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Analysis High Energy Absorption and Numerical Study of Crashbox

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***Abstract*— A study on the design of a three-dimensional (3D) model for a crash box system used in four-wheel vehicles consists of two crash box design models: Square and Decagonal. Two crash box models are designed by altering the geometry of the structural components, such as adding a Honeycomb Model Plus Front-end Trigger. This study utilizes numerical analysis to evaluate the designed structures under impact loads based on vehicle crashworthiness. The parameters used in this research include crashworthiness factors such as energy absorption (EA), Initial Peak Force (IPF), and Mean Crushing Force (MCF). The crash box model with the best crashworthiness will be selected for geometric modifications. The crash box model with the best energy absorption is the Square crash box model with honeycomb, front-end trigger, and trigger slot, which has an energy absorption (EA) value of 146.48 kJ. Parameters used to assess crash robustness include Energy Absorption (EA), Specific Energy Absorption (SEA), Initial Peak Force (IPF), Mean Crushing Force (MCF), and Crushing Force Efficiency (CFE). The study also involves numerical analysis.**

***Keywords*— Crash Box, Crash Beads, Triggers, Crashworthiness.**

I. INTRODUCTION

Vehicles involved in accidents can cause serious injuries to passengers. Enhancing vehicle crashworthiness is crucial to prevent passenger injuries [1]. The efficiency of a crash box depends on its dimensions, material type, and design model [2]. A crash box is an energy-absorbing component in vehicles that significantly absorbs impact energy through a plastic deformation process [3]. To design a crash box that ensures high crashworthiness, it must have a low initial peak force and a high mean crushing force [4].

In this study, honeycomb structures were selected for their advantages. Honeycomb structures have a lightweight and a high strength-to-weight ratio. Honeycomb-filled crash boxes are capable of absorbing energy effectively [5]. Research involving modifications to honeycomb structures has also been conducted by several studies. These studies found that the smaller the honeycomb cell size, the better the energy absorption capability [5]. Previous research comparing the geometry of crash boxes by introducing a wavy structure, known as crash beads, to crash boxes without crash beads found that the design with crash beads performed better [5].

When designing vehicles or other structures, crashworthiness must take into account various potential accident scenarios, including frontal, side, and rear crash tests, as well as impacts with different types of objects. The goal is to create a system that can provide optimal protection for occupants or cargo in every accident condition. Research in the field of crashworthiness is ongoing to develop more advanced and effective technologies for protecting people and goods from the adverse consequences of accidents.

II. CRASHWORTHINESS

There are several parameters used for crashworthiness assessment, namely energy absorption, specific energy absorption, initial peak force, crush force efficiency, mean crushing force, peak acceleration, and peak velocity. Energy Absorption is a parameter used to assess the amount of energy absorbed. This parameter is typically identified as the area under the Force-Displacement curve. This energy is the energy converted from kinetic energy into plastic strain energy as a result of the material deforming beyond its elastic limit. Mathematically, it can be formulated as follows:

$$EA = \int_0^s F(x)\,dx \tag{1}$$

This parameter is used to calculate the amount of energy absorbed per unit mass, which is often used to estimate the energy absorption capability of a structure. Mathematically, it can be formulated as follows:

$$SEA = \frac{EA}{M} \tag{2}$$

Where EA is the energy absorption during the process, and MM is the mass of the structure.

This force represents the initial peak force due to the impact of mass striking in the axial direction. The maximum buckling resistance force typically increases at the beginning of structural compression. A larger initial peak force indicates higher initial resistance of the structure to buckling, resulting in higher damage and more severe injuries.

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The Mean Crushing Force (MCF) is another important index to demonstrate the energy absorption capability of a structure. Mathematically, it is formulated as follows:

$$MCF = \frac{EA}{d} \quad (3)$$

Crush Force Efficiency (CFE) is the peak resistance force (early loading phase) divided by the mean force, which is a very important parameter as it directly influences the deceleration of passengers inside the vehicle. CFE is an indication to demonstrate the stability of the structure during the destruction process. Mathematically, CFE is formulated as:

$$CFE = \frac{MCF}{F_{max}} \quad (4)$$

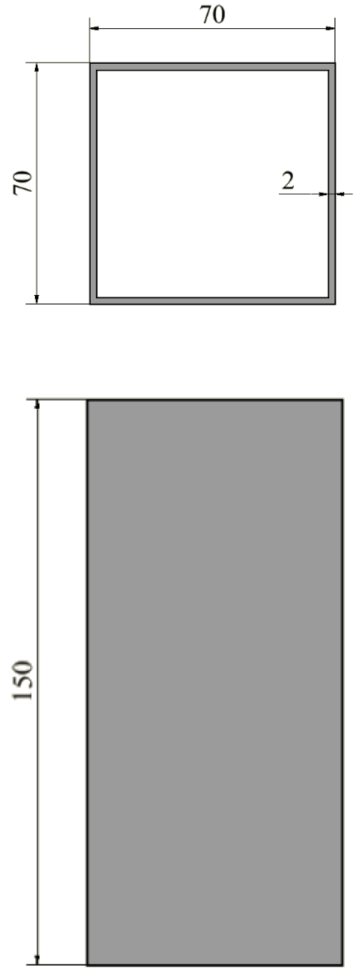

Fig. 1. Dimensi Crash Box Rectangle

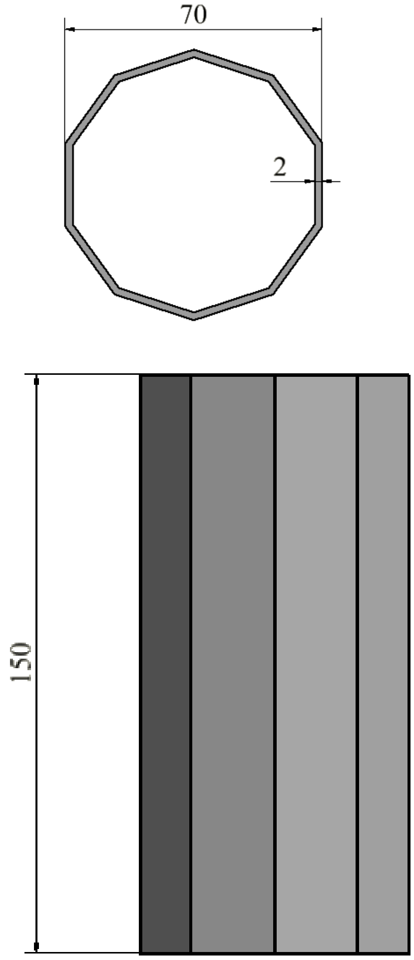

Fig. 2. Dimensi Crash Box Decagonal

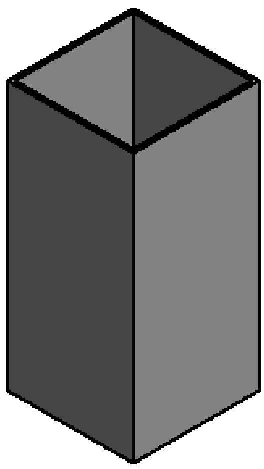

Fig. 3. 3D Crash Box Rectangle

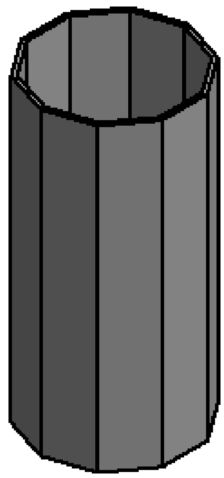

Fig. 4. 3D Crash Box Decagonal

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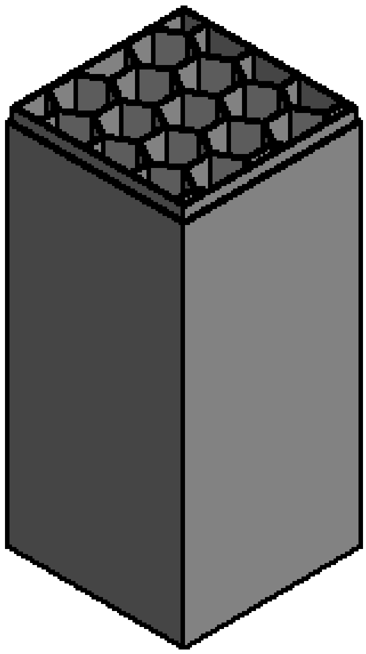

Fig. 5. Crash Box Rectangle + Honeycomb + Fornt End trigger

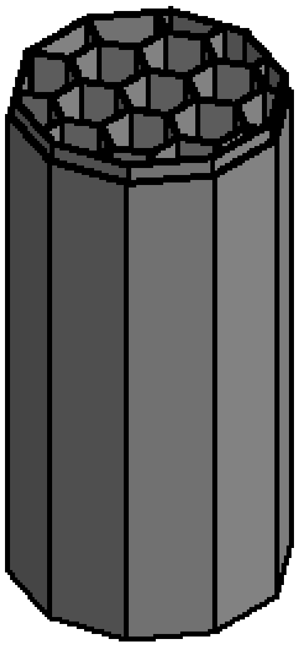

Fig. 6. 3D Crash Box Decagonal + honeycomb + Front End Triger

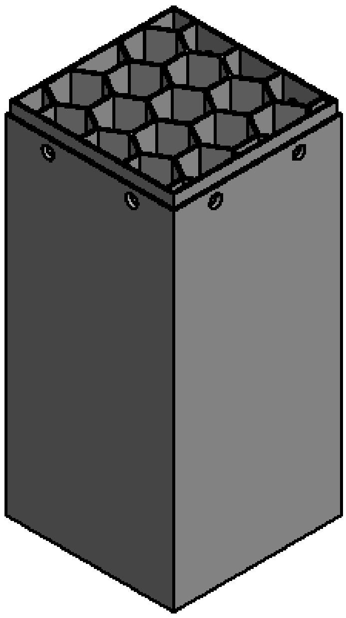

Fig. 7. Crash Box Rectangle + Honeycomb + Fornt End trigger + Triger Slot

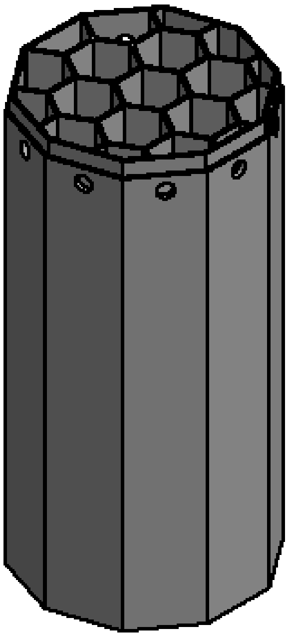

Fig. 8. 3D Crash Box Decagonal + honeycomb + Front End Triger + Triger Slot

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In the study, geometric changes were applied to the crash box structure, such as the addition of honeycomb, Front End Trigger, and Trigger Slot, as shown in Figure 8.

III. METHODOLOGY

The crash box design model adheres to the standard dimensions of a 4-passenger vehicle. This research employs simulation aided by ANSYS software. In the study, the material utilized for the crash box is Aluminum Alloy 6063-T6. Table 1 elucidates the mechanical properties of the material.

TABLE I. Material Properties Of Aluminum Alloy 6063-T6

Material Properties	**Value**
Density	2700 Kg/m^3
Young's Modulus	73000 Mpa
Poisson's Ratio	0,3
Yield Strength	206 Mpa
Tangent Modulus	28100 Mpa

TABLE II. DESIGN PARAMETERS OF SOME CRASH BOX MODEL

Profil	**Thickness (mm)**	**Length (mm)**
Square	2 mm	150
Square (RHFT)	2 mm	150
Square (RHFTS)	2 mm	150
Decagonal	2 mm	150
Decagonal (DHFT)	2 mm	150
Decagonal (DHFTS)	2 mm	150

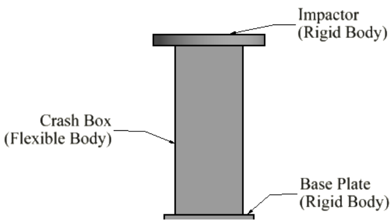

Fig. 9. Set up Numerical Simulation of Crash Box

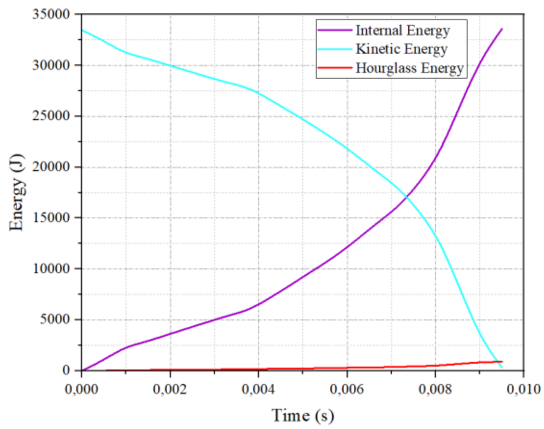

Fig. 10. Graph of Energy Conservation Numerical Simulation

A. Design Of Crash box

In this study, the front crash box of the vehicle, undergoes changes in geometry, dimensions, and model alterations, all of which are factors influencing the crash box's performance in energy absorption. The analysis involves design modifications to the crash box, incorporating two different cross-sectional shapes, followed by alterations in dimensions or shape. In this research, two cross-sectional designs of the crash box are created: Square and Decagonal, with a length of 150 mm and a thickness of 2 mm. Several geometric model variations are implemented, as depicted in Figure 2. The six crash box models consist of three Square-based models: Square Base without modifications, Square with the addition of Honeycomb and Front End Trigger (RHFT), and Square with the addition of Honeycomb, Front End Trigger, and Trigger Slot (RHFTS). The second set of models comprises Decagonal-based designs, divided into three variations: Standard Decagonal (DSTD), Decagonal with the addition of Honeycomb and Front End Trigger (DHFT), and Decagonal with the addition of Honeycomb, Front End Trigger, and Trigger Slot (DHFTS).

B. Numerical Simulation Method

In the crash box analysis, the software utilized is Ansys, specifically employing Explicit Dynamics, a time integration method for dynamic analysis considering rapidly changing conditions involving nonlinear dynamics. The crash box is subjected to impact loads in this simulation. The mesh size used in this study is 2 mm.

The crash box and the base plate, set in the numerical simulation system, are rigidly modeled. The mass of the impactor is 275 kg, and the velocity used is 56 km/h. These parameters align with the testing standards of the New Car Assessment Program (NCAP) by the National Highway Traffic Safety Administration (NHTSA).

Material properties for this study are specified in Table 1. The material plasticity model is characterized by isotropic bilinear hardening to observe the material under nonlinear behavior conditions..

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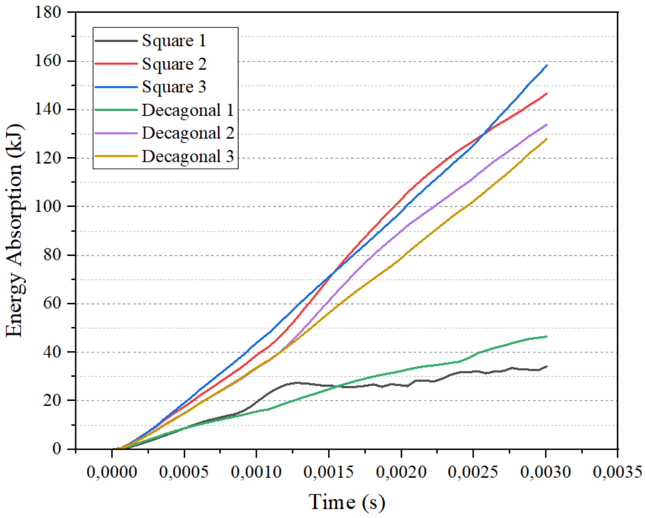

Fig. 11. Energy Absorption graph of crash box

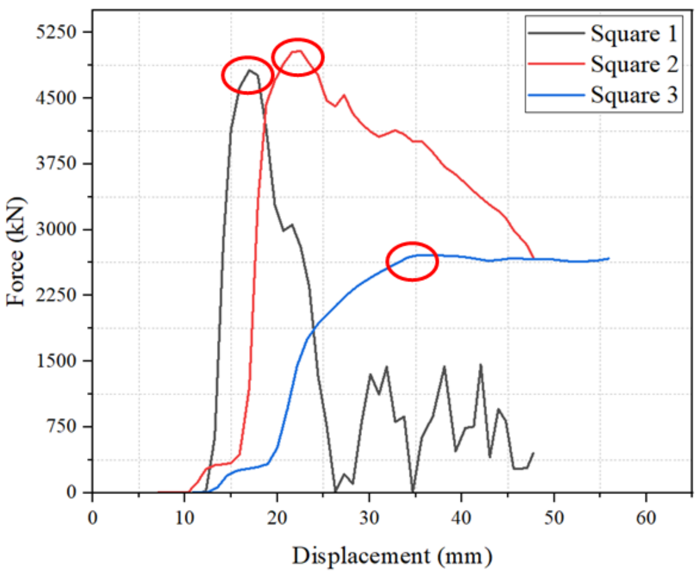

Fig. 12. Energy Absorption graph of crash box

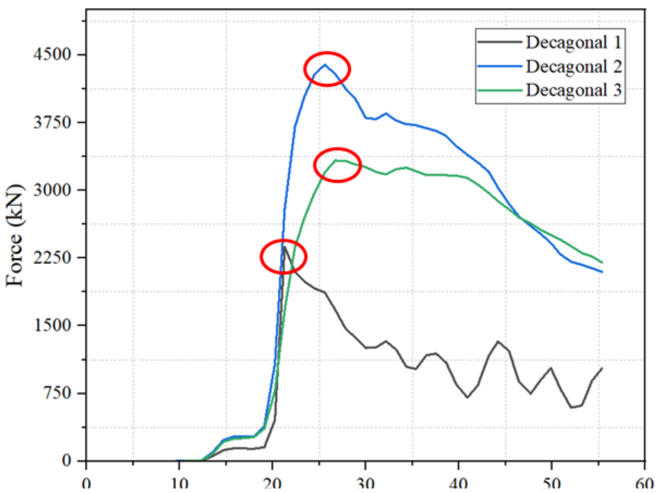

Fig. 13. Energy Absorption graph of crash box

TABLE III. RESULTS OF NUMERICAL SIMULTION ANALYSIS ON VARIOUS CRASH BOX DESIGNS

Crash Box Type	**EA (kJ)**	**SEA (kj/kg)**	**IPF (kN)**	**MCF (kJ/mm)**	**CFE (%)**	**Displacment (mm)**
Square	34,223	226,09	4818	717,00	14,88	47,731
Square (RHFT)	146,64	355,00	5038,5	2624,10	52,08	55,882
Square (RHFTS)	158,25	383,90	2713,3	2886,67	106,39	54,821
Decagonal	46,451	259,55	2373,2	849,29	35,79	54,694
Decagonal (DHFT)	133,87	402,07	4391,7	2418,48	55,07	55,353
Decagonal (DHFTS)	127,99	385,64	3330,9	2328,87	69,92	54,958

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IV. RESULT AND DISCUSSION

A. Validation of Numerical Model

In this research, it is essential to ensure that the numerical simulation can predict accurate results. The explicit solver continually checks the total energy balance and monitors how energy is distributed within the system. The total energy in the system must remain constant, adhering to the law of energy conservation, which states that energy cannot be created or destroyed; it can only be transformed from one form to another. Figure 10 illustrates the energy conservation graph from the numerical simulation. In this study, during the collision process, kinetic energy decreases while internal energy increases..

B. Performance of Crash Box

This research utilizes parameters used to measure the crashworthiness of the crash box aimed at enhancing crash feasibility, namely energy absorption (EA), specific energy absorption (SEA), initial peak force (IPF), mean crushing force (MCF), and crush force efficiency (CFE).

1) Analisa Energy Absorption and Specific Energy Absorption Crash Box

Energy absorption (EA) refers to the capacity of a structure to absorb energy during an impact process. It is a primary parameter in assessing the crashworthiness performance of a structure during impact. The force-displacement curve, where the integral of the area under the force-displacement curve represents the total absorbed energy. Specific energy absorption (SEA) is obtained by comparing the energy absorption with the mass of the structure. Analysis of energy absorption is carried out on each designed crash box model. Table III presents the results of numerical simulation of energy absorption and specific energy absorption for each crash box model. The crash box model without honeycomb, front end trigger, and slot trigger (base model), the decagonal 1 model has higher values of energy absorption and specific energy absorption compared to the square 1 model, namely 46.451 kJ and 259.55 kJ, respectively. In the crash box model with the addition of honeycomb, front end trigger (model 2), and the addition of honeycomb, front end trigger, slot trigger (model 3), the crash box model with a square cross-section has better energy absorption than the crash box model with a decagonal cross-section. However, for specific energy absorption, the crash box model with a decagonal cross-section has a higher value, as the decagonal model has a relatively smaller mass.

2) Initial Peak Force

Initial peak force is another important parameter considered in determining the performance of the crash box structure. A lower initial peak force with higher energy absorption is required for selecting the crash box design model. The table below shows the initial peak force in the numerical simulation results of the crash box. The square model with the addition of honeycomb, front end trigger (square 2), increases energy absorption and IPF by 328.5% and 4.6%, respectively, compared to the base model (square 1). In the square model with the addition of honeycomb, front end trigger, slot trigger (square 3), energy absorption increases by 362.5% and IPF decreases by 43.7% compared to the base model (square 1). The decagonal model with the addition of honeycomb, front end trigger (decagonal 2) increases energy absorption and IPF by 188.2% and 85%, respectively, compared to the base model (decagonal 1). In the decagonal model with the addition of honeycomb, front end trigger, slot trigger (decagonal 3), energy absorption and IPF increase by 175.5% and 40.3%, respectively. The force reaction curve of each crash box model with different cross-sections is shown in Figures 12 and 13.

The force reaction curve indicates that crash boxes with the addition of honeycomb, front end trigger, or the addition of honeycomb, front end trigger, slot trigger generally show higher initial peak force points and larger curve areas compared to the base model. However, in model square 3, besides having a larger curve area of energy absorption, it also has a smaller initial peak force point compared to the base model or other models. A smaller initial peak force value is required to reduce the larger impact force transmitted to the main compartment of the car. Although model decagonal 1 has a slightly smaller IPF value than model square 3, in terms of energy absorption structure performance, model decagonal 1 has significantly lower values compared to model square 3. Therefore, in terms of IPF parameter performance, model square 3 performs better than other models. The comparison of EA and IPF values of each model in a diagram can be seen in Figure 14.

3) Mean Crushing Force crash box

The Mean Crushing Force also indicates the energy absorption capability for a structure, which is the average value of all peak loads obtained on the force-displacement curve. Mean Crushing Force is the ratio of energy absorption to displacement. The MCF value is influenced by two parameters: EA and displacement. Structures with a high EA value and a small displacement value will have a better MCF value. The numerical simulation results of MCF for each crash box model are shown in the table below. Deformation and comparison diagrams of MCF and EA for each crash box model are shown in Figures 15 and 17.

Based on the numerical simulation results, the addition of triggers on average to square or decagonal crash box models can increase the MCF value. The increase in the average MCF value is accompanied by an increase in the EA value of the crash box. The MCF value for square models is better than that of decagonal models, mainly because the EA value of square models is higher. Decagonal models are more easily deformed compared to square models because they have fewer honeycombs in the structure, resulting in lower rigidity. Overall, square model 3 performs better than other models with higher energy absorption and MCF values compared to other models.

4) Crush Force Efficency Crash Box

CFE (Crush Force Efficiency) is the ratio of MCF to the maximum peak force value, indicating the stability of the structure during the destruction process. Structures with a larger MCF value and a smaller Fmax value will have a better CFE value. Model square 3 has a better CFE value compared to other models. The square model has a higher energy absorption value, namely 106.39%, with a not too large Fmax value of 2713.3 kN. Although model decagonal 1 has a smaller Fmax value compared to square model 1, model

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decagonal 1 has a smaller energy absorption value compared to square model 1. The main consideration in the performance of the crash box structure is the energy absorption in the structure. Figure 16 shows that model square 1 performs better in energy absorption structure with a relatively small initial peak force or Fmax value. The numerical simulation results of CFE for each crash box model are shown in Table III..

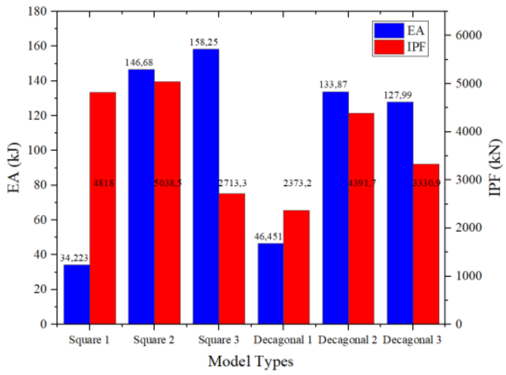

Fig. 14. EA – IPF diagram of crash box models

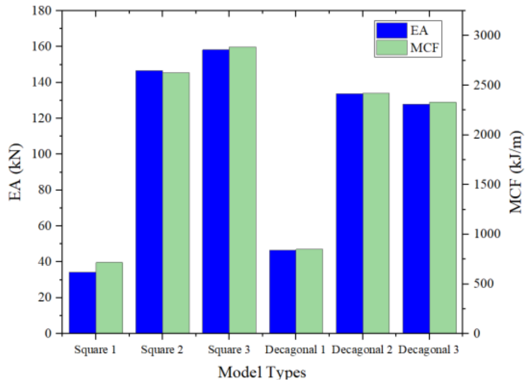

Fig. 15. EA – MCF diagram of crash box models

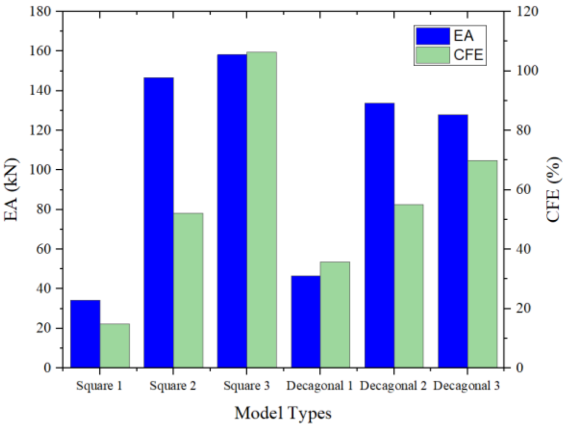

Fig. 16. EA – CFE diagram of crash box models

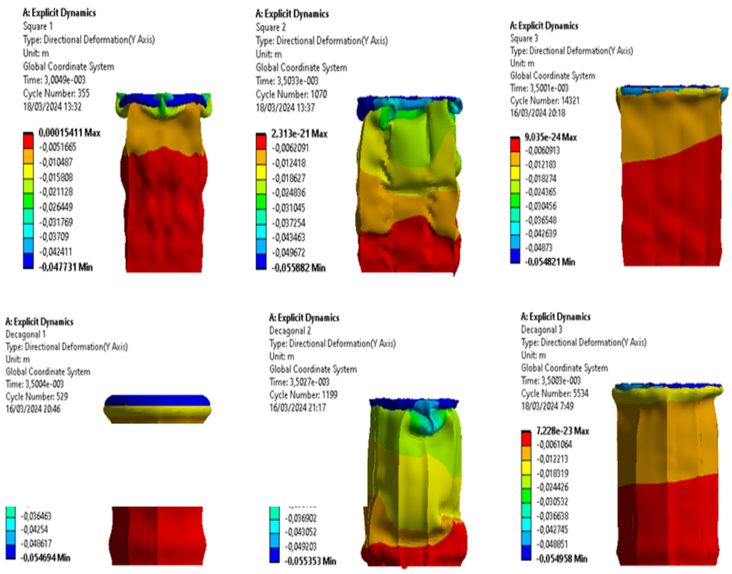

Fig. 17. Deformation Patterns form all crash box models

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V. CONCLUSION

In the analysis of the crash box, a numerical analysis was conducted to determine the performance of the crash box structure under impact loads based on crashworthiness assessment parameters. Some points in this study are as follows::

- A crash box with square and decagonal cross-sections, and the addition of geometric imperfections to the structure by adding honeycomb, front-end triggers, and trigger slots can improve energy absorption.
- A crash box with a square cross-section and the addition of honeycomb, front-end triggers, and trigger slots is the best model.
- Based on design planning in accordance with the vehicle crash box dimensions, numerical simulation results show that the RHFTS type design has the best crashworthiness..

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