

Research Paper

A Comparative Study of Winding Angle Configurations for Improved Crashworthiness in Hybrid Al/CFRP Crash Boxes

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Abstract

This study investigates the crashworthiness performance of circular hybrid aluminum/carbon fiber reinforced polymer (Al/CFRP) crash boxes under dynamic axial impact, with particular focus on the influence of winding angle configurations. An explicit finite element model, validated against both experimental and numerical results from the literature, was developed using finite element software. The parametric analysis systematically varied CFRP winding angles from $[\pm 15^\circ]_s$ to $[\pm 85^\circ]_s$ in 10° increments and compared the outcomes with single and double cell aluminum crash boxes. Key crashworthiness indicators, including peak crushing force (PCF), mean crushing force (MCF), crushing force efficiency (CFE), stroke efficiency, and folding stability, were evaluated. The results reveal that hybridization significantly enhances load bearing capacity compared to conventional aluminum designs. Intermediate winding angles from 35 to 55 degrees yielded the best balance between PCF reduction, MCF enhancement, and stable progressive folding, with the $[\pm 45^\circ]_s$ configuration achieving the highest MCF and CFE, while $[\pm 35^\circ]_s$ minimized PCF. In contrast, winding angles greater than or equal to $[\pm 65^\circ]_s$ generated excessively high PCF, compromising occupant safety. The findings provide actionable insights for the design of hybrid crash boxes, demonstrating that optimized fiber orientation can advance crashworthiness beyond current aluminum or narrow angle hybrid configurations.

Keywords: Crash box; Hybrid Al/CFRP; Winding angle; Crashworthiness; Finite element analysis.

1. Introduction

The vehicle safety system is regarded as a critical parameter in the design of passenger cars. It functions to prevent accidents (active system) and to mitigate risks in the event of a collision (passive system). A crash box is a structural component of a vehicle designed to absorb collision energy through controlled deformation processes, thereby preventing its transmission to occupants and critical vehicle components [1]. Consequently, crash boxes are strategically positioned in impact-prone zones, including the front [2], rear [3], and lateral regions of the vehicle [4].

Crash box performance is strongly influenced by both its geometric design and material selection. The geometric configuration dictates the deformation mode during impact, which directly affects the stability of energy absorption. Conventional shapes such as square [5] and circular tubes [6] have been widely studied, while multi-cell designs [7] have been introduced to enhance crashworthiness. More recently, bio-inspired geometries drawing inspiration from natural structures such as honeycombs, bamboo, beetle elytra, and fish scales have been proposed to enhance progressive folding patterns and improve energy absorption efficiency under loading conditions [8], [9], [10]. These designs not



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only improve crash energy dissipation but also offer more predictable deformation paths, which are critical for ensuring occupant safety. While geometry dictates deformation stability, the choice of material is equally critical, as it determines how effectively the crash box can dissipate energy under impact. This highlights that material selection is another decisive factor in achieving optimal crash box performance.

The selection of crash box material is a critical design parameter due to its reliance on deformation patterns to absorb impact energy [11]. Crash box materials must maximize energy absorption capacity while minimizing weight to reduce vehicle mass, thereby enhancing fuel efficiency [12]. Conventionally, crash boxes are fabricated from metallic materials, with aluminum alloys being widely adopted for their favorable combination of low density and high toughness [13]. However, the relatively low yield strength of aluminum limits its energy absorption capacity [14].

Therefore, researchers have increasingly turned their attention to composite materials as potential alternatives. Composite materials, such as carbon fiber-reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP), have emerged as promising alternatives due to their superior strength-to-weight ratios compared to metals [15]. Among these, CFRP is often prioritized despite its higher cost, owing to its exceptional energy absorption-to-mass ratio, which outperforms both metallic and other composite counterparts [16]. However, a key limitation of CFRP crash box structures is their tendency to fail abruptly through mechanisms such as fiber breakage, matrix cracking, and delamination, rather than undergoing stable plastic deformation like metals, which makes their crash behavior less predictable [17].

To address these material limitations, hybrid crash box designs have emerged as an innovative solution that combines two different materials, allowing their properties to complement each other for improved performance. Aluminum, known for its high ductility, has often been paired with CFRP, which provides high rigidity. Previous studies have shown that such hybrid configurations enhance energy absorption capability compared to conventional crash boxes made solely from metals. For example, Liang et al.

[18] conducted a crashworthiness analysis on multi-cell tubes made from Al/CFRP with varying thicknesses and found that the use of multi-cell Al tubes contributed to structural instability. Dong et al. [19] examined the effect of different damage positions on hybrid Al/CFRP tubes under axial compression loads, while Cetin et al. [20] demonstrated that introducing a trigger hole could improve specific energy absorption (SEA) and crushing force efficiency (CFE) by 39.1% and 61.7%, respectively.

Although numerous studies on hybrid Al/CFRP crash boxes have been conducted, few have performed in-depth experimental investigations by systematically varying multiple design parameters to determine the most optimal crash box configuration. One of the main reasons is the high cost and complexity of manufacturing hybrid crash box specimens for impact testing. Hybrid Al/CFRP tubes are typically fabricated using the filament winding method, in which continuous CFRP fibers are wound around the aluminum tube at specific angles, directly controlling fiber orientation and thereby influencing energy absorption performance [21], [22], [23]. Consequently, dynamic impact and quasi-static tests on these specimens are often limited to a small number of samples, restricting the scope of experimental studies. To overcome these limitations, numerical simulations provide a cost-effective approach for investigating a wider range of design parameters.

Specifically, explicit finite element methods are generally employed for dynamic impact analyses, as they can accurately capture high-strain-rate responses and complex progressive deformation behaviors [24]. In contrast, implicit finite element methods are typically used for quasi-static crushing simulations, which require stable convergence and precise prediction of slow deformation modes [25]. By leveraging both explicit and implicit numerical approaches, it is possible to systematically investigate the effects of winding angle variations on the crashworthiness performance of hybrid Al/CFRP tubes.

The winding angle, which governs fiber orientation in the CFRP layers, plays a decisive role in determining deformation modes, stiffness, and overall crashworthiness of hybrid crash boxes [26],[27]. Specific stacking sequence designs can be employed to control deformation and folding

behavior while simultaneously enhancing energy dissipation and mitigating the risk of more severe impacts on vehicles and occupants. Previous studies, such as those conducted by Quanjin et al. [28], [29], Zhang et al. [30], and Yang et al. [31] have primarily focused on the influence of winding angle on the crashworthiness performance of CFRP crash boxes. Demir et al. [32] performed quasi-static experiments on Al/CFRP tubes but investigated only limited winding angles of 45° and 90°, whereas Ma et al. [33] carried out quasi-static axial compression tests validated by numerical methods on Al/CFRP tubes.

Despite these contributions, existing research has largely been constrained to a narrow variation of winding angles and has predominantly focused on quasi-static compression tests rather than dynamic impact conditions. As a result, the current understanding of the crashworthiness performance of hybrid Al/CFRP crash boxes under actual impact loading remains limited. To address this gap, the present study conducts a comprehensive numerical investigation on circular hybrid Al/CFRP crash boxes by systematically varying winding angles under dynamic impact loading. Furthermore, this study seeks to identify the most effective winding angle as a key design parameter to enhance crashworthiness performance, thereby providing deeper insights into the potential of hybrid structures for improving vehicle safety.

2. Methods

The explicit finite element method using LS-Dyna software is employed to solve the numerical model of the hybrid crash box subjected to dynamic impact loading. The explicit dynamic model is chosen due to its shorter computational time, smaller time step, and greater stability for impact scenarios compared to implicit numerical models. In the simulations to be conducted, prior to their application in the parametric study, the numerical model will first be validated against laboratory test results previously conducted by other researchers, as published in the available literature.

The material model is a crucial factor in ensuring the accuracy of results obtained from numerical simulations. In this study, the materials employed for the crash box are Aluminum A6063-

T6 and CFRP T700S, with their mechanical properties sourced from the existing literature [34],[35]. The numerical simulation software used provides various material model types, including MAT18 (Power-law plasticity model) and MAT54 (Enhanced Damage Composite Model), which are applied for modeling Aluminum and CFRP, respectively. The use of MAT54 for modeling the composite material allows for material degradation and the implementation of the Hashin failure criteria. Additionally, to optimize computational time, a rigid material model (MAT20) is employed for the impactor and tube support. The mechanical properties of A6063-T6 and T700S are presented in [Table 1](#) dan [Table 2](#).

The boundary conditions for the simulations conducted were adapted to the impact experiment setup, specifically by applying a fixed support at the support and constraining the movement of the impactor in all directions except along the axial direction of the tube. No boundary conditions were applied to the tube, other than the contact settings between the hybrid tube and its support, as well as the impactor, which were modeled using the automatic nodes to surface contact model. Additionally, the contact between the Aluminum and CFRP layers was modeled using the automatic surface to surface tiebreak contact model. This latter contact model requires the definition of interlaminar material properties that link Aluminum and CFRP materials. The numerical model of the simulation and the associated boundary conditions are shown in [Figure 1](#), while the parameters for the interlaminar shear properties used in the simulation are provided in [Table 3](#).

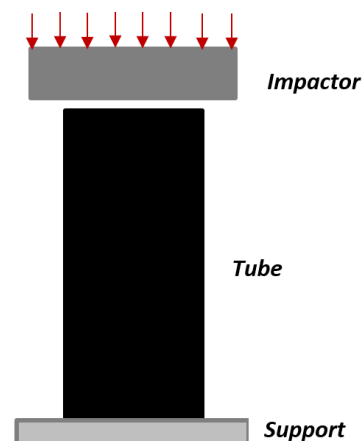


Figure 1. Dynamic impact model of the crash box under axial impact load.

Table 1. Mechanical properties of Aluminum A6063-T6 as reported in the literature [34]

Properties	Symbol	Value	Unit
Yield strength	σ_y	204	MPa
Modulus of elasticity	E	65	GPa
Strength coefficient	K	321	MPa
Hardening exponent	n	0.088	-

Table 2. Mechanical properties of CFRP T700S as reported in the literature [35]

Properties	Symbol	Value	Unit
Density	ρ	1.52	g/cm ³
Longitudinal modulus	E11	127	GPa
Transverse modulus	E22	8.41	GPa
Shear modulus	G12	4.21	GPa
Major Poisson's ratio	ν_{12}	0.309	-
Minor Poisson's ratio	ν_{23}	0.02049	-
Tensile longitudinal strength	XT	2200	MPa
Compressive longitudinal strength	XC	1470	MPa
Tensile transverse strength	YT	48.9	MPa
Compressive transverse strength	YC	199	MPa
In-plane shear strength	S	154	MPa

Table 3. Interlaminar material properties, from [36]

Property	Symbol	Value	Unit
Normal peak traction	T	40	MPa
Shear peak traction	S	50	MPa
Normal energy release rate	G_{Ic}	0.26	MPa.mm
Shear energy release rate	G_{IIc}	0.52	MPa.mm

In the finite element simulation, both aluminum and CFRP materials are modeled with the same mesh size of 4x4 mm, using two different types of shell element: the under-integrated four-node Belytschko-Tsay (ELFORM 2) and the fully integrated (ELFORM 16), applied respectively to the aluminum and CFRP materials. The use of ELFORM 16 is intended to achieve more accurate results, albeit with longer computational time compared to other element types, and its ability to mitigate the hourglass effect, which is highly dominant in impact simulations of composite materials [37],[38]. Similar to the shell model for the aluminum tube, the CFRP tube is modeled as a single shell, with the thickness of each layer and winding angle defined using the *PART_COMPOSITE* module. With this model, delamination between each composite layer cannot be observed; however, it does not reduce the accuracy of the overall simulation results, such as the contact force and deformation. **Figure 2** shows the hybrid Al/CFRP crash box modeling

technique using shell elements applied in this study.

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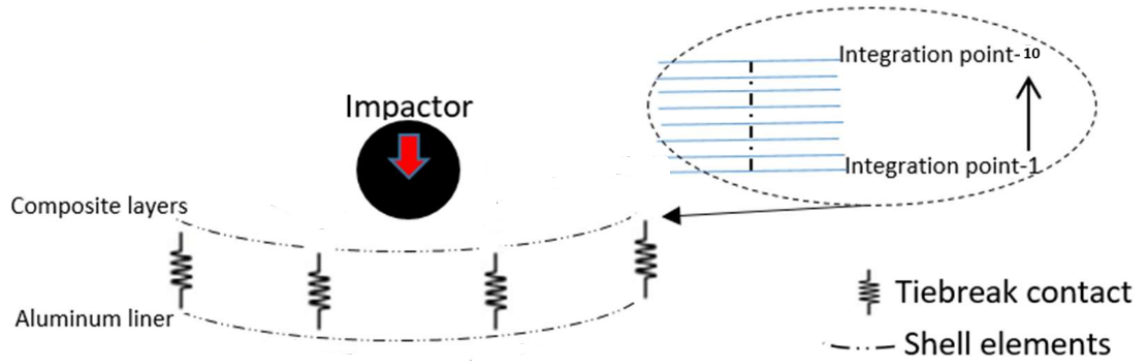


Figure 2. The tie-break contact model for the numerical model used in the finite element simulations.

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The analyzed hybrid Al/CFRP crash box model consists of 10 layers of CFRP with a total thickness of 2 mm, wound around an aluminum tube with an outer radius and thickness of 40 mm and 2 mm, respectively. The impactor velocity used follows the standard Euro NCAP (New Car Assessment Program) test speed of 17.78 m/s [39]. The length of the crash box and the mass of the impactor are 200 mm and 80 kg, respectively. A parametric study is designed in this research by varying the winding angle, or fiber orientation, of the CFRP material in each layer. There are eight variations

of the winding angle analyzed, namely $[\pm 15^\circ]_5$, $[\pm 25^\circ]_5$, $[\pm 35^\circ]_5$, $[\pm 45^\circ]_5$, $[\pm 55^\circ]_5$, $[\pm 65^\circ]_5$, $[\pm 75^\circ]_5$, and $[\pm 85^\circ]_5$. **Figure 3** shows the cross-section of the three crash box models to be simulated. In this study, a comparison is made between the conventional crash box, which uses one or two aluminum tubes, and the hybrid Al/CFRP tube with a stacking sequence that exhibits varying fiber orientations.

3. Results and Discussion

The research output comprises finite element simulation results from a parametric study investigating various stacking sequences. These results are compared with those of a conventional crash box. A validation process was also conducted during the initial phase of the research.

3.1. Numerical Validations

The validation process involved comparing the finite element simulation results with experimental data available in the literature [40]. Additionally, validation was performed against numerical simulation data for the same case from a previous researcher [41]. Validation was conducted for the dynamic impact case on a square aluminum single-cell crash box with a cross-section of 80x80 mm, wall thickness of 2.5 mm,

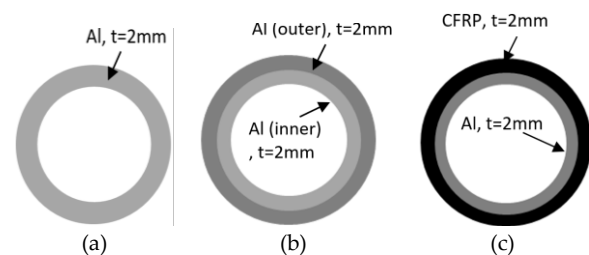


Figure 3. Cross-sectional model of the crash box: (a) single aluminum tube, (b) double aluminum tube, and (c) hybrid Al/CFRP

free length of 310 mm, impacted by a 56 kg rigid mass with an initial velocity of 15.6 m/s. A comparison of the numerical simulation results obtained in this study with both the experimental data and the numerical simulations performed by the previous researcher is presented in [Figure 4](#).

The validation results in [Figure 4](#) demonstrate the validity of the numerical model employed in this study. Overall, similar patterns are observed in the force versus deformation curves across the three compared datasets. For the peak force value, an error of 9.92 % was observed between the present simulation results and the experimental data, and an error of 1.72 % was found when compared to the numerical simulations performed by the previous researcher. It is concluded that the numerical model used in this study is validated and suitable for further application in parametric research study.

Energy conservation during an impact event serves as a fundamental parameter for validating the accuracy of explicit dynamic impact simulations [42]. The kinetic energy, determined by the mass and initial velocity of the impactor, is partially absorbed by the crash box material and converted into internal energy. The sum of these components represents the total energy throughout the impact event, while minor contributions dissipated through friction, hourglass effects, damping, and rigid wall interactions are considered negligible. [Figure 5](#) illustrates the energy balance for the impact case of a hybrid Al/CFRP crash box with a winding angle of 45°.

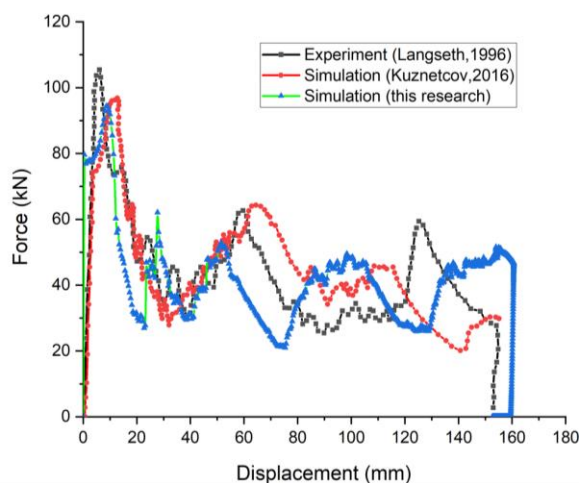


Figure 4. Validation of the numerical simulation results of the crash box model in this study, compared with experimental results and numerical simulations conducted by other researchers.

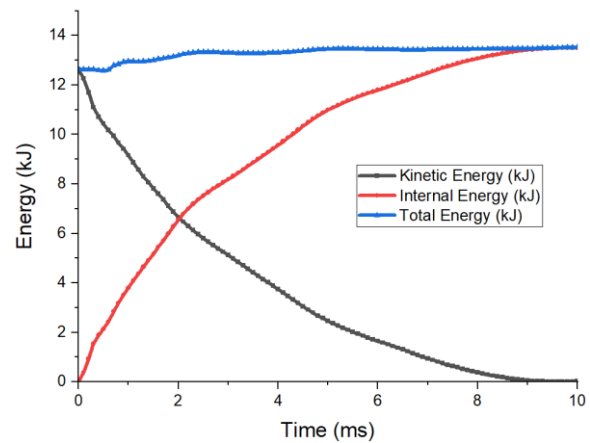


Figure 5. Energy balance curve for the hybrid Al/CFRP crash box model at $[\pm 45^\circ]_5$ winding angle.

3.2. Parametric Studies

A parametric study determined the optimal hybrid Al/CFRP crash box design by maintaining a constant impactor mass and initial velocity, thereby ensuring identical kinetic energy across all numerical models. [Figure 6](#) compares the force-displacement responses of three configurations: a single 2-mm aluminum tube, a 4-mm double aluminum tube, and a 4-mm hybrid Al/CFRP with circumferential fiber directions. The implementation of multi-cell tubes augments load-bearing capacity due to increased structural rigidity of the crash box. However, this design concurrently reduces the crushing distance, corresponding to an elevation in contact force between the impactor and the tube. The double aluminum tube design reduces crushing distance by 49.1% (achieving 72.40 mm) compared to the single aluminum tube (142.10 mm), while the hybrid configuration shortens it by 77.0% (32.75 mm).

Moreover, the superiority of the hybrid Al/CFRP design is evident in this comparison ([Figure 7](#)), exhibiting a mean crushing force of 379.80 kN—representing a 328.53% increase over the single-cell aluminum crash box (88.63 kN) and a 119.59% increase over the multi-tube aluminum crash box (172.96 kN). These results suggest that while multi-cell configurations improve crashworthiness through enhanced rigidity, they compromise energy absorption efficiency due to the reduced crushing distance. In contrast, the hybrid Al/CFRP configuration offers a balanced compromise, significantly improving energy absorption capacity through optimized winding angle configurations, which enhance material crashworthiness performance during impact.

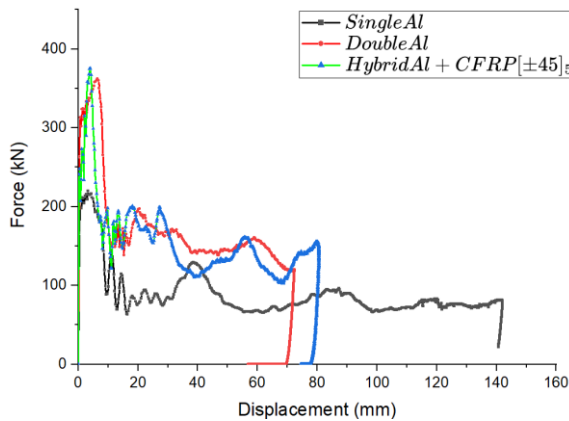


Figure 6. Comparison of the force-displacement curves between conventional and hybrid Al/CFRP crash boxes

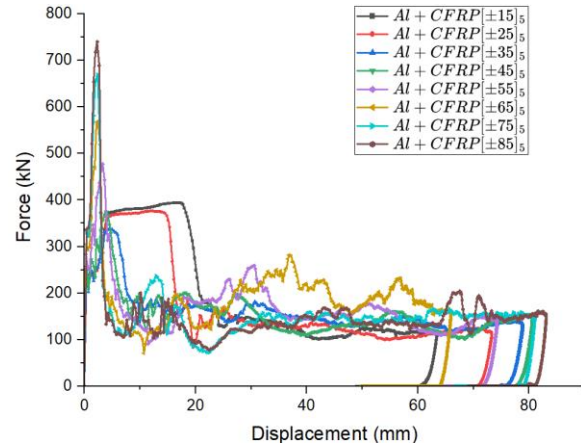


Figure 7. Comparison of the force-displacement curves for hybrid Al/CFRP crash boxes with varying winding angles

Figure 8 summarizes the peak crushing force (PCF) magnitudes for all simulated crash box models, based on the force-displacement curves presented in previous figure. Generally, the hybrid tube configuration enhances the PCF compared to the conventional aluminum crash box. This can be understood as the greater stiffness of the composite material in the hybrid tube enables it to withstand higher loads before experiencing plastic deformation, leading to higher peak forces. The results also indicate a general trend of increasing PCF with higher winding angles. Among the hybrid designs, the model with a $[\pm 35^\circ]$ winding angle exhibits the lowest PCF. Notably, the curves reveal that winding angles exceeding $[\pm 65^\circ]$ generate exceptionally high PCF values (>500 kN).

Several simulated configurations show a high initial PCF at impact, which is undesirable for crash box design. Elevated PCF may lead to high deceleration rates experienced by both the vehicle and its occupants. For occupants, high deceleration significantly increases the risk of injury as the body is subjected to abrupt inertial forces [43], and it may also induce secondary collisions within the occupant compartment [44]. For the crash box structure, excessive peak force poses the risk of premature structural failure, compromising its ability to absorb energy optimally and progressively through controlled deformation.

Subsequent evaluation of crash box performance focuses on stroke efficiency, defined as the percentage of the cylinder length that deforms during impact. This metric is particularly

important as it quantifies how effectively a crash box utilizes its full geometric capacity to absorb energy, thereby directly influencing the level of occupant protection [45]. Analysis of this parameter (**Figure 9**) indicates that the single aluminum tube configuration achieves the highest stroke efficiency, while the hybrid $[\pm 15^\circ]$ tube exhibits the lowest deformation extent. The superior performance of the aluminum tube is attributed to its ability to undergo controlled deformation through progressive folding of the tube wall, despite absorbing less energy compared to composite materials [46]. In hybrid tube designs, variations in winding angle configurations result in differing stroke efficiency values, which are attributable to their correlation with the stiffness characteristics specific to each model. This study demonstrates that hybrid tubes with $[\pm 35^\circ]$, $[\pm 45^\circ]$, $[\pm 75^\circ]$, and $[\pm 85^\circ]$ winding angles achieve stroke efficiency values comparable to those of multi-cell aluminum crash boxes.

Mean Crushing Force (MCF) serves as a critical crashworthiness metric representing the average force sustained during progressive deformation under impact loading, directly reflecting a crash box's energy absorption efficiency. As established in literature, higher MCF values indicate controlled collapse modes that minimize peak loads transmitted to vehicle structures and enhance energy dissipation [33]. Our numerical simulations data (**Figure 10**) corroborates this principle, demonstrating that the hybrid crash box with $[\pm 45^\circ]$ winding angle achieves the highest MCF among all configurations. Specifically, this

model exhibits a 39.02% increase in MCF compared to the double aluminum tube benchmark—closely aligning with Ma et al.'s findings of 46% MCF enhancement in CFRP/aluminum hybrids [33]. This significant improvement confirms the $[\pm 45^\circ]$ hybrid design's

superior capacity to utilize its full geometric potential for controlled energy absorption, validating that optimized winding angles can effectively leverage composite-aluminum synergies to maximize crashworthiness performance.

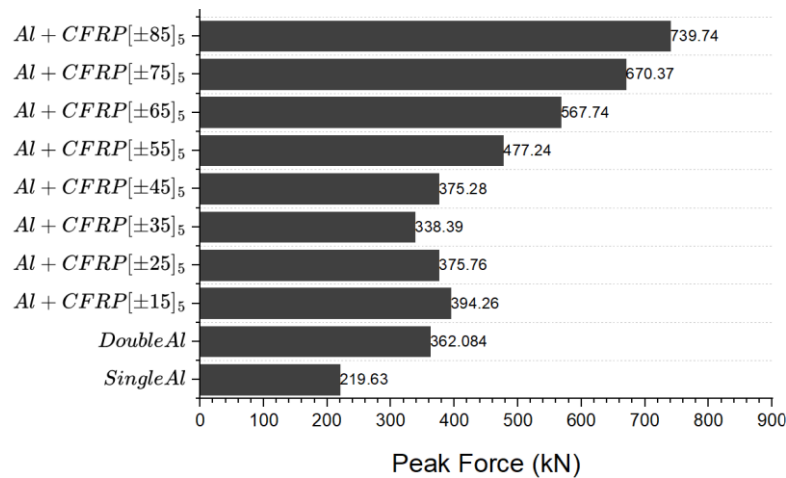


Figure 8. Peak crushing force values all simulated crash box models

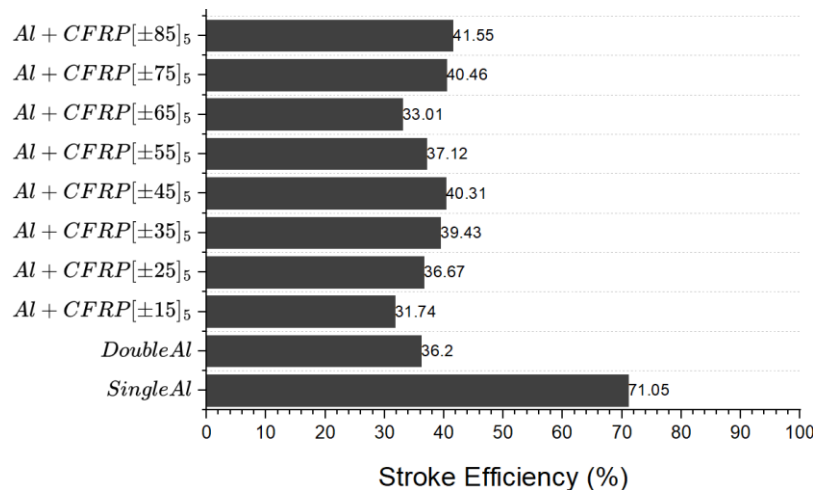


Figure 9. Stroke efficiency values for all simulated crash box models

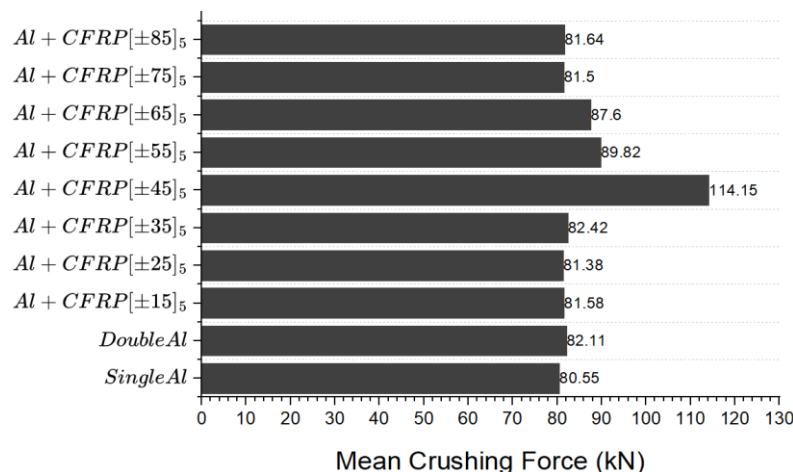


Figure 10. Mean crushing force values for all simulated crash box models

Another important parameter for evaluating the crashworthiness performance of a crash box is the crushing force efficiency (CFE), defined as the ratio of mean crushing force (MCF) to peak crushing force (PCF), expressed as a percentage. As shown in [Figure 11](#), among all simulated hybrid models, the configuration with a winding angle of 45° exhibits the highest CFE. This result is consistent with the conclusions reported by Bidadi et al. [47] in their study, even though their work focused on hybrid Al/CFRP beams under quasi-static bending. The $\pm 45^\circ$ winding angle exhibits superior performance in hybrid crash boxes due to optimized fiber-matrix interaction and controlled delamination [22]. Its diagonal fiber orientation reduces stress concentrations and bending-induced cracks, enabling progressive folding and energy absorption, with composite fragments filling aluminum folds like foam [48]. This configuration maintains reinforcement throughout crushing, making it the most effective design for hybrid crash boxes. This finding further reinforces the superiority of this configuration when considered alongside the other crashworthiness indicators.

The progressive folding mechanism, characterized by sequential, controlled collapse into discrete folds along the crash box axis, is fundamental for effective energy dissipation under axial impact loading [49], [50], [51]. This deformation mode enables uniform kinetic energy absorption while minimizing peak forces, as demonstrated by our simulation results ([Figure 12](#)) where only $[\pm 35^\circ]$, $[\pm 45^\circ]$, and $[\pm 55^\circ]$ hybrid configurations achieved stable folding patterns.

In the single aluminum tube ([Figure 12a](#)), the initial folding pattern occurs in the upper section due to the peak crushing force; subsequently, because of the extended deformation, further folding develops at the support region until the impact force is fully dissipated. When a double-cell aluminum tube is employed ([Figure 12b](#)), the impact load can only induce deformation, generating several folds within the upper portion of the cylinder. Furthermore, among the eight winding angle configurations analyzed ([Figure 12c-Figure 12j](#)), only the $[\pm 35^\circ]$, $[\pm 45^\circ]$, and $[\pm 55^\circ]$ angles produced stable folding patterns. For the other winding angles, the CFRP material failed prematurely under the impact load, despite folding occurring within the inner aluminum tube. Energy absorption (EA) and specific energy absorption (SEA) are also important parameters in evaluating crashworthiness. In the simulations conducted, the applied kinetic energy was identical for all crash box models, namely 12.65 kJ, determined by the mass and initial velocity of the impactor. In this study, for some of the analyzed crash boxes (single-cell crash boxes), this impact energy already corresponds to the maximum load that can be absorbed, whereas for others there remains additional capacity to absorb higher impact loads. This can be observed from the residual length of the material after deformation at the end of the impact process. Therefore, EA or SEA is not considered a relevant comparative parameter for assessing crashworthiness performance across all the models investigated in this study.

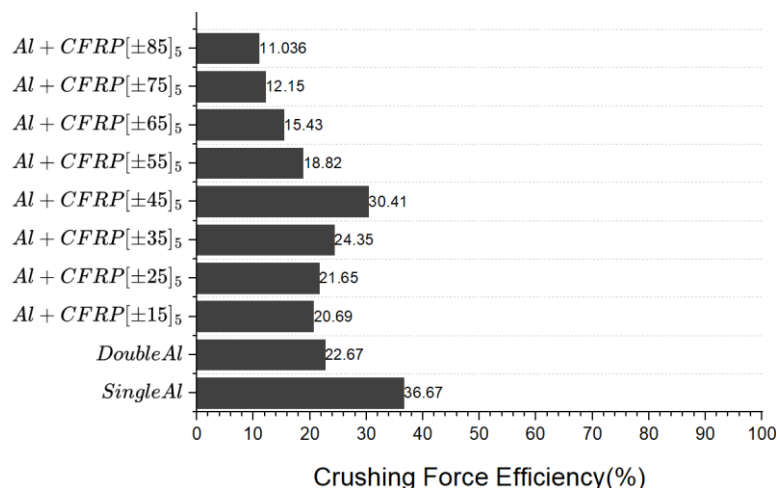


Figure 11. Crushing force efficiency values for all simulated crash box models.

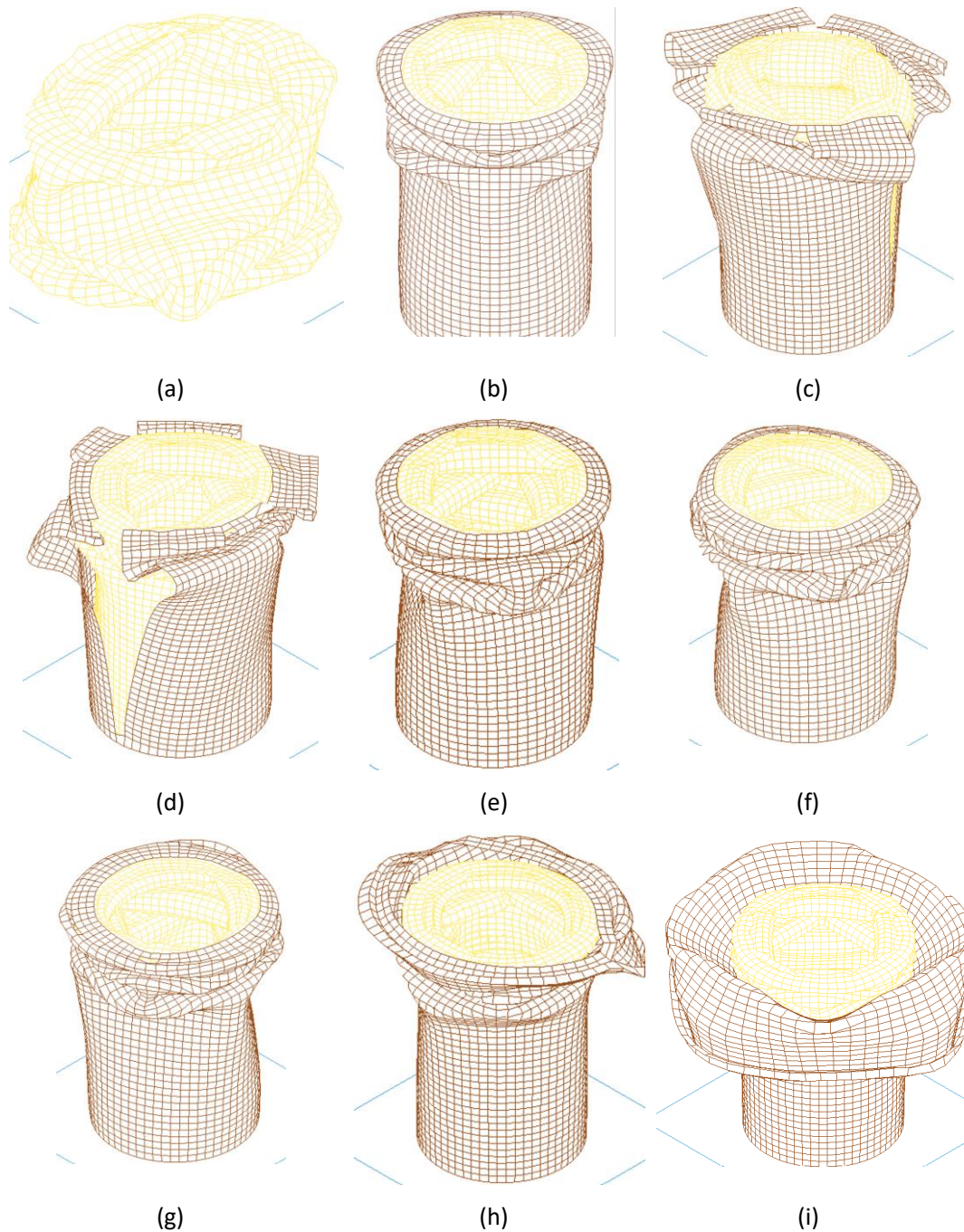


Figure 12. Deformation patterns of the folds on the crash box tube after the impact process for the conventional and hybrid crash boxes: (a) single aluminum, (b) double aluminum, (c) $[\pm 15^\circ]_5$, (d) $[\pm 25^\circ]_5$, (e) $[\pm 35^\circ]_5$, (f) $[\pm 45^\circ]_5$, (g) $[\pm 55^\circ]_5$, (h) $[\pm 65^\circ]_5$, (i) $[\pm 75^\circ]_5$, and (j) $[\pm 85^\circ]_5$.

4. Conclusion

This study validates an explicit finite element model and compares cylindrical hybrid Al/CFRP crash boxes with single- and double-cell aluminum crash boxes, while also mapping the influence of CFRP winding angles $[\pm 15^\circ]_5$ – $[\pm 85^\circ]_5$ on PCF, MCF, CFE, stroke efficiency, and folding stability under dynamic impact. Hybridization significantly enhances load capacity and MCF

compared to aluminum, with the $[\pm 45^\circ]_5$ configuration yielding the highest MCF and CFE, $[\pm 35^\circ]$ producing the lowest PCF, whereas angles $\geq [\pm 65^\circ]$ trigger excessively high PCF, indicating that intermediate angles provide the best balance between energy absorption and occupant safety metrics. Stable progressive folding patterns were predominantly achieved at $[\pm 35^\circ]$, $[\pm 45^\circ]$, and $[\pm 55^\circ]$. Several hybrid configurations matched the

stroke efficiency of multi-cell aluminum designs, and since the input kinetic energy was kept constant, PCF/MCF/CFE and folding stability served as more reliable comparative indicators than EA/SEA in this parametric scenario.

The main contribution of this work lies in its validated modeling framework, which demonstrates that intermediate winding angles of approximately 35°–55° optimize the crashworthiness of hybrid Al/CFRP crash boxes under axial impact. This advances fiber-orientation-based crash box design beyond previous studies that were limited to narrower angle ranges. Future research directions include conducting targeted dynamic tests around the identified optimal range, incorporating strain-rate sensitivity and cohesive interlaminar modeling to capture delamination, and extending the investigation to oblique impacts and design optimizations, such as the use of triggers or graded wall thicknesses, to reduce PCF without compromising MCF and CFE.

Author's declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

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