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Optimization, Design and Analysis of Battery Bracket for Electric Vehicle

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Abstract- ***The increasing demand for lightweight and efficient components in Electric Vehicles (EVs) necessitates the optimization of structural elements such as battery brackets, which play a vital role in supporting and protecting battery packs under dynamic operating conditions. This study presents the design, analysis, and optimization of an EV battery bracket using advanced computational techniques. A detailed three-dimensional model is developed using CAD software and analyzed through Finite Element Analysis (FEA) to evaluate stress distribution, deformation characteristics, natural frequencies, and overall structural performance. Optimization strategies, including geometric refinement and material considerations, are implemented to achieve weight reduction while maintaining required strength, stiffness, and vibration resistance. The results demonstrate that the optimized design provides improved structural efficiency without compromising safety and reliability. The proposed approach contributes to enhanced vehicle performance, increased energy efficiency, and supports the development of cost-effective and manufacturable solutions for modern electric mobility systems.***

I.INTRODUCTION

The global shift toward sustainable transportation has significantly accelerated the development and adoption of electric vehicles (EVs). As governments and industries aim to reduce greenhouse gas emissions and dependence on fossil fuels, EVs have emerged as a viable solution for clean mobility. One of the most critical subsystems in an electric vehicle is the battery pack, which not only governs the vehicle's driving range but also contributes substantially to its overall weight and structural configuration. Ensuring the safe and efficient integration of the battery pack within the vehicle chassis is therefore of paramount importance, and this function is largely facilitated by the battery bracket or support structure.

Battery brackets are designed to securely hold the battery pack in place while withstanding various mechanical loads such as acceleration, braking, cornering forces, and road-induced vibrations. Additionally, these structures must endure thermal effects generated during battery operation and environmental variations. Conventional battery bracket designs often rely on metallic materials such as aluminium and steel due to their high strength and durability. However, these designs are frequently over-engineered, resulting in increased weight, which directly affects vehicle efficiency and energy consumption. With the growing demand for extended driving range and improved performance, there is a pressing need to develop lightweight yet structurally robust battery support systems.

Recent advancements in computational modeling and simulation techniques, particularly Finite Element Analysis (FEA), have enabled engineers to predict structural behavior with high accuracy and optimize designs before physical prototyping. Furthermore, topology optimization has emerged as a powerful tool for material distribution, allowing designers to remove non-critical material while maintaining structural integrity. Alongside these developments, additive manufacturing technologies such as Fused Deposition Modeling (FDM) have opened new possibilities for producing complex geometries with reduced material wastage and shorter development cycles. The use of polymer materials like Acrylonitrile Butadiene Styrene (ABS) in prototyping further enhances the feasibility of rapid and cost-effective design iterations. Despite these advancements, challenges remain in achieving an optimal balance between weight reduction, strength, vibration resistance, and manufacturability. Therefore, it is essential to evaluate both metallic and polymer-based designs through a combination of numerical simulation and experimental validation to ensure reliable performance.

In this context, the present study focuses on the design, analysis, and optimization of a battery bracket for electric vehicle applications. An initial aluminium model is analyzed to establish baseline structural performance through modal and static analyses. Subsequently, topology optimization is applied to obtain a lightweight design, which is then evaluated using ABS material to explore additive manufacturing feasibility. A scaled prototype is fabricated using 3D printing, and experimental validation is carried out using a Universal Testing Machine (UTM). The results are compared with simulation data to assess the accuracy of the proposed methodology. This integrated approach aims to develop an efficient, lightweight, and structurally reliable battery bracket, contributing to improved performance and sustainability in electric vehicles.

I.LITERATURE REVIEW

1. Zhang et al. (2024)

Zhang et al. developed an optimization-based design approach for EV battery brackets using 3D printing technology. The study integrates parametric modeling with finite element analysis to identify stress concentrations and improve load distribution. Topology optimization is used to eliminate excess material, resulting in a lightweight lattice-supported structure. The bracket is fabricated using Selective Laser Melting (SLM), enabling complex geometries and improved stiffness-to-weight ratio. The results show significant weight reduction and enhanced vibration performance, demonstrating the effectiveness of additive manufacturing in EV component design.

2. Ma (2022)

Ma investigated the parallel optimization of carbon fiber battery pack structures by integrating design and manufacturing considerations. A multi-scale finite element approach is used to evaluate stress distribution at the ply level. The study applies a hybrid genetic algorithm to optimize laminate stacking and geometric parameters simultaneously. Results indicate that carbon fiber composites can significantly reduce weight while maintaining high structural strength. The work highlights the importance of considering anisotropy and manufacturability in composite battery enclosure design.

3. Ruan et al. (2021)

Ruan et al. conducted simulation and optimization of EV battery pack structures using advanced finite element techniques. The study considers multiple loading conditions, including mechanical, thermal, and vibrational effects. Structural optimization is performed by modifying geometry and reinforcing critical regions. The results demonstrate improved stiffness and reduced stress concentrations with optimized designs. The authors conclude that integrated simulation-based optimization enhances both performance and reliability of battery structures.

4. Zhouji & Zulkepli (2024)

Zhouji and Zulkepli analyzed vibration characteristics and optimized the structural design of EV battery brackets. Modal and harmonic analyses were performed to evaluate dynamic response under operational conditions. The study shows that optimized stiffener placement significantly reduces vibration amplitudes. Topology optimization is used to remove unnecessary material while maintaining structural integrity. The results highlight the importance of vibration control in improving battery bracket durability and safety.

5. Sun et al. (2022)

Sun et al. examined the challenges associated with laser welding of 6xxx series aluminum extrusions used in EV battery trays. The study identifies defects such as porosity and cracking that affect joint strength. Process parameters including heat input and welding speed are optimized to improve weld quality. Thermal modeling is used to analyze residual stresses and distortion. The findings emphasize the need for advanced welding techniques to ensure structural integrity in lightweight battery enclosures.

6. Yang et al. (2020)

Yang et al. performed static and dynamic analysis of an EV battery box using finite element modeling. The study evaluates deformation and stress under various loading conditions. Modal analysis is conducted to identify potential resonance issues. The authors propose design improvements such as rib reinforcement and thickness variation. The optimized structure shows enhanced stiffness and durability, making it suitable for real-world applications.

7. Pal (2021)

Pal proposed an intelligent optimization framework for EV battery enclosures using machine learning techniques. The study integrates AI with structural and thermal simulations for efficient design optimization. Multi-objective optimization is performed considering weight, strength, and thermal performance. The results show improved design efficiency and reduced computational time. The research demonstrates the potential of AI-driven approaches in modern engineering design.

8. Sasane & Kharad (2024)

Sasane and Kharad designed and analyzed a battery bracket using CAD and finite element analysis. The study evaluates stress and deformation under static loading conditions. Optimization is performed to reduce material usage while maintaining structural safety. Modal analysis is also conducted to assess vibration behavior. The results confirm that optimized geometry improves performance and reduces weight.

9. Gao et al. (2024)

Gao et al. studied the thermal–mechanical behavior of aluminum battery housings in electric vehicles. The research focuses on the effect of temperature variations on structural performance. Coupled simulations reveal that thermal expansion significantly influences stress distribution. The study suggests design improvements such as enhanced cooling and structural reinforcement. The findings highlight the importance of considering thermal effects in battery housing design.

10. Berger (2023)

Berger investigated the use of composite materials for lightweight and safe battery housings. The study evaluates mechanical and thermal performance of fiber-reinforced polymers. Results show that composites provide excellent weight reduction and vibration damping. Various manufacturing methods and failure modes are analyzed. The study concludes that composite materials are a promising alternative for future EV battery structures.

Novelty of work: This study presents an integrated approach combining design, FEA, topology optimization, and experimental validation for an EV battery bracket. A key novelty is the comparison between aluminium and optimized ABS models, highlighting performance and weight trade-offs. The use of topology optimization with 3D printing (FDM) enables the development of a lightweight and manufacturable design. Additionally, the work includes experimental validation using UTM, ensuring reliability of the simulation results. This approach provides a cost-effective and practical solution for optimized EV structural components.

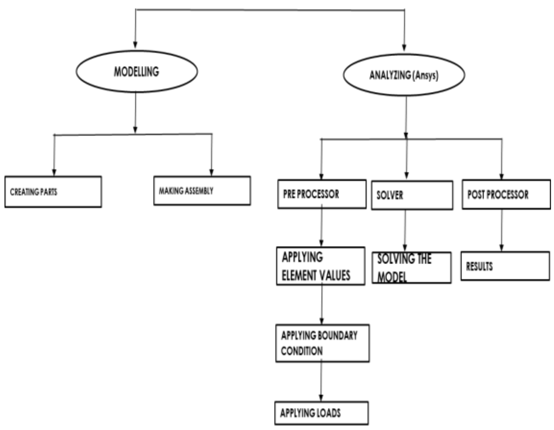
II.PROBLEM STATEMENT

- Conventional bracket designs are often overweight, material-inefficient, and lack optimized structural integrity, leading to reduced vehicle efficiency and potential safety concerns.
- Therefore, there is a need to design, analyze, and optimize a lightweight yet durable battery bracket that ensures structural reliability, improved vibration resistance, and enhanced overall performance of the electric vehicle.

III.OBJECTIVES

- To design and develop an EV Battery mounting Bracket that ensures the safety and protection of the battery pack.
- To design and create a CAD model of an EV battery bracket.
- To analyze the battery bracket using simulation tools like ANSYS and validate the results.
- To compare the results from finite element analysis (FEA) with experimental data for the battery bracket.

IV.RESEARCH METHODOLOGY



V.FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a numerical method used to analyze the structural behavior of components by dividing a complex geometry into smaller, simpler elements. These elements are connected at discrete points called nodes, forming a mesh that approximates the actual structure. The governing equations of mechanics, based on principles such as equilibrium, compatibility, and constitutive relations, are applied to each element to predict the response under external loads.

In static structural analysis, FEA determines parameters such as total deformation, equivalent (von Mises) stress, and strain, which are used to assess the strength and safety of the component. In modal analysis, the method solves an eigenvalue problem to determine the natural frequencies and mode shapes of the structure, which are critical for understanding vibration behavior and avoiding resonance.

FEA allows engineers to evaluate multiple design iterations efficiently, identify critical regions of stress concentration, and optimize material distribution. It is widely used in automotive applications, including battery bracket design, to ensure structural integrity, reduce weight, and improve overall performance before physical prototyping.

FEA of EV battery Bracket:

Geometry:

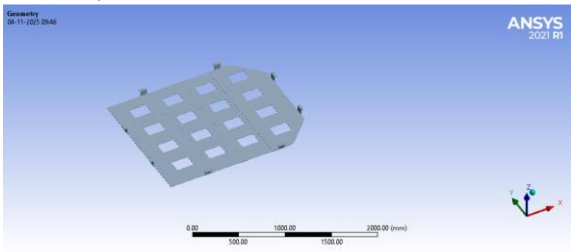


Fig. Geometry of EV Battery Bracket.

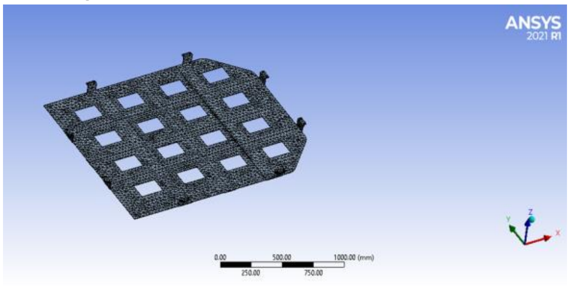
Material Properties:

Properties of Outline Row 3: Aluminum Alloy

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	2770	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	2.3E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modulu...	
8	Young's Modulus	7.1E+10	Pa
9	Poisson's Ratio	0.33	
10	Bulk Modulus	6.9608E+10	Pa
11	Shear Modulus	2.6692E+10	Pa

Fig. Material Properties of Aluminium Alloy.

Meshing:



Statistics	
Nodes	44807
Elements	21587

Fig. Meshing details of EV Battery Bracket.

Modal Analysis of EV Battery Bracket:

Boundary Conditions:

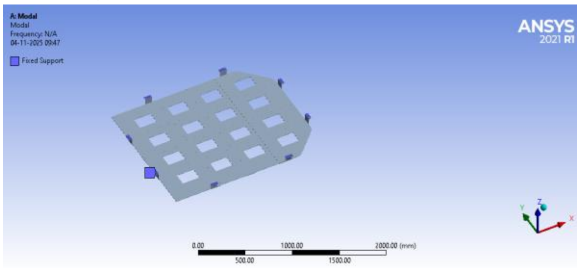


Fig. Boundary conditions for EV Battery Bracket.

Results:

Mode Shape 1

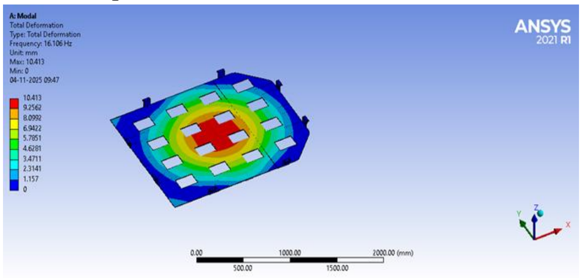


Fig. Frequency for Mode Shape 1.

Mode Shape 2

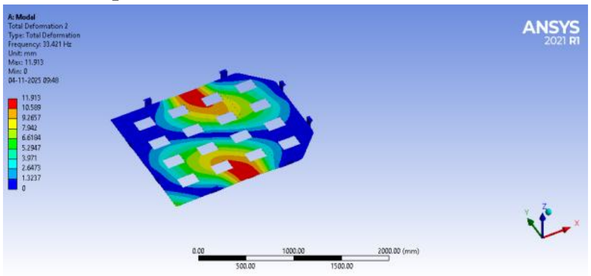


Fig. Frequency for Mode Shape 2.

Mode Shape 3

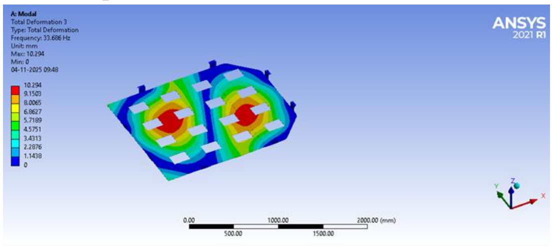


Fig. Frequency for Mode Shape 3.

Mode Shape 4

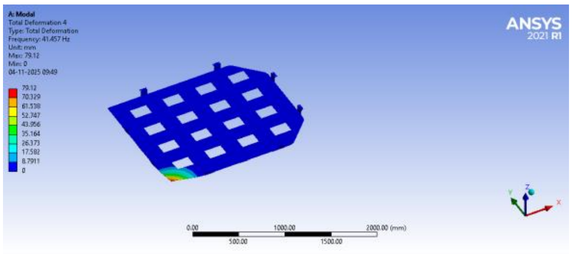


Fig. Frequency for Mode Shape 4.

Mode Shape 5

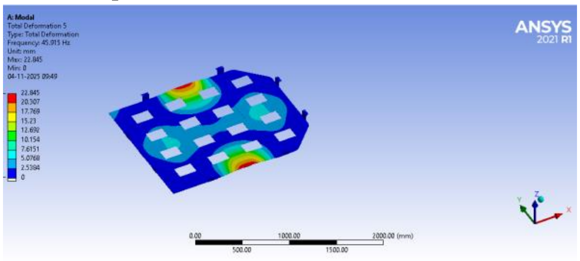


Fig. Frequency for Mode Shape 5.

Mode Shape 6

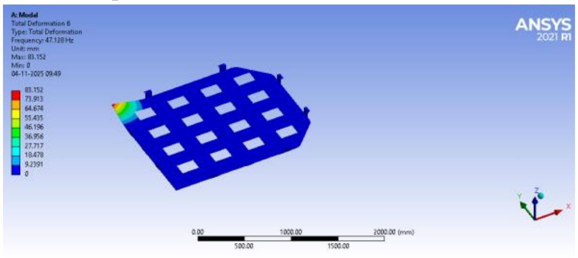


Fig. Frequency for Mode Shape 6.

Results Table:

Tabular Data

	Mode	Frequency [Hz]
1	1.	16.106
2	2.	33.421
3	3.	33.686
4	4.	41.457
5	5.	45.915
6	6.	47.128

Fig. Mode no. and frequencies.

Static Structural Analysis:

Boundary Conditions:

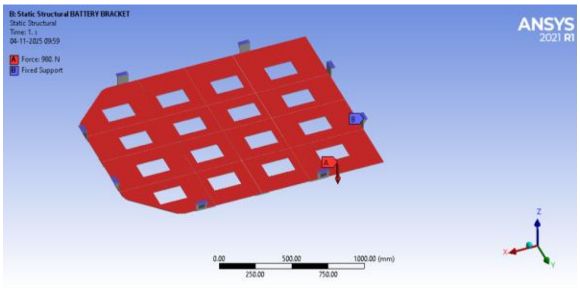


Fig. Boundary conditions for EV battery bracket.

Results:

Total Deformation:

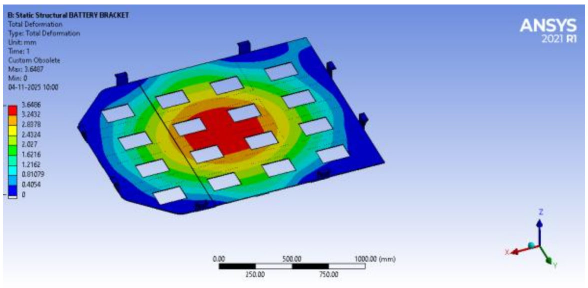


Fig. Total deformation of EV battery bracket.

Equivalent Stress:

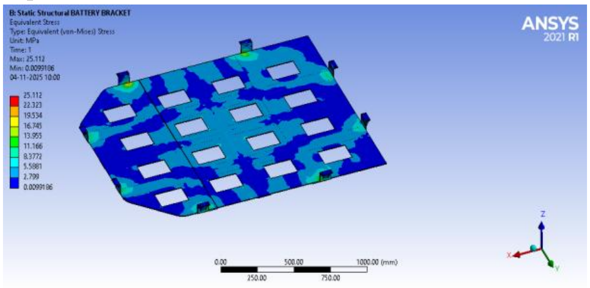


Fig. Equivalent stress of EV battery bracket.

Equivalent Elastic Strain:

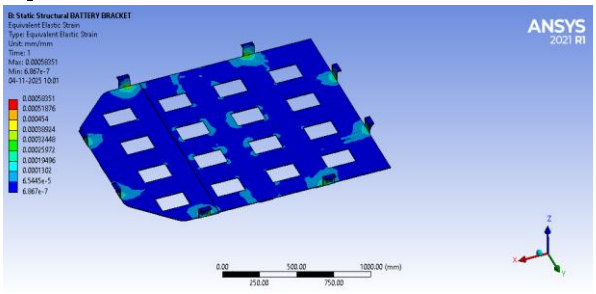


Fig. Equivalent Elastic Strain of EV battery bracket.

Topology Optimization:

Boundary condition

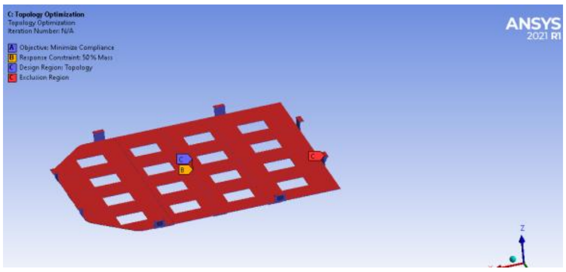
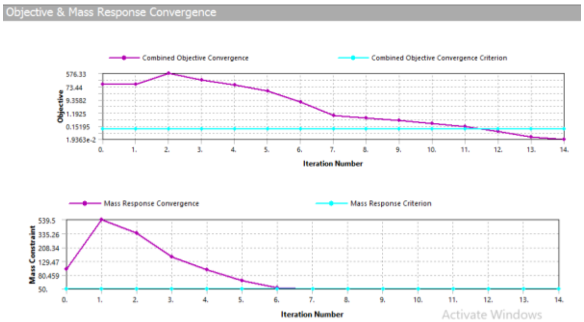


Figure. boundary conditions for topological optimization of battery bracket



Results

Topology Density

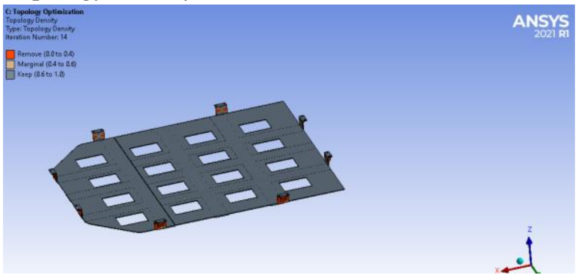


Fig. Topology density of battery bracket.

Modal analysis of Optimized battery bracket ABS

Material properties

Properties of Outline Row 3: ABS

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	1020	kg m^-3
4	Isotropic Elasticity		
5	Derive from	Young's Modulus...	
6	Young's Modulus	2.3	GPa
7	Poisson's Ratio	0.364	
8	Bulk Modulus	2.8186E+09	Pa
9	Shear Modulus	8.4311E+08	Pa
10	Bilinear Isotropic Hardening		
11	Yield Strength	45	MPa
12	Tangent Modulus	2	GPa

Fig. Material Properties of ABS.

Geometry

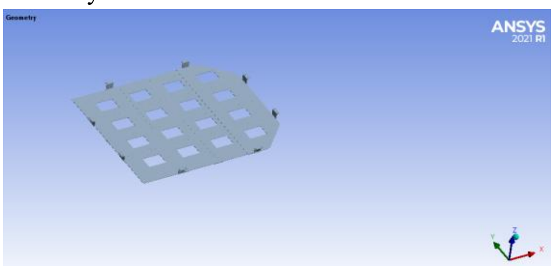
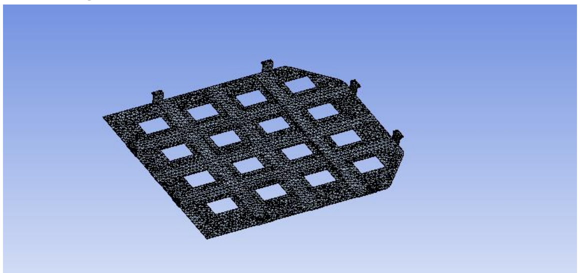


Fig. Geometry of New Optimized ABS Battery Bracket.

Meshing



Statistics	
Nodes	44807
Elements	21587

Fig. Final battery bracket mesh model, it contains 44807 nodes and 21587 elements

Boundary conditions

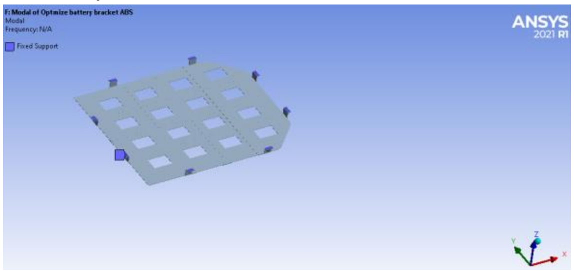


Fig. Boundary conditions for Modal Analysis of Optimized Battery Bracket ABS.

Mode shape 01

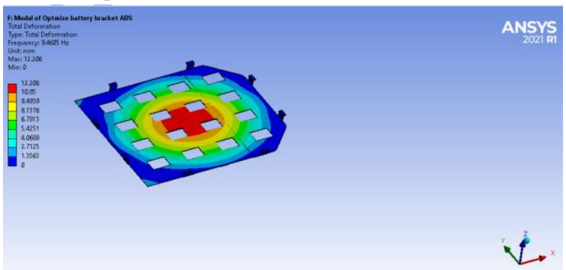


Fig. Frequency for Mode Shape 1.

Mode shape 02

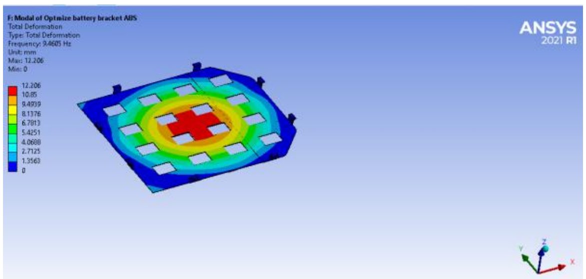


Fig. Frequency for Mode Shape 1.

Mode shape 03

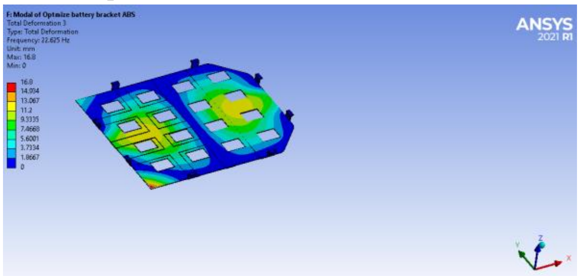


Fig. Frequency for Mode Shape 1.

Mode shape 04

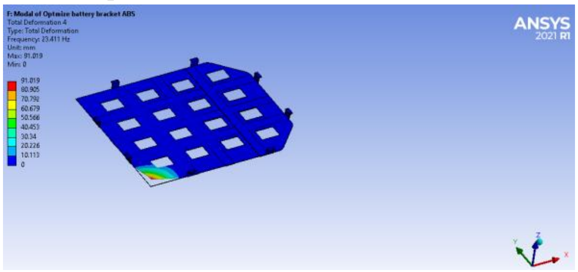


Fig. Frequency for Mode Shape 1.

Mode shape 05

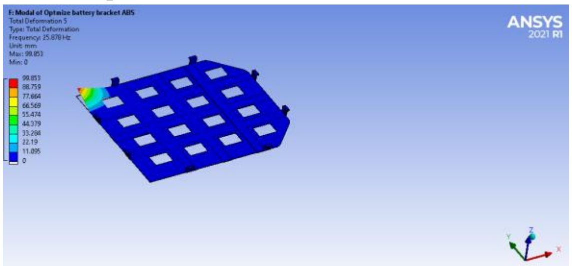


Fig. Frequency for Mode Shape 1.

Mode shape 06

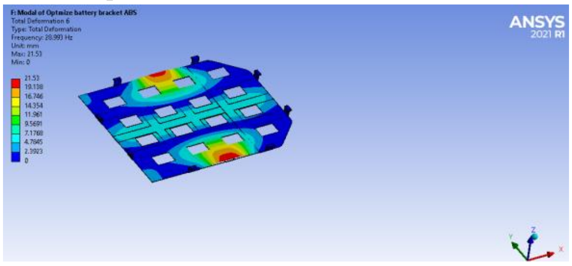


Fig. Frequency for Mode Shape 1.

Results Table:

Tabular Data

	Mode	Frequency [Hz]
1	1.	9.4605
2	2.	18.163
3	3.	22.625
4	4.	23.411
5	5.	25.878
6	6.	28.993

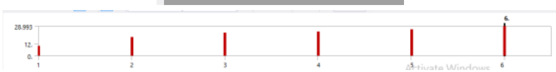


Fig. Mode no. and frequencies.

Static structural analysis

Boundary conditions

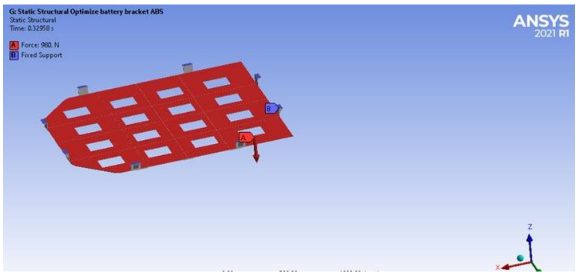


Fig. Boundary conditions for Static Structural analysis of Optimized Battery Bracket.

Results

Total deformation

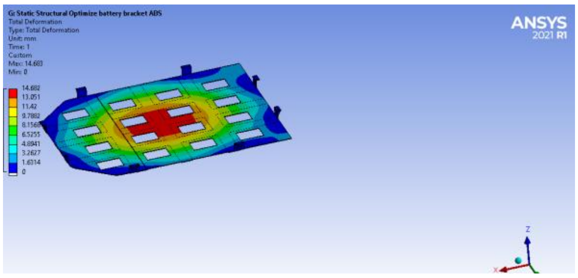


Fig. Total deformation of Optimized Battery Bracket.

Equivalent stress

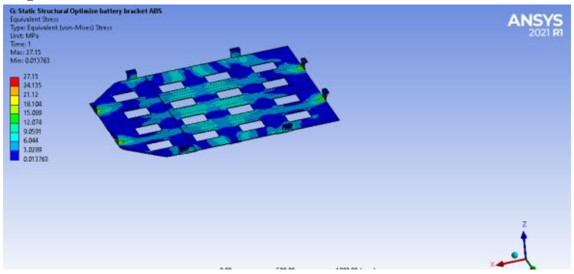


Fig. Equivalent Stress of Optimized Battery Bracket.

Equivalent elastic strain

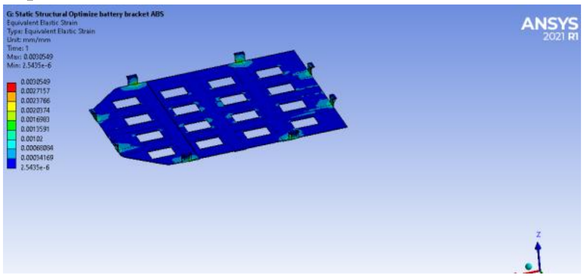


Fig. Equivalent Elastic Strain of Optimized Battery Bracket.

FEA RESULTS

Finite Element Analysis (FEA) was initially performed on the aluminium battery bracket model to evaluate its structural and dynamic performance.

The modal analysis results showed natural frequencies of 16.106 Hz, 33.421 Hz, 33.686 Hz, 41.457 Hz, 45.915 Hz, and 47.128 Hz for the first six mode shapes, indicating high stiffness and reduced susceptibility to low-frequency vibrations.
Static structural analysis revealed a maximum total deformation of 3.6486 mm, maximum equivalent (von Mises) stress of 25.112 MPa, and maximum equivalent elastic strain of 0.00058351, confirming that the design remains within safe stress limits.

Following this, topology optimization was applied to reduce material usage and improve weight efficiency. The optimized geometry was then analyzed using ABS material to evaluate its suitability for lightweight and additively manufactured applications.
Modal analysis of the optimized model yielded natural frequencies of 9.4605 Hz, 18.163 Hz, 22.625 Hz, 23.411 Hz, 25.878 Hz, and 28.993 Hz, reflecting a decrease in stiffness compared to aluminium.
Static analysis showed a maximum deformation of 14.682 mm, maximum equivalent stress of 27.15 MPa, and maximum equivalent elastic strain of 0.0030549.

V.MANUFACTURING OF THE COMPONENT

The optimized battery bracket was manufactured using Fused Deposition Modeling (FDM), an additive manufacturing technique, with Acrylonitrile Butadiene Styrene (ABS) as the material.

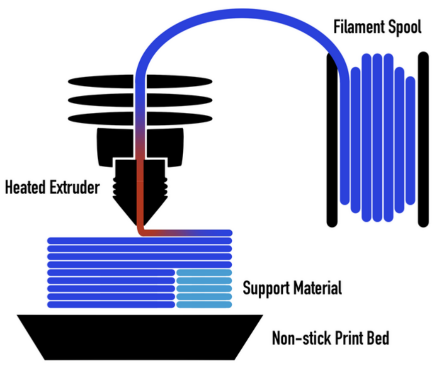


Fig. Schematic diagram of FDM.

The CAD model was exported in STL format and processed using slicing software to generate layer-wise toolpaths. The bracket was printed by depositing molten ABS filament layer by layer at controlled temperature and speed conditions.

Appropriate print orientation and support structures were used to ensure dimensional accuracy and structural integrity. Post-processing operations such as support removal and surface finishing were carried out before experimental testing.

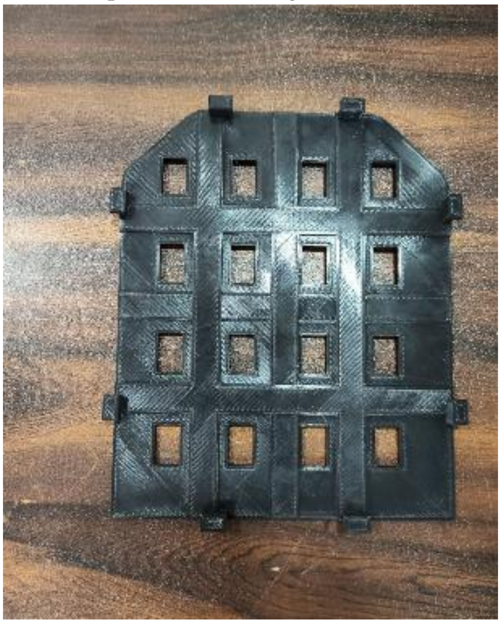


Fig. Final Manufactured ABS Specimen.

VI.EXPERIMENTAL TESTING

A Universal Testing Machine (UTM) is used to determine the mechanical behavior of materials by applying controlled loads and measuring the resulting deformation. It operates based on the principle of generating a stress–strain response by recording load and displacement during testing.

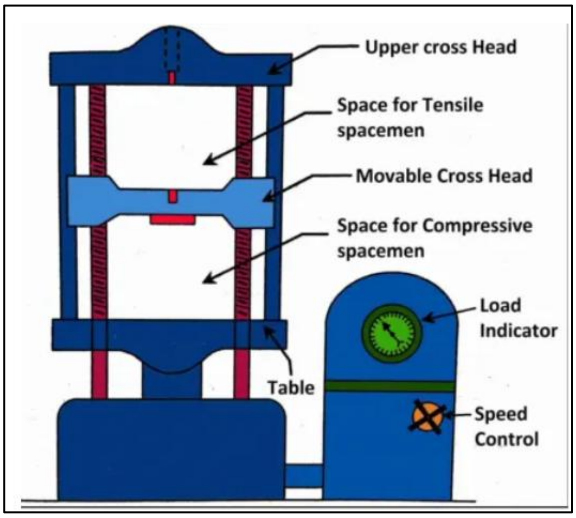


Fig. Components of a UTM.

In this study, the battery bracket is subjected to compression loading to evaluate its strength and deformation characteristics.

Testing Photograph:

Fig. Specimen under compression testing using UTM.

Testing Graph:

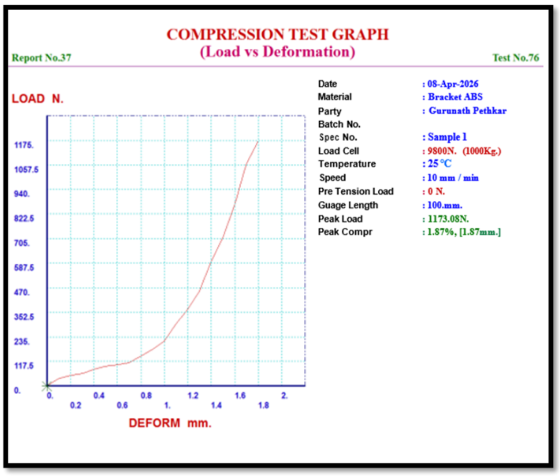


Fig. Compression test graph of the specimen.

The experimental results are compared with Finite Element Analysis (FEA) outcomes to validate the numerical model. This approach ensures the reliability of the optimized design under practical loading conditions.

FEA OF OPTIMIZED TESTING BRACKET ABS

Geometry

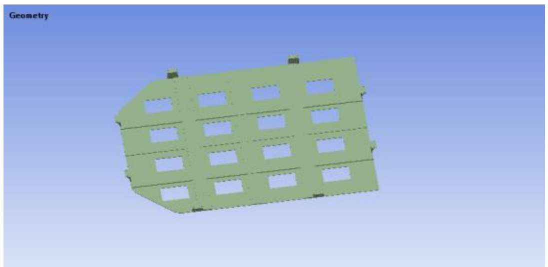


Fig. Geometry of optimized ABS battery bracket

Mesh

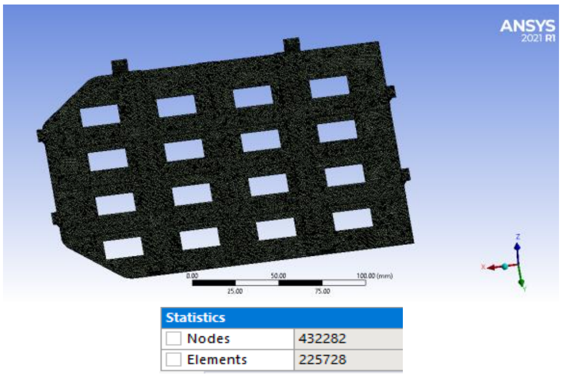


Fig Meshing of optimized ABS battery bracket

Boundary condition

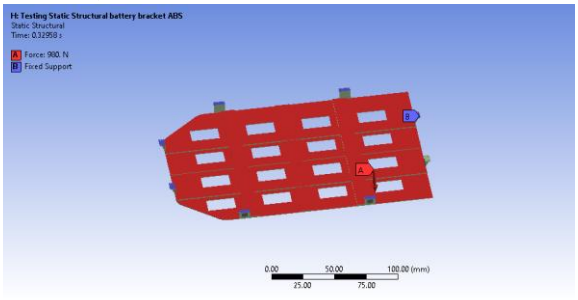


Fig Boundary condition of optimized ABS battery bracket

Results

Total deformation

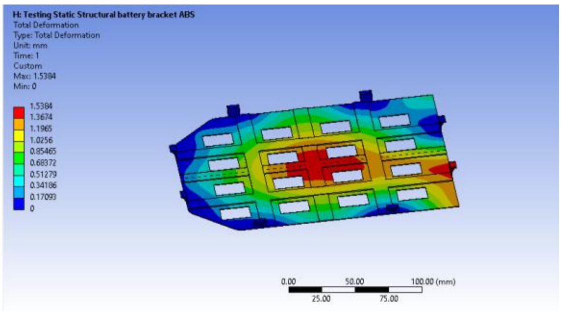


Fig: Total deformation of optimized ABS battery bracket

Equivalent Stress

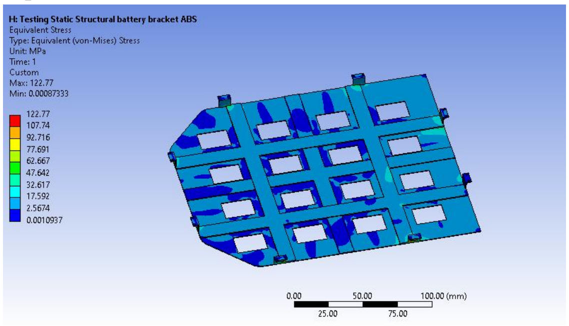


Fig: Equivalent Stress of optimized ABS battery bracket

Equivalent Elastic Strain:

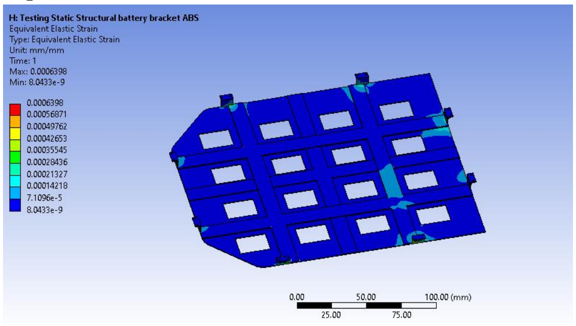


Fig: Equivalent Stress of optimized ABS battery bracket

Maximum Stress

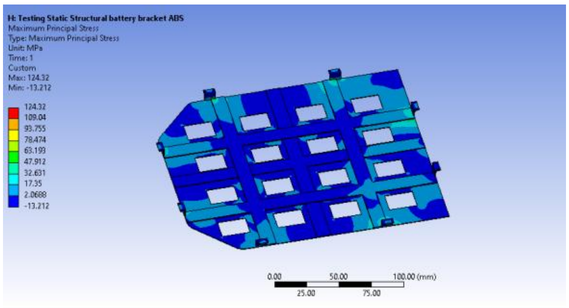


Fig: Maximum Principal Stress of optimized ABS battery bracket

VII.CONCLUSION

- This study presented the design, analysis, and optimization of a battery bracket for electric vehicle applications using a combination of Finite Element Analysis (FEA), topology optimization, and experimental validation.
- The initial aluminium model demonstrated high stiffness and low deformation, confirming its suitability for structural applications.
- Topology optimization significantly reduced material usage, resulting in a lightweight design that maintains acceptable stress levels.
- The optimized model, analyzed using ABS material, showed increased deformation and lower natural frequencies due to reduced stiffness; however, the stress values remained within allowable limits.
- A scaled prototype was successfully fabricated using additive manufacturing, and experimental testing using a Universal Testing Machine (UTM) showed good agreement with simulation results, validating the accuracy of the FEA approach.
- Overall, the study demonstrates that an optimal balance between weight reduction and structural performance can be achieved through integrated design and analysis techniques.
- The proposed methodology provides a reliable and cost-effective approach for developing lightweight and efficient battery support structures for electric vehicles.

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