Lightweight and Sustainable Car Bumper Design for Pedestrian Safety Using Waste Aluminum Cans

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A Thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Science in Industrial and Production Engineering

Department of Mechanical and Production Engineering (MPE)

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Candidate's Declaration

This is to certify that the work presented in this thesis, titled, "Lightweight and Sustainable Car Bumper Design for Pedestrian Safety Using Waste Aluminum Cans", is the outcome of the investigation and research carried out by me under the supervision of Dr. Mohammad Nasim, Assistant Professor, MPE, IUT.

It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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Recommendation of the Thesis Supervisors

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CO-PO Mapping of ME 4800 -Theis and Project

COs	Course Outcomes (CO) Statement	(PO)	Addressed by	
CO1	Discover and Locate research problems and illustrate them via figures/tables or projections/ideas through field visit and literature review and determine/Setting aim and objectives of the project/work/research in specific, measurable, achievable, realistic and timeframe manner.	**PO2 Problem analysis**	Thesis Book	✓
			Performance by research	✓
			Presentation and soft skill	✓
CO2	Design research solutions of the problems towards achieving the objectives and its application. Design systems, components or processes that meets related needs in the field of mechanical engineering	**PO3 Design/development of solutions**	Thesis Book	
			Performance by research	✓
			Presentation and soft skill	
CO3	Review, debate, compare and contrast the relevant literature contents. Relevance of this research/study. Methods, tools, and techniques used by past researchers and justification of use of them in this work.	**PO4 Investigation**	Thesis Book	✓
			Performance by research	✓
			Presentation and soft skill	
CO4	Analyse data and exhibit results using tables, diagrams, graphs with their interpretation. Investigate the designed solutions to solve the problems through case study/survey study/experimentation/simulation using modern tools and techniques.	**PO5 Modern tool usage**	Thesis Book	✓
			Performance by research	
			Presentation and soft skill	✓
CO5	Apply moral values and research/professional ethics throughout the work, and justify genuine referencing on sources, and demonstration of own contribution.	**PO8 Ethics**	Thesis Book	✓
			Performance by research	
			Presentation and soft skill	✓
CO6	Perform own self and manage group activities from the beginning to the end of the research/work as a quality work.	**PO9 Individual work and teamwork**	Thesis Book	✓
			Performance by research	✓
			Presentation and soft skill	✓
CO7	Compile and arrange the work outputs, write the report/thesis, a sample journal paper, and present the work to wider audience using modern communication tools and techniques.	**PO10 Communication**	Thesis Book	✓
			Performance by research	✓
			Presentation and soft skill	✓
CO8	Recognize the necessity of life-long learning in career development in dynamic real-world situations from the experience of completing this project.	**PO12 Life-long learning**	Thesis Book	
			Performance by research	✓
			Presentation and soft skill	

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Signature of the Supervisor: ____________________

Name of the Supervisor: **Dr. Mohammad Nasim**

K-P-A Mapping of ME 4800 -Theis and Project

COs	POs	Related Ks								Related Ps							Related As				
		K1	K2	K3	K4	K5	K6	K7	K8	P1	P2	P3	P4	P5	P6	P7	A1	A2	A3	A4	A5
CO1	PO2	√	√	√	√					√											
CO2	PO3					√				√	√	√				√	√	√	√		
CO3	PO4								√	√	√	√					√	√			
CO4	PO5						√			√				√							
CO5	PO8							√													
CO6	PO9																				
CO7	PO10																				
CO8	PO12																				

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Acknowledgment

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We would like to express our deepest and sincerest gratitude to our respected supervisor, Dr. Mohammad Nasim, Assistant Professor, Department of Mechanical and Production Engineering (MPE), Islamic University of Technology (IUT), for his constant guidance, insightful feedback, and encouragement throughout the course of this research. His patient supervision, knowledge, and genuine dedication have inspired us to think critically and work diligently. His support at every stage of our project not only helped us overcome challenges but also motivated us to pursue excellence in our work.

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Abstract

This study explores a sustainable and pedestrian-friendly alternative to traditional steel car bumpers by repurposing discarded aluminum beverage Cans as lightweight energy-absorbing elements. Conventional steel bumpers, while effective at protecting the vehicle, transmit high impact forces to pedestrians, increasing the risk of severe lower-limb injuries. At the same time, large quantities of recyclable aluminum cans end up as waste, presenting an opportunity for circular reuse. To address these issues, this research proposes a bumper design that utilizes recycled aluminum Cans and evaluates its performance through a combined experimental and numerical approach. Drop-weight impact tests were conducted on Cans in vertical and horizontal orientations to assess deformation behavior and energy absorption. The validated Finite Element (FE) model of the Aluminum Can was developed in LS-DYNA and validated using the experimental results of the drop weight impact test. Simulations were carried out using a FE model of the Toyota Camry vehicle model and the THUMS human body FE model to compare the recycled aluminum bumper with a conventional steel bumper under identical conditions. The results show that the aluminum-can bumper significantly reduces transmitted impact force by as much as 87% and keeps tibia and fibula stress below common fracture thresholds of 150 MPa by the Euro NCAP, indicating a meaningful improvement in pedestrian safety. The findings demonstrate that waste aluminum cans can be engineered into an effective bumper core material, offering a practical pathway toward safer and more environmentally responsible vehicle design.

Executive Summary

This thesis investigates a sustainable and safety-driven design approach by using recycled aluminum beverage cans as the core material for a new type of car bumper. Pedestrian injuries in vehicle collisions remain a major concern, largely because traditional steel bumpers are rigid and transfer high impact forces directly to the lower limbs. At the same time, large numbers of aluminum cans are discarded every day despite being lightweight, recyclable, and suitable for reuse. This research aims to address both issues by developing a bumper that reduces pedestrian injury while promoting environmentally responsible material use.

The study combines experimental drop-weight impact tests with finite element simulations to evaluate how aluminum cans absorb energy under dynamic loading. Cans were tested in vertical and horizontal orientations, revealing clear differences in deformation behavior. Vertical cans showed more predictable folding and efficient energy absorption, while horizontal cans experienced localized flattening with higher peak forces. These experimental results were used to validate LS-DYNA simulations, which closely matched the force-time responses and deformation patterns, confirming the reliability of the numerical models.

The validated model was then applied to pedestrian crash simulations using a Toyota Camry vehicle model and the THUMS human body model at 40 km/h. Two bumper types were compared: a conventional steel bumper and the proposed aluminum can bumper. The aluminum bumper reduced the peak impact force on the pedestrian by nearly 87% and kept tibia stress below the Euro NCAP fracture threshold of 150 MPa. In contrast, the steel bumper exceeded this limit, indicating a higher likelihood of serious lower-limb injuries.

Beyond safety improvements, the design contributes to environmental sustainability. Recycling aluminum requires far less energy than producing new aluminum, reduces landfill waste, and supports circular-economy principles. Additionally, using a lightweight bumper core can help reduce overall vehicle weight and improve fuel efficiency.

In conclusion, the findings show that bumpers made from recycled aluminum cans can provide meaningful improvements in pedestrian safety while offering notable environmental benefits. Further work includes testing full bumper assemblies, optimizing can arrangements, and assessing long-term durability which could help transition this concept toward practical automotive applications.

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Chapter 1: Introduction

Road traffic accidents are a major cause of injuries and fatalities worldwide, with pedestrians being especially vulnerable. The design of a vehicle's front bumper is vital in determining how severely a pedestrian might be injured in a crash. Typically, bumpers are made from high- strength steel, which protects the vehicle but often transfers dangerous impact forces to pedestrians, leading to a greater risk of leg fractures and serious injuries. At the same time, we're facing an environmental issue with the increasing amount of aluminum beverage can waste. Although aluminum is recyclable, a lot of it ends up in landfills because of inefficient recycling practices. By repurposing this waste into useful automotive parts, we can tackle environmental problems while supporting a circular economy that maximizes the life span of materials. This thesis presents a groundbreaking bumper design made from recycled aluminum beverage cans. The goal is to see if these cans can serve as a safer alternative to traditional bumper materials. We conducted simulations using Finite Element Analysis (FEA) to study how well the new bumper absorbs energy, distributes stress, and responds to pedestrian impacts. Ultimately, we want to show that a bumper made from recycled cans can effectively absorb impact energy, reduce pedestrian injuries while also helping the environment.

1.1 Background of Study

Accidents involving road traffic are a significant public health issue globally, and pedestrians often bear the brunt of these incidents. When a vehicle hits a pedestrian, the bumper and the front end of the car play crucial roles in determining how much force is transmitted to the person. Standard bumpers, typically made from steel or stiff composites, are designed mainly to protect the vehicle and its occupants. Unfortunately, this focus often results in bumpers that deliver dangerous, concentrated forces to a pedestrian's lower limbs, increasing the chance of severe injuries. In parallel, the waste generated from aluminum beverage cans is immense. While aluminum is highly recyclable, many cans still end up in landfills due to inefficiencies in waste management. Transforming these used cans into structural components not only addresses environmental concerns but is also economically smart. Aluminum has an excellent strength-to-weight ratio and is known for its ability to absorb energy through deformation.Therefore, creating bumpers from recycled cans could help us use fewer new materials and foster a circular economy. This study is positioned at the crossroads of pedestrian safety and sustainable material use. We aim to explore whether a bumper made from recycled aluminum cans can effectively absorb impact energy enough to lower the forces on pedestrians and serve as an environmentally friendly alternative to traditional steel bumpers. We combine controlled drop-weight tests that measure how well these can assemblies absorb impact energy with detailed finite element crash simulations, including a standardized pedestrian model. This approach allows us to validate our simulation methods and assess both individual components and the overall performance of vehicle-pedestrian interactions. By investigating recycled aluminum can assemblies for energy absorption, our research aims to fill two key gaps: the lack of knowledge on the practical reuse of lightweight aluminum for reducing vehicle impacts and the need for innovative solutions to enhance pedestrian safety.

1.2 Problem Statement

Standard car bumpers are usually made from rigid steel, which does a great job at protecting the vehicle. However, this design often ends up transferring a lot of impact force to pedestrians, potentially leading to serious injuries, especially to their lower limbs. On another note, millions of aluminum beverage cans are thrown away every year, with a large number of them ending up in landfills, even though they can easily be recycled. There's a golden opportunity here to use these lightweight cans in a new way—by turning them into energy-absorbing components for bumpers. This idea hasn't been fully explored yet, but it could provide an innovative solution to two pressing issues: making bumpers safer for pedestrians and finding smart ways to reduce waste while promoting a circular economy.

1.3 Research Gap

Many studies on automotive bumpers have primarily centered around enhancing the safety of vehicles for occupants during crashes. However, not enough attention has been given to protecting pedestrians, especially during low- to medium-speed collisions. Traditional bumpers, which are often made from high-strength steel or rigid materials, don't effectively absorb energy, which can lead to serious injuries for pedestrians, particularly to their lower limbs. While innovations in lightweight materials, like aluminum alloys, have been considered for various vehicle components, the idea of reusing post-consumer aluminum beverage cans to create functional bumper parts is still relatively unexplored. Moreover, there's a lack of research that combines practical drop-weight tests with validated simulations to examine how well these recycled materials might perform in real-world pedestrian impacts. This absence of research into sustainable bumper designs using recycled aluminum for pedestrian safety highlights an important gap that our study aims to fill. By addressing this issue, we hope to contribute to both automotive safety and environmental sustainability.

1.4 Objectives of the Study

The primary objectives of this study are:

- To design a lightweight car bumper using repurposed waste aluminum cans, offering a cost-effective and eco-friendly solution that enhances pedestrian safety while supporting environmental sustainability through circular material reuse.
- To evaluate the energy-absorbing capacity of the proposed bumper design under controlled drop-weight impact tests and LS-DYNA simulations.
- To assess pedestrian safety performance by comparing stress and force responses on pedestrian leg models (tibia and fibula) between the proposed aluminum bumper and a conventional steel bumper.

1.5 Structure of the Thesis

Chapter 1 – Introduction: Presents the background of the study, outlines the research problem, states the objectives, and highlights the significance of the research.

Chapter 2 – Literature Review: Summarizes existing studies on bumper design, pedestrian safety analysis, lightweight materials in automotive applications, and previous work on sustainable material reuse.

Chapter 3 – Methodology: Describes the research approach, including the design of the experimental setup, LS-DYNA simulation process, material modeling, and boundary conditions for impact testing.

Chapter 4 – Results and Discussion: Presents the simulation and experimental results on energy absorption, stress analysis, and pedestrian impact responses, followed by discussions comparing the performance of the proposed aluminum bumper with the traditional steel bumper.

Chapter 5 – Conclusion and Future Scopes: Provides the key findings, conclusions drawn from the study, and potential directions for future research, such as expanding the use of other waste materials in vehicle components.

Chapter 2: Literature Review

The automotive industry is currently driven by two interconnected, yet often conflicting, objectives: reducing vehicle mass to improve fuel efficiency and minimize environmental impact and simultaneously enhancing crash safety performance for both occupants and pedestrians [1].

2.1 The Shift to Lightweight Materials

Traditional bumper beams, the primary energy-absorbing structure in low-speed and pedestrian collisions, were commonly made of high-strength steel due to its low cost and high strength [1]. However, the push for weight reduction has rendered steel non-viable for modern designs[1].

Composite materials, such as Carbon Fiber Reinforced Polymer (CFRP) and Long Fiber-Reinforced Thermoplastics (LFT), have emerged as superior alternatives due to their high specific strength and specific energy absorption (SEA) [1], [2].Studies show that composite beams can achieve weight reductions of up to 45% compared to steel, while significantly improving energy absorption [1].

Aluminum alloys are also key to lightweighting, offering a lower density and excellent crash performance [2]. Using aluminum for car parts can reduce the overall vehicle weight, leading to a 5-10% fuel saving for a 10% weight reduction [3].

2.2 Pedestrian Safety and Regulatory Compliance

The bumper's role has evolved from merely protecting the vehicle to primarily mitigating injury to Vulnerable Road Users (VRUs) [4], [5]. The lower leg, specifically the knee and tibia, is highly vulnerable to serious injury in car-pedestrian collisions [5], [6].

2.2.1 Injury Mitigation and Criteria

Pedestrian safety is a major concern in vehicle design, which is why regulations from organizations like Euro NCAP are pushing for changes to the front-end of vehicles. The goal is to create designs that better absorb the impact energy in the event of a collision, ultimately protecting pedestrians from serious injuries.

Recent research is focusing on making bumpers softer and reshaping them to improve how they respond during an impact. This involves increasing the time it takes for the impact force to a stop and reducing the stress on someone's knees. There are even innovative active bumper systems that create a cushioning gap upon impact, which have been shown to significantly lower the risk of injuries to the lower legs.

When it comes to understanding the severity of these injuries, medical professionals often reference something called the Tibia Index (TI). This helps quantify how badly the lower limbs might be affected in an accident. To ensure that the materials used in car design are effective, biomechanical studies are vital. For instance, research on human tibia (the shin bone) has revealed that its average failure stress is between 150.6 MPa and 192.3 MPa. This means that around 150 MPa is considered a safe threshold that indicates a lower risk of fractures in a collision. So, by focusing on these designs and materials, we can help make our roads safer for everyone.

2.3 Numerical Simulation and Methodology

Understanding the complex dynamics of crashes is crucial for designing effective bumper structures, which is why we rely on numerical modeling to test and validate our designs.

2.3.1 Finite Element Analysis (FEA)

At the heart of our simulation efforts is the Finite Element Method (FEM). This technique is essential when it comes to simulating the unpredictable and high-speed events that occur during vehicle-pedestrian collisions. We often use explicit solvers, such as Ansys LS-DYNA, which have become the go-to tools in the industry for crash simulation. These advanced tools allow us to model the intricate interactions that happen during a collision, including significant deformations, material failures, and the contact between various components, like the bumper and the legform impactor. By doing so, we can accurately predict the consequences of a crash. Simulations performed with LS-DYNA help us assess critical injury parameters, such as the forces and stresses that could affect a pedestrian's bones. This is essential to ensure our designs meet regulatory standards before we invest in costly physical tests. Ultimately, this process reassures us that we've chosen materials and structural designs that effectively absorb energy during a collision, enhancing safety for pedestrians.

2.4 The Circular Economy and Sustainable Bumper Design

In line with the global push for sustainability, the automotive sector is increasingly prioritizing the circular economy, a model focused on eliminating waste and the continuous use of resources [3].

2.4.1 Aluminum and Recyclability

Aluminum is highly valued in this context. Recycling aluminum requires only about 5% of the energy needed for primary production, dramatically reducing the carbon footprint by up to 95% [3], [7].

Automakers are actively pursuing closed-loop recycling programs, often using specialized aluminum alloys with up to 75% recycled content in new vehicle components [3].

The ability of thin-walled aluminum structures to absorb significant kinetic energy through controlled, progressive plastic deformation (folding) is well-documented [2], [8]Conventional crush boxes often use multi-cell or foam-filled aluminum tubes to maximize Specific Energy Absorption (SEA) [9].

2.5 Research Gap: Repurposing Waste for Structural Safety

While the literature confirms the benefits of aluminum, lightweight structures, and FEA for pedestrian safety, a critical gap remains: the direct, structural repurposing of common post-consumer waste as a functional crash-absorbing element.

The issue of high recyclability rates for aluminum alloys coexisting with significant waste from items like aluminum beverage cans presents a major environmental challenge [9]. Current studies predominantly focus on the use of virgin or dedicated recycled alloys in typical geometries (e.g., tubes, foam) [1].

This research addresses the intersection of these fields by proposing and validating a novel bumper design that utilizes waste aluminum cans as the primary energy-absorbing material [9]. The focus is on demonstrating a mass-produced waste stream, when geometrically arranged within a bumper core, can meet stringent pedestrian safety criteria (maintaining tibia stress below the fracture threshold of 150 MPa [9]. while simultaneously providing a unique, sustainable, and cost-effective solution.

Chapter 3: Methodology

3.1 Framework

This research adopts a combined experimental and computational approach to investigate the feasibility of utilizing waste aluminum cans in automobile bumper design for enhanced pedestrian safety. The study was conducted in three main phases: (i) experimental drop-weight impact testing of aluminum cans in different orientations, (ii) finite element simulations using LS-DYNA to replicate and extend experimental conditions, and (iii) pedestrian impact simulations incorporating a vehicle model and a detailed human body model.

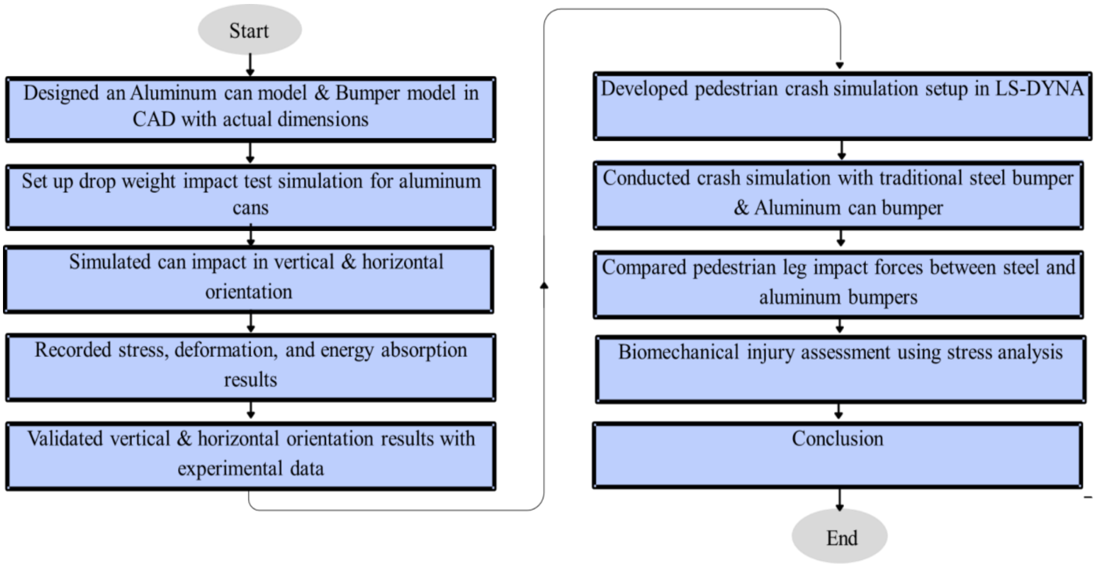

Figure 1:Flowchart of the research methodology

The overall workflow of the research is illustrated in Figure 1, which outlines the sequential stages from material preparation to validation and performance evaluation. This integrated framework ensures that the study is both empirically grounded and computationally validated.

3.2 CAD Design

The research began with creating 3D CAD models of both the proposed aluminum can bumper and the conventional steel bumper using SolidWorks. These models captured the essential geometry and physical characteristics needed for impact simulations. Figure

2 illustrates the SolidWorks model of the aluminum can, with Table 1 providing detailed geometrical specifications for accurate modeling. Similarly, Figure 3 shows the SolidWorks model of the traditional steel bumper, whose full dimensions are summarized in Table 2, allowing direct comparison with the proposed recycled aluminum design.

Table 1: Dimensions of Aluminum Can

Parameter	Value
Circumference (Body)	16.6 cm
Diameter	5.28 cm
Height	13.5 cm
Upper Tapered Circumference	16.4 cm
Upper Groove Height	0.8 cm
Lower Fillet Height	0.5 cm

Figure 2:Design of Aluminum can in SolidWorks

Table 2: Dimensions of Traditional Bumper

Parameter	Value
Total Bumper Length	100.3 cm
Upper section length	39.5 cm
Side extension length (upper)	30 cm
Offset from center (extension)	8 cm
Pipe diameter	6 cm

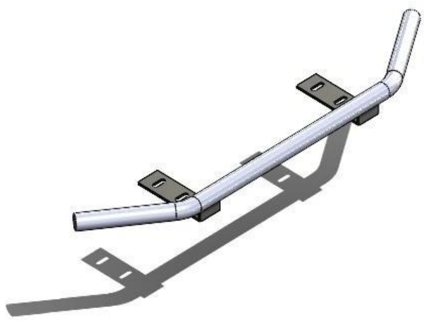

Figure 3:Design of Traditional steel bumper in SolidWorks

3.3 Experimental Setup (Drop-Weight Impact Test)

The drop-weight impact test was conducted to evaluate the energy absorption capacity of aluminum beverage cans under controlled dynamic loading. This experiment served as a preliminary step for validating the finite element simulation results and for understanding the deformation behavior of cans in different orientations. The setup used to perform the impact tests is shown in Figure 4, illustrating the drop-weight machine.

Figure 4:Drop weight impact test setup: (a)Drop weight impact testing apparatus;(b) Drop weight impact tests on aluminum can in (b)Horizontal orientation and (c)Vertical orientation

The drop-weight impact test was carried out using a specially designed testing apparatus that ensured controlled and repeatable loading conditions for evaluating the energy absorption characteristics of aluminum beverage cans. At the core of the setup was a rigid cylindrical impactor with a mass of 5 kg, selected to generate sufficient kinetic energy to deform the can while remaining within the safe operating limits of the test rig. The chosen mass allowed the can to experience a realistic crash-like loading scenario while maintaining safe handling conditions for the operator. The impactor was supported and guided by a vertical steel frame equipped with precise linear guides that kept it aligned throughout its descent, preventing any lateral motion that could influence the accuracy and consistency of the results. This guiding mechanism was essential for ensuring that each impact occurred exactly at the center of the specimen, thereby eliminating unnecessary variations that could arise from off-axis loading.

A manually operated release mechanism, positioned at the top of the frame, allowed the operator to set the drop height consistently, enabling the impactor to achieve the required velocity of approximately 4.5 m/s at the moment of contact. This drop height was calculated based on energy requirements to sufficiently deform the can and simulate dynamic crash conditions. Figure 4(b) shows the horizontal orientation test configuration, where the can is positioned laterally under the falling impactor, replicating loading that would cause ovalization and localized flattening of the structure. Similarly, Figure 4(c) displays the vertical orientation during testing, demonstrating the axial loading condition applied in the experiment, which encouraged progressive buckling and folding along the height of the can.

To measure the impact force generated during the collision, a high-sensitivity load cell was mounted beneath the specimen and connected to a digital data acquisition system. This system recorded force values at high sampling rates, ensuring that rapid force fluctuations and peak loads were captured with accuracy and clarity. The collected data was then processed to plot force–time curves, enabling direct comparison between simulation and experiment. In addition to the quantitative data, a high-speed camera—when used—provided visual documentation of the deformation process, capturing moment-by-moment changes in the can's geometry. This footage was valuable for understanding localized buckling, folding patterns, crack initiation, and failure progression, which are often difficult to interpret using force data alone. It also served as supportive evidence for evaluating the reliability of the finite element model.

3.4 Drop Weight Simulation Setup in LS-DYNA

The finite element simulation was carried out using LS-DYNA to replicate and analyze the drop-weight impact behavior of aluminum beverage cans under controlled dynamic loading which is illustrated in figure 5. This simulation acted as an extension of the experimental study, enabling a more detailed investigation of stress distribution, deformation patterns, and energy absorption mechanisms in both vertical and horizontal orientation.

The geometry of a standard waste aluminum beverage can was modeled in two orientations: vertical and horizontal. The finite element mesh was refined to adequately capture localized deformations during impact. To replicate real-world conditions, the base of the can was fixed, while the top surface was subjected to loading from a rigid impactor.

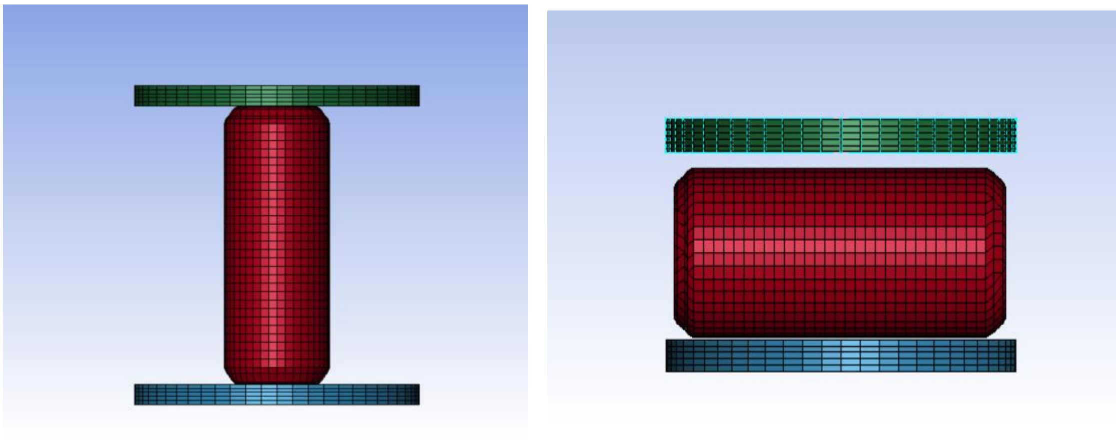

Figure 5:Drop weight impact test simulation of Aluminum can using LS-DYNA in vertical orientation(left) and in horizontal orientation(right)

3.4.1 Material Models

Two material models were defined in LS-DYNA:

Aluminum Can Material: The Can was assigned *MAT024 (Piecewise Linear Plasticity with Failure)* with a thickness of 0.2 mm. This model allows for elastic– plastic deformation and incorporates strain rate dependency, making it suitable for crash simulation scenarios.

Steel Plate / Impactor: The impactor was modeled using *MAT020 (Rigid)*, representing a non-deformable surface to ensure that energy dissipation occurred primarily within the aluminum can specimen. The top model is the impactor and base model is where we place the Aluminum Can, proper boundary conditions were defined.

3.4.2 Simulation Parameters

The impact simulations were conducted under certain conditions. The impact simulations in LS-DYNA were carried out using an initial impact velocity of 4.5 m/s and an impactor mass of 5 kg to match the experimental conditions. Each simulation ran for a total duration of 30 milliseconds to capture the full impact event and allow observation of both the initial peak force and the progressive deformation phase. To accurately model the interaction between the impactor and the aluminum can, the Automatic Surface-to-

Surface and Automatic Single Surface contact algorithms were applied. These parameters ensured consistent and reliable simulation of the can's deformation behavior under dynamic loading. Additionally, the simulation was set up with fine time-step control to maintain numerical stability and prevent non-physical penetration between surfaces. The combination of realistic contact conditions and controlled time integration helped to achieve a close correlation between the simulated results and the experimental force-time curves.

3.4.3 Boundary Conditions

The boundary conditions were defined to closely replicate the constraints observed in the experimental drop-weight impact setup. In the simulation model, the base of the aluminum can was fully constrained to prevent any translational movement, ensuring that the lower surface remained fixed throughout the loading process. This setup mimicked the real-world experimental condition where the can rested firmly on a rigid platform during impact. Meanwhile, the impactor was permitted to move exclusively along the vertical axis, allowing it to strike the top of the can in a controlled and realistic manner, similar to the guided path in the physical test apparatus. By restricting all other degrees of freedom for the impactor, the model ensured that the applied load was purely vertical, eliminating unintended lateral or rotational effects that could lead to inaccurate results. These boundary conditions played a crucial role in maintaining consistency between the physical experiment and the numerical simulation, enabling accurate comparison of deformation modes, energy absorption behavior, and force–time response. Ensuring this alignment strengthened the validity of the simulation and supported the credibility of the numerical findings.

3.5 Material Selection and Properties

The selection of suitable materials is a fundamental aspect of designing any automotive component, as it directly influences the structural integrity, performance, and overall safety of the vehicle. In this study, material choice plays an especially important role because the aim is not only to achieve effective impact energy absorption but also to consider sustainable engineering practices. For this purpose, two materials were identified for comparative investigation: waste aluminum beverage cans and conventional automotive-grade steel. This combination was chosen based on the dual objectives of improving pedestrian safety—by developing a bumper design capable of mitigating lower-limb injuries—and simultaneously contributing to environmentally conscious vehicle design. Reusing aluminum cans aligns with sustainability goals by reducing waste and promoting circular-economy principles, while steel serves as a baseline material commonly used in current automotive structures. Together, these choices allow the study to evaluate both performance benefits and ecological advantages that may arise from adopting recycled materials in modern vehicle safety systems.

The primary material investigated in this study was Aluminum Alloy 3004 H34 sheet, the standard alloy used in beverage can production. The H34 temper condition indicates strain- hardened and stabilized material, offering improved strength while maintaining good ductility and formability. Key advantages of Al 3004 H34 include:

Energy absorption: Its thin-walled cylindrical geometry (typical can thickness 0.20 mm, diameter 6.0 cm) undergoes progressive buckling under-load, enabling efficient crash energy dissipation.

Lightweight: With a density of 2.73 g/cm^3, the use of aluminum reduces overall vehicle mass and improves fuel economy.

Corrosion resistance and recyclability: Al 3004 H34 offers excellent resistance to atmospheric corrosion and is highly recyclable, aligning with circular economy principles.

Availability and cost-effectiveness: Beverage cans are produced in large quantities worldwide, making them readily available for reuse in engineering applications.

Furthermore, the choice of materials in this study was guided not only by mechanical performance, but also by practical feasibility and long-term engineering considerations. Since waste aluminum cans already undergo large-scale industrial production, their geometry, thickness, and alloy composition remain consistent enough to support repeatable engineering analysis. This makes them a reliable candidate for controlled deformation-based energy absorption systems. In contrast, steel was included as a benchmark because of its widespread use in conventional bumper structures and its well-documented mechanical behavior in crash scenarios. By comparing recycled aluminum cans with a standard steel configuration, the study establishes a clear reference point for evaluating improvements in energy absorption, weight reduction, and pedestrian safety.

The typical mechanical properties of Al 3004 H34 are presented in Table 3 [13].

Table 3: Material Properties of Aluminum 3004 H-34 Sheet

Properties	Value
Mass Density (RO)	2.71×10^{-6} kg/mm³
Young's modulus(E)	68.95 GPa
Poisson's ratio (PR)	0.330
Yield stress (SIGY)	1.9046×10^{-1} GPa
Failure flag (FAIL)	9.31×10^{-2}

And in terms of selecting the top impactor plate and the bottom base plate, the material that was selected was steel. The mechanical property of steel is presented in Table 4[10].

Table 4: Material Properties of Steel

Properties	Value
Mass Density (RO)	7.8×10^{-6} kg/mm³
Young's modulus(E)	200 GPa
Poisson's ratio (PR)	0.330

3.6 Pedestrian Impact Simulation Setup

The pedestrian impact simulation was performed in LS-DYNA to analyze and compare the performance of the recycled aluminum Can bumper with that of a conventional steel bumper under realistic collision conditions. This simulation aimed to evaluate pedestrian safety by examining the magnitude of impact forces and the resulting stress distribution on critical lower limb bones during a frontal vehicle–pedestrian collision. A Toyota Camry V6 model was used to represent a typical passenger vehicle, while the THUMS (Total Human Model for Safety) Version 4.0 human body model, known for its anatomical detail and validated bio fidelity, served as the pedestrian representation. Specific focus was placed on critical injury metrics such as the Tibia Index and knee ligament strain, which are standard indicators in pedestrian safety assessment. By integrating these models, the simulation provided a realistic environment to study how each bumper configuration influences injury outcomes, enabling a direct comparison between the traditional steel bumper and the proposed recycled aluminum bumper in terms of their ability to reduce pedestrian lower-limb injuries.

3.6.1 Car Model Used

A Toyota Camry V6 model was chosen to represent a standard passenger vehicle in urban crash conditions.

The vehicle geometry employed in the pedestrian simulation is shown in Figure 6, representing the 2012 Toyota Camry model used for analysis. This model was selected to represent a standard mid-sized passenger car commonly found in urban environments. This model provides realistic vehicle geometry, mass distribution, and structural characteristics, making it suitable for evaluating pedestrian impact responses. Its use ensures that the simulated collision conditions closely resemble those encountered in real-world pedestrian accident.

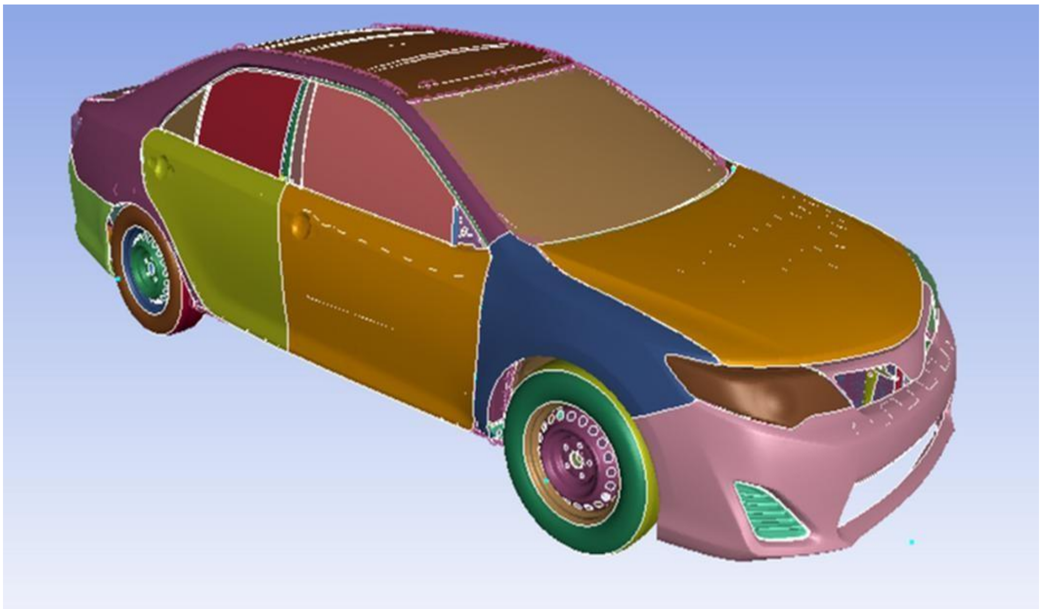

Figure 6:2012 Toyota Camry

3.6.2 Human Body Model

For the pedestrian, the THUMS (Total Human Model for Safety) version 4.0 was employed due to its anatomically detailed structure and validated response to impact loading.

The pedestrian was modeled using the THUMS (Total Human Model for Safety)

Version 4.0, shown in Figure 7, an anatomically detailed full-body human model widely used in biomechanical and crash safety research. THUMS provides realistic representations of bones, soft tissues, and joints, enabling accurate prediction of stress, deformation, and potential injury in different body regions. In this study, the model was particularly valuable for analyzing lower-limb injury mechanisms under vehicle impact.

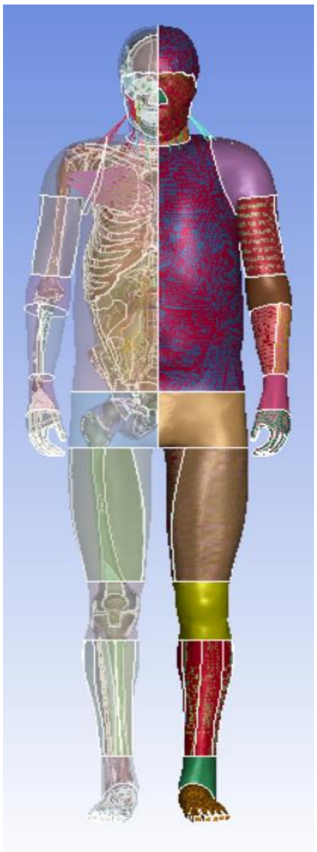

Figure 7:Total Human Model for Safety (THUMS) model

3.6.3 Crash Simulation Setup

The vehicle was defined as a mass of 1645 kg and at a speed of 40 km/h, constrained to motion along the longitudinal x-axis. The pedestrian model was initially positioned in front of the vehicle with no pre-impact velocity. The pedestrian impact configuration using the traditional steel bumper and the Aluminum bumper is shown in Figure 8 and Figure 9, respectively. Additionally, the stress analysis examined how stress was distributed along the tibia and fibula during the impact, helping identify regions most prone to injury. Evaluating how stress developed over time provided a clearer understanding of the fracture risk and the effectiveness of each bumper design in reducing harmful loading.

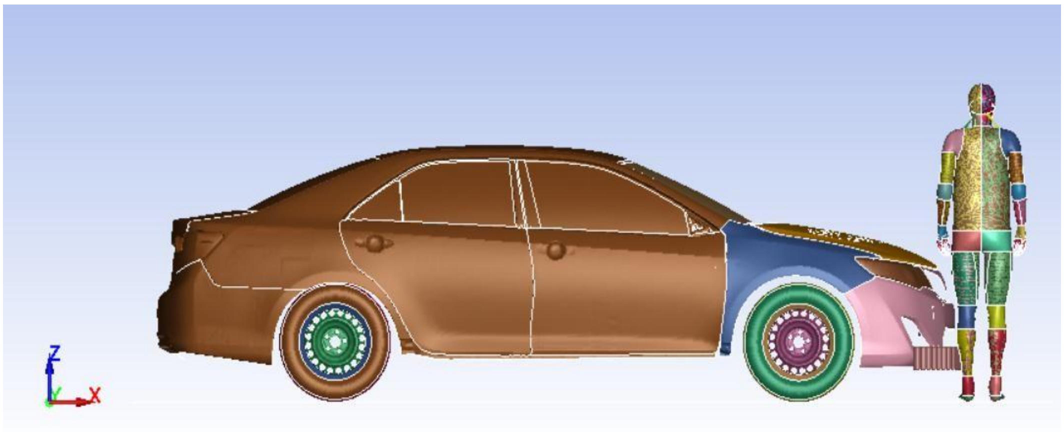

Figure 9:Pedestrian Impact Simulation Setup with Traditional bumper

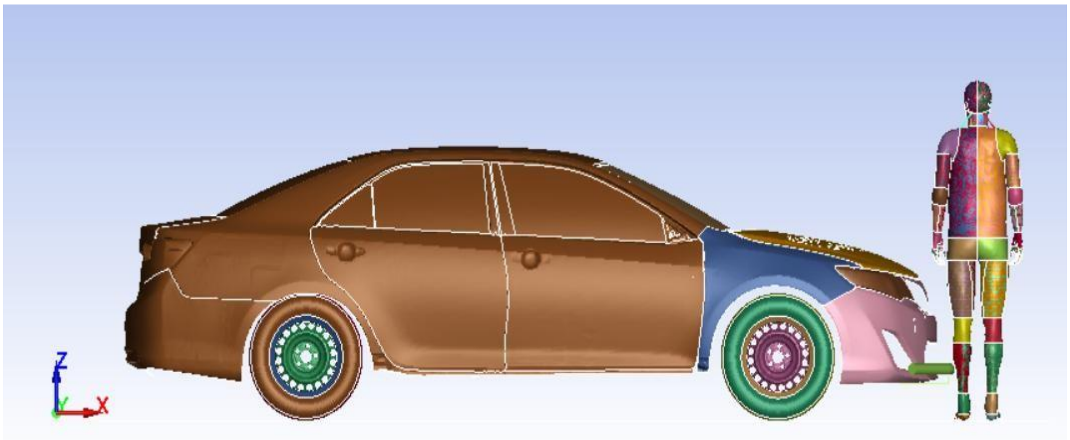

Figure 8:Pedestrian Impact Simulation Setup with Reused Aluminum can bumper

3.6.4 Boundary Conditions and Contact Definitions

The movement of the vehicle was restricted to a single axis to replicate frontal collisions. Contact interactions between the vehicle and the pedestrian were modeled using automatic surface-to-surface and automatic single surface algorithms, ensuring accurate capture of collision forces with change.

3.7 Mechanical Effect Analysis

The analysis of stress and force responses was conducted to quantify the effectiveness of the recycled aluminum can bumper in reducing pedestrian injury risk. Since lower limb injuries are among the most common outcomes in vehicle–pedestrian collisions, particular attention was given to the tibia and fibula bones as primary indicators of impact severity.

The resultant force acting on the pedestrian body was extracted from the simulation outputs. Peak force values for both bumper configurations were compared to evaluate the relative reduction achieved with the recycled aluminum bumper. Special emphasis was placed on the force transmitted to the tibia, as this parameter directly correlates with fracture likelihood under dynamic loading conditions.

Stress distribution in the tibia and fibula bones was examined using the pedestrian finite element model. The criterion for evaluation was the comparison of maximum simulated stress with established fracture thresholds defined in international safety guidelines (e.g., Euro NCAP). By monitoring stress magnitudes and distributions across the bones, the likelihood of fracture or serious injury could be estimated.

The results from force and stress analyses were used to compare the two bumper configurations. The comparison was based on relative reductions in peak force and stress levels, as well as alignment with regulatory safety thresholds. Specifically, the percentage reduction in the peak forces transmitted to the tibia and femur was calculated for the recycled aluminum Can bumper relative to the traditional steel bumper. Furthermore, the maximum von Mises stress experienced by the bone structures was assessed against injury tolerance limits defined by relevant safety protocols. This integrated approach ensured that the evaluation emphasized both effective impact energy absorption and strict compliance with pedestrian safety standards.

3.8 Data Processing and Validation

The final step in the methodology involved processing the raw data obtained from both experimental testing and numerical simulations and carrying out a validation study to confirm the accuracy and reliability of the finite element models.

The raw data obtained from both the drop-weight impact experiments and the finite element simulations were processed and analyzed to evaluate the performance of the proposed bumper design. For the experimental results, the recorded force–time histories were exported from the data acquisition system and filtered to remove noise, ensuring smooth and interpretable curves. The absorbed energy was determined from the area under the force–displacement curve, where displacement was derived from the impactor velocity and time relationship. In addition, the deformation patterns of the cans after impact were carefully documented through visual inspection and photographs, providing qualitative evidence of the crushing and folding behavior. This documentation was essential for correlating the physical failure modes observed in the test with the computational predictions.

In parallel, the simulation data generated in LS-DYNA were processed using LS-PrePost. From the simulations, the force–time responses, von Mises stress distributions, energy balance outputs, and deformation modes were extracted. The energy analysis accounted for the transformation of initial kinetic energy into internal, sliding, and hourglass energies, verifying the accuracy of the numerical model. The proportion of hourglass energy was kept minimal (typically less than 5% of the total internal energy) to verify the computational stability and accuracy of the numerical model's solution.

Validation of the FE model was achieved by directly comparing the simulation outputs with the experimental findings under identical loading and boundary conditions. The comparison focused on peak impact forces, the shape of the force–time curves, the degree and pattern of deformation, and the total absorbed energy. Close agreement was observed between experimental and simulation results for both vertical and horizontal can orientations, confirming the reliability of the numerical approach. This successful validation confirmed that the FE model was a robust tool for reliably simulating the complex dynamic behavior of the proposed recycled aluminum bumper design.

Chapter 4: Results and Discussion

4.1 Validation of Aluminum Can FE Model

The drop-weight impact experiments were conducted to evaluate the energy absorption characteristics of waste aluminum beverage cans under controlled dynamic loading. Tests were performed using a rigid steel impactor of 5 kg mass, released at an initial velocity of 4.5 m/s, with a total impact duration of approximately 30 milliseconds. Both vertical and horizontal orientations of the cans were examined in order to assess the effect of orientation on deformation mechanisms and energy dissipation. The setup utilized a high-speed data acquisition system and a load cell positioned directly beneath the specimen to accurately capture the impact forces.

The recorded force–time histories from the data acquisition system provided the primary basis for analysis. These histories were instrumental in calculating key metrics, including the peak impact force and the total impulse transferred during the collision. In addition, deformation patterns after impact were meticulously documented and compared, providing crucial visual evidence of the crushing, folding, and local buckling phenomena that define the cans' crashworthiness performance.

4.1.1 Vertical Orientation of Aluminum Can

In the vertical configuration, the can axis was aligned parallel to the impact direction. Figure 10 compares the force–time response from experiments and simulations for the vertically oriented can. The force–time response illustrated in Figure 11, showed a rapid rise in force, reaching a peak of approximately 2.45 kN at around 5 ms. After the peak, the force gradually decreased with oscillations, corresponding to successive local buckling and folding of the thin-walled cylindrical shell. The deformation mode was primarily axisymmetric. This collapse mechanism allowed the specimen to dissipate impact energy in a controlled and repeatable manner.

The total energy absorbed in this orientation was relatively high, confirming the effectiveness of vertical can alignment in crash energy management application.

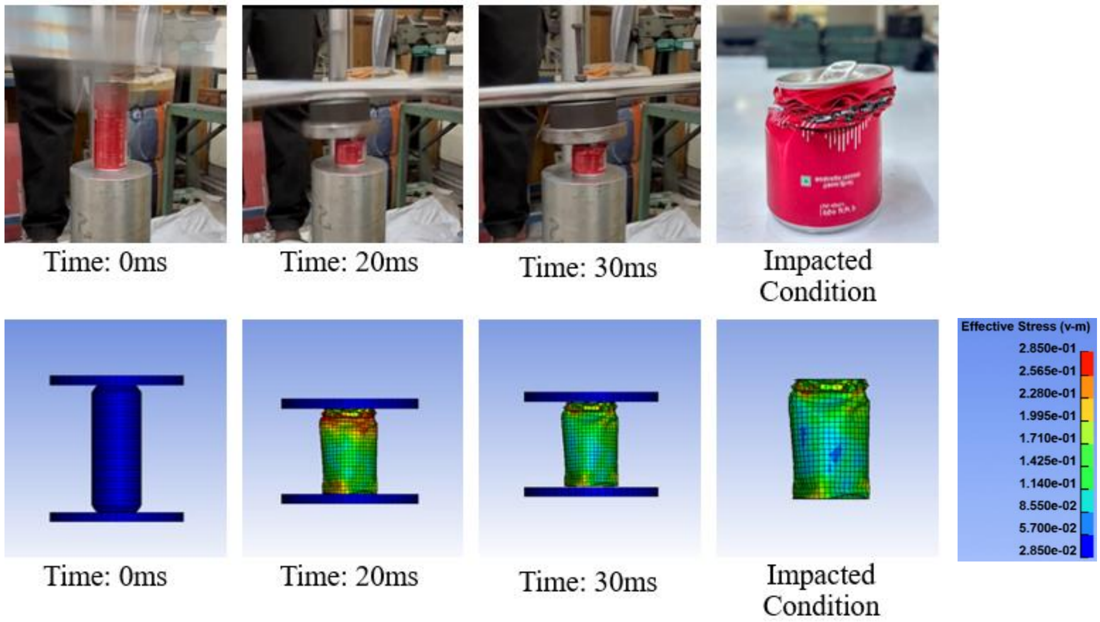

Figure 10:Validation of LS-DYNA simulation against experimental results for aluminum can impact (Vertical Orientation)

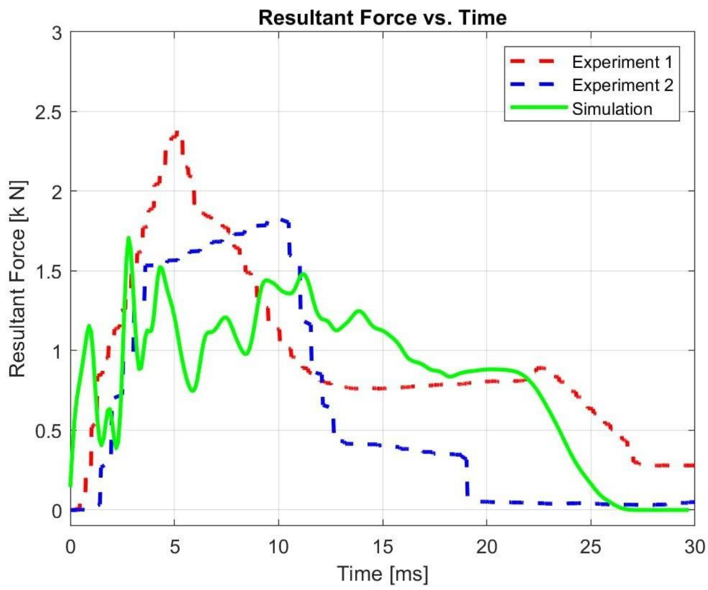

Figure 11:Comparison of LS-DYNA simulation and experimental drop-weight test results for vertical impact orientation showing close correlation between both methods

4.1.2 Horizontal Orientation of Aluminum Can

When tested in the horizontal configuration, the can axis was oriented perpendicular to the direction of loading. As shown in Figure 12, the horizontal impact also shows strong agreement between simulated and experimental responses. The corresponding force–time response illustrated in Figure 13, exhibited a higher peak force of approximately 2.8 kN, followed by a more sustained plateau phase before a gradual decline.

The deformation behavior differed significantly from the vertical case. Instead of uniform axial folding, the cans experienced ovalization, bending, and localized flattening at the point of impact. This produced non-uniform force responses and less predictable deformation modes. The peak force was higher in this orientation.

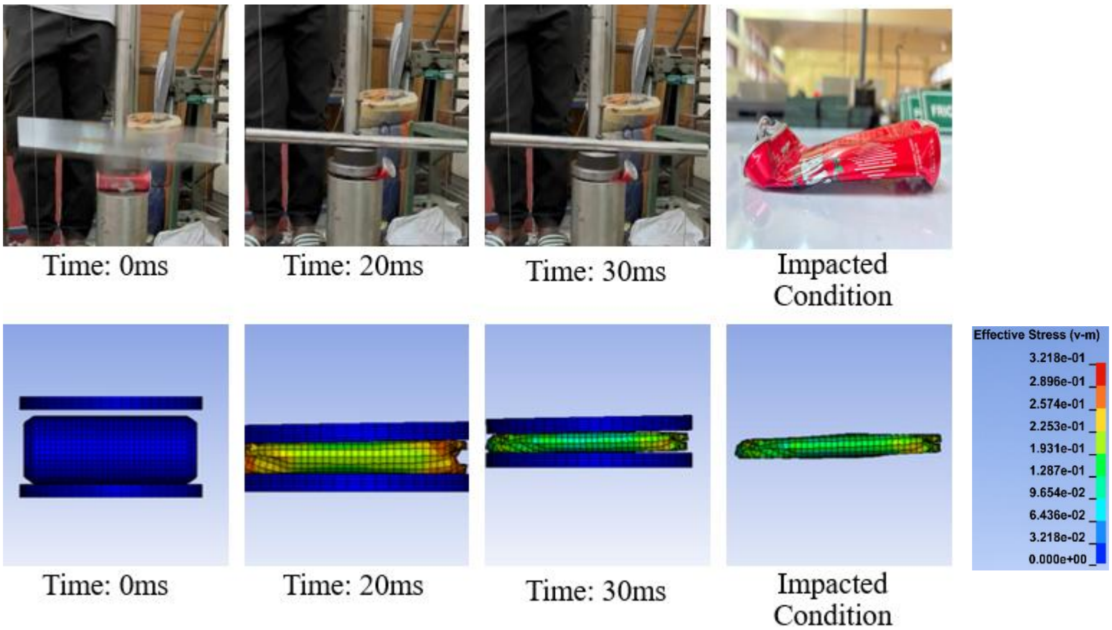

Figure 12:Validation of LS-DYNA simulation against experimental results for aluminum can impact (Horizontal Orientation)

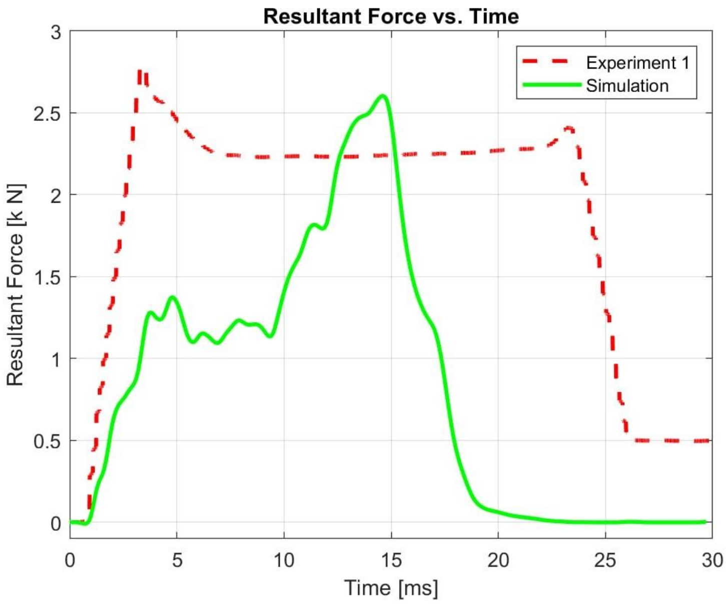

Figure 13:Comparison of LS-DYNA simulation and experimental drop-weight test results for horizontal impact orientation showing close correlation between both methods

Overall, the comparison between the vertical and horizontal orientations clearly highlights the influence of initial can positioning on deformation behavior and energy absorption capacity. The vertical orientation demonstrates a more predictable and progressive buckling pattern, allowing the can to absorb impact energy efficiently through controlled folding. This controlled collapse leads to a more uniform and prolonged force plateau in the force-displacement curve, which is ideal for impact protection. In contrast, the horizontal orientation experiences a broader deformation zone and irregular collapse, leading to greater lateral displacement and a less stable energy-dissipation response. This irregular behavior often results in a lower average crush force and less consistent energy absorption per unit of crush distance. These fundamental differences show that orientation plays a significant role in determining structural performance under dynamic loading, and understanding this behavior is essential for selecting the most effective configuration for impact-mitigation applications.

4.2 LS-DYNA Simulation Results

Numerical simulations were carried out in LS-DYNA to replicate the drop-weight impact tests and further analyze the crashworthiness of aluminum beverage cans. The finite element models included the aluminum can (modeled using the Al 3004 H34 material properties), a rigid steel impactor, and a steel support plate, with boundary conditions closely matching those of the physical experiments. The contact interactions between the impactor and the can, as well as the can and the support plate, were precisely defined to model the dynamics accurately. The simulation results provided detailed insights into force–time responses, energy absorption mechanisms, and stress distributions, enabling a direct comparison with the experimental data.

4.2.1 Energy Absorption and Balance

When analyzing collisions using the principle of conservation of energy, the kinetic energy lost in a collision must be transformed into other types of energy, including hourglass, sliding, and internal energy. The energy balance output from LS-DYNA was analyzed to evaluate the stability of the simulation and to ensure that the impact energy was properly accounted for in all deformation processes. At the onset of impact, the system contained only kinetic energy, associated with the motion of the impactor. As the simulation progressed, this kinetic energy was gradually converted into internal energy within the aluminum can as plastic deformation and folding occurred.

The energy history plots indicated that internal energy accounted for the majority of the total energy, confirming that the primary mechanism of energy dissipation was plastic deformation of the thin-walled aluminum structure. This is desirable in crash energy management, as it reflects controlled energy absorption through material yielding rather than elastic rebound.

Other components of the energy balance, namely sliding contact energy and hourglass energy, remained minimal throughout the simulation. The hourglass energy fraction was consistently below 5% of the total energy system, which is within the recommended threshold for stable LS-DYNA analyses. This validates that the mesh density and element formulation were sufficient to prevent numerical instabilities such as artificial energy modes

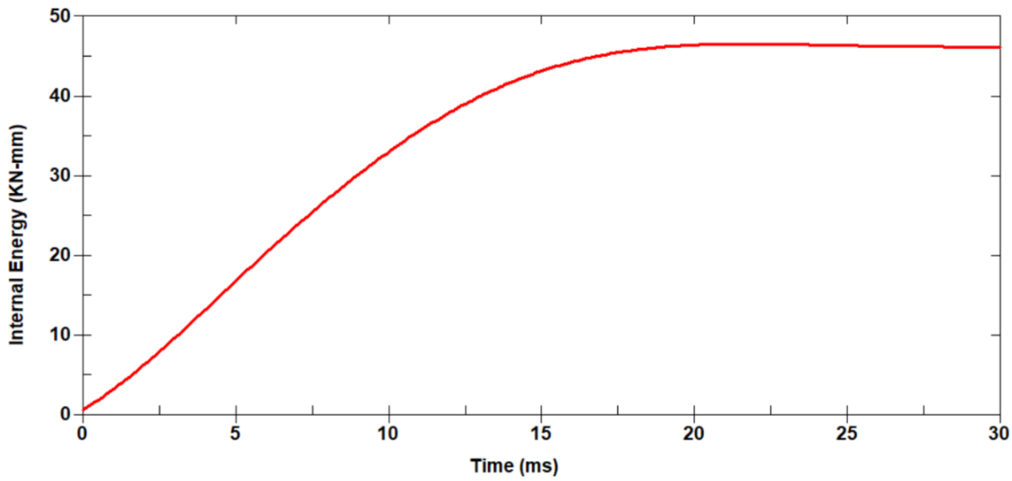

Figure 14:Internal Energy (KN-mm) Vs Time (ms) of Aluminum Can

Figure 14 illustrates the evolution of internal energy in the aluminum can during the drop-weight impact simulation. Internal energy represents the amount of impact energy that is absorbed through plastic deformation, which is the main mechanism by which thin-walled aluminum structures dissipate crash forces. This focus on internal energy is a key indicator of the material's crashworthiness.

The upward trend of the curve indicates that the can is continuously absorbing energy through plastic deformation as the impact progresses. This steady increase shows that the structure is effectively converting the kinetic energy of the impact into internal energy by deforming, which is the primary mechanism for energy absorption in thin-walled aluminum components. The steepness of the initial curve portion reflects the high force required to initiate the initial buckling and plastic yielding of the structure.

By the end of the simulation, the internal energy curve stabilizes, indicating that the can has absorbed nearly all of the energy it can take through deformation. The dominance of internal energy in the overall energy distribution confirms that the aluminum can behaves as an efficient energy-absorbing element, with minimal energy lost to other sources such as contact or numerical effects. The final plateau value of the internal energy curve directly corresponds to the total energy absorbed by the structure, a critical parameter for crash performance assessment.

4.3 Pedestrian Impact Simulation

The pedestrian impact simulations compared the performance of the traditional steel bumper and the recycled aluminum can bumper in terms of force–time responses and tibia and fibula stress levels.

4.3.1 Force–Time Responses of Aluminum vs. Steel Bumpers

The force–time response curves demonstrated a clear difference between the two bumper configurations. For the steel bumper, the pedestrian experienced a peak impact force of 0.3 kN at approximately 1 ms after initial contact. The comparative force response between the steel and recycled aluminum bumpers shown in Figure 15, clearly shows a sharp rise in force, indicating rapid energy transfer to the pedestrian.

In contrast, the aluminum bumper produced a peak force of only 0.04 kN at 1 ms, representing an 86.7% reduction compared to the steel bumper. The force–time curve was smoother, suggesting improved energy absorption and lower stress transmission to the pedestrian's body. Figure 15 gives a clear idea on why Aluminum Bumpers are a better and safer alternative than the traditional bumper as the resultant force that is generated and transferred to the pedestrian is much less than the resultant force generated by the traditional bumper.

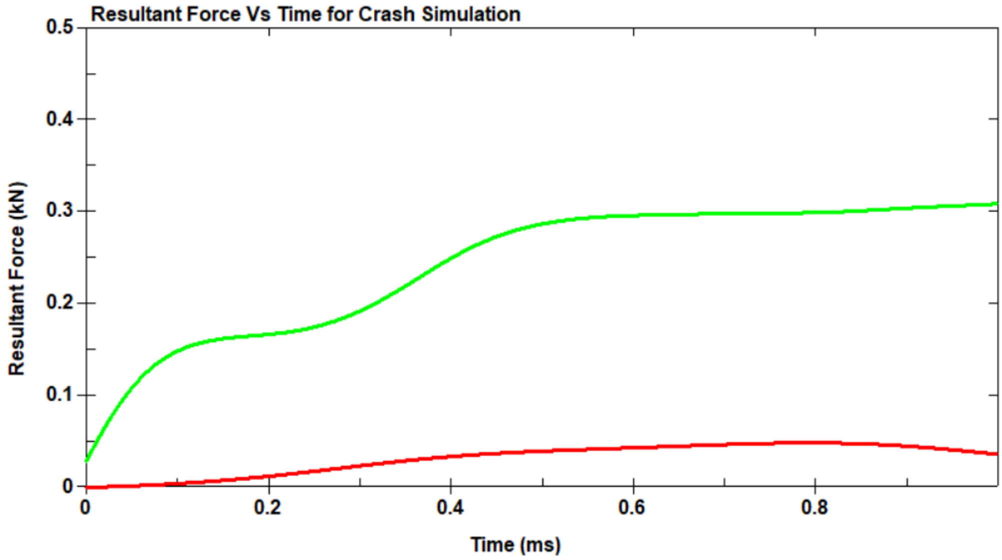

Figure 15:Resultant force Vs time response for pedestrian impact using a traditional steel bumper (green) and the proposed aluminum bumper (red)

4.3.2 Tibia and Fibula Stress Analysis (vs. Euro NCAP Threshold)

The stress analysis of the lower limb bones further validated the benefits of the aluminum bumper which is shown in Figure 16. The maximum stress on the tibia with the recycled aluminum bumper was 148 MPa, which remained below the Euro NCAP fracture threshold of 150 MPa. This indicates a reduced risk of serious fracture related injury and enhanced safety for the pedestrian.

On the other hand, the steel bumper produced stress levels exceeding the 150 MPa limit, suggesting a higher likelihood of bone fracture under similar impact conditions. The fibula showed a similar trend, with stress magnitudes substantially lower for the aluminum configuration compared to the steel one. An effective stress comparison of the tibia and fibula bone in the time intervals of 0 ms,1ms,2ms,3ms,4ms,5ms and 6ms is given below.

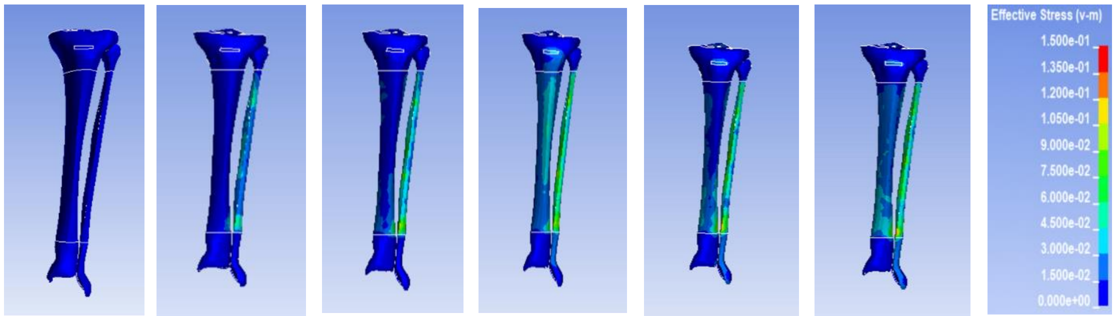

Figure 16:Effective stress analysis on the Tibia and Fibula bone

4.4 Comparison Between Experimental and Simulation Results

A direct comparison was made between the experimental drop-weight impact tests and the LS-DYNA simulation results in both vertical and horizontal orientations. The comparison focused on force–time histories, peak forces, deformation modes, and energy absorption capacity

The force–time responses showed strong agreement in overall trends. For the vertical orientation, the experiment recorded a peak force of approximately 2.45 kN, while the simulation predicted a slightly lower peak of 1.7 kN. Both responses exhibited oscillations corresponding to successive folding events, though the experimental data contained sharper peaks due to real-world irregularities such as surface imperfections, friction, and variability in can wall thickness. In contrast, the simulation smoothed these effects because of its idealized geometry and uniform material properties.

For the horizontal orientation, the experiment produced a peak force of about 2.8 kN, while the simulation yielded a comparable peak of 2.6 kN. Both results demonstrated a broad force plateau, indicative of sustained localized deformation. The similarity in magnitude and curve shape confirms that LS-DYNA was able to capture the essential mechanics of the horizontal crushing mode with high accuracy.

The deformation patterns also correlated strongly. Experimentally, vertically oriented cans exhibited axisymmetric progressive folding, while horizontally oriented cans showed localized flattening and asymmetric collapse. These modes were reproduced faithfully in the simulations, as confirmed by the von Mises stress contours and energy balance outputs.

Minor discrepancies between experimental and simulation results can be attributed to the variability of recycled aluminum cans (e.g., non-uniform wall thickness, prior dents or imperfections), simplifications in the finite element model (e.g., idealized geometry, constant material properties), and boundary condition assumptions (e.g., perfect contact definition). Despite these differences, the deviations remained within an acceptable range, thereby validating the accuracy and reliability of the finite element model.

The comparison of experimental and simulated force–time responses for the Vertical Can shows close agreement in overall trend. The simulation predicted a peak force of approximately 1.7 kN, which is slightly lower than the experimental values of 2.45 kN. Both results, however, exhibited the characteristic oscillations associated with progressive folding of the thin-walled aluminum can. The smoother response of the simulation can be attributed to the idealized geometry and uniform material properties in LS-DYNA, whereas the experiments reflected real-world imperfections such as wall thickness variation and surface dents. Despite these differences, the correlation between the two methods validates the accuracy of the finite element model in capturing the essential deformation and energy absorption mechanisms of the vertical orientation.

The comparison of experimental and simulated force–time responses for the Horizontal Can shows strong consistency in peak force and overall curve shape. The simulation predicted a peak force of approximately 2.6 kN, closely matching the experimental peak of about 2.8 kN. Both results displayed a sustained plateau following the peak, reflecting localized flattening of the can wall rather than uniform progressive folding. Minor deviations in the curve shape can be attributed to material variability in the recycled cans and simplifications in the numerical model. Nevertheless, the close alignment in force magnitude and deformation behavior confirms that the LS-DYNA simulation reliably reproduces the physical response of the horizontal.

4.5 Application and Future Scope

The findings from both experimental and simulation analyses provide important insights into the potential of recycled aluminum cans as a material for automotive bumper design. This section discusses the effectiveness of the proposed design in energy absorption, its implications for pedestrian safety, the environmental benefits of material reuse, and the limitations of the current study.

4.5.1 Effectiveness of Recycled Aluminum Cans in Energy Absorption

The results demonstrated that bumpers fabricated from recycled aluminum cans exhibited superior energy absorption compared to conventional steel bumpers. The drop-weight and LS-DYNA simulations confirmed that the aluminum configuration dissipated collision energy more efficiently, as evidenced by the smoother force–time response and significant reduction in peak force [1], [8]. These outcomes indicate that lightweight recycled aluminum structures can function as effective energy-absorbing components in impact scenarios.

4.5.2 Implications for Pedestrian Safety

The pedestrian crash simulations revealed a marked improvement in safety performance with the aluminum bumper design. The peak force acting on the pedestrian was reduced by approximately 86.7% compared to the steel bumper, while the tibia stress values remained below the Euro NCAP fracture threshold (150 MPa) [4]. This demonstrates that the recycled aluminum bumper not only minimizes the likelihood of severe lower-limb injuries but also aligns with international pedestrian protection standards. The design therefore holds promise for integrating sustainability with enhanced occupant and pedestrian safety.

4.5.3 Environmental Benefits of the Design

Recycling aluminum cans for bumper applications provides clear sustainability advantages. It reduces landfill waste and supports a circular economy by enabling continuous reuse [3], [7]. Compared to primary production, recycled aluminum requires up to 95% less energy and generates significantly lower carbon emissions [3], [7]. Moreover, lightweight aluminum contributes to improved vehicle efficiency and reduced lifecycle environmental impact [2], [3].

4.5.4 Recommendations for Future Research

Future studies should explore optimized geometric configurations of aluminum can assemblies. While this work investigated only basic vertical and horizontal orientations, advanced stacking patterns, multi-cell arrangements, and structural reinforcements could significantly improve energy absorption efficiency. Investigating these configurations would help identify the most effective structural layout for real-world bumper applications.

Another promising direction is the development of hybrid or composite bumper systems. Combining recycled aluminum cans with lightweight polymers, natural fibers, foams, or bio-based materials may produce enhanced crashworthiness and multifunctional properties such as improved vibration damping or better recyclability. Such hybrid structures could offer a balance between strength, energy absorption, and sustainability.

Additionally, future research should include full-scale pedestrian impact tests following established regulatory standards such as Euro NCAP or FMVSS. While simulations in this study showed encouraging trends, experimental validation at full scale is essential to confirm the real-world safety performance of recycled aluminum bumpers.

Long-term durability assessments are also needed. Investigating how factors such as fatigue loading, corrosion, humidity, and temperature variations affect recycled aluminum can structures over time would provide insight into their feasibility for long-term automotive use. These environmental evaluations are crucial to ensure structural reliability throughout the lifespan of a vehicle.

Finally, industrial implementation should be explored through large-scale prototyping and cost–benefit analyses. Collaborations with automotive manufacturers could evaluate production feasibility, assembly techniques, and economic advantages. Such work would help determine whether recycled aluminum can bumper can be scaled into mainstream automotive manufacturing.

Chapter 5: Conclusions

5.1 Summary of the Research

This study examined the feasibility of repurposing waste aluminum beverage cans into lightweight car bumpers as a sustainable alternative to traditional steel designs. Using both drop-weight impact tests and LS-DYNA simulations, the research evaluated the energy absorption behavior of aluminum cans and their role in pedestrian crash scenarios [11]. The results highlighted the potential of recycled aluminum to enhance safety while addressing environmental concerns through material reuse [3], [7].

The Key findings and Contributions showed that recycled aluminum bumpers absorbed collision energy more effectively than steel bumpers, reducing peak forces and keeping tibia stress below Euro NCAP fracture thresholds [4]. The close agreement between experimental and simulation results validated the numerical framework [11]. Beyond safety improvements, the study demonstrated the viability of incorporating waste aluminum into automotive components, contributing to sustainable vehicle design [3].

The proposed bumper design offers practical advantages for the automotive industry. Replacing steel bumpers with recycled aluminum can reduce vehicle weight, improve energy absorption, and enhance pedestrian protection [5], [12]. At the same time, it lowers production costs and supports environmental sustainability by reducing demand for virgin materials. The concept may also be extended to other vehicle parts, reinforcing the integration of safety and eco-friendly practices in automotive engineering[3].

Limitations: The limitations of the study are that the experimental tests were conducted only on individual recycled aluminum cans rather than on a full bumper assembly, which limits the ability to fully predict real-world structural performance. Additionally, the numerical simulations relied on simplified boundary conditions and uniform material properties, whereas actual waste aluminum cans may have variations in thickness and prior dents that influence behavior. The pedestrian impact analysis was restricted to a single collision scenario at 40 km/h, without exploring different vehicle speeds, angles, or multi-directional impacts. Furthermore, the study did not consider long-term durability factors such as fatigue, corrosion, or repeated loading, which are essential for assessing the lifecycle performance of automotive components. These limitations highlight the need for expanded experimental setups, more detailed simulations, and broader testing conditions in future research.

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