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Design and Analysis of differently shaped automotive crash boxes

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Abstract- The crash box is a critical energy-absorbing component in modern automotive structures, designed to minimize the impact forces transmitted to the passenger cabin during a collision. This project focuses on the design and optimization of an automotive crash box with the aim of improving crashworthiness while maintaining lightweight and cost-effective characteristics. Various geometric configurations, materials, and structural parameters are analyzed to enhance energy absorption, reduce peak impact forces, and improve deformation behavior under axial and oblique loading conditions. Numerical simulations using finite element analysis (FEA) are employed to evaluate performance parameters such as specific energy absorption, crush force efficiency, and deformation modes. Design iterations are carried out to identify the optimal configuration that provides a balance between safety, manufacturability, and material efficiency. The optimized crash box design is expected to significantly enhance vehicle safety, reduce material wastage, and contribute to the overall improvement of automotive crash management systems.

I. INTRODUCTION

Vehicle safety has become a defining parameter in modern automotive engineering, driven by increasing urban traffic density, stringent regulatory standards, and rising consumer expectations. Frontal collisions remain one of the most common and severe forms of vehicular impacts, prompting continuous advancements in passive safety systems. Among the critical structural components responsible for managing crash energy, the automotive crash box—positioned between the bumper and the front longitudinal member—plays a vital role in absorbing kinetic energy during low- and medium-speed frontal impacts. Its controlled deformation through progressive buckling minimizes the force transmitted to the passenger cabin, reduces structural damage, and lowers repair costs, making it indispensable in both regulatory crash tests and real-world safety performance.

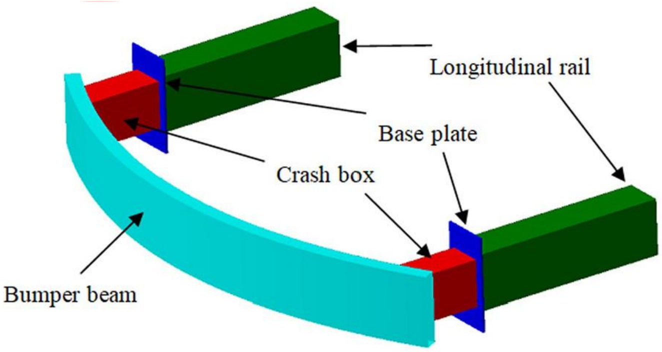


Fig.1 Crashbox Assembly

In recent years, organizations such as the Research Council for Automobile Repairs (RCAR) have highlighted the importance of low-speed crashworthiness, as frequent urban collisions contribute significantly to insurance claims and maintenance expenses. A well-designed crash box must therefore achieve an optimal balance of high energy absorption, low initial peak force, stable buckling behavior, lightweight construction, and cost-effective manufacturability. To meet these requirements, researchers have explored various materials, cross-sectional geometries, trigger mechanisms, and hybrid structures, supported by advanced simulation tools such as finite element analysis (FEA). Despite these efforts, there remains a need for a systematic and comparative evaluation of how different crash box geometries influence energy absorption, deformation modes, and overall crashworthiness.

This research aims to address this gap by designing, simulating, and comparing crash boxes with multiple cross-sectional shapes such as square, circular, hexagonal, and rectangular profiles, under standardized frontal impact conditions. Using FEA-based modelling in ANSYS and supported by experimental validation, the study seeks to identify the most effective crash box geometry capable of maximizing energy absorption while maintaining structural integrity and predictable deformation. The findings contribute to the development of improved crash box architectures for modern vehicles, offering potential enhancements in passenger safety, structural performance, and compliance with international safety and reparability standards.

II. LITERATURE REVIEW

1. Abdullah et al. (2020)

Abdullah et al. (2020) review the crashworthiness of crash-box structures, emphasizing geometry and material selection as the two most influential performance factors. They report that cylindrical and multi-cornered tubes provide higher specific energy absorption, while square and rectangular sections help reduce peak forces. Steel and aluminum remain widely used due to their cost-effectiveness and strength-to-weight benefits, whereas composites like GFRP and CFRP offer superior SEA for lightweight applications. Hybrid metal–composite crash boxes also show improved deformation stability. Structural enhancements such as foam filling, multi-cell designs and geometric triggers further increase crash efficiency. The authors highlight the need for better simulation–experiment correlation and more integrated design approaches.

2. Harhash et al. (2021)

Harhash et al. (2021) investigate how different trigger geometries influence the crushing behavior of steel/polymer/steel sandwich crash boxes. Their experiments show that triggers such as corner cuts and bead patterns greatly reduce peak forces and promote stable, progressive folding. The modified bead trigger performs best, achieving the lowest peak force and most controlled collapse. Untriggered tubes tend to buckle globally, resulting in poor energy absorption. LS-DYNA simulations correlate well with experiments, though limitations exist in modeling delamination. The study concludes that triggered SPS crash boxes offer reliable, repeatable deformation suitable for lightweight automotive applications.

3. Aktaş et al. (2022)

Aktaş et al. (2022) examine tetra-chiral and reentrant auxetic crash box designs using experiments and validated FE simulations. Their results show that reentrant structures achieve higher SEA and crash load efficiency due to their long plateau collapse region. Tetra-chiral tubes, however, produce lower peak loads through twisting-based deformation. Surrogate modelling and genetic algorithm optimization reveal optimal designs balancing SEA and peak force. The authors highlight auxetic structures' natural resistance to imperfections and their potential to outperform conventional crash boxes. They conclude that auxetic geometries offer a promising approach for lightweight, high-efficiency crash absorbers.

4. Xiong et al. (2023)

Xiong et al. (2023) develop a robust optimization method for foam-filled double-hexagonal crash boxes using Taguchi-grey relational analysis. Their tests show that foam filling stabilizes deformation and greatly increases mean crushing force. The double-hexagonal geometry demonstrates enhanced energy absorption due to its multi-corner structure. Simulation results match experimental data well, confirming model reliability. Robustness analysis shows optimized designs are less sensitive to manufacturing deviations. The study demonstrates that Taguchi-grey methods efficiently identify high-performance, manufacturable crash box configurations.

5. Valente et al. (2023)

Valente et al. (2023) analyze aluminum foam-filled honeycomb crash absorbers to improve lightweight structural energy absorption. Their experiments show that foam filling enhances cell-wall support, raises SEA and delays catastrophic buckling. FE simulations accurately capture elastic–plastic collapse behavior, validating the hybrid design approach. They observe that foam density and placement strongly influence folding patterns. Bonding quality and manufacturing tolerances also significantly impact crash performance. The authors conclude that foam-honeycomb combinations provide compact, high-efficiency crash absorbers for EV and aerospace applications.

6. Ang et al. (2024)

Ang et al. (2024) evaluate natural-fiber bio-composite crash boxes made from OPEFB and kenaf reinforced epoxy. Compared to metals, the bio-composites show lower absolute energy absorption but competitive SEA due to reduced mass. Multi-cell decagonal designs substantially improve folding stability and reduce brittle failure. Failure modes include fiber pull-out, matrix cracking and delamination. The authors note potential for sustainable automotive components but acknowledge limitations in thermal and long-term durability. They recommend bio-composites primarily for secondary crash structures or hybrid designs.

7. Ciampaglia et al. (2024)

Ciampaglia et al. (2024) develop a CFRP origami crash box for Formula Student cars and validate it through experiments and FE modeling. The origami pattern reduces peak loads and enhances progressive energy absorption. Hybrid FE models with cohesive elements accurately capture delamination and fiber–matrix debonding. The optimized design achieves significant mass reduction while meeting safety requirements. Manufacturing effects like fiber waviness are incorporated for improved prediction. The study highlights origami composites as lightweight, high-performance crash absorber solutions.

8. Silva et al. (2018)

Silva et al. (2018) study thin-walled crash boxes joined using forming processes and show that forming-induced imperfections strongly affect folding behavior. Experimental results reveal that minor geometric variations can trigger premature buckling and reduce energy absorption. Different forming-based joining methods produce varying joint stiffness and collapse characteristics. FE models capture deformation patterns but require inclusion of forming effects to match peak forces. The study stresses the need for process-aware crash box design. It highlights that integrating manufacturing simulations improves reliability and crashworthiness outcomes.

9. Saber et al. (2025) — Tapered FDM Crash Boxes

Saber et al. (2025) analyze tapered FDM-printed crash boxes using PLA+, PLA-CF and reinforced polymers. They find wall thickness to be the dominant factor governing SEA and CFE, while taper angle also improves collapse stability. PLA-CF provides higher stiffness and SEA but shows brittle failure at low thickness. Experimental results closely match FE predictions, confirming model validity. The optimal design—a 3 mm, 7.5° tapered PLA-CF tube—outperforms previous FDM crash boxes. The study shows that additive manufacturing enables rapid exploration of geometry for lightweight crash absorbers.

10. Saber et al. (2025) — Comparative FDM Crash Boxes

In their second study, Saber et al. compare multiple FDM materials and structural configurations for crash box applications. Carbon-fiber reinforcement improves strength and SEA but increases brittleness at high strain rates. Multi-cell and rib-reinforced tubes achieve better energy absorption than simple hollow sections. Failure patterns depend strongly on printing orientation and layer adhesion. Calibrated FE models accurately reproduce experimental collapse behavior. The study confirms that FDM crash boxes are well-suited for prototyping and low-energy applications, with potential for hybrid reinforcement.

Novelty of work**:** The novelty of this research lies in conducting a comprehensive comparative study of multiple crash box geometries including square, circular, hexagonal, and rectangular sections, specifically under standardized frontal impact conditions relevant to modern passenger vehicles. Unlike prior studies that focus on material changes, trigger mechanisms, or isolated geometries, this work systematically evaluates how cross-sectional shape alone influences energy absorption, deformation behavior, and progressive buckling characteristics. The study integrates high-fidelity finite element simulations in ANSYS with experimental validation on a selected optimized geometry, ensuring both computational accuracy and real-world reliability. Additionally, the research explores the interaction between geometric stability and crash force efficiency, providing design insights that existing literature has not addressed holistically. By identifying the most effective crash box shape for maximizing energy absorption while minimizing peak loads and structural damage, the work offers practical, geometry-driven guidelines for next-generation lightweight automotive crashworthiness design.

III. PROBLEM STATEMENT

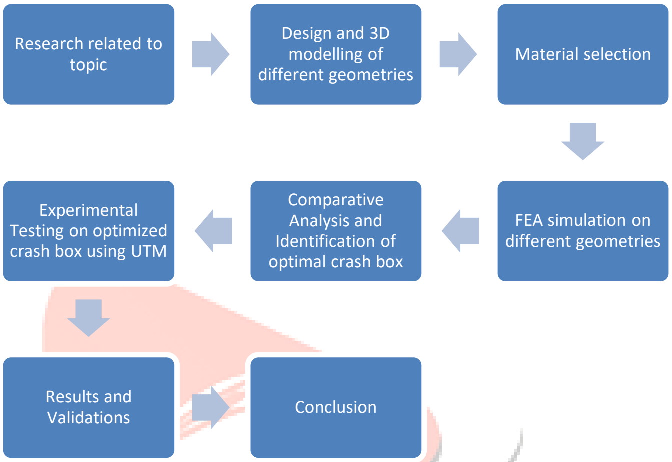
- ➢ Despite extensive research on crash box materials, triggers, and local structural modifications, there is still a lack of a systematic and comparative understanding of how different crash box geometries influence energy absorption, peak force behavior, and deformation stability during frontal impacts.
- ➢ Existing designs often exhibit unpredictable buckling patterns or insufficient progressive folding, leading to inefficient crash energy management and increased damage to the vehicle's structural members.
- ➢ This gap in geometric performance analysis limits the ability of automotive designers to select shapes that maximize crashworthiness while maintaining weight and manufacturability constraints.
- ➢ Therefore, there is a need for a comprehensive evaluation of various crash box cross-sections, supported by validated numerical and experimental methods, to identify the geometry that offers the optimal balance of high energy absorption, low peak force, and stable collapse behavior.
- ➢ This research aims to address this critical gap and contribute to the development of safer and more efficient crash box designs for modern vehicles.

IV. OBJECTIVES

The aim of this research is to design and optimize an automotive crash box that provides improved crashworthiness by studying different cross sections' maximizing energy absorption, minimizing peak impact forces, and reducing overall weight through optimized geometry, material selection, and numerical simulation techniques. The primary objectives are:

- Design and 3D modelling of crash boxes of different geometries.
- Finite element analysis for different geometries of the crash box.
- Experimentation and validation of final optimized crash box.

RESEARCH METHODOLOGY



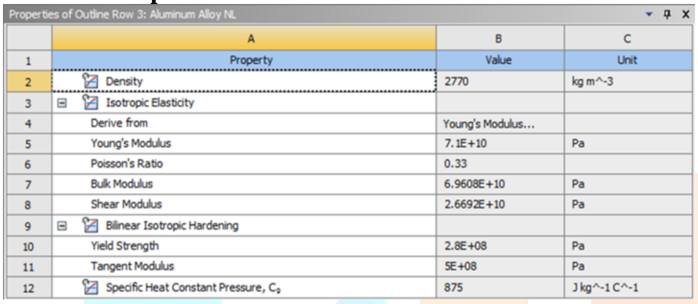
V. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a numerical technique used to approximate the behavior of complex engineering structures subjected to various loading conditions. The method works by discretizing a continuous domain into a finite number of smaller, interconnected elements, each governed by mathematical shape functions that approximate displacement fields. By assembling these individual elements into a global stiffness matrix, FEA enables the evaluation of stresses, strains, deformations and failure modes that would otherwise be extremely difficult or impossible to compute analytically. The approach is particularly powerful in nonlinear problems—such as material plasticity, large deformations, contact interactions and crash events—where conventional closed-form solutions do not exist. FEA provides engineers with the ability to simulate realistic boundary conditions, explore parametric variations and evaluate multiple design alternatives without the need for repeated physical testing.
As a result, the technique has become a fundamental tool in structural mechanics, crashworthiness, fatigue evaluation and optimization-driven design workflows. Its ability to capture detailed local phenomena while still accounting for global structural behavior makes FEA indispensable for modern automotive safety studies.

ANSYS Workbench is a widely used engineering simulation platform that integrates pre-processing, solver execution and post-processing into a unified environment. Built on the finite element method, ANSYS offers a comprehensive suite of tools for structural, thermal, fluid and coupled analyses, making it suitable for multi-physics engineering problems. Within crashworthiness applications, ANSYS Mechanical enables accurate prediction of nonlinear behavior through advanced element formulations, material models, contact algorithms and explicit dynamic solvers. The software supports the definition of detailed geometry, mesh control, material properties and realistic load conditions, ensuring that simulation results closely replicate physical behavior. Its robust solvers efficiently handle large deformation, strain-rate-sensitive materials and impact-based contact scenarios commonly encountered in crash box studies. Additionally, Workbench provides automated meshing, parametric modelling and optimization modules that facilitate rapid design evaluations and sensitivity analysis. High-quality visualization tools help interpret stress distributions, deformation patterns and energy absorption characteristics, aiding in data-driven decision-making. Due to its accuracy, flexibility and integration with CAD systems, ANSYS has become a standard platform for developing, analyzing and optimizing crashworthy automotive components.

FEA of Crashboxes:

Material Properties:



Properties of Outline Row 3: Aluminum Alloy NL

	A	B	C
1	Property	Value	Unit
2	Density	2770	kg m^-3
3	Isotropic Elasticity		
4	Derive from	Young's Modulus...	
5	Young's Modulus	7.1E+10	Pa
6	Poisson's Ratio	0.33	
7	Bulk Modulus	6.9608E+10	Pa
8	Shear Modulus	2.6692E+10	Pa
9	Bilinear Isotropic Hardening		
10	Yield Strength	2.8E+08	Pa
11	Tangent Modulus	5E+08	Pa
12	Specific Heat Constant Pressure, C_p	875	J kg^-1 C^-1

Table.1 Material Properties of Aluminium Alloy NL

Square Crashbox:

Geometry:

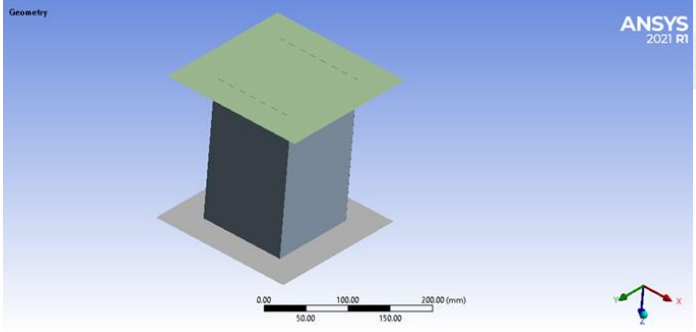
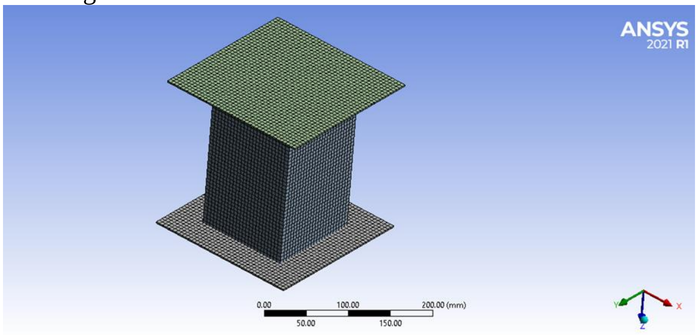


Fig.1 Geometry of Square Crashbox

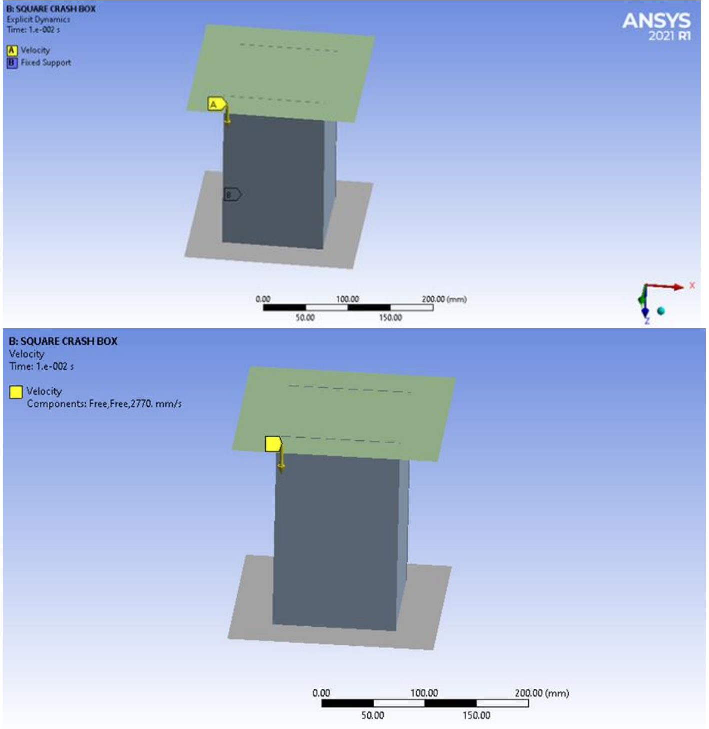
Meshing:



Statistics	
☐ Nodes	7298
☐ Elements	7040

Fig.2 Meshing details of Square Crashbox.

Boundary Conditions:



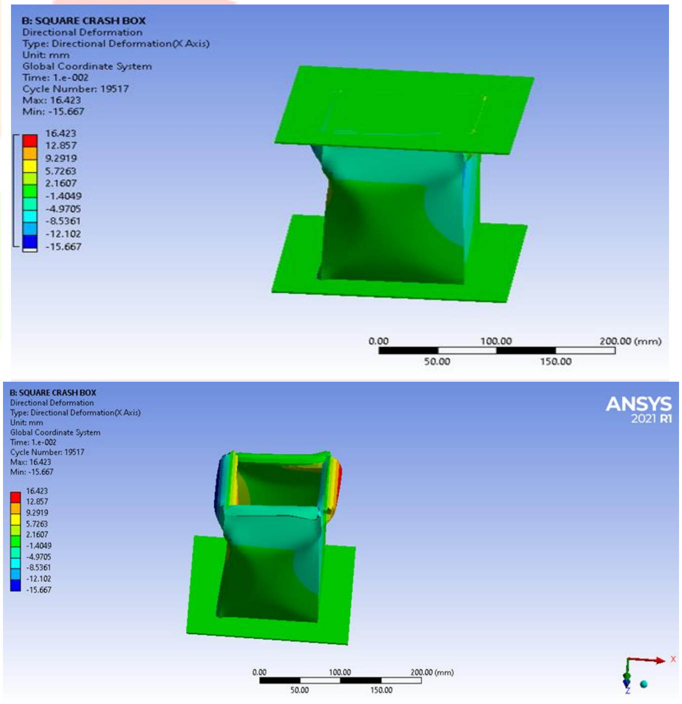
B: SQUARE CRASH BOX
Explicit Dynamics
Time: 1.e-002 s

B: SQUARE CRASH BOX
Velocity
Time: 1.e-002 s
Velocity
Components: Free,Free,2770. mm/s

Fig.3 Boundary Conditions for Square Crashbox

Results:

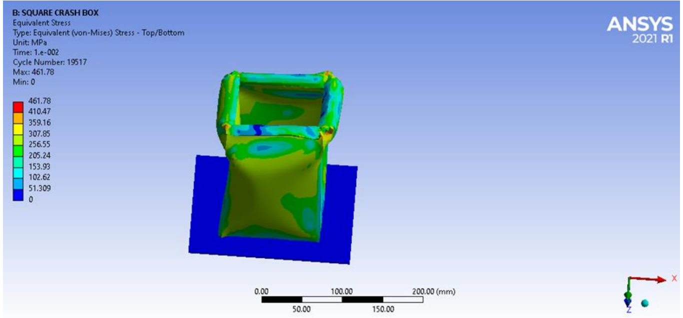
Directional Deformation



B: SQUARE CRASH BOX
Directional Deformation
Type: Directional Deformation(X Axis)
Unit: mm
Global Coordinate System
Time: 1.e-002
Cycle Number: 19517
Max: 16.423
Min: -15.667

Fig.4 Directional Deformation (X Axis) of square crashbox.

Equivalent Stress



B: SQUARE CRASH BOX
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top/Bottom
Unit: MPa
Time: 1.e-002
Cycle Number: 19517
Max: 461.78
Min: 0

Fig.5 Equivalent Stress of square crashbox.

Energy Probe

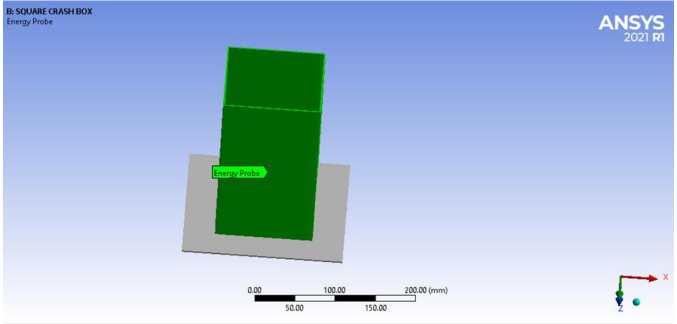
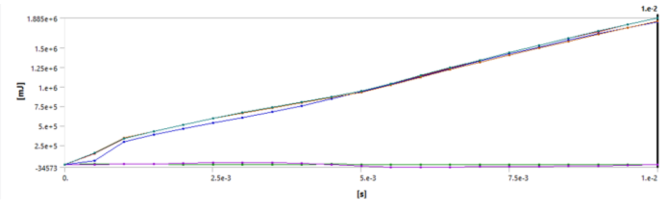
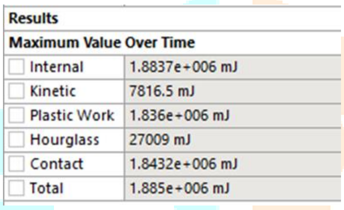


Fig.6 Energy Probe of square crashbox.

Energy Absorption vs Time graph





Results

Maximum Value Over Time	
☐ Internal	1.8837e+006 mJ
☐ Kinetic	7816.5 mJ
☐ Plastic Work	1.836e+006 mJ
☐ Hourglass	27009 mJ
☐ Contact	1.8432e+006 mJ
☐ Total	1.885e+006 mJ

Rectangular Geometry:

Geometry:

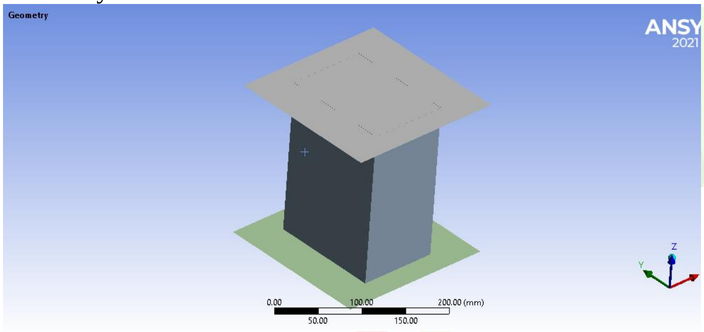
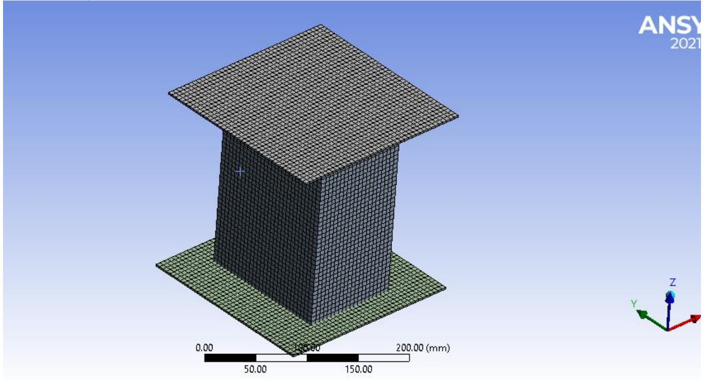
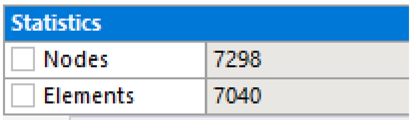


Fig.7 Geometry of Rectangular Crashbox

Meshing:





Statistics	
☐ Nodes	7298
☐ Elements	7040

Fig.8 Meshing details of Rectangular Crashbox.

Boundary Conditions:

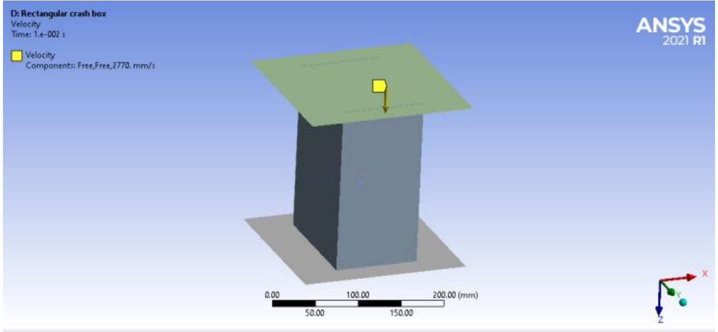


Fig.9 Boundary Conditions for rectangular Crashbox

Results:

Directional Deformation

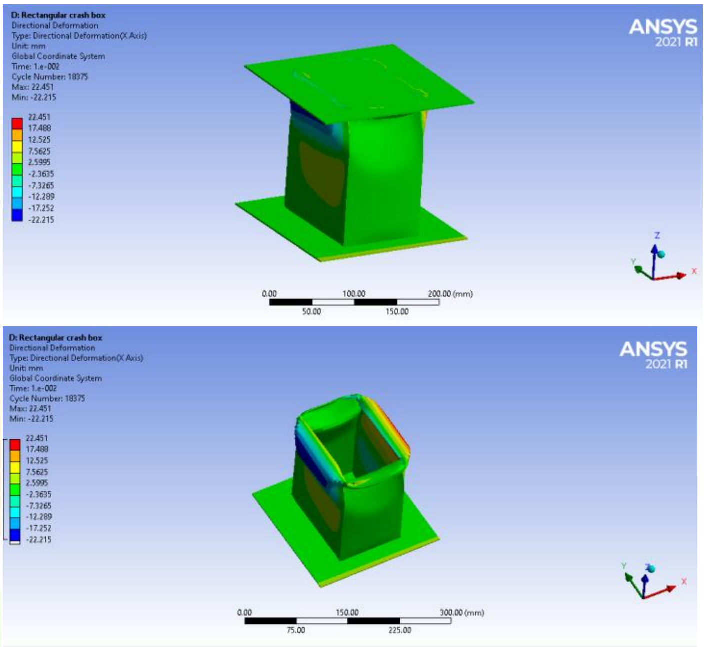


Fig.10 Directional Deformation (X Axis) of rectangular crashbox.

Equivalent Stress

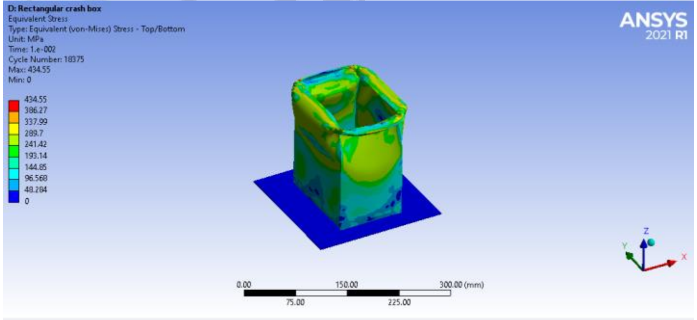


Fig.11 Equivalent Stress of rectangular crashbox.

Energy Probe

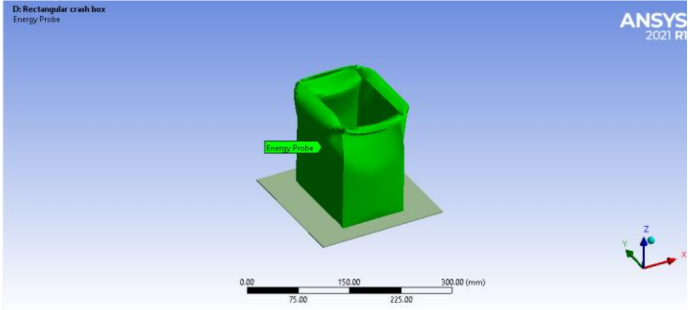
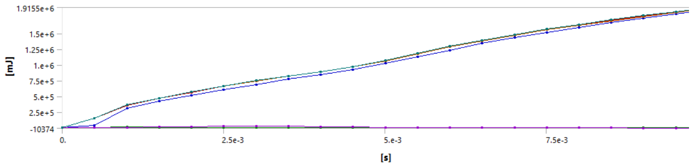
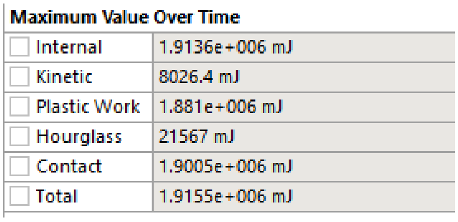


Fig.12 Energy Probe of rectangular crashbox.

Energy Absorption vs Time graph





Maximum Value Over Time	
☐ Internal	1.9136e+006 mJ
☐ Kinetic	8026.4 mJ
☐ Plastic Work	1.881e+006 mJ
☐ Hourglass	21567 mJ
☐ Contact	1.9005e+006 mJ
☐ Total	1.9155e+006 mJ

Circular Geometry:

Geometry:

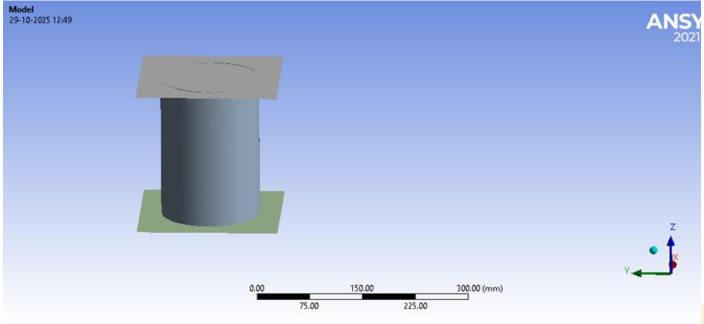
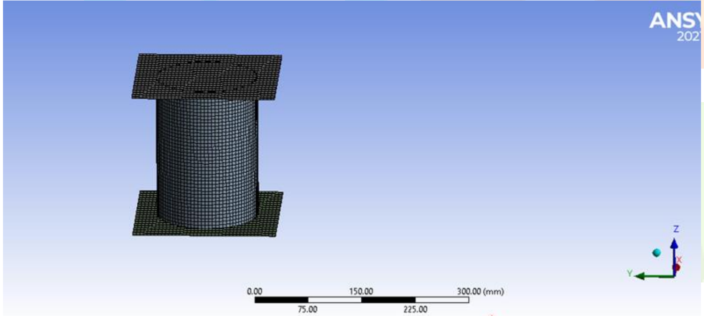
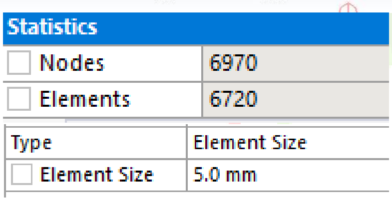


Fig.13 Geometry of Circular Crashbox

Meshing:



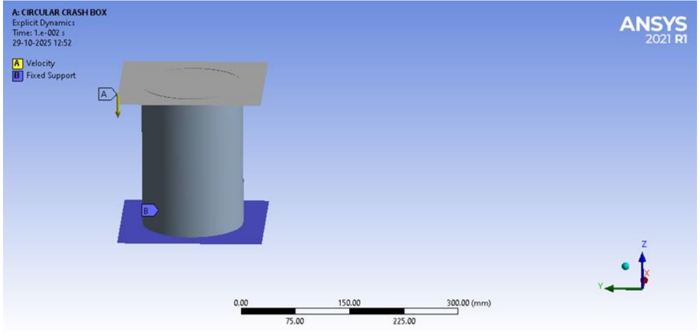


Statistics	
☐ Nodes	6970
☐ Elements	6720

Type	Element Size
☐ Element Size	5.0 mm

Fig.14 Meshing details of Circular Crashbox.

Boundary Conditions:



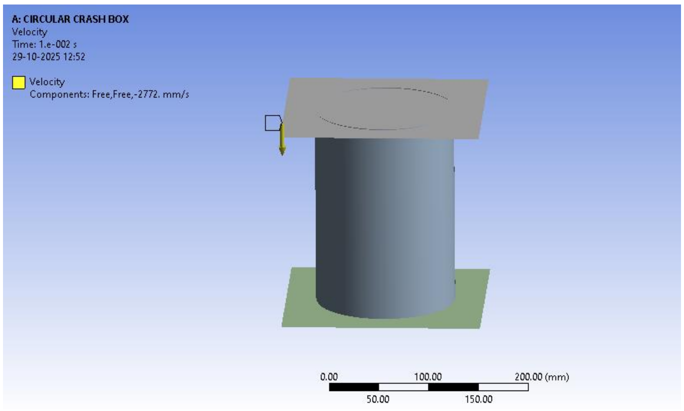
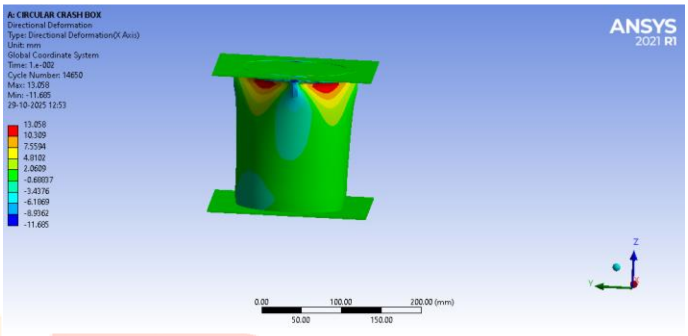


Fig.15 Boundary Conditions for Circular Crashbox

Results:

Directional Deformation



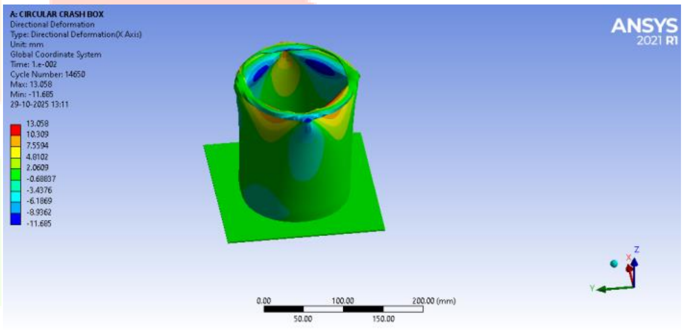


Fig.16 Directional Deformation (X Axis) of circular crashbox.

Equivalent Stress

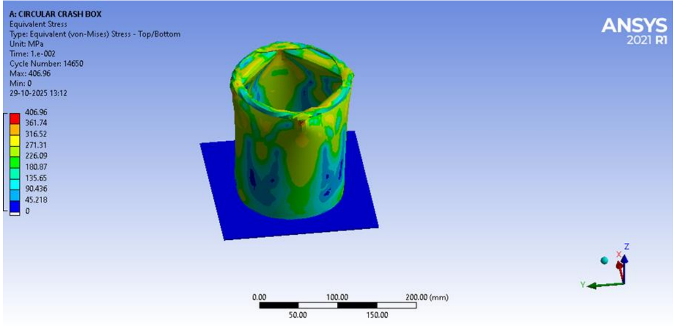


Fig.17 Equivalent Stress of circular crashbox.

Energy Probe

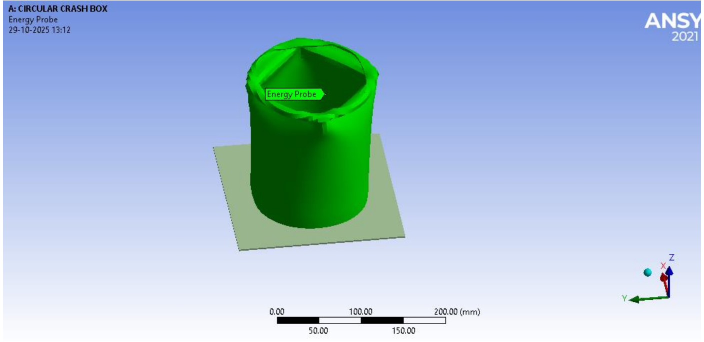
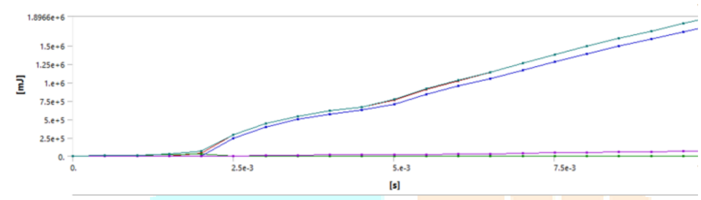
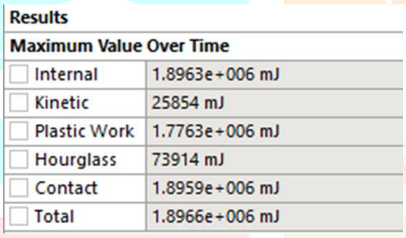

A: CIRCULAR CRASH BOX
Energy Probe
29-10-2025 13:12

Fig.18 Energy Probe of circular crashbox.

Energy Absorption vs Time graph





Results	
Maximum Value Over Time	
☐ Internal	1.8963e+006 mJ
☐ Kinetic	25854 mJ
☐ Plastic Work	1.7763e+006 mJ
☐ Hourglass	73914 mJ
☐ Contact	1.8959e+006 mJ
☐ Total	1.8966e+006 mJ

Hexagonal Geometry:

Geometry:

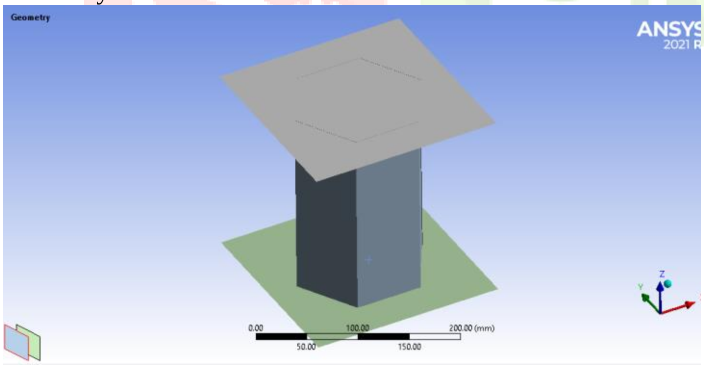
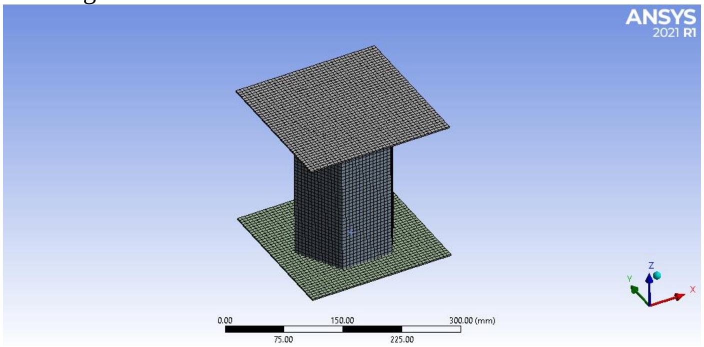
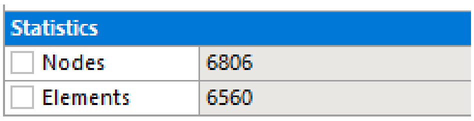

Geometry

Fig.19 Geometry of Hexagonal Crashbox

Meshing:





Statistics	
☐ Nodes	6806
☐ Elements	6560

Fig.20 Meshing details of Hexagonal Crashbox.

Boundary Conditions:

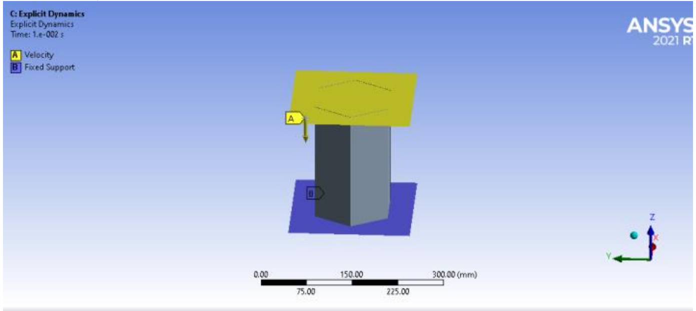
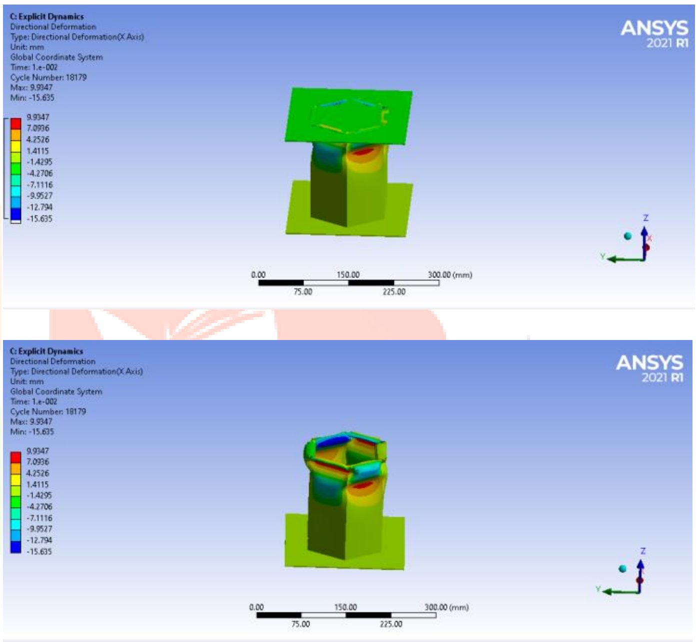

C: Explicit Dynamics
Explicit Dynamics
Time: 1.e-002 s
A Velocity
B Fixed Support

Fig.21 Boundary Conditions for hexagonal Crashbox

Results:

Directional Deformation


C: Explicit Dynamics
Directional Deformation
Type: Directional Deformation(X Axis)
Unit: mm
Global Coordinate System
Time: 1.e-002
Cycle Number: 18179
Max: 9.9347
Min: -15.635

C: Explicit Dynamics
Directional Deformation
Type: Directional Deformation(X Axis)
Unit: mm
Global Coordinate System
Time: 1.e-002
Cycle Number: 18179
Max: 9.9347
Min: -15.635

Fig.22 Directional Deformation (X Axis) of hexagonal crashbox.

Equivalent Stress

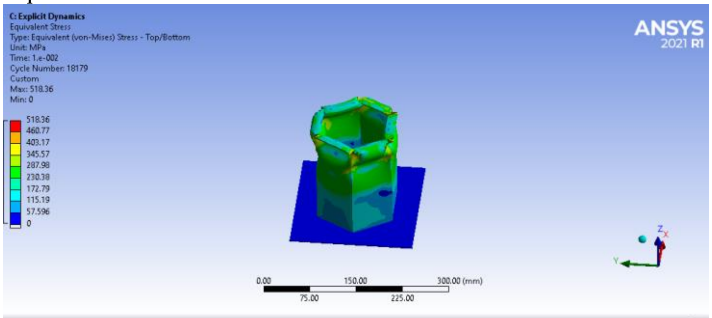

C: Explicit Dynamics
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top/Bottom
Unit: MPa
Time: 1.e-002
Cycle Number: 18179
Custom
Max: 518.36
Min: 0

Fig.23 Equivalent Stress of hexagonal crashbox.

Energy Probe

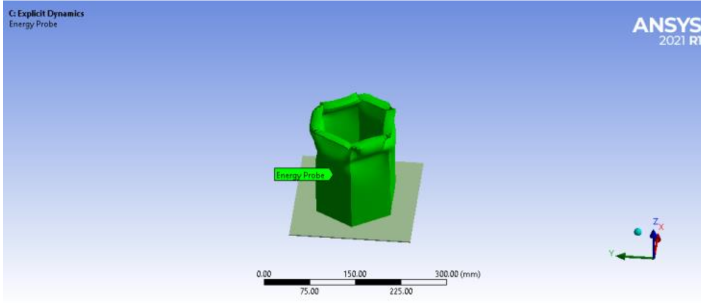
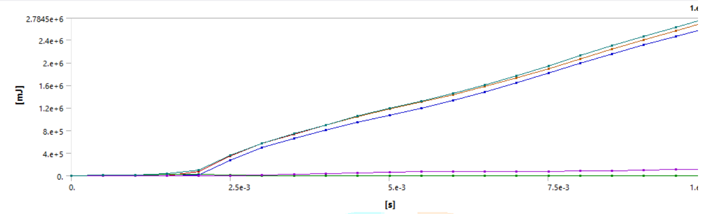
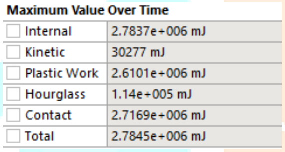


Fig.24 Energy Probe of hexagonal crashbox.

Energy Absorption vs Time graph





Maximum Value Over Time

☐ Internal	2.7837e+006 mJ
☐ Kinetic	30277 mJ
☐ Plastic Work	2.6101e+006 mJ
☐ Hourglass	1.14e+005 mJ
☐ Contact	2.7169e+006 mJ
☐ Total	2.7845e+006 mJ

Glass Fiber Reinforced Hexagonal Geometry:

Geometry:

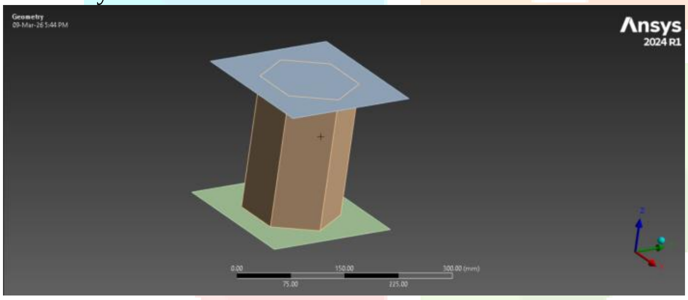
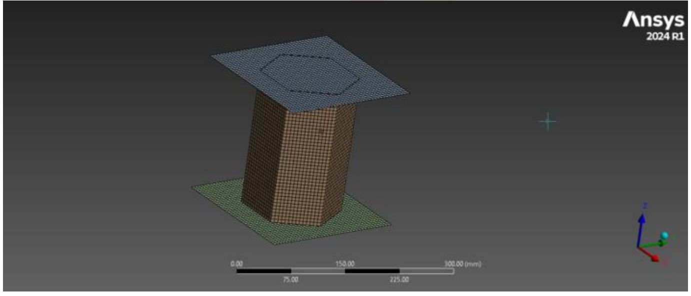
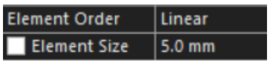


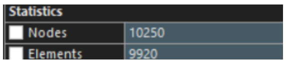
Fig.25 Geometry of Hexagonal Crashbox

Meshing:





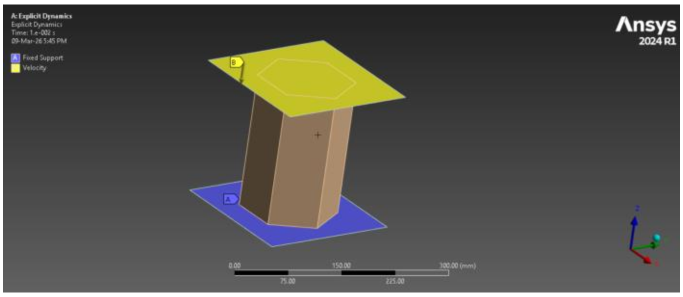
Element Order	Linear
☐ Element Size	5.0 mm

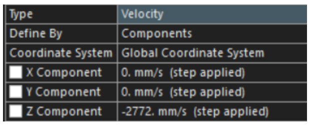


Statistics	
☐ Nodes	10250
☐ Elements	9920

Fig.26 Meshing details of Hexagonal Crashbox.

Boundary Conditions:





Type	Velocity
Define By	Components
Coordinate System	Global Coordinate System
☐ X Component	0. mm/s (step applied)
☐ Y Component	0. mm/s (step applied)
☐ Z Component	-2772. mm/s (step applied)

Fig.27 Boundary Conditions for hexagonal Crashbox

Results:

Directional Deformation

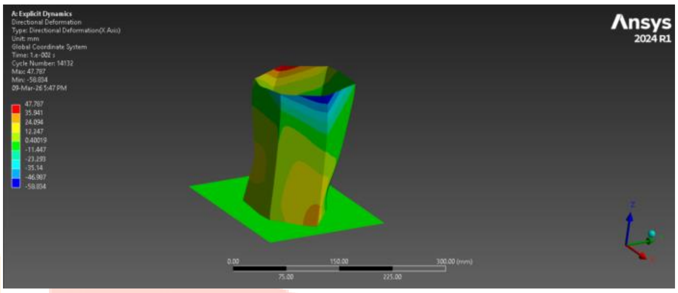


Fig.28 Directional Deformation (X Axis) of hexagonal crashbox.

Equivalent Stress

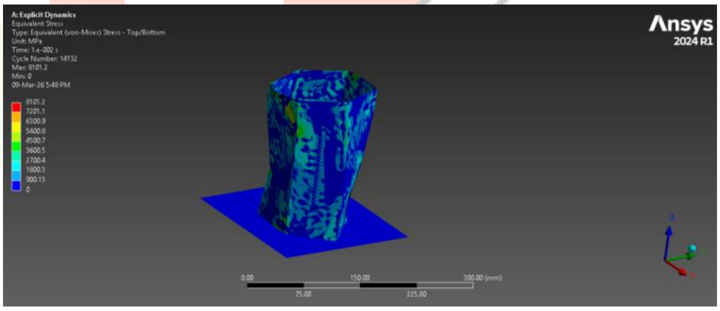


Fig.29 Equivalent Stress of hexagonal crashbox.

Energy Probe

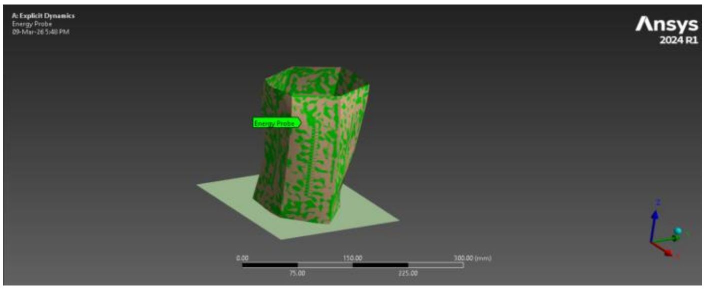
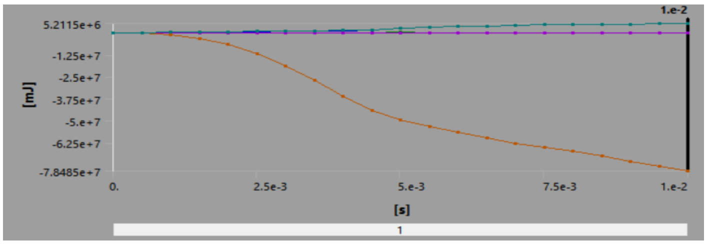
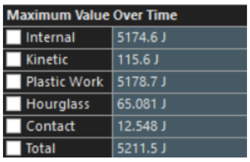


Fig.30 Energy Probe of hexagonal crashbox.

Energy Absorption vs Time graph



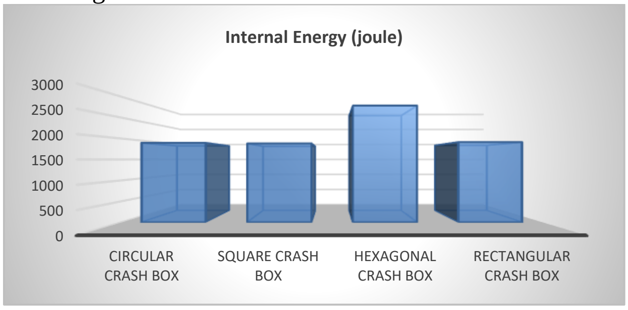


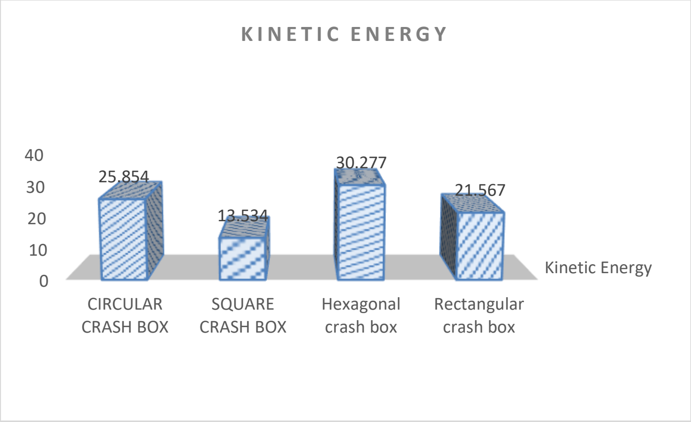
Maximum Value Over Time	
☐ Internal	5174.6 J
☐ Kinetic	115.6 J
☐ Plastic Work	5178.7 J
☐ Hourglass	65.081 J
☐ Contact	12.548 J
☐ Total	5211.5 J

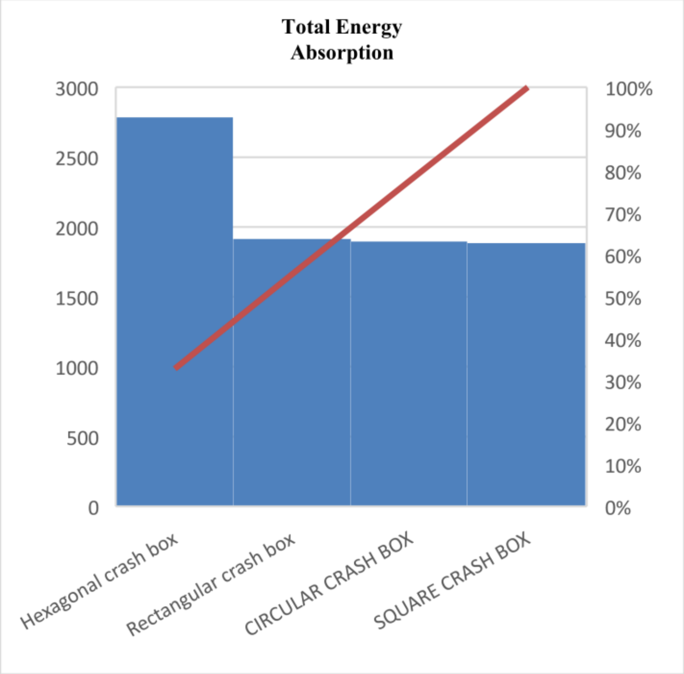
Fig.31 Energy Absorption vs Time graph

FEA RESULTS

The internal energy, kinetic energy and total energy absorption of all four geometries obtained is as follows:







	Internal Energy [J]	Kinetic Energy [J]	Total Energy Absorption[J]
CIRCULAR CRASH BOX	1896.3	25.854	1896.6
SQUARE CRASH BOX	1883.7	13.534	1885
HEXAGONAL CRASH BOX	2783.7	30.277	2784.5
RECTANGULAR CRASH BOX	1913.6	21.567	1915.5

Table.2 Energy Comparison for different crashbox shapes

From the above values, we can conclude that the hexagonal crash box geometry has the highest Internal energy, Kinetic energy and total energy absorption among all four geometries, and hence, is the most crashworthy geometry.

FEA was then performed on the Glass Fiber reinforced hexagonal crash box geometry.

Finite Element Analysis (FEA) on the glass fiber reinforced hexagonal crash box yielded a maximum internal energy absorption of 5174.6 J, kinetic energy absorption of 115.6 J, and total energy absorption of 5211.5 J. These values represent a substantial improvement—over 85% increase in total energy absorption—compared to the baseline hexagonal geometry.

V. MANUFACTURING OF THE COMPONENT

The fabrication of the hexagonal crash box was carried out using a combination of sheet metal forming and composite layering techniques. The process involved shaping an aluminium sheet into a hexagonal cross-section followed by reinforcement using a glass fiber–resin composite layer to enhance structural performance and energy absorption.
The aluminium sheet was bent along the marked lines using a sheet metal bending process to form a regular hexagonal cross-section. The bending was carried out sequentially to ensure dimensional accuracy and uniformity of sides.

Fig. Aluminium Hexagonal Crash box before Glass Fiber Reinforcement.

After forming the hexagonal crash box, a composite reinforcement layer was applied:

1. A layer of resin solution was first coated uniformly over the aluminium surface.
2. Glass fiber sheets were then carefully wrapped around the crash box.

3. Another layer of resin was applied over the glass fiber to ensure proper bonding and impregnation.
4. The assembly was left to cure at room temperature to achieve sufficient strength.

Fig.33 Application of Glass Fiber Layer using resin solution.

Fig.34 Final Glass Fiber Reinforced Specimen.

VI. EXPERIMENTAL TESTING

A Universal Testing Machine (UTM) is a versatile device used to determine the mechanical properties of materials and structures under different loading conditions such as tension, compression, and bending.

It operates by applying a controlled load to a specimen through a movable crosshead, while simultaneously measuring the applied force using a load cell and the corresponding deformation using displacement sensors.

In compression testing, the specimen is placed between two platens and subjected to an increasing compressive load. The machine records the force–displacement response, which is used to evaluate parameters such as peak load, mean crushing force, and energy absorption.

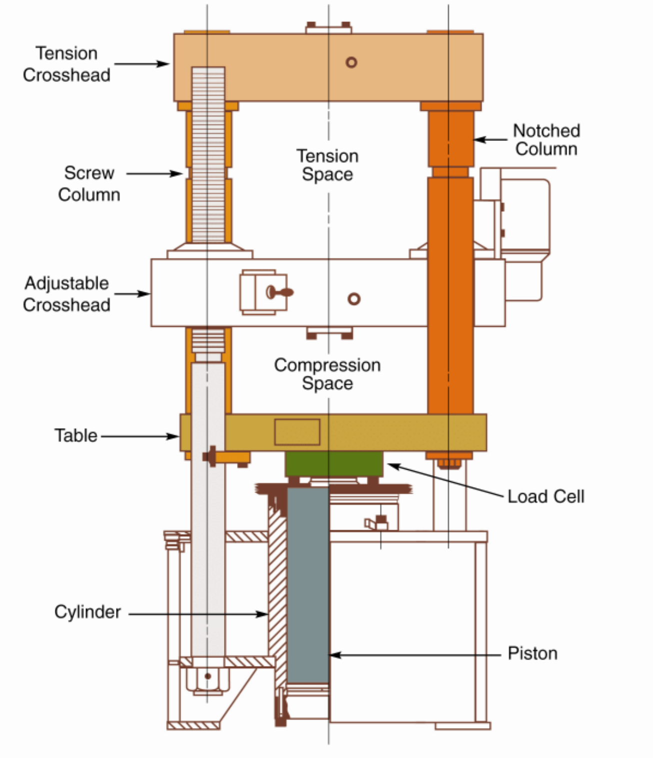


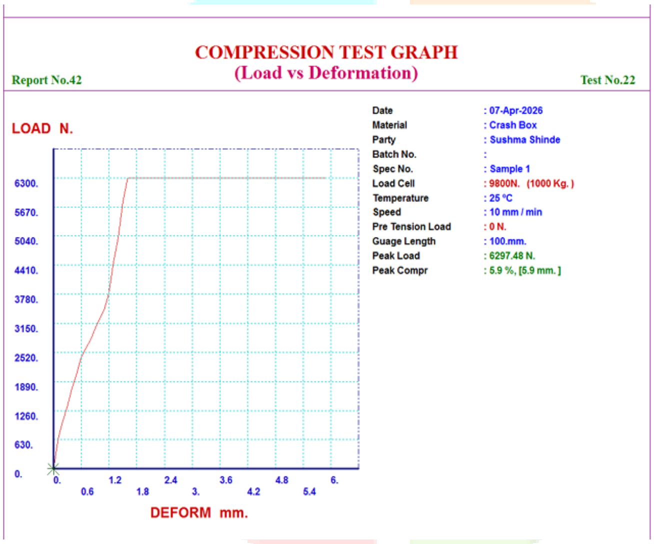
Fig.35 Schematic Diagram of a UTM.

Testing Procedure:

1. The fabricated hexagonal crash box specimen was prepared and inspected for dimensional accuracy and defects.
2. The specimen was placed vertically between the upper and lower platens of the UTM.
3. Proper alignment was ensured to avoid eccentric loading during compression.
4. The UTM was set to compression mode, and a constant displacement rate was applied.
5. The load was gradually increased until significant deformation of the crash box was observed.
6. The force–displacement data was recorded throughout the test.

Fig.36 Specimen under compression testing using UTM.

Testing Graph:



COMPRESSION TEST GRAPH
(Load vs Deformation)
Report No.42
Test No.22

Date : 07-Apr-2026
Material : Crash Box
Party : Sushma Shinde
Batch No. :
Spec No. : Sample 1
Load Cell : 9800N. (1000 Kg.)
Temperature : 25 °C
Speed : 10 mm / min
Pre Tension Load : 0 N.
Guage Length : 100.mm.
Peak Load : 6297.48 N.
Peak Compr : 5.9 %, [5.9 mm.]

Fig.37 Load vs Deformation Graph.

Graph shows load vs deformation for the compression test. The Y-Axis represents the load in Newtons; the X-Axis represents the deformation of the specimen in mm.

Conclusion

- This study presented the design and optimization of an automotive crash box with the objective of enhancing crashworthiness through improved energy absorption and controlled deformation.
- A comparative analysis of different cross-sectional geometries—square, rectangular, circular, and hexagonal—was carried out using analytical methods.
- Among these, the hexagonal configuration demonstrated superior performance in terms of internal energy, kinetic energy, and total energy absorption, establishing it as the most efficient geometry for impact energy management.
- To further enhance performance, the hexagonal crash box was reinforced with a glass fiber–resin composite layer.
- Finite Element Analysis (FEA) revealed a significant improvement in energy absorption characteristics, with the reinforced model achieving total energy absorption of 5211.5 J, representing an increase of over 85% compared to the baseline configuration.
- The reinforced structure also exhibited stable progressive deformation and improved load distribution during compression.

- Experimental validation was performed using a Universal Testing Machine (UTM) under compressive loading conditions.
- The force–displacement response and deformation patterns obtained experimentally showed good agreement with the FEA results, thereby confirming the accuracy and reliability of the numerical model.

- Overall, the study demonstrates that the integration of optimized geometry and composite reinforcement can substantially improve crash box performance.
- The proposed glass fiber–reinforced hexagonal crash box offers a lightweight and effective solution for automotive impact energy absorption. The methodology adopted in this work can be extended for further optimization and real-world implementation in vehicle safety systems.

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