hexagonal crash box with foam filled produces upward trend of curves in the end of the deformation. It can be connected to deform the patterns where folding increment is more identified compared to crash box without foam filled.

### Acknowledgement

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