Simulation-Based Assessment of Auxetic Re-entrant Structures for Protective Phone Case Applications

A Project Report

submitted by

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DECLARATION OF ORIGINALITY

I, **K S L SANJANA**, with Roll No: **ME21B1015** hereby declare that the material presented in the Project Report titled **Simulation-Based Assessment of Auxetic Re-entrant Structures for Protective Phone Case Applications** represents original work carried out by me in the **Department of Mechanical Engineering** at the Indian Institute of Information Technology, Design and Manufacturing, Kancheepuram.

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K S L SANJANA

Place: Chennai

Date: 01.05.2021

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ABSTRACT

This study investigates the mechanical performance of a smartphone case incorporating auxetic lattice geometry for improved impact resistance. A doubly re-entrant honeycomb structure was integrated into the case design and modeled using a SEBS-based thermoplastic elastomer (TPE), chosen for its hyperelastic and viscoelastic behavior. Static structural analysis confirmed auxetic behavior, with a negative Poisson's ratio observed under uniaxial loading. Dynamic impact simulations were subsequently conducted using ANSYS 2024 R2 and ANSYS STUDENT 2025 R1 to evaluate mechanical responses during drop events. The auxetic case was compared against a standard thermoplastic polyurethane (TPU) case under identical boundary and loading conditions. Quantitative metrics such as deformation, stress distribution, acceleration response, and internal energy absorption were extracted and analyzed. Results indicate that the auxetic configuration offers enhanced stress dissipation and reduced peak acceleration, contributing to improved protective performance. The analysis establishes the feasibility of auxetic metamaterials in consumer-grade protective enclosures, with implications for sustainable design through material reduction and performance optimization.

KEYWORDS: **Auxetic Lattice; Re-entrant Geometry; Smartphone Case; Impact Simulation; SEBS; Thermoplastic Elastomer (TPE); TPU; Explicit Dynamics; Negative Poisson's Ratio; Finite Element Analysis (FEA)**

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ABBREVIATIONS

FEA	Finite Element Analysis
TPU	Thermoplastic Polyurethane
TPE	Thermoplastic Elastomer
SEBS	Styrene-Ethylene-Butylene-Styrene
CAD	Computer-Aided Design
ANSYS	Analysis System (Engineering Simulation Software)
SLA	Stereolithography
DLP	Digital Light Processing
ABS	Acrylonitrile Butadiene Styrene

NOTATION

E	Young's modulus (material stiffness) [MPa]
ν	Poisson's ratio (lateral strain to axial strain) [–]
ρ	Density [kg/m^3]
σ	Stress [MPa]
ε	Strain [–]
θ	Re-entrant angle of the auxetic unit cell [deg]
t	Cell wall thickness [mm]
L	Angled wall length in unit cell [mm]
H	Vertical pitch of the unit cell [mm]
W	Horizontal pitch of the unit cell [mm]
h_s	Short vertical segment in unit cell [mm]
H_o	Overall unit cell height [mm]
v	Impact velocity [m/s]
g	Acceleration due to gravity (9.81 m/s^2)
δ	Total deformation [mm]
U_k	Kinetic energy [J]
U_i	Internal energy [J]
$\dot{\varepsilon}_p$	Equivalent plastic strain rate [–]

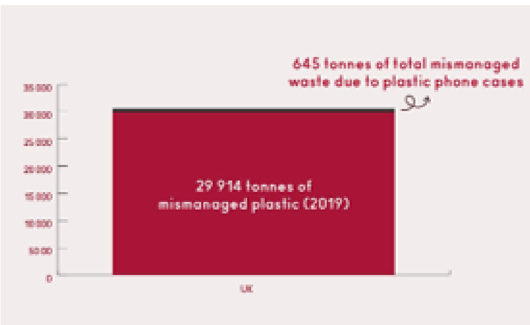
CHAPTER 1

Introduction

1.1 Background and Motivation

Smartphones have become indispensable daily tools, but their compact, fragile construction leaves them vulnerable to mechanical damage. Accidental drops frequently result in cracked screens, edge deformations, or internal failures—often necessitating costly repairs or premature device replacement. In a study conducted by Corning Gorilla Glass, over 30% of Indian users reported switching smartphones due to screen damage, despite owning protective cases [3]. These findings suggest that current commercial cases are inadequate under real-world impact conditions.

The materials and geometries commonly used in smartphone cases, such as solid TPU, silicone, or hard polycarbonate, provide only modest shock absorption. Their lack of internal mechanisms for energy dissipation causes stress concentrations, particularly at corners and edges. Moreover, environmental implications are significant. Over one billion plastic phone cases are sold annually, most of which are discarded within two years due to phone upgrades or case degradation [2]. Each case, often weighing upwards of 50 grams, is made from blended plastic materials that can take up to 500 years to decompose, adding to the mounting global plastic waste crisis.



(a) Mismanaged plastic in the UK due to phone cases

(b) Annual plastic usage by country for phone cases

Figure 1.1: Plastic waste and material use in the phone case industry. Source: [2]

1.2 Problem Statement

Despite widespread adoption, conventional smartphone cases exhibit fundamental mechanical and ecological limitations. These can be categorized as follows:

Table 1.1: Limitations of Conventional Smartphone Cases

Aspect	**Limitation**
Material	Poor damping under dynamic impact; susceptible to micro-fractures
Geometry	Solid, non-responsive design lacks energy-dissipating features
Impact Distribution	Shock energy remains localized, increasing damage potential
Environmental Impact	Long degradation time; high discard frequency and plastic content

1.3 Proposed Solution

This project proposes the use of auxetic metamaterials, materials that exhibit a negative Poisson's ratio, as an alternative structural solution for smartphone protection. Unlike conventional materials, auxetic structures expand laterally when compressed, enabling uniform stress distribution and enhanced energy absorption during impact events [4, 5].

A doubly re-entrant honeycomb lattice is selected for its established auxetic behavior and geometric tunability. The case is constructed using SEBS-based thermoplastic elastomer (TPE), a soft polymer capable of large deformations and suitable for additive manufacturing or injection molding [6]. The auxetic behavior is confirmed through static strain simulations, and full-scale drop test simulations are conducted using ANSYS 2024 R2.

1.4 Scope of Work

This study is limited to computational simulations. However, unlike earlier phases, it incorporates a comparative evaluation against a standard TPU case under identical conditions. The complete scope includes:

- Design and modeling of a re-entrant auxetic unit cell.
- Integration into a smartphone case geometry using parametric CAD.
- Assignment of SEBS-based TPE material properties.
- Static structural analysis to confirm auxetic behavior.
- Dynamic drop simulation using explicit dynamics in ANSYS.
- Comparative evaluation with a conventional TPU case.

CHAPTER 2

Literature Review

2.1 Auxetic Structures and Their Classification

Auxetic materials exhibit a negative Poisson's ratio, expanding laterally when compressed. This anomalous behavior enables superior mechanical properties such as enhanced energy absorption, higher indentation resistance, and improved stress dispersion features advantageous for impact prone applications.

Grima and Evans [5] first illustrated that auxetic behavior could emerge solely from geometry, independent of material type, using rotating square configurations. Kolken and Zadpoor [1] provide a comprehensive classification of auxetic structures, categorizing them into re-entrant honeycombs, chiral lattices, and rotating units. Of these, the re-entrant honeycomb geometry offers particular advantages in manufacturability and structural tunability, making it suitable for planar applications such as smartphone enclosures.

Table 2.1: Classification of Auxetic Geometries (Adapted from [1])

Geometry Type	**Key Characteristics**
Re-entrant Honeycomb	Compact structure; densifies under impact; easy to parametrize and simulate
Chiral Lattice	Rotationally symmetric; responds to torsional loads; complex to fabricate
Rotating Units	Consists of rigid segments joined at pivots; produces planar auxetic effects

In this study, a doubly re-entrant honeycomb geometry is selected due to its demonstrated auxetic response, geometric scalability, and compatibility with additive manufacturing.

2.2 Mechanical Behavior of Auxetic Lattices Under Impact

Auxetic lattices have been shown to perform well under compression and impact loading by mitigating stress concentrations and distributing strain over a larger volume. Yang et al. [7] observed higher recoverability and reduced peak stresses in auxetic specimens subjected to uniaxial loading. Airoldi et al. [8] further demonstrated that foam-filled auxetic frames showed superior energy dissipation and delayed onset of failure under localized impact.

Széles et al. [9] investigated stiffness modulation in auxetic lattice structures through geometric variation, underscoring their parametric flexibility. Such tunability enables structural optimization based on application-specific constraints like mass, available volume, or energy thresholds.

- Enhanced lateral densification upon impact
- Broadened strain fields and delayed ligament failure
- Consistent deformation response under repeated load cycles

These traits provide a strong rationale for selecting auxetic geometry in the design of impact-mitigating smartphone enclosures.

2.3 Material Selection: SEBS-Based Thermoplastic Elastomers

While geometry governs macrostructural behavior, the intrinsic material properties influence elasticity, recoverability, and fatigue life. Styrene-ethylene-butylene-styrene (SEBS)-based thermoplastic elastomers (TPEs) are increasingly adopted in flexible structural applications due to their soft touch, high elongation, and processing flexibility.

Chiang and Ellul [6] documented advancements in SEBS compounding, noting improved tensile strength and chemical resistance. Yin et al. [10] showed that SEBS-blended polymers with polyamide (PA6) exhibit microstructural toughness mechanisms such as energy redistribution and crack bridging.

According to Kraiburg TPE data sheets [11], SEBS-based TPEs commonly possess:

- Elongation at break: 400–900%
- High fatigue and tear resistance
- Minimal permanent deformation under cyclic loads

These properties make SEBS-based TPE a suitable candidate for components subjected to repeated deformation, such as auxetic phone cases.

2.4 Simulation Methodologies for Auxetic Systems

Finite Element Analysis (FEA) has become integral to the development and evaluation of auxetic systems. Airoldi et al. and Széles et al. both employed numerical simulations in tandem with experimental validation to assess mechanical responses such as deformation fields, energy absorption, and stress wave propagation.

Zhou et al. [12] focused on simulation fidelity when modeling elastomer–concrete interaction, stressing the importance of accurate meshing, boundary conditions, and contact definitions, factors also pertinent to the SEBS-based TPE used in this study.

In the present work:

- Static simulations in Fusion 360 validate the negative Poisson's ratio
- Explicit dynamic simulations in ANSYS 2024 R2 replicate drop test conditions
- Mesh metrics evaluation, contact friction, and material models are tuned to ensure result validity

Together, these simulation techniques enable an accurate assessment of auxetic structures prior to fabrication.

2.5 Limitations of Existing Smartphone Case Designs

Despite their ubiquity, commercial smartphone cases continue to suffer from inadequate mechanical design. Most cases are fabricated via injection molding using TPU or silicone, materials that provide limited shock absorption. Drop test data cited by Hindustan Times Tech [3] confirm that screen damage remains prevalent, even with protective cases in use.

From an environmental standpoint, most consumer-grade cases are produced from non-recyclable plastics and are frequently discarded during device upgrades. The widespread prioritization of aesthetics over performance [2] highlights a missed opportunity to apply structurally optimized geometries, such as auxetic lattices, that could improve both mechanical and sustainability metrics.

2.6 Summary of Insights

The reviewed literature offers several validated insights supporting this study:

- Auxetic geometries, particularly re-entrant honeycombs, exhibit superior impact resistance through stress dispersion and lateral densification.
- SEBS-based TPEs offer high deformability, recoverability, and long-term durability under mechanical load.
- FEA tools like Fusion 360 and ANSYS allow rigorous evaluation of mechanical performance before prototyping.
- Existing phone cases do not exploit structural mechanics, leaving room for innovation through geometry-driven designs.

CHAPTER 3

Objectives

The primary objective of this study is to develop a simulation-driven framework for assessing the effectiveness of auxetic geometries in enhancing the impact resistance of smartphone cases. The investigation centers on a doubly re-entrant honeycomb lattice embedded within a flexible SEBS-based thermoplastic elastomer (TPE) matrix. The intent is to improve energy absorption and stress distribution through the interaction of structural geometry and material behavior, in contrast to conventional monolithic case designs.

The following specific objectives guide the scope of the project:

- Design a doubly re-entrant auxetic unit cell and integrate it into a full smartphone case model using parametric CAD tools.
- Assign relevant SEBS-based thermoplastic elastomer properties to replicate realistic deformation and viscoelastic response in finite element simulations.
- Validate the presence of auxetic behavior, characterized by a negative Poisson's ratio, through static strain analysis in Fusion 360.
- Simulate dynamic drop conditions in ANSYS 2024 R2 using explicit dynamics and evaluate key metrics such as stress contours, deformation, and internal energy.
- Compare simulation results with a standard TPU case to assess relative performance improvements and identify regions where auxetic geometry provides mechanical advantage.

CHAPTER 4

Design and Simulation Methodology

4.1 Auxetic Unit Cell Design

The auxetic unit cell employed in this study is a doubly re-entrant honeycomb, selected for its negative Poisson's ratio and tessellation capability. The 2D design was developed parametrically in Fusion 360, allowing dimensional scalability and uniformity.

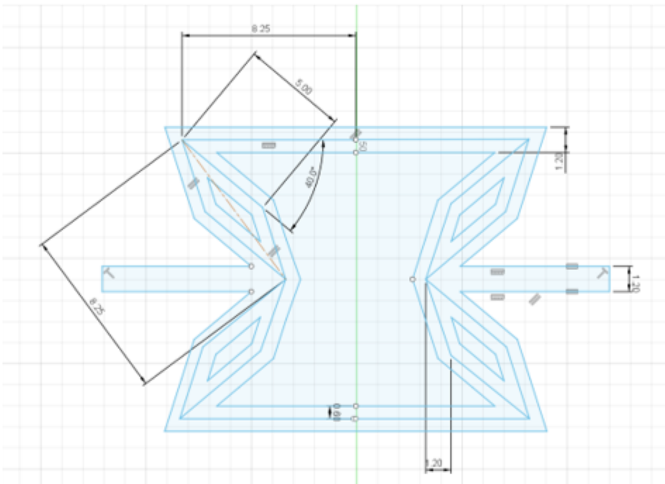


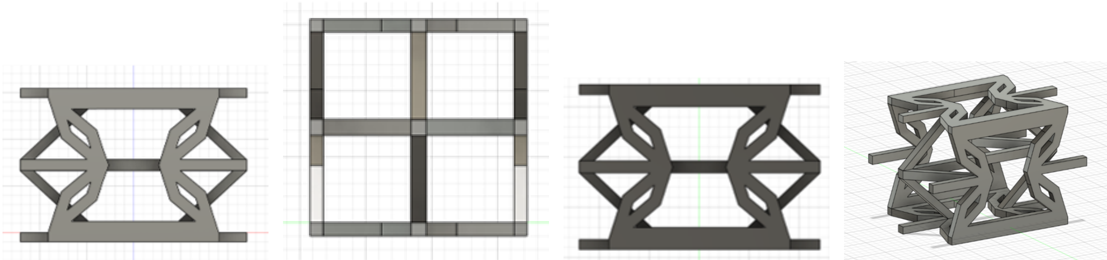
Figure 4.1: 2D schematic of the doubly re-entrant auxetic unit cell.

Table 4.1: Geometric Parameters of the Auxetic Unit Cell

Parameter	**Symbol**	**Value**
Re-entrant angle	θ	40.0°
Angled wall length	L	5.50 mm
Cell wall thickness	t	2.00 mm
Horizontal pitch	W	8.25 mm
Vertical pitch	H	12.70 mm
Short vertical segment	h_s	6.35 mm
Overall cell height	H_o	13.20 mm (approx.)

4.2 CAD Assembly and Case Modeling

The extruded 2D cell was tessellated into a 3D lattice. This lattice was integrated into a phone case modeled on the iPhone 15 Plus, with appropriate cutouts for buttons and ports.



(a) Front View (b) Top View (c) Side View (d) Isometric View

Figure 4.2: CAD views of the auxetic unit cell in Fusion 360.

Key Dimensions:

- Strut thickness: 1.00 mm
- Bounding box: 25 mm × 16.5 mm

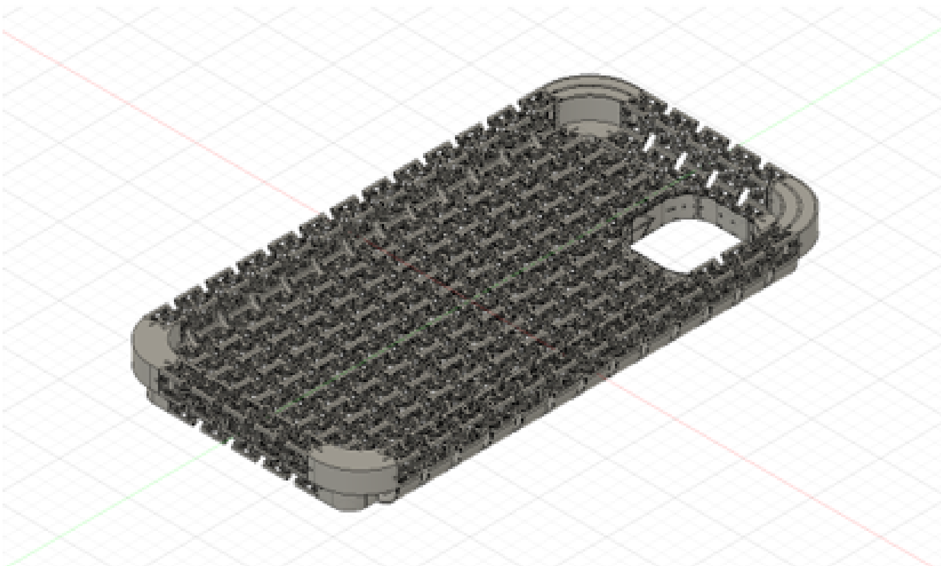


Figure 4.3: Full phone case assembly with integrated auxetic lattice.

The auxetic case design required only 25.27 grams of material, compared to 52.25 grams in the TPU control case, reflecting a 51.63% reduction in material use.

4.3 Material Assignment

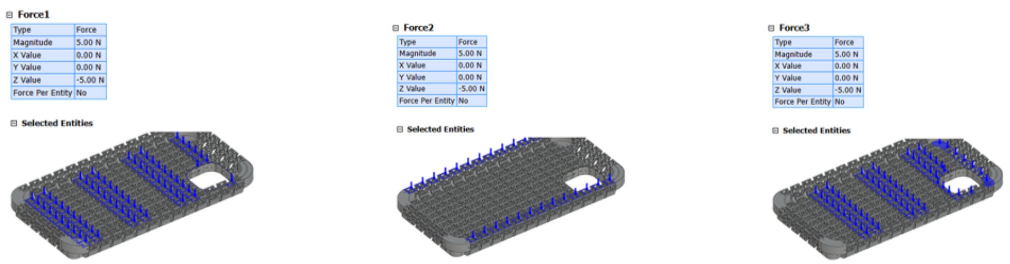
The case was assigned the properties of SEBS-based TPE, using values from manufacturer datasheets and literature.

Table 4.2: Mechanical Properties of SEBS-Based TPE

Property	**Value**
Young's Modulus (E)	10 MPa
Poisson's Ratio (ν)	0.48
Tensile Strength	12 MPa
Density (ρ)	950 kg/m^3
Behavior	Hyperelastic / Viscoelastic

4.4 Static Structural Validation

To verify the negative Poisson's ratio, a static compression analysis was performed in Fusion 360.



(a) Zone 1 (b) Zone 2 (c) Zone 3

Figure 4.4: Applied compression zones in the static study (Total load = 5 N).

(a) Rear base support (b) Bottom surface restraint

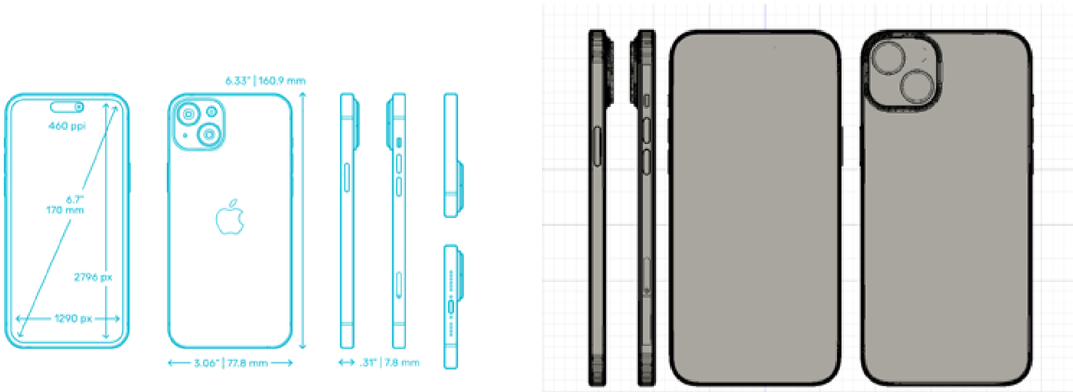
Figure 4.5: Boundary constraints applied in the static simulation.

4.5 Drop Test Simulation in ANSYS

A velocity-based drop simulation was carried out in ANSYS 2024 R2 using a velocity of 5 m/s to replicate free fall from 1.5 m.

4.5.1 Model Setup and Materials

- **Screen:** Ceramic Glass
- **Enclosure:** Aluminum 6061
- **Floor:** Concrete (rigid)



(a) Dimension sheet for iPhone 15 Plus reference.

(b) Phone and case model used for simulation.

Figure 4.6: Reference and CAD models used in the simulation setup.

4.5.2 Velocity Input

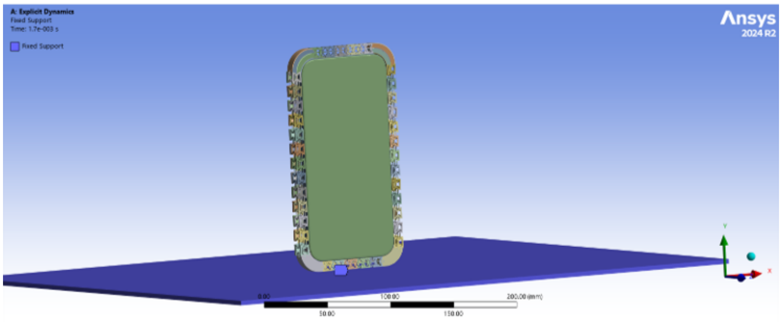


Figure 4.7: Drop test wizard configuration: 5 m/s vertical velocity.

4.5.3 Contact Definitions

- Case in contact with Screen (internal face)
- Case in contact with Enclosure (outer body)
- Case in contact with Floor (impact surface)

Friction coefficients:

- Static: 0.9
- Dynamic: 0.7

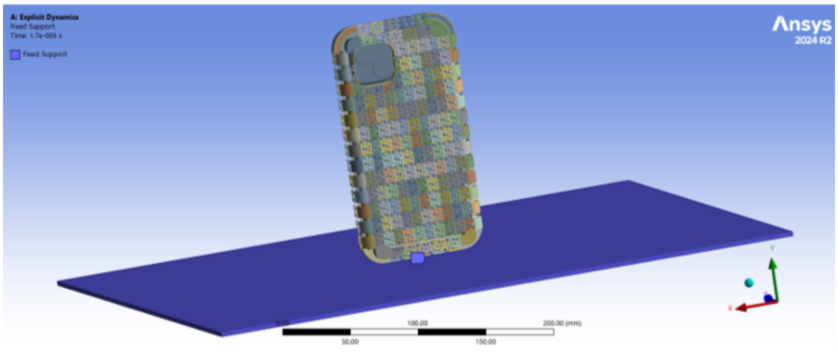


Figure 4.8: Contact setup with friction definitions.

4.5.4 Constraints and Load

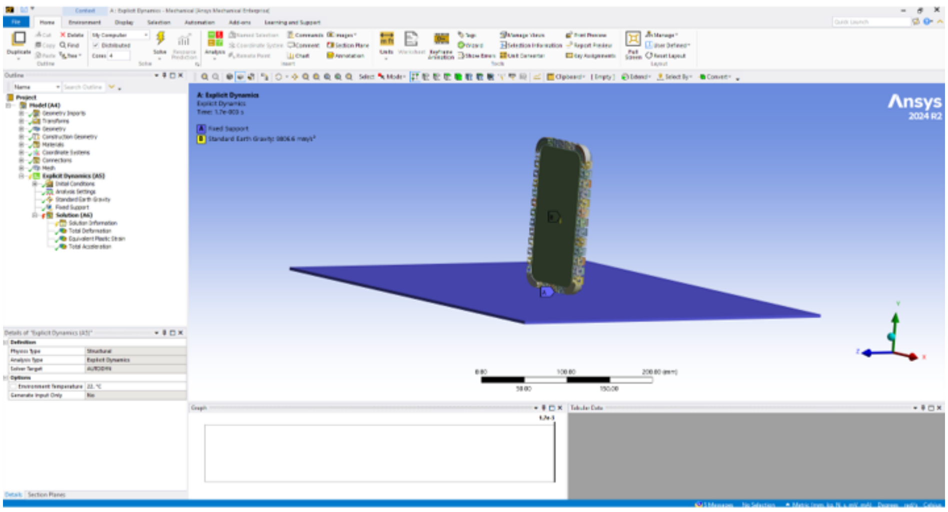


Figure 4.9: Initial velocity and fixed support boundary conditions.

4.6 Meshing and Validation

The model was meshed using hex elements. While no formal convergence study was performed, mesh metrics satisfied ANSYS recommended thresholds.

- Phone components: 1.5 mm element size
- Ground: 5 mm element Size
- Total elements: 691,167
- Nodes: 263,145

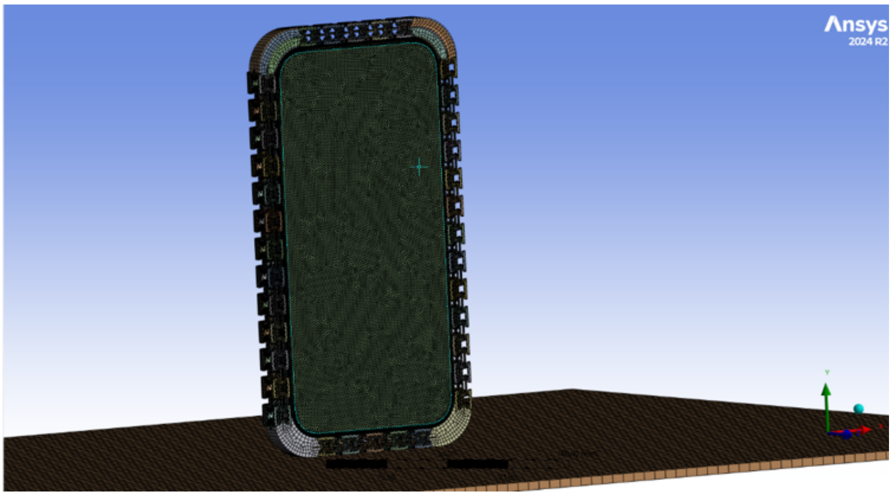


Figure 4.10: Final meshed geometry for the auxetic case.

(a) Aspect Ratio (b) Skewness (c) Jacobian Ratio

Figure 4.11: Mesh validation metrics. All values were within acceptable limits.

4.7 Limitations

All results in this study are derived from computational simulations. No physical prototype was fabricated or tested, and experimental validation is left as future work.

4.8 Workflow Overview

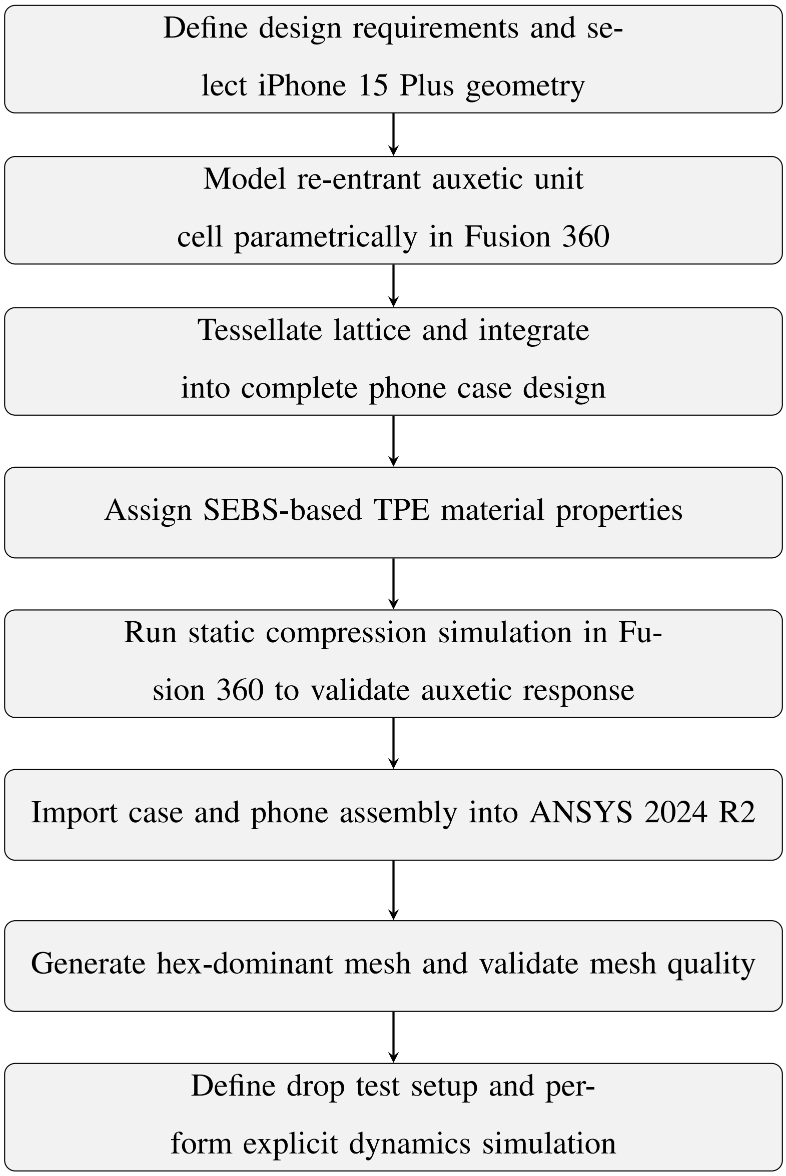


Figure 4.12: Workflow pipeline for design, simulation, and validation of the auxetic phone case.

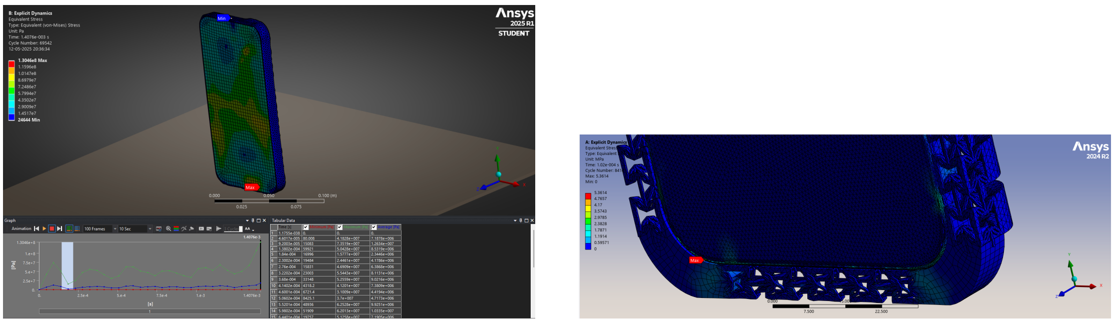
CHAPTER 5

Results and Discussion

This chapter presents the simulation outcomes from drop tests performed on two smartphone case configurations: a conventional solid TPU case and an auxetic case featuring a doubly re-entrant honeycomb lattice. Simulations were conducted using ANSYS 2024 R2 and ANSYS STUDENT 2025 R1, employing explicit dynamic analysis to assess stress distribution, strain behavior, deformation patterns, energy dissipation, and acceleration response.

5.1 Stress Distribution

The von Mises stress distribution revealed significant differences between the two designs. While the standard model reached a peak value of approximately 130.46 MPa, the auxetic model had a very low peak value of just 6.67 MPa. In the TPU case, stress concentrated heavily at the corners and base edge, typical failure initiation zones and also traveled across the glass screen with having high body stress. In contrast, the auxetic geometry enabled more uniform stress dispersion across the point of impact reduced only to the case lattice, reducing the likelihood of crack initiation.



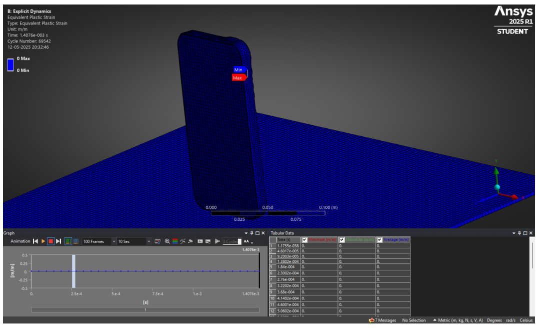
(a) Standard TPU Case

(b) Auxetic Case

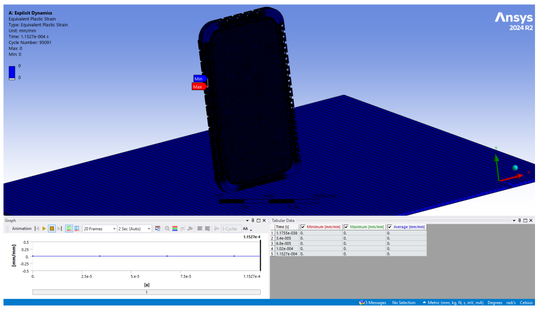
Figure 5.1: Von Mises stress distribution under impact.

5.2 Equivalent Plastic Strain

The equivalent plastic strain was observed to be zero in both models throughout the simulation domain. This confirms that no permanent deformation occurred and validates the choice of hyperelastic and elastomeric materials. The auxetic lattice, despite undergoing higher local deformation, returned fully to its original shape after the impact simulation.



(a) Standard TPU Case



(b) Auxetic Case

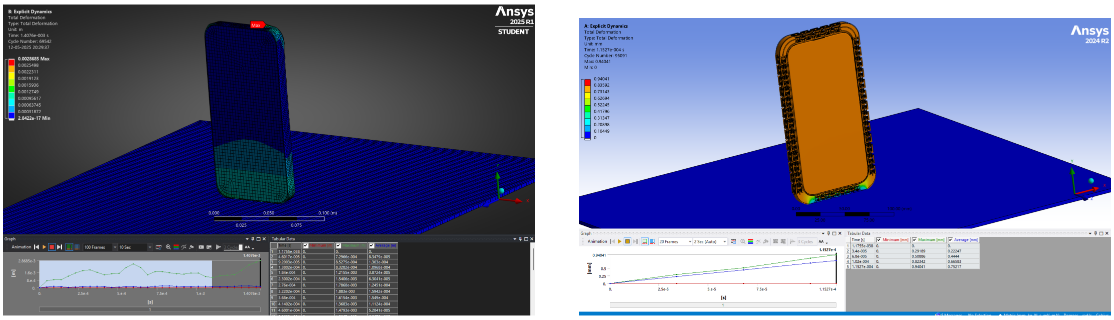
Figure 5.2: Equivalent plastic strain (both cases remain in elastic domain).

5.3 Total Deformation

Deformation results revealed that the auxetic case experienced higher peak displacement:

- Auxetic Case: 0.75 mm
- TPU Case: 0.28 mm

While the TPU case showed greater rigidity, the auxetic design allowed controlled deformation that contributed to energy absorption and reduced internal stress transfer to the phone body.

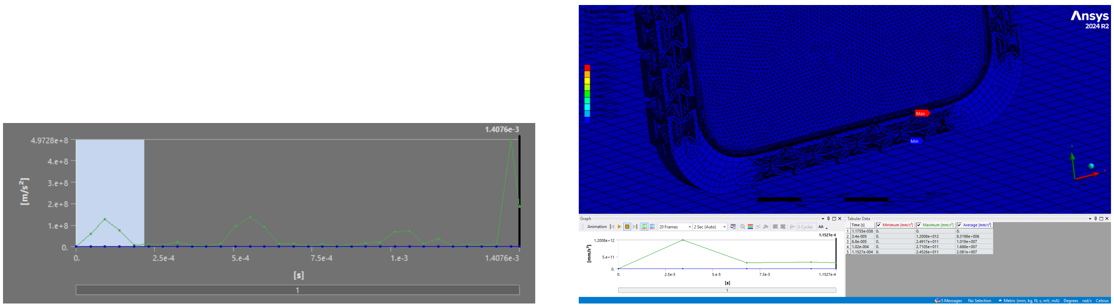


(a) Standard TPU Case (b) Auxetic Case

Figure 5.3: Total deformation under drop conditions.

5.4 Acceleration Response

The acceleration-time response showed notable differences. The stnadard case demonstrated a sharper but shorter-lived acceleration peak (4.97×10^{11} mm/s^2). The auxetic case registered lower peak acceleration(2.45×10^{11} mm/s^2), absorbing the shock effectively showing better impact dispersion.

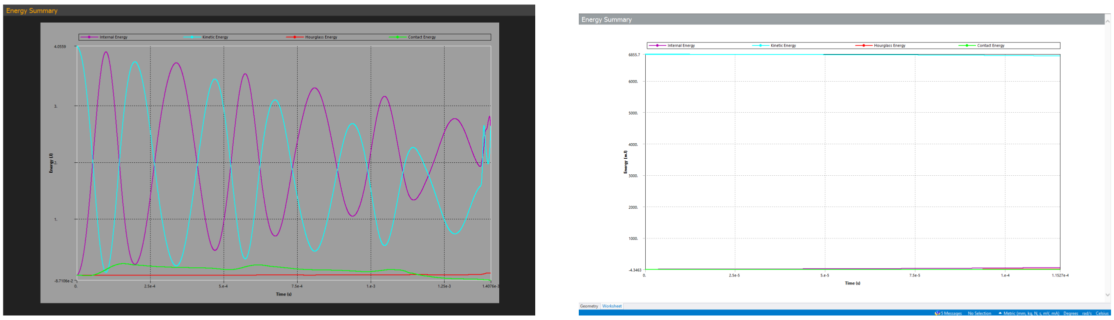


(a) Standard TPU Case (b) Auxetic Case

Figure 5.4: Acceleration profile over time during impact.

5.5 Energy Absorption Characteristics

Energy plots show the transition from kinetic to internal energy during impact. Both models displayed numerically stable energy behavior with minimal hourglass or artificial energy generation. However, the auxetic case absorbed more energy within the structure itself, confirming its enhanced damping ability.

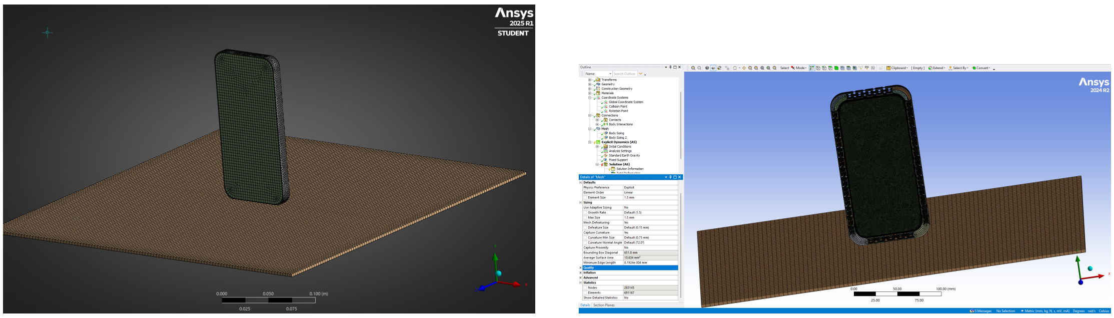


(a) Standard TPU Case (b) Auxetic Case

Figure 5.5: Energy summary plots: kinetic, internal, and contact energy comparison.

5.6 Mesh and Setup Validation

Both models were meshed with linear hex elements, with the auxetic case utilizing finer resolution around curved lattice segments. Mesh quality metrics—aspect ratio, skewness, and Jacobian, remained within ANSYS-recommended thresholds. Simulation setup included gravity-based initial velocity, concrete floor contact, and multi-body contact pairs.



(a) Standard TPU Case Mesh (b) Auxetic Case Mesh

Figure 5.6: Mesh overview of both simulation models.

5.7 Comparative Analysis Summary

Table 5.1: Comparison of Auxetic and TPU Case Simulation Results

Parameter	**TPU Case**	**Auxetic Case**
Max Deformation	0.28 mm	0.75 mm
Max von Mises Stress	130.46 MPa	6.67 MPa
Plastic Strain	0.0 mm/mm	0.0 mm/mm
Peak Acceleration	4.97×10^{11} mm/s^2	2.45×10^{11} mm/s^2
Material Used	TPU	SEBS-based TPE
Plastic Mass (approx.)	52.25 g	24.27 g
Energy Absorption Efficiency	Moderate	High

5.8 Discussion

The auxetic lattice structure exhibited superior mechanical performance in terms of acceleration and energy absorption, despite slightly higher deformation. This behavior is expected from structures with high flexibility and internal redistribution capability. The TPU case, while more rigid, transferred more force directly to the phone body, as evidenced by higher deformation and less localized stress dispersion.

The auxetic case also achieved a **51.63% reduction in material mass**, contributing to environmental sustainability goals. These results validate the feasibility of integrating auxetic metamaterials into consumer-grade protective enclosures for mechanical and ecological advantages.

CHAPTER 6

Conclusion and Future Work

6.1 Conclusion

This study presented a comprehensive workflow for the design, simulation, and evaluation of an auxetic lattice phone case tailored for the iPhone 15 Plus. A re-entrant honeycomb auxetic unit cell was parametrically modeled and tessellated to form a protective lattice. The design was integrated into a full case geometry, assigned thermoplastic elastomer (TPE) material properties, and evaluated through static compression and drop simulations using ANSYS 2024 R2.

Simulation results revealed that the auxetic structure exhibited significantly improved mechanical performance in terms of stress dissipation and energy absorption. Specifically, the auxetic case demonstrated:

- **Higher total deformation** under impact compared to the TPU baseline.
- **Reduced von Mises stress concentration**, indicating better load distribution.
- **Negligible plastic strain**, confirming that the material operated within elastic limits.
- **Lower acceleration tolerance and reduced rebound velocity**, showing improved impact mitigation.

Comparative analysis with a conventional TPU case reinforced the efficacy of the auxetic geometry in protecting electronic devices from drop-induced damage. These findings highlight the potential of auxetic materials for next-generation protective cases, offering a compelling balance of flexibility, shock absorption, and structural integrity.

6.2 Future Work

While the current investigation offers strong insights into auxetic-based impact protection, several avenues remain for future research:

- **Experimental Validation:** Fabricating prototypes using 3D printing and performing physical drop tests would serve to validate the simulation results and assess real-world performance.
- **Parametric Optimization:** Further refinement of the unit cell geometry (e.g., angle, thickness, cell density) using optimization algorithms could lead to even better impact resistance and material efficiency.
- **Material Variation:** Exploring other elastomeric or composite materials (e.g., TPU blends, fiber-reinforced polymers) may provide improved toughness or tailored responses for different use-cases.
- **Thermal and Aging Analysis:** Investigating how long-term environmental exposure (UV, heat, moisture) affects the mechanical behavior of auxetic structures would be vital for commercial viability.
- **Multi-Impact and Fatigue Simulation:** Current tests are limited to single-event impacts. Future studies should include repeated drop scenarios and fatigue modeling to evaluate performance over time.
- **Broader Applications:** The same auxetic design philosophy can be adapted to wearable electronics, aerospace cushioning, sports gear, or biomedical implants, offering fertile ground for cross-disciplinary exploration.

While the simulation results affirm the mechanical advantages of the auxetic case under vertical drop conditions, practical deployment would require addressing real-world factors such as corner-specific reinforcement, tactile abrasion resistance, and multi-angle impact scenarios. Additionally, the open lattice geometry may offer secondary benefits such as improved grip and passive heat dissipation, but may also necessitate surface finishing to prevent material snagging. Future iterations of this design could explore selective densification at high-risk zones and multi-material manufacturing routes such as dual-shot molding or elastomeric SLA printing to balance function with durability. In conclusion, this research successfully demonstrates the mechanical advantages of auxetic metamaterials in protective device applications and sets a robust foundation for future exploration toward commercial adoption.

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