

Numerical Investigation of Crush Response in Aluminum and Tin Cans Using Finite Element Analysis

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Abstract—The structural integrity and energy absorption behavior of thin-walled metallic cans are vital in packaging, transportation, and crashworthiness applications. This study presents a finite element investigation of aluminum and tin cans with circular, square, and hexagonal cross-sections using ANSYS Explicit Dynamics. The analysis focuses on understanding the influence of geometry and material properties on stress distribution and deformation under compressive loading. Finite element models were developed in SpaceClaim and evaluated under uniform boundary and loading conditions.

Results indicate that can geometry plays a critical role in determining structural response. The hexagonal configuration exhibited superior strength and lower deformation compared to circular and square models, demonstrating better resistance to crushing. Validation with existing studies confirmed the accuracy of the simulation outcomes. Overall, the research highlights that optimizing can geometry, particularly with aluminum material, enhances mechanical performance, energy absorption, and design efficiency for sustainable manufacturing applications.

Index Terms—Thin-walled cylinders, Aluminum, Tin, Explicit dynamics, Finite element analysis, Crush response

I. INTRODUCTION

Thin-walled metallic cans are widely used in packaging, transport, and energy absorption applications due to their light weight, strength, and recyclability. Among various materials, aluminum and tin are preferred for their corrosion resistance, formability, and cost-effectiveness. Studying their crush behavior provides valuable insight into

deformation and failure mechanisms of thin-walled shells, which are critical in aerospace, automotive, and structural design [1-3]. The crush and buckling response of thin shells depend on material, geometry, and wall thickness. Finite Element Analysis (FEA) has proven effective in predicting these behaviors. Khalili et al. [1] and Kazanci and Bathe [2] demonstrated that geometric configuration and aspect ratio significantly affect energy absorption efficiency. Dube et al. [3] and Trilochan et al. [4] showed that composite and foam-filled tubes enhance crashworthiness, while Joseph and Kamaji [5] highlighted the role of optimized shape in impact mitigation. Gokhale [6] emphasized the importance of mesh accuracy in FEA, and Barrera et al. [7-8] examined deformation in cracked shells. Sawant and Venkatesh [9] related can thickness to improved crush resistance, and Raju et al. [10] validated finite element predictions with experimental data for GFRP shells. Recent research has expanded to buckling and vibration of advanced composites. Jiao et al. [11] and Tian et al. [12] investigated localized compression and buckling in steel and stiffened shells. Wagner and Niemann [13] developed reliable knockdown factors for composite structures, while Chakraborty et al. [14] and Jiao et al. [15] studied CNT-reinforced and functionally graded composites for improved stiffness and stability. Despite these advances, limited work has compared the crush response of aluminum and tin cans of different geometries under identical conditions. This study addresses this gap using ANSYS Explicit Dynamics to analyze circular, square, and hexagonal cans, evaluating stress distribution and deformation to determine the most efficient and sustainable design.

1.1 Stages of Can Crushing

Force Application: Crushing begins when an external force is applied to the thin-walled Can either manually (by hand/foot) or using a mechanical crusher. At this stage the can walls are still mostly intact and start to bend slightly under load.

Elastic to Plastic Deformation: As the force increases, the can wall loses its circular stability and local buckling starts. Wrinkles or folds appear on the surface, marking the transition from elastic deformation to plastic collapse.

Progressive Collapse or Folding: The side walls fold inward forming sequential circumferential folds. The height of the can reduces significantly as material undergoes plastic deformation. Stress concentrates at fold lines.

Complete Crushing / Final Compaction: Eventually the folds stack and the Can flatten almost completely. The side walls meet and the can becomes a compact flattened disc-like form with minimal volume suitable for storage, recycling, or disposal, all four stages are shown in fig 1.1



Fig 1.1 Various stages of Can Crushing

II. METHODOLOGY

This study employed a Finite Element Analysis (FEA) to numerically investigate the crush response of thin-walled cans. The methodology encompassed four key stages: (1) geometric modeling of three cross-sections, (2) assignment of material properties, (3) FEA setup with explicit dynamics, and (4) model validation

2.1. Geometric Modeling and Materials:

Three distinct thin-walled cylindrical shell geometries were designed, each with a uniform height of 104 mm, representing common beverage can dimensions. The models were created using ANSYS SpaceClaim, a direct 3D solid modeling tool. The key geometric parameters are summarized in Table 2.1 and the models are depicted in Figures 2.1a-c. Two materials Aluminum and Tin, were selected with their properties defined as shown in Table 2.2.

Table 2.1 Geometric Parameters of the Can Models

Shape	Cross-Sectional Dimensions	Height (mm)	Wall Thickness (mm)
Circular	Radius: 23 mm	104	2.0
Square	Side: 38 mm	104	2.0
Hexagonal	Side: 23 mm	104	2.0

Table 2.2 Material Properties of Aluminum and Tin

Property	Aluminum	Tin
Young's Modulus (Pa)	7.1×10^{10}	5.0×10^{10}
Poisson's Ratio	33	0.36
Density (kg/m ³)	2770	7300

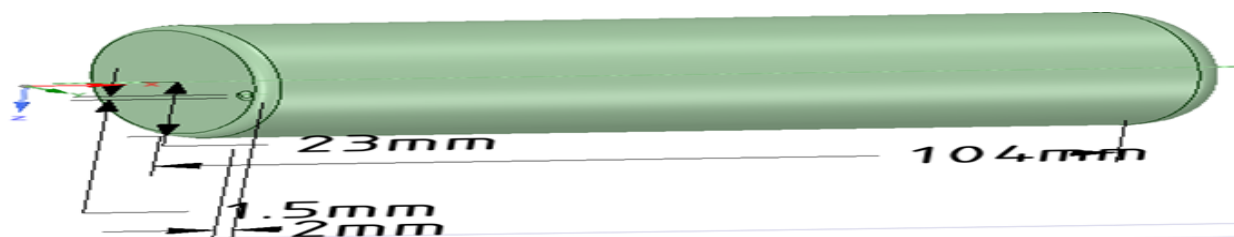


Fig 2.1a. Schematic diagram of a Circular Can

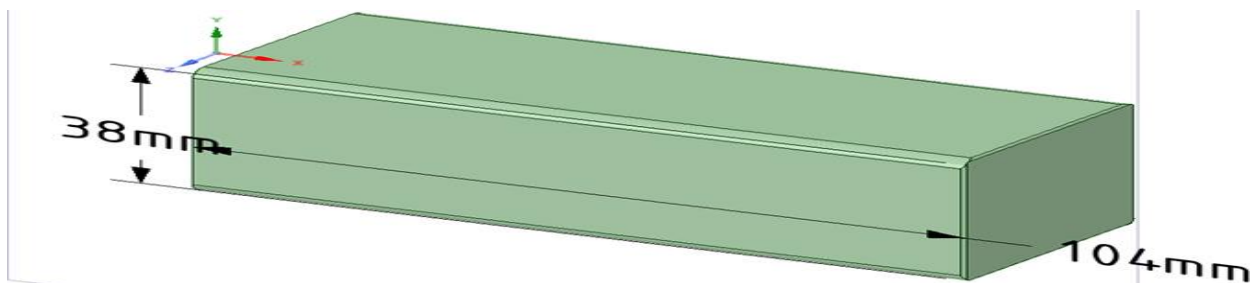


Fig 2.1b. Schematic diagram of a Circular Can

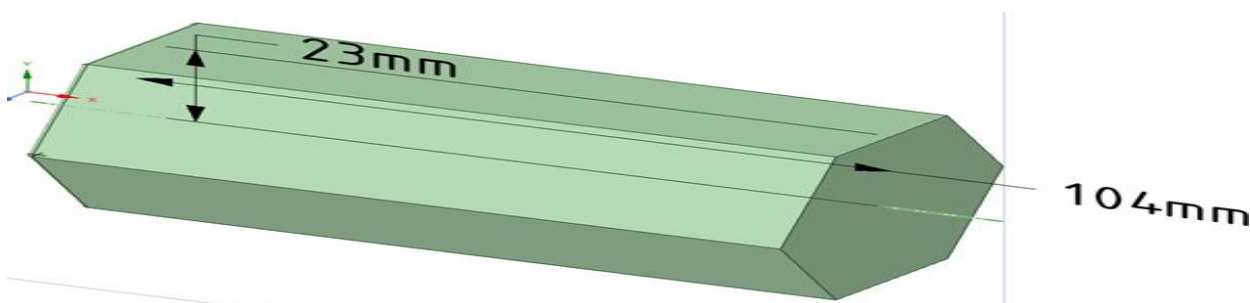


Fig 2.1c. Schematic diagram of a Hexagonal Can

2.2 Finite Element Analysis Setup: The models were discretized using an unstructured mesh, refined to capture stress concentrations. A Fixed Support boundary condition was applied to the bottom surface. A compressive crushing load was simulated using an Explicit Dynamics solver in ANSYS, which is suited for large deformation and non-linear problems. **Meshing:** A critical step in FEA, meshing involves discretizing the geometric models into smaller, solvable elements. An unstructured mesh was generated for all models using ANSYS Meshing. The mesh was refined to ensure sufficient element density for accurately capturing stress concentrations and deformation patterns, particularly at the corners of the square and hexagonal shells. To simulate a crushing load, appropriate boundary conditions were applied. The bottom surface of each can was assigned a Fixed Support constraint, restricting all degrees of freedom. A compressive load was applied to the top surface, simulating the action of a crusher. The analysis was

performed using an Explicit Dynamics solver in ANSYS. This approach is particularly suited for simulating short-duration, high-speed events involving large deformations, complex contact conditions, and non-linear material behavior, all of which are characteristic of a can-crushing process. The explicit method calculates the state of the system at a given time based on its state from the previous time step, making it highly efficient for dynamic problems like impact and crushing.

2.3 Results and discussion:

A. Cylindrical Can Response: The crushing response of the cylindrical cans made of aluminum and tin was first examined under identical explicit dynamic loading. As shown in Fig. 2.3.1 and Fig. 2.3.2, the aluminum cylinder experienced a higher equivalent stress compared to tin, consistent with its higher stiffness and yield strength. The stress field remained uniformly distributed along the curvature, with no

sharp localized bands due to the absence of flat faces or corners. In terms of deformation, the cylindrical geometry showed moderate displacement (refer Table 2.3.1 and 2.3.2), indicating a ductile collapse pattern governed by shell ovalization rather than localized folding. This is consistent with prior findings by Zafer Kazanci and Bathe that circular profiles delay onset of plastic hinge formation due to curvature continuity.

Table 2.3.1 Stress (Pa) values for different geometrical shapes Cans made of aluminum and tin		
Shape	Aluminum	Tin
Hexagonal	6.11×10^{10}	4.3×10^{10}
Square	2.07×10^{10}	1.1×10^{10}
Cylindrical	4.7×10^{10}	2.3×10^{10}

Table 2.3.2 Deformation (mm) for different geometrical shapes of Cans made of al and tin		
Shape	Aluminum	Tin
Hexagonal	0.058765	0.058865
Square	0.060005	0.060002
Cylindrical	59.661	0.059661

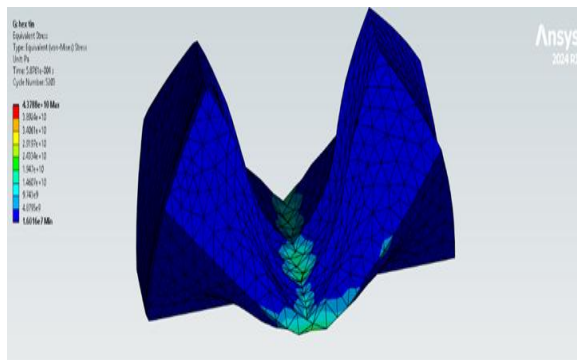


Fig 2.3.1. Equivalent stress of circular Can made of Aluminum

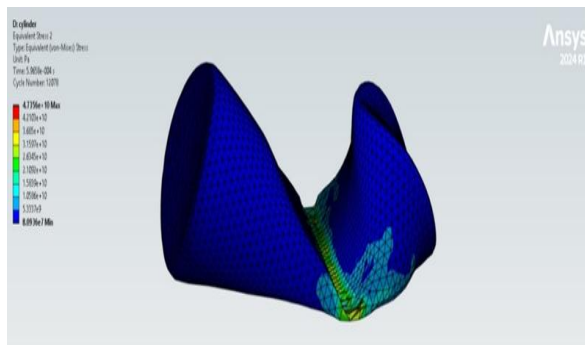


Fig 2.3.1. Equivalent stress of circular cross-section Can made of Tin

B. Square Can Response: Square Cans exhibited a distinctly different collapse morphology due to the presence of flat walls and sharp edges. As visible in Fig. 2.3.3 and Fig. 2.3.4, the stress field concentrated at corner intersections, forming high-intensity lobes. Tin exhibited lower stress magnitude compared to aluminum, but followed the same localization pattern. Deformation values for the square cross-section were slightly higher than hexagonal and comparable to cylindrical configurations. The structural instability initiated earlier due to bending at mid-wall spans, validating the observations by Piyush Dube et al. that polygonal shells with low bending rigidity suffer premature instability.

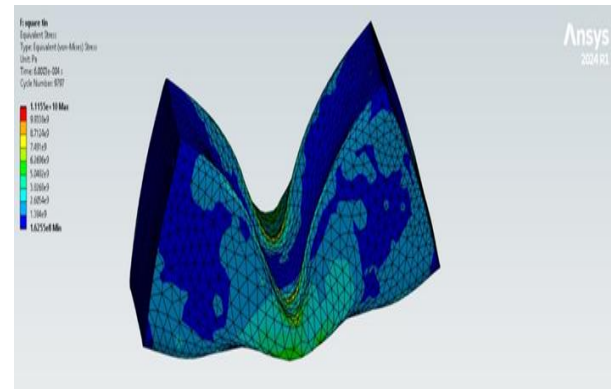


Fig 2.3.3. Equivalent stress of square cross-section Can made of Aluminum

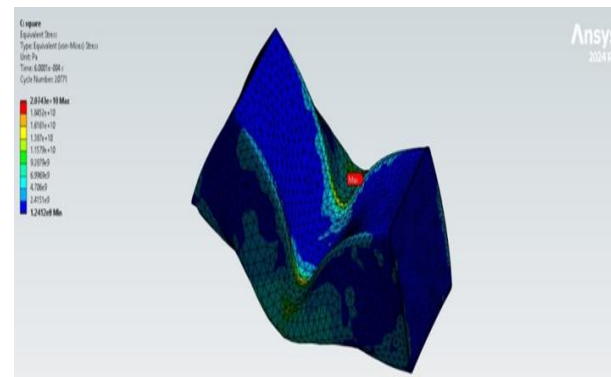


Fig 2.3.3. Equivalent stress of square cross-section Can made of Tin

C. Hexagonal Can Response: The hexagonal configuration exhibited the highest equivalent stress for both aluminum and tin cans. This is attributed to internal stress triangulation in six-panel configuration, which increases line-edge stiffness at each vertex. Despite the high stress, the deformation for hexagonal

cans remained the lowest among all shapes, demonstrating superior crush stability. This behavior agrees with Trilochan et al. who reported that multi-corner tubes serve as effective energy absorbers by distributing membrane stress between shorter flat segments.

D. Comparative Stress Evaluation: Based on Table 2.3.1, equivalent stress followed a consistent hierarchical trend across both materials, Aluminum consistently recorded higher stress values than tin due to higher modulus and yield strength. The stress differences between geometries were more pronounced in aluminum, indicating that geometric sensitivity is amplified in stiffer materials.

E. Deformation Characteristics: From Table 2.3.2, total deformation trends were inversely correlated with stress: The hexagonal shells, despite carrying the highest stress, deformed the least, indicating structural efficiency under crushing. This is mechanically logical: higher stiffness and distributed stress reduce lateral wall deflection.

2.4 Validation

In order to ensure that the finite element framework employed for the Numerical Investigation of Crush Response in Aluminum and Tin Cans Using Finite Element Analysis is credible, a validation study was carried out against a published benchmark. The reference study by M. Raju et al. [10] reports the buckling response of a glass-fiber cylindrical shell of 210 mm diameter, 500 mm height and 6 mm thickness subjected to an axial compressive load of 232 kN with a fixed-free configuration.

The same loading and boundary conditions were reproduced in ANSYS, and the corresponding buckling mode strengths (Mode-1 to Mode-3) were extracted. The mode shapes obtained in the present simulation closely resemble those reported in literature, as illustrated in Fig. 2.4.1 to 2.4.3. A quantitative comparison of resistance strength is presented in Table 2.4.1, showing that the maximum deviation between the present FEA results and the reference work is less than 2%.

This close agreement demonstrates that the numerical methodology used for the present crush analysis of aluminum and tin cans is capable of accurately capturing the structural response of thin-walled cylindrical shells under compressive loads. The low error margin validates the fidelity of the adopted

meshing strategy, material modeling and solver configuration. Therefore, the same validated framework is confidently extended in this study to analyze crush response characteristics of cans made of aluminum and tin with different cross-sectional geometries.

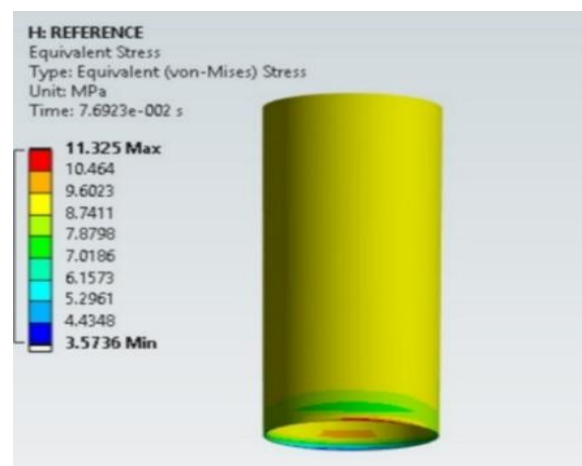


Fig 2.4.1. Mode-1 of cylindrical Can

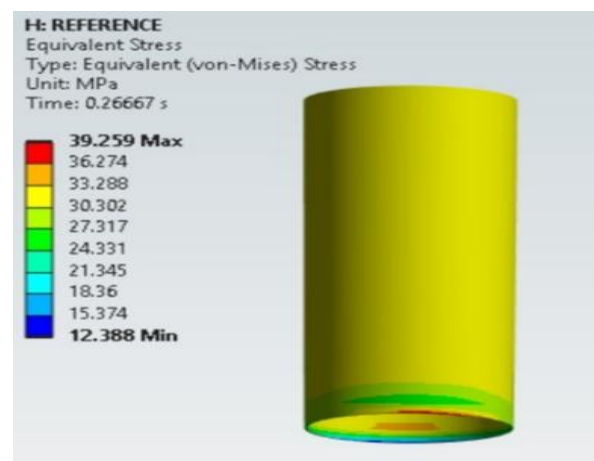


Fig 2.4.2 .Mode-2 of cylindrical Can

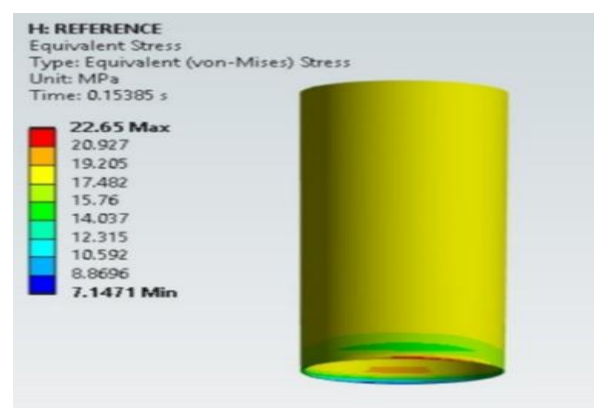


Fig 2.4.3. Mode-3 of cylindrical Can

Table 2.4.1 Resistance strength (N/mm ²) of cylindrical Can made of glass fiber at various modes			
Mode	M. Raju et al @IJRAR 2019	Present work-Ansys	% Error
Mode 1	11.11	11.32	1.89%
Mode 2	22.29	22.65	1.61%
Mode 3	39.14	39.25	0.28%

III.COCLUSIONS

- The equivalent stress values are obtained from ANSYS for circular thin-walled cylindrical shell are very close agreement with the existing findings of M. Raju et al @IJRAR 2019 [10] with a maximum error of 1.89%
- The Hexagonal thin-walled cylindrical shell exhibited the highest equivalent stress values 6.11×10^{10} N/m² and 4.3×10^{10} N/m² for materials aluminum and tin respectively.
- The Circular thin-walled cylindrical shell had moderate equivalent stress values 4.7×10^{10} N/m² and 2.3×10^{10} N/m² followed by square thin-walled cylindrical shell had lowest stress values 2.07×10^{10} N/m² and 1.1×10^{10} N/m² for materials aluminum and tin respectively.
- The Hexagonal thin-walled cylindrical shell showed minimal deformation 0.058765 mm and 0.058765 mm for materials aluminum and tin respectively to make the structure more stable.
- The Square thin-walled cylindrical shell exhibited moderate deformation 0.060005 mm and 0.060002 mm and Circular thin-walled cylindrical shell had significantly higher deformation 59.661 mm and 0.059661 mm for materials aluminum and tin respectively.
- The Hexagonal thin-walled cylindrical shell is the best choice as it withstands the highest stress levels while maintaining low deformation compared to Square and Circular thin-walled cylindrical shells.

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