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Deformation Analysis of Electric SUV Crash Box: Comparison Between Hollow and 3D-Printed Lattice Core Models Using ANSYS Explicit Dynamics

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Abstract

The development of SUV electric vehicles requires a crash box system that is able to reduce deformation more effectively than conventional hollow designs that tend to be unstable when subjected to high-energy impacts. This study compared the performance of three crash box models, namely hollow, lattice 3D-printed core, and lattice with internal divider wall using ANSYS Explicit Dynamics simulation. The main parameters analyzed include the folding pattern of collapse and maximum deformation as indicators of structural stability. The simulation results showed that all models were in concertina deformation mode, but the stability levels differed significantly. The crash box hollow recorded the largest deformation of 47,579 mm, while the divider-less lattice model decreased to 38,899 mm. The lattice configuration with divider walls is the most superior design with a minimum deformation of 31,098 mm, as well as a more symmetrical and controlled fold pattern. These findings confirm that the integration of the lattice structure, especially with the internal divider is capable of increasing rigidity and inhibiting axial buckling without significant mass gain. Further research is recommended evaluating lattice topology variations and experimental tests as verification of numerical results.

Keywords: Crash box, Electric Vehicle SUV, Lattice structure, Explicit Dynamics, Deformation analysis

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INTRODUCTION

As awareness of the environmental impact of fossil fuel-based transportation increases, many countries and global automotive manufacturers are starting to accelerate the transition to electric vehicles (EVs), as a key solution to reduce carbon emissions and reliance on non-renewable energy [1]. Notably, the electric SUV segment is experiencing significant growth due to its ability to accommodate larger battery capacity as well as the flexibility of use in various road conditions [2]. However, shifts in drivetrain technology and vehicle structural design demand a redesign of passive safety systems capable of dealing with collision scenarios with different energy characteristics [3]. Frontal collisions remain a major contributor to fatal vehicle incidents, so the effectiveness of energy-absorbing structures such as crash boxes is a vital element in the design of modern electric vehicles [4]. In this context, the development of innovative solutions based on new materials such as lattice structures resulting from 3D printing is increasingly being studied to replace conventional designs in crash boxes for increased crashworthiness without sacrificing weight efficiency [5].

The crash box is a key component in the modern vehicle crumple zone system designed to absorb and distribute impact energy so that it is not directly transmitted to the passenger cabin structure [6]. In electric vehicles, especially SUVs, the role of the crash box becomes more complex because it is also responsible for protecting the battery pack which is more susceptible to damage due to impact forces than the internal combustion engine [7]. An effective crash box design must be able to produce a progressive and controlled deformation pattern to avoid over-force transmission to the rear of the vehicle [8]. This deformation stability is important because it prevents unexpected collapse modes that could endanger cabin occupants [9]. Therefore, the integration of innovative structures such as foam or core lattice is an increasingly researched solution to optimize crashworthiness by keeping weight efficient[10].

Hollow-shaped crash boxes made of aluminum are often used because they are light in weight and the production process is efficient, but these structures tend to produce unstable collapse patterns on high-energy impacts, triggering global deformation of buckling and asymmetrical folds resulting in suboptimal absorption of impact energy [11]. This challenge is even more critical when applied to electric vehicles, especially SUVs, which have a larger total mass due to the use of high-capacity batteries. The additional mass in the EV increases the impact force during an accident, so conventional hollow crash boxes often fail to maintain the progressive deformation necessary to maintain the safety of the cabin and energy storage systems [12]. The performance of this type of crash box also shows fluctuating Specific Energy Absorption (SEA) and Crushing Force Efficiency (CFE) values, especially in dynamic simulations [13]. For this reason, a crash box design that is more adaptive to the characteristics of SUV models is needed, one of which is through the use of a 3D printing-based lattice internal structure that is able to direct the collapse pattern in a more controlled manner without significantly increasing the mass of the vehicle [14].

Lattice-shaped internal structures produced through 3D printing technology are increasingly being researched because they are able to direct the deformation mode precisely, increase local rigidity, and keep the deformation folds in high-energy impact scenarios [15]. Some geometries such as gyroids, honeycombs, and conformal lattices have been shown to show improved crashworthiness performance in explicit simulations and experimental testing [16]. To date, very few studies have specifically analyzed the structural deformation behavior of SUV-type electric vehicle crash boxes by comparing lattice models on ANSYS Explicit Dynamics [17]. This condition shows that there is a research gap that has not been comprehensively filled, and it is important to explore further in the context of large-weight electric vehicles [18].

This study is focused on the deformation analysis of crash box crash boxes of SUV type electric vehicles by comparing the performance of conventional hollow models and reinforced models with lattice structures resulting from 3D printing [19]. The simulation using ANSYS Explicit Dynamics was chosen because it was able to realistically represent the behavior of materials and structures under high-speed impact conditions [20]. From this simulation, it is hoped that a deeper understanding of the stability of the folds, the direction of collapse, and the structural response to dynamic loads will emerge [21]. A focus on structural deformation, not just energy absorption efficiency, is key to improving safer and lighter crash box designs [22]. With the increasing use of electric SUVs, this kind of research is becoming crucial to meet the demands of structural safety in the modern automotive industry[23].

METHOD

This study uses a simulation method by designing and comparing three models of SUV electric car crash boxes, namely the hollow model, a lattice structure model based on 3D printing, and one other comparative design made with uniform dimensions with different lattice patterns to ensure the validity of the test under controlled conditions [24]. The entire model was then analyzed through impact simulation using ANSYS Explicit Dynamics to obtain data on deformation, folding patterns, and structural responses during the impact process. The results of the simulation were then compared to evaluate the influence of design variations on the crash box collapse mechanism and the degree of deformation that occurred.

Crash Box Design

The crash box design in this study was designed using a uniform size of 90 mm × 70 mm × 150 mm with a wall thickness of 2 mm to maintain the same shape and proportions between the models. The determination of the specification aims to ensure that the performance of each variant, both hollow and lattice types, can be tested and compared fairly in the evaluation of deformation during impact. The selection of these dimensions is also based on the consideration that these measurements are widely applied to SUV electric vehicle crash boxes, so that the simulations carried out are able to describe the actual conditions of use and provide relevant results to be applied in the industrial environment as well as the development of the structural design of future vehicles.

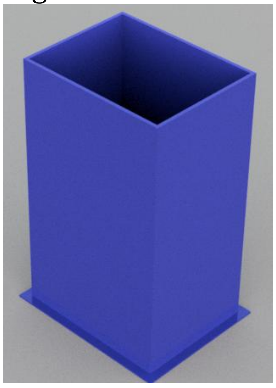

Figure 1. 3D Model of Hollow Crash Box Used as Baseline Control to Compare Structural Response Against Lattice-Based Configurations

This image shows the first design in the form of a crash box hollow without a 3D printing core structure. The model is in the form of a thin-walled square tube with a blank inside, This basic design is used as a reference for comparison with two other models with a lattice structure.

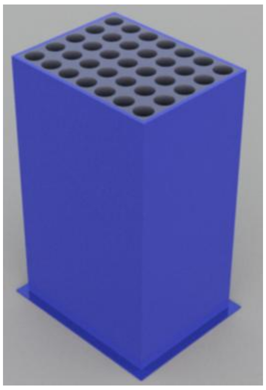

Figure 2. Full 3D-Printed Lattice Core Crash Box Model Designed to Improve Load Distribution and Stability During Axial Impact

This image shows the design of the second crash box equipped with a 3D printed lattice structure on the inside. The lattice is made up of many small cylindrical elements that are neatly arranged to add rigidity while improving energy absorption in the event of a collision. With the lattice core, this crash box is expected to have a more controlled deformation pattern than the hollow model.

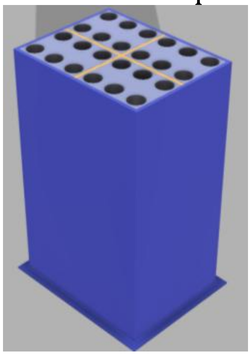

Figure 3. Lattice-Core Crash Box Model Equipped With Central Divider to Enhance Load Distribution and Delay Buckling During Impact

The third design uses an additional 2 mm thick partition wall in the center of the crash box, so that the 3D print core is divided into four separate parts. Each part is still filled with 3D printed cylindrical elements, but the arrangement pattern is different from the previous design to obtain variations in internal rigidity. The addition of this separation wall aims to improve the stability of the structure and help direct deformation to be more controlled when experiencing a collision.

Material Crash Box

In this study, the main material used to form the crash box is Aluminum 6061-T6, chosen because it has a relatively light weight but still offers structural strength and good toughness in absorbing impact energy. In some design configurations, the core is reinforced with Polyethylene HDP material produced through the 3D printing process, where this component plays a role in increasing internal stability while helping to distribute energy during deformation. As a source of impact in the simulation, a Structural Steel impactor is used due to its high degree of rigidity, so that it is able to represent the mass of the fist consistently and close to real conditions in the collision dynamics test. Below is a table of crash box materials and their impactors:

Table 1. Mechanical properties of Aluminium 6061-T6, Polyethylene, and Structural Steel used in the crash box models.

Material	Density (kg/m^3)	Young's Modulus (Pa)	Poisson's Ratio	Shear Modulus (Pa)	Yield Strength (Pa)
Aluminium 6061-T6	2700	6.7843×10^{10}	0.33	2.6015×10^{10}	2.8×10^{8}
Polyethylene (HDPE)	950	1.1×10^{9}	0.42	3.8732×10^{8}	2.5×10^{7} *(Tensile Yield)*
Structural Steel	7850	2.0×10^{11}	0.30	7.6923×10^{10}	2.5×10^{8}

Meshing

Meshing is the process of breaking a continuous object into finite small elements so that they can be analyzed numerically using the element method of up to [25]. Through this process, the original shape of a model is represented into a collection of elements that allow simulations of deformation, stress, and dynamic responses to be carried out more accurately. In this study, the mesh was formed automatically using a triangular element with a size of 5 mm on the crash box to obtain good deformation details. Meanwhile, the impactor uses a solid element measuring 30 mm, because this part does not require a high level of precision and only functions as a fist in the impact scenario.

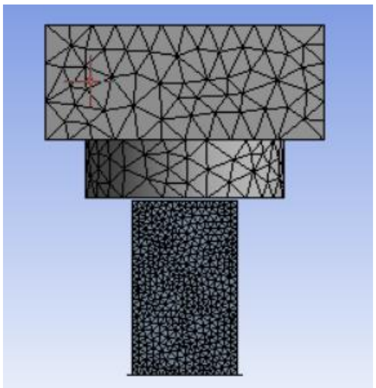

Figure 4. Meshing Configuration Crash Box And Impactor

Impact Simulation

The simulation process in this study begins with the initial condition where the impactor and crash box are attached to each other. The impactor is modeled as a rigid body, while the crash box is a flexible body to capture its deformation response more accurately. A fixed support base is placed at the bottom of the crash box as the main anchor during the simulation process. In the next stage, the impactor is axically driven to pound the crash box at a speed of 41.67 m/s (150 km/h). The impact at this speed causes the crash box to deform according to the characteristics of the material and design tested.

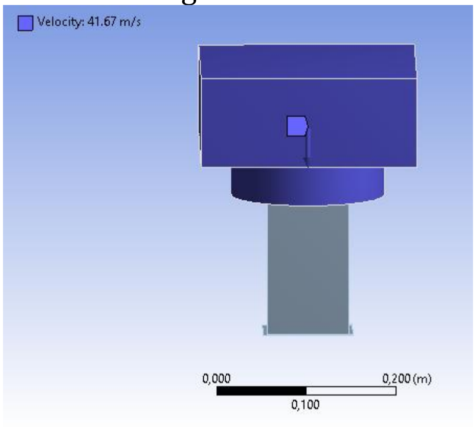

Figure 5. Initial Setup of The Axial Impact Simulation Between The Impactor And Crash Box

RESULT AND DISCUSSION

Deformation Pattern

Overall, the crash box deformation pattern in this study is in line with the findings of Choiron et al. [2017], which states that crash box structures with axial loading can experience two types of collapse modes, namely axisymmetric or concertina mode, and diamond mode which is characterized by the formation of transverse and longitudinal folds. Based on the simulation results, all crash box models in this study show a concertina-type collapse pattern. Meanwhile, diamond mode usually only appears on crash boxes with no variation in thickness or without wall tapering. If a crash box has undergone diamond-type deformation, then its collapse cannot turn into concertina mode again.

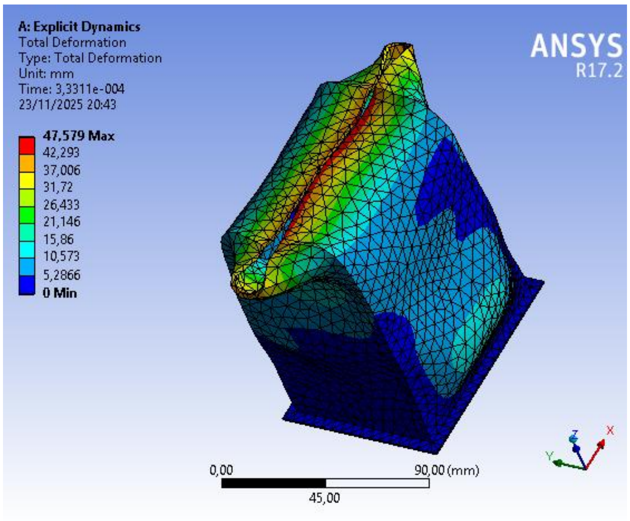

Figure 6. Total Deformation Contour Of Hollow Crash Box

The simulation results on the design of the crash box without fillings showed a deformation pattern consistent with the axial crushing characteristics proposed by Choiron et al. [2017], where the structure tends to collapse in concertina mode. In this model, the main fold forms on the top side of the crash box and expands downwards asymmetrically, resulting in a dominant inward bend on one side. Hollow conditions cause the crash box wall to have no internal retainer, so the structural stability is low and collapse is easier to follow the path of the weakest point. This is reflected in the maximum deformation value of 47.579 mm, which is the highest value among the three designs. The magnitude of this deformation indicates that the unfilled crash box has the lowest energy absorption ability and experiences faster loss of rigidity during the impact process, so that the folds develop in an irregular shape but remain in a typical concertina pattern.

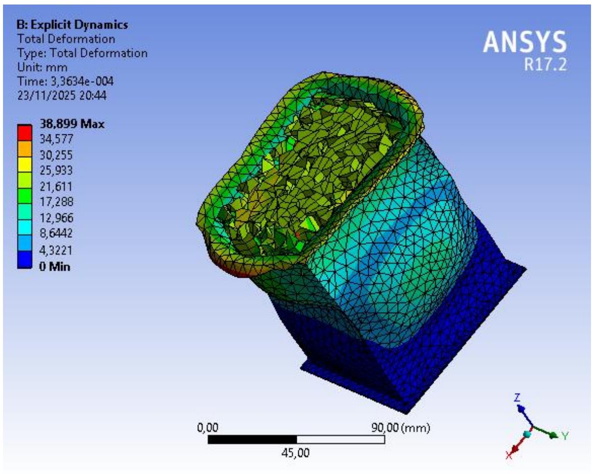

Figure 7. Total Deformation Contour of Crash Box With A Full 3D-Printed Core

The deformation of the crash box with 3D printed fillings without dividing walls showed a collapse pattern that was still in the concertina category, but with a more stable folding behavior than the model without filling. The presence of a core structure that fills the inner space provides additional rigidity so that the initial folds formed at the top are spread more evenly across the entire side of the crash box wall. Unlike hollow models that experience sharp bending on one side, this design exhibits more controlled dents with a more uniform deformation distribution due to the presence of internal cylindrical elements that help to resist the compression force. The maximum deformation value of 38,899 mm, which is lower than the first design, indicates that the 3D print fill is effective in slowing down the axial buckling process and better resisting impact energy. This indicates that although the collapse is still occurring, the crash box has increased structural rigidity so that the deformation does not develop to the extreme and remains in a more regular concertina pattern.

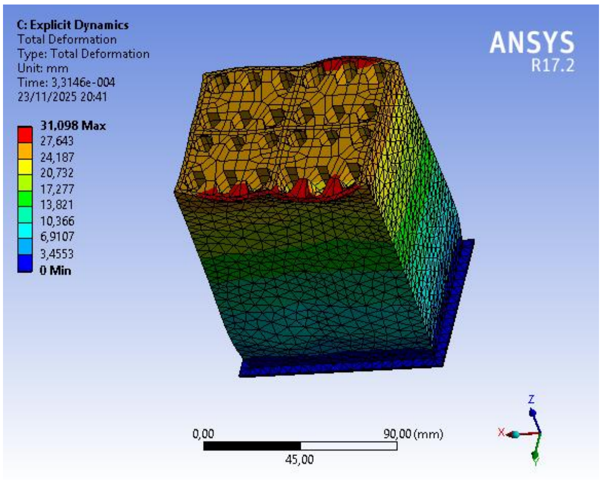

Figure 8. Total Deformation Contour of Crash Box With A 3D-Printed Core And Central Divider

The deformation of the crash box with 3D printing fillings equipped with a center divider wall shows the most stable collapse behavior among all designs. The internal structure, which is divided into four parts by a 2 mm separation wall, serves to increase local rigidity and direct the distribution of impact forces more evenly. This can be seen from the initial folds that form in the top area of the crash box and develop in a controlled manner without producing sharp dents on one side as happens with hollow designs. The deformation pattern remains in the concertina category, but appears much more symmetrical and orderly due to the presence of a central divider that retains lateral movement during the compression process. The maximum deformation value of 31,098 mm, being the lowest among the three designs, confirms that this configuration has the best ability to inhibit the occurrence of axial buckling and increase the resistance of the structure to high-speed impacts. This more controlled deformation behavior shows that the addition of dividing walls is effective in optimizing the performance of the crash box as an energy absorber.

Evaluation and Comparison between crash boxes

Table 2. Numerical Comparison of Deformation, Safety Factor, and Stress Distribution for Three Crash Box Designs

Design and Internal Configuration	**Maximum Deformation (mm)**	**Safety Factor**		**Stress**	
		Min	Max	Min (Pa)	Max (Pa)
Hollow (No internal core)	47.579 mm	0,017562	15	1.5944×10^{10}	$2{,}5369\times10^{5}$
3D-printed core full (no divider)	38.899 mm	0,0092919	15	3.0134×10^{10}	7.4015×10^{6}

3D-printed core + central divider	31.098 mm	0,010962	15	2.5543×10^{10}	2.4646×10^{7}

A comparison of the performance of the three crash box designs shows that the internal configuration has a significant influence on the deformation and stability of the structure during impact. The hollow model produced the largest deformation of 47,579 mm, which indicates that the absence of internal support caused buckling to occur faster because the impact force was directly received by the outer wall without an energy distribution mechanism. In a design with a full lattice, the deformation decreases to 38,899 mm or a reduction of about 18.3% compared to the hollow model, which shows that the lattice structure acts as a load distribution path so that the compressive force can be absorbed more evenly, the fold is more stable, and the collapse process is not directly focused on one weak point. The best performance is demonstrated by the design with a lattice and a center divider with a deformation of only 31,098 mm, or 34.6% lower than a hollow and 20% smaller than a full lattice, as the divider wall forms four internal cells that resist lateral movement and direct the concertina fold more symmetrically. This significant variation in deformation values explains that the more complex the internal structure, the better the crash box is at slowing down the spread of folds and improving deformation control, so that impact energy can be channeled gradually and more effectively before plastic failure occurs. Thus, it can be concluded that the lattice structure, especially with the addition of a center divider, has superior potential to be applied to SUV electric vehicle crash boxes because it is able to increase crashworthiness without significantly increasing mass.

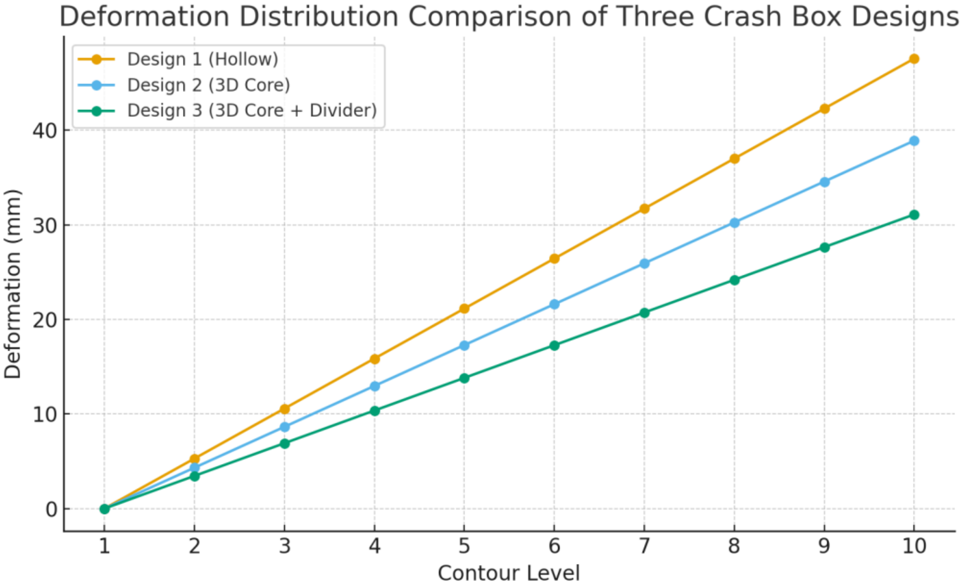

Figure 9. Deformation comparison chart among the three crash box designs

The pattern of comparison between designs is increasingly evident in the deformation distribution graph, where each contour level shows that Design 3 consistently produces the lowest deformation value, followed by Design 2, while Design 1 remains the highest. The three-line graph confirms that the addition of an internal core is able to increase resistance to axial buckling, and the presence of a divider wall in the third design contributes the most to maintaining the stability of the crash box shape during the compression process. Overall, the internal configuration proves to be a major factor in improving the performance of the crash box, with Design 3 appearing as the most optimal option in reducing deformation while maintaining structural stability. These findings are in line with the study of Hou et al. [2023] which states that the addition of lattice structures is able to improve crashworthiness through increased local rigidity and more stable deformation distribution. These results are also consistent with the report of Bunsri et al. [2024] Regarding the performance of the crash box with truss-lattice which shows a decrease in deformation and a more controlled folding pattern. In addition, the research of Alagesan et al. [2025] confirms that the multi-cell configuration or internal partition can significantly improve the efficiency of energy absorption, so that the crash box is not easily subjected to lateral buckling. Thus, the findings of this study have a strong empirical foundation and are on the path of modern research development related to lattice-structure-based crash boxes for electric vehicles.

CONCLUSION

This study highlights the problem of low stability of conventional crash boxes in electric SUVs that causes large deformations and uncontrolled buckling during high-speed axial impacts, resulting in the need for more effective structural design innovations. Through ANSYS Explicit Dynamics simulations, it was obtained that the hollow crash box produced the greatest deformation, while the crash box with a lattice core and center divider showed the least deformation as well as a more stable concertina pattern, confirming that the internal configuration plays an important role in controlling the direction of collapse and delaying buckling. These findings show that the application of lattice design with bulkheads has the potential to be adapted to the mass production of electric vehicle crash boxes because it can increase energy absorption capacity without significantly increasing the weight of components, thus being able to improve the level of passenger safety while protecting the battery as a critical component of EVs. With manufacturing properties compatible with 3D printing technology and the possibility of lightweight material combinations, the design can be further developed for the needs of the modern automotive industry through lattice cell topology optimization, and physical experiment validation to ensure its performance reliability in real-world scenarios.

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