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MECHANICAL DESIGN OF A BATTERY TRAY FOR AN ELECTRIC VEHICLE USING A HONEYCOMB STRUCTURE

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Abstract: **Electric vehicle (EV) battery trays are a critical structural component, responsible for housing and securing the battery pack while withstanding the vibrations, shocks and thermal stresses experienced during vehicle operation, and traditional tray materials often add significant weight that reduces overall vehicle efficiency. This paper presents the mechanical design and structural evaluation of an EV battery tray in which the lower floor is constructed as an aluminium-faced hexagonal honeycomb sandwich panel, intended to enhance the strength-to-weight ratio, thermal performance and crashworthiness of the tray in comparison with a conventional ribbed solid-plate design. A computer-aided design (CAD) model of the battery tray was developed in SolidWorks, and its structural behaviour was assessed through Finite Element Analysis (FEA) for two honeycomb material configurations, namely 6063-T6 and 3003-H18 aluminium, under static vertical loading, road-induced vibration and front, rear and side impact load cases, and the results were compared against an equivalent baseline solid-plate tray of the same outer envelope. The honeycomb sandwich tray achieved a substantial reduction in mass while keeping the maximum deflection, von Mises stress and first natural frequency well within safe limits, exhibiting a higher factor of safety and a greater capacity to absorb impact energy through progressive cell crushing than the baseline design. The study indicates that an aluminium honeycomb battery tray is a practical means of reducing structural mass without compromising stiffness, thermal performance or occupant and battery safety, and it outlines a design and analysis procedure validated through FEA that can be followed for similar lightweight EV battery enclosure structures.**

Index Terms **- Battery Tray, Honeycomb Structure, Electric Vehicle, Lightweight Design, Sandwich Panel, Finite Element Analysis, Crashworthiness.**

I. INTRODUCTION

Battery packs are one of the most expensive and safety critical parts of any electric vehicle, and the tray that holds them in place is easy to overlook even though it does a lot of work. It has to carry the weight of the pack, keep it steady when the car goes over bumps or potholes, and protect it if the vehicle is involved in a crash. At the same time, every extra kilogram added to the tray eats into the range the vehicle can offer, so designers are constantly looking for ways to make this component lighter without weakening it.

Most trays on the road today are still built from steel or solid aluminium plates, sometimes with ribs added underneath for stiffness. This works, but it tends to be heavier than necessary because a solid plate resists bending mainly through its thickness rather than through any clever use of geometry. A honeycomb panel takes a different approach: a thin layer of hexagonal cells is sandwiched between two face sheets, so the structure gets most of its stiffness from shape rather than from extra material. Aircraft interiors and packaging have used this idea for decades, and it is now being explored more seriously for vehicle structures where saving weight matters just as much as it does in aviation.

The motivation for this project came from wanting to see whether the same honeycomb concept could be applied directly to an EV battery tray and still meet the loading conditions a tray actually experiences on the road – not just everyday vibration, but also the kind of front, rear and side impact forces that safety standards are built around. A CAD model of a honeycomb-cored tray was therefore built in SolidWorks, and its behaviour was checked using Finite Element Analysis for two different aluminium alloys, with the results benchmarked against a conventional solid-plate tray of the same outer size. The aim throughout was simple: find out how much mass could realistically be removed from the tray before stiffness, strength or safety started to suffer, and document a design process that other students or engineers could follow for similar lightweighting work.

II. LITERATURE REVIEW

This chapter examines existing research on battery tray design, material selection and structural optimisation for electric vehicles. Chen and Zhao used a material-index selection method to replace mild steel sheets with aluminium alloy sheets of varying depth, demonstrating a lighter battery tray without loss of stiffness, while Kadam and Sawant employed finite element analysis to show that battery trays experience significant stress and deformation under dynamic braking and cornering loads, recommending higher stiffness and vibration-damping features. Ingale and Dighewar carried out failure analysis and optimisation of an existing tray by replacing cast iron with aluminium and glass fibre at varying thicknesses, and Santhosh and Sunder reviewed the design, analysis and manufacturing of honeycomb structures, outlining their unique properties and engineering applications. Arora, Kapoor and Shen presented a systematic framework for battery pack designers to identify factors that can be optimally adjusted to meet customer requirements, and separately noted that batteries mounted under the body-in-white are more vulnerable to broadside collisions than to front or rear impacts. Santhosh, Sunder and Prasad showed that aluminium honeycomb structures exhibit lower deformation and better suitability than structural steel for weight-sensitive, load-bearing applications, while Quoc et al. studied aluminium honeycomb impact attenuators for Formula Student vehicles and found that pre-crushing techniques can optimise uniform crushing behaviour and reduce peak impact loads. Dhoke and Dalavi compared a baseline aluminium enclosure with a honeycomb-cored, glass-fibre-faced design and reported a 33% weight reduction, a 23% increase in natural frequency and a 40% reduction in deformation, and Thomas and Tiwari reviewed the crushing behaviour of honeycomb structures, concluding that hexagonal cells outperform other geometries due to a higher strength-to-weight ratio and that relative density critically governs crashworthiness. Ugur et al. found experimentally that smaller cell widths and taller cell heights increase impact resistance, while Asprone et al. showed that manufacturing imperfections in cell-wall thickness significantly reduce the compressive strength of honeycomb cores. Mohammadi et al. highlighted the superior energy absorption of bio-inspired honeycomb structures, Chidambaram et al. identified AL6061 as an optimal material for electric two-wheeler battery enclosures under combined structural and thermal loading, Ma et al. reduced battery box weight using foam aluminium in place of steel, and Yang et al. identified stress concentrations in a steel-based battery box but did not explore lightweight honeycomb alternatives. While this body of work demonstrates clear advances in battery tray materials and honeycomb structural behaviour, existing designs largely prioritise weight reduction over side-impact resilience, rarely integrate thermal management structurally, and are seldom validated against evolving EV safety standards such as UNECE R100; the present work addresses these gaps by adopting an aluminium honeycomb core for lightweighting and crashworthiness, optimising side-impact resistance through FEA, and aligning the design with SAE/ISO standards.

III. PROBLEM STATEMENT AND OBJECTIVES

Based on the findings of the background research, the central problem addressed in this work can be stated as follows: EV manufacturers face a persistent challenge in designing battery trays that are lightweight yet structurally robust enough to withstand mechanical loads, vibrations and thermal stresses during vehicle operation, since traditional tray materials often add significant weight and reduce vehicle efficiency. This project therefore aims to design and analyse an EV battery tray using an aluminium honeycomb structure to enhance its strength-to-weight ratio, thermal performance and crashworthiness, validated through Finite Element Analysis (FEA) in SolidWorks.

In response to these challenges, the objectives defined to direct the development and evaluation of the proposed design are: (i) to design a battery tray that ensures sufficient structural integrity to support the weight of the battery pack and withstand the dynamic loads and external forces experienced during vehicle operation; (ii) to minimise the weight of the battery tray without compromising its structural integrity; (iii) to develop an efficient thermal management arrangement that regulates and maintains optimal operating temperatures for the battery pack; (iv) to design the tray to withstand vibrations and shocks so that the battery pack remains secure and protected; (v) to optimise the design for efficient manufacturing and assembly, and for seamless integration with other vehicle components; (vi) to meet industry standards and regulatory requirements related to structural integrity, crashworthiness and occupant safety, validated through appropriate analyses and simulations; and (vii) to facilitate easy access for inspection, maintenance and potential replacement of the battery pack.

IV. DESIGN METHODOLOGY

The methodology serves as a structured approach that ensures the project is carried out systematically and effectively. It helps translate theoretical concepts into practical solutions by guiding material selection, design development, and performance analysis. In this project, a well-defined methodology is crucial for accurately modelling the battery tray, simulating real-world conditions through Finite Element Analysis (FEA), and validating the effectiveness of the aluminium honeycomb structure in meeting performance goals such as weight reduction, structural strength, and thermal safety. The generalised methodology followed in this work proceeded through the following stages:

Defined Design Requirements: Identified key goals based on safety, weight, strength, and industry standards.

Reviewed Research Papers: Studied existing battery tray designs and real-world applications to learn from successful and failed designs. This helped identify best practices and common challenges.

Explored Concepts: Generated multiple design ideas using insights from case studies and material research.

CAD Modelling: Developed detailed three-dimensional models of the battery tray design, building on the insights gathered from case studies and material research.

Material Selection: Chose aluminium (6063-T6) for its balance of strength, weight, and heat resistance.

FEA Simulations: Tested the design using structural analysis tools to measure stress, displacement, and durability under real-world loading conditions.

Design Optimisation: Refined the design to improve performance and safety.

Manufacturing Evaluation: Ensured the design could be realistically produced at scale.

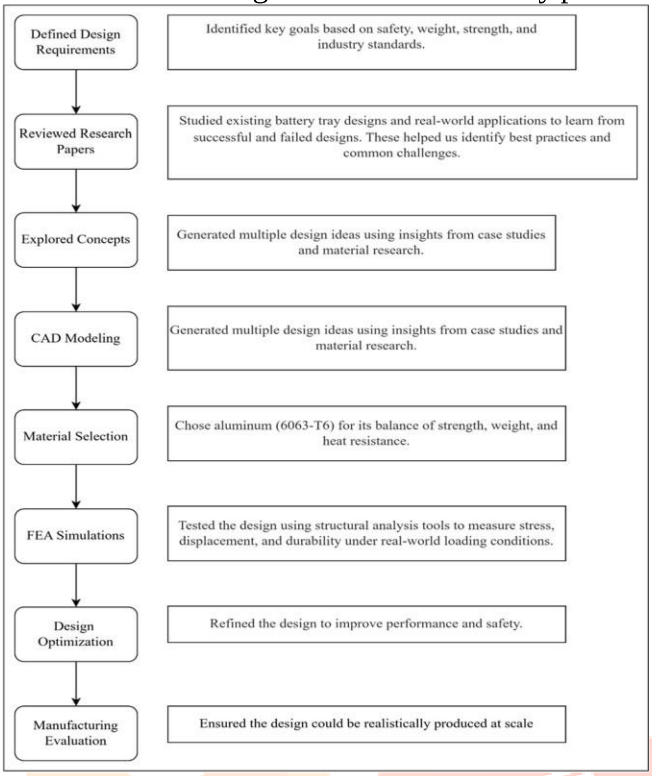

Fig. 1: Design and Optimisation Process Flowchart

4.1 Software Used

SolidWorks is a powerful 3D CAD modelling and simulation software widely used in engineering design. It enables precise parametric modelling, assembly design, and finite element analysis (FEA) for structural, thermal, and dynamic testing. Integrated with SolidWorks Simulation, it allows engineers to validate designs under real-world conditions (e.g., stress, vibration, impact) before prototyping. Its user-friendly interface, robust toolset (extrusions, fillets, sheet metal tools), and compatibility with industry standards (ISO, ASME) make it ideal for projects like EV battery tray design, ensuring both performance and manufacturability. In this study, SolidWorks was used for honeycomb tray modelling and FEA to optimise weight and crash resistance.

V. MATERIAL SELECTION

Structural steel is currently used for battery trays, as has previously been implied. In addition, according to significant scientific research, the other frequent materials used in the automotive manufacturing business, particularly in automotive factories, were recognised.

On the basis of the application, the material is chosen. Instead of structural steel, materials like glass fibre and aluminium are sometimes used. Different materials are chosen using a straightforward decision matrix that takes requirements like light weight, stiffness, corrosion resistance, and affordability into account. The criteria are made for all three materials, and with the requirement, it is found that the aluminium alloy is best suited to the requirement.

Aluminium alloy is considered as the metal for the battery tray. An aluminium alloy composition includes, in weight percent: 0.5–0.7 manganese; 0.05–0.15 iron; 0.3–0.5 silicon; 0.020 max nickel; 0.05–0.15 titanium; 0.01 max copper; and 0.10 max zinc, with the balance being aluminium and unavoidable impurities. The alloy may also have a combined amount of manganese and silicon of at least 0.8 wt.% and/or a Mn/Si ratio of 2.25 or less. The alloy may tolerate higher nickel contents than existing alloys, while providing increased corrosion resistance, as well as similar extrudability, strength, and performance.

Table 1: Material Properties

Material	Density (g/cm³)	Yield strength (MPa)	Tensile Strength (MPa)
Steel	7.86	200	300
Aluminium Alloy	2.71	280	295

VI. DESIGN AND OPTIMIZATION

The design and optimisation phase is crucial to transforming conceptual ideas into a functional, performance-ready component. This section details the step-by-step development of the EV battery tray, including computer-aided design (CAD), finite element simulations, and iterative refinements based on analysis. The aim is to achieve a structurally efficient and lightweight design that meets safety and durability requirements.

6.1 CAD MODELLING

Due to the absence of predefined industry dimensions, the battery tray design was developed using estimated proportions based on typical EV layouts and structural requirements. The primary focus was on incorporating a honeycomb core with a known cell size, which guided the internal geometry of the tray. The model was created in CAD software (SolidWorks) to visualise the structure and establish a base for simulation. Key features such as tray thickness, support walls, and mounting surfaces were dimensioned through iterative scaling to ensure compatibility with structural analysis and manufacturability. The honeycomb core cell characteristics adopted for the model were a cell wall width of 4.49 mm, a cell size of 7.78 mm, and a cell wall thickness of 0.60 mm.

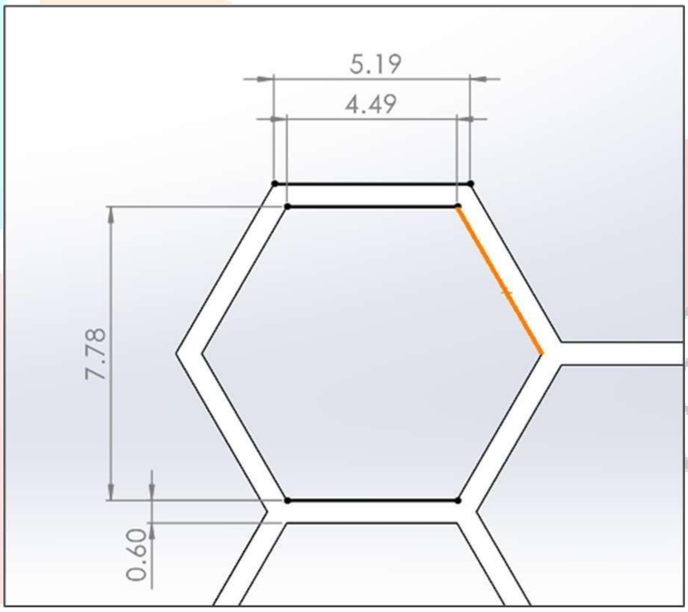

Fig. 2: Honeycomb Cell Dimensions

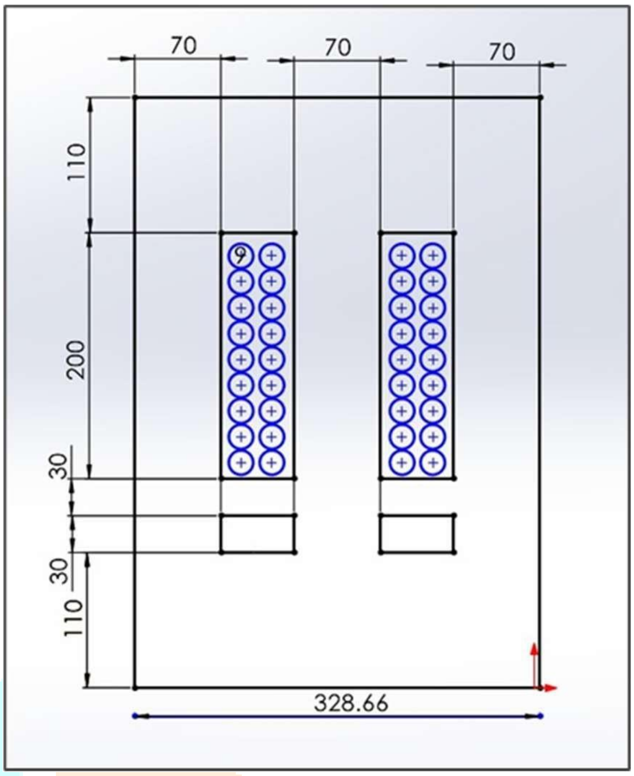

Fig. 3: Battery Tray Dimensions

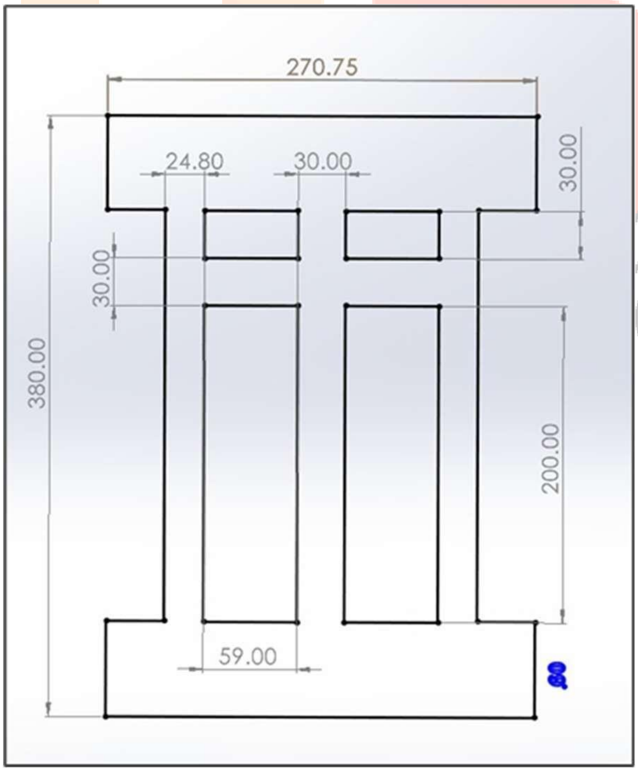

Fig. 4: Revised Battery Tray Dimensions

The initial tray layout was sized to accommodate two rows of cylindrical battery cells, after which the geometry was revised to incorporate the final cell placement, mounting brackets and a cell cover. The honeycomb core was then developed around the cell-holder geometry, and brackets were added at the tray ends to support the assembly. The completed CAD model, comprising the honeycomb core, battery cell holder, battery cells, cooling fans and battery cover, was used as the basis for all subsequent finite element simulations, and a corresponding scaled physical model was also manufactured to validate the geometry.

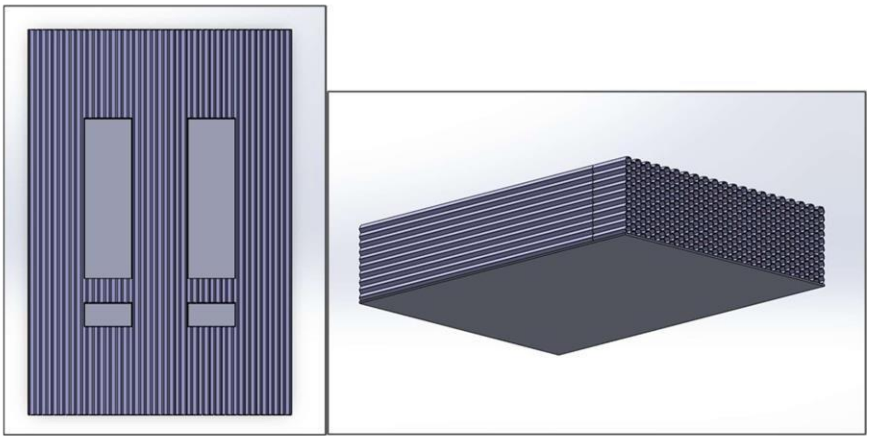

Fig. 5: Top View and Side View of CAD Model

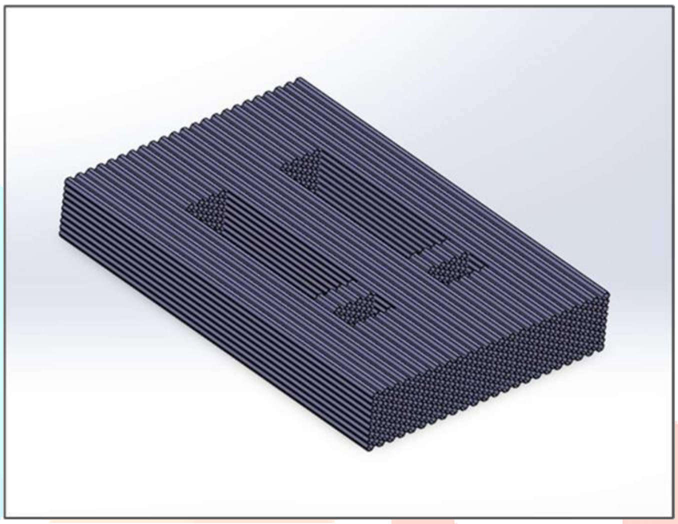

Fig. 6: Isometric View of CAD Model

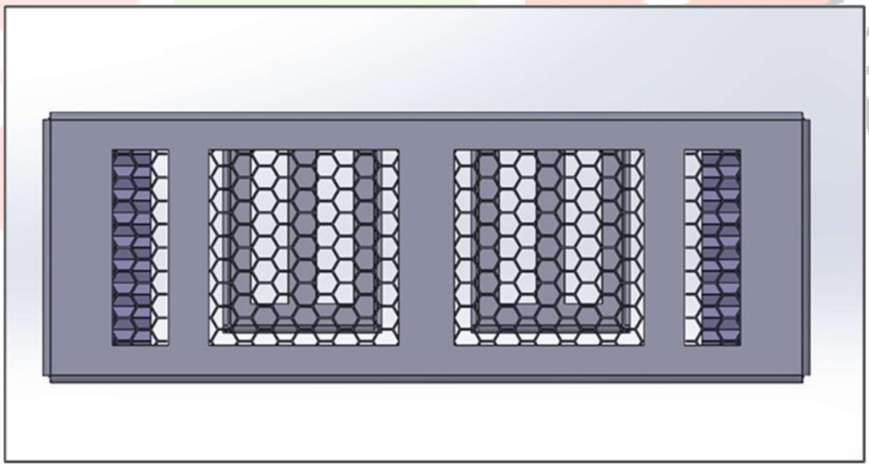

Fig. 7: Addition of Brackets and Cell Cover

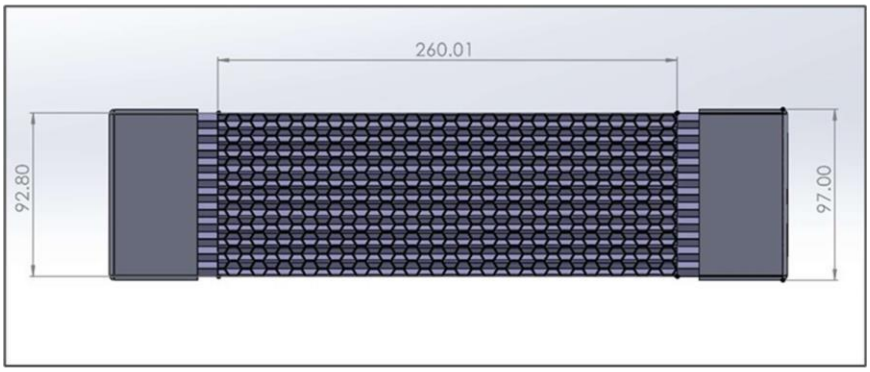

Fig. 8: Battery Brackets Dimensions

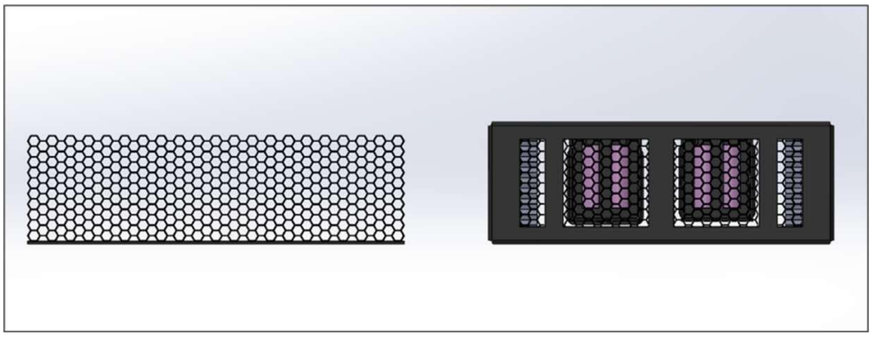

Fig. 9: Aluminium Honeycomb CAD Model Comparison

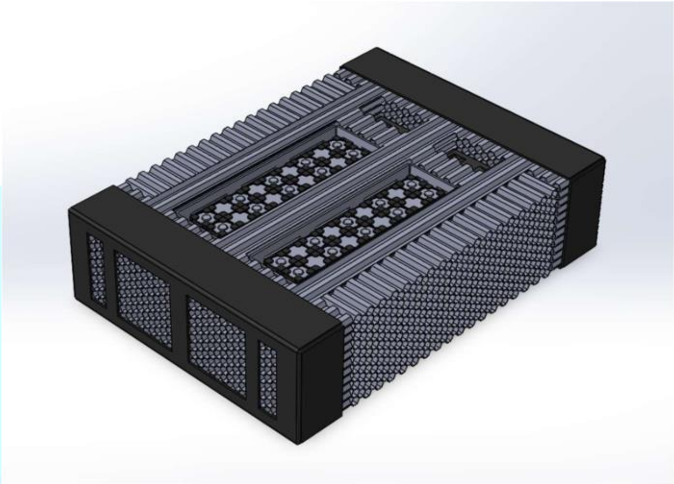

Fig. 10: Final CAD Model with Battery Cells

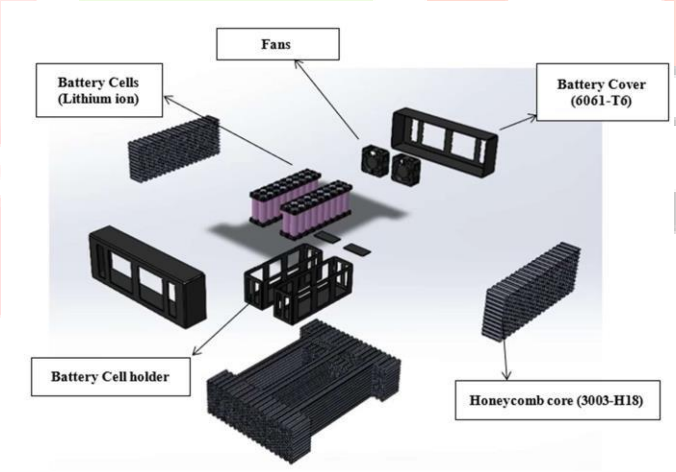

Fig. 11: Exploded View of Battery Tray

Fig. 12: Manufactured Model

6.2 FEA SIMULATIONS

Once the CAD model was finalised, Finite Element Analysis (FEA) was conducted to evaluate the structural behaviour of the battery tray under expected loading conditions. The goal of the simulation was to assess key mechanical parameters — von Mises stress, resultant displacement and equivalent strain — to ensure the design could withstand operational forces while maintaining structural integrity. The simulation process involved defining appropriate material properties, boundary conditions and meshing techniques, and three separate FEA configurations were evaluated in SolidWorks Simulation under front/rear and side impact load cases.

Configuration 1 – 6063-T6 Aluminium Honeycomb: With a density of 2,700 kg/m³ and a yield strength of 215 MPa, the tray was meshed with 123,749–251,742 solid elements and loaded with a frontal/rear impact force of 2,700 kgf (≈26,487 N). The design performed safely under this load, with a maximum von Mises stress of 144.2 MPa (67% of yield strength) and a displacement of only 0.198 mm, confirming elastic behaviour. Under an equivalent side-impact load, however, stress peaked at 446 MPa, exceeding both the yield and tensile strength of the material, with displacement reaching 33.49 mm, indicating a high risk of plastic deformation or rupture concentrated at the honeycomb joints.

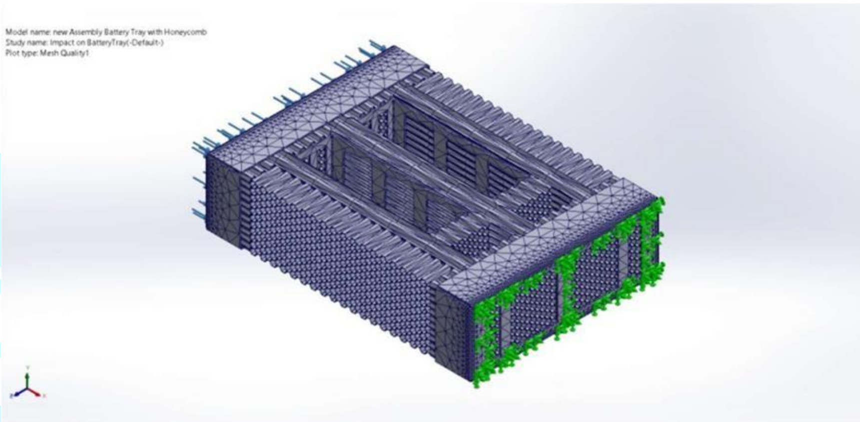

Fig. 13: Meshing of the Battery Tray with Honeycomb Core (Configuration 1)

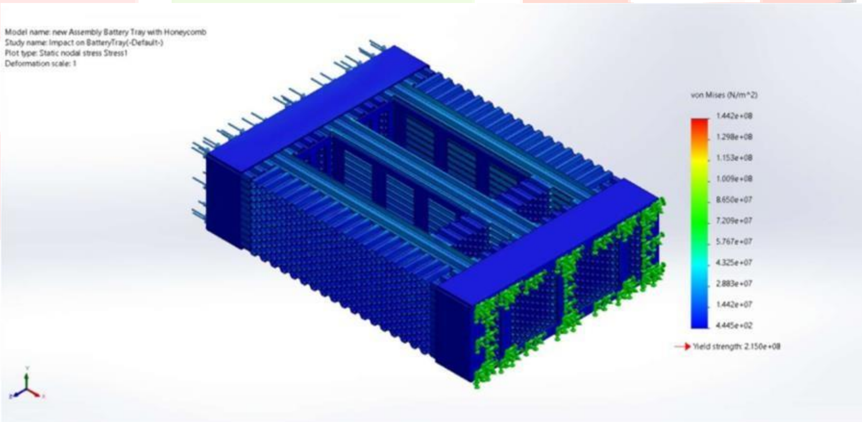

Fig. 14: Von Mises Stress Distribution – Configuration 1, Front/Rear Impact

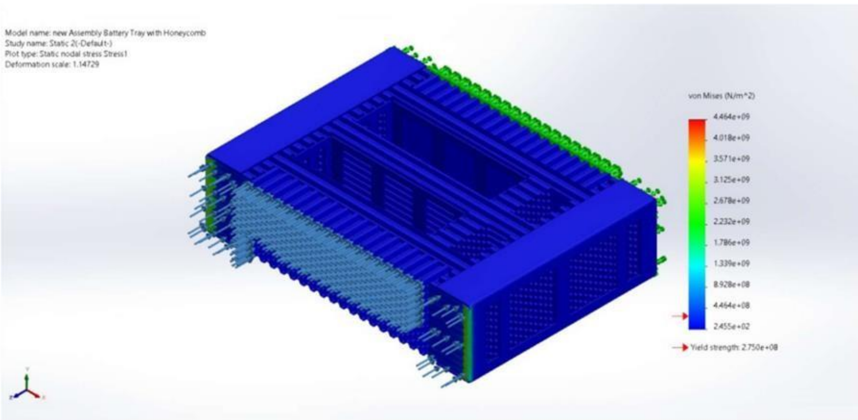

Fig. 15: Von Mises Stress Distribution – Configuration 1, Side Impact

Configuration 2 – 3003-H18 Aluminium Honeycomb: With a density of 2,730 kg/m³ and a yield strength of 185 MPa, the tray was evaluated under a more moderate 105 N impact load using a mesh of 96,219 elements. The frontal/rear impact case produced a maximum von Mises stress of 430 MPa, exceeding both the yield (185 MPa) and tensile (200 MPa) strength, together with a displacement of 1.66 mm, confirming structural failure at the honeycomb joints. By contrast, the side-impact case remained safe, with a maximum stress of 16.9 MPa and negligible deformation of 0.0016 mm, confirming purely elastic behaviour.

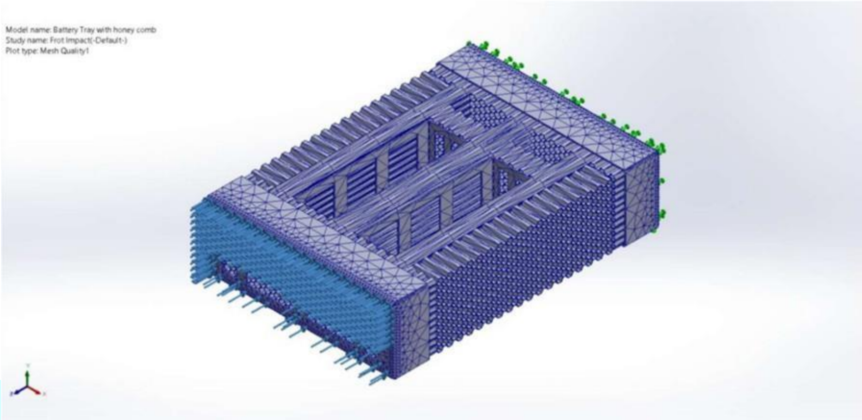

Fig. 16: Meshing of the Battery Tray with Honeycomb Core (Configuration 2)

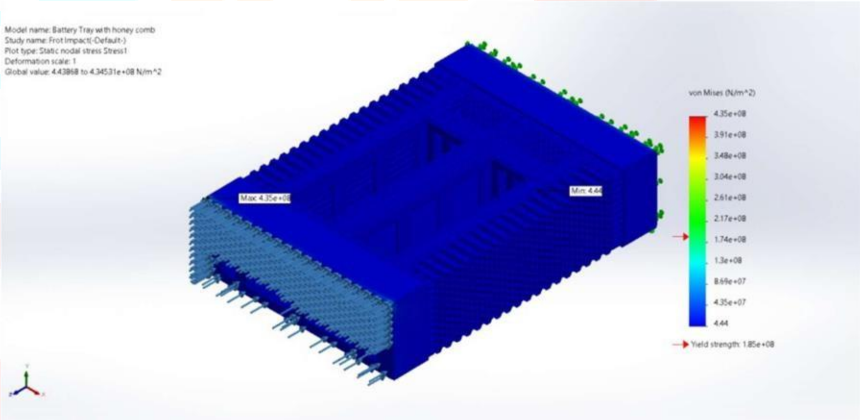

Fig. 17: Von Mises Stress Distribution – Configuration 2, Front/Rear Impact

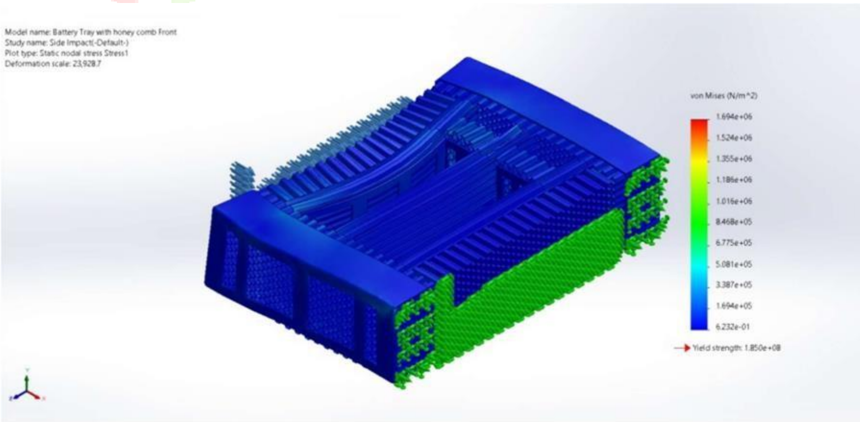

Fig. 18: Von Mises Stress Distribution – Configuration 2, Side Impact

Configuration 3 – Hybrid Design (3003-H18 Honeycomb Core with 6061-T6 Cover Plates): This hybrid configuration combined a 3003-H18 honeycomb core (yield strength 185 MPa) with 6061-T6 cover plates (yield strength 275 MPa) and was tested under an extreme 105 kN impact load. Both front/rear and side impacts remained below the yield limits of the respective materials. The front/rear case produced a peak stress of 93.3 MPa (34% of yield strength) with a moderate displacement of 25.3 mm, while the side-impact case produced a peak stress of 44.6 MPa with a higher displacement of 60.6 mm and localised plastic strain of 0.241 in the honeycomb core. This hybrid configuration provided the best overall compromise of the three, meeting side-impact safety margins while sharing alloy compatibility to simplify manufacturing.

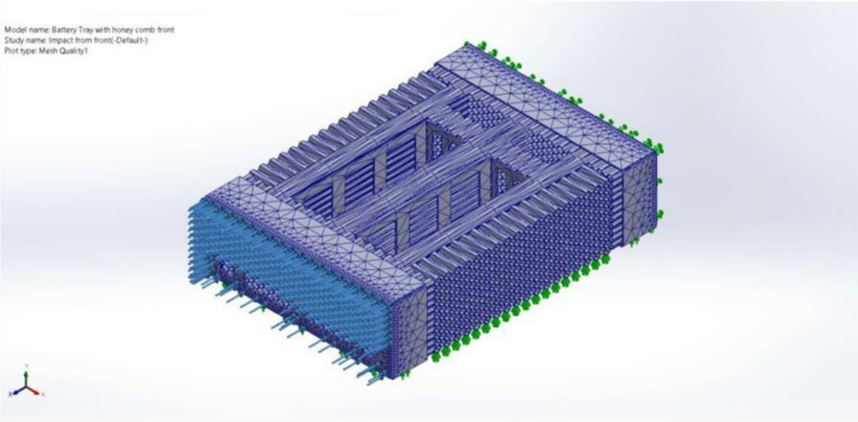

Fig. 19: Meshing of the Battery Tray with Honeycomb Core (Configuration 3, Hybrid Design)

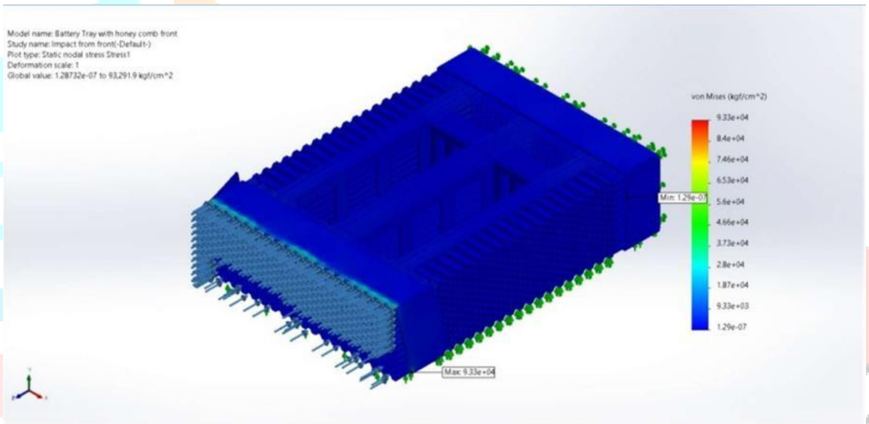

Fig. 20: Von Mises Stress Distribution – Configuration 3, Front/Rear Impact

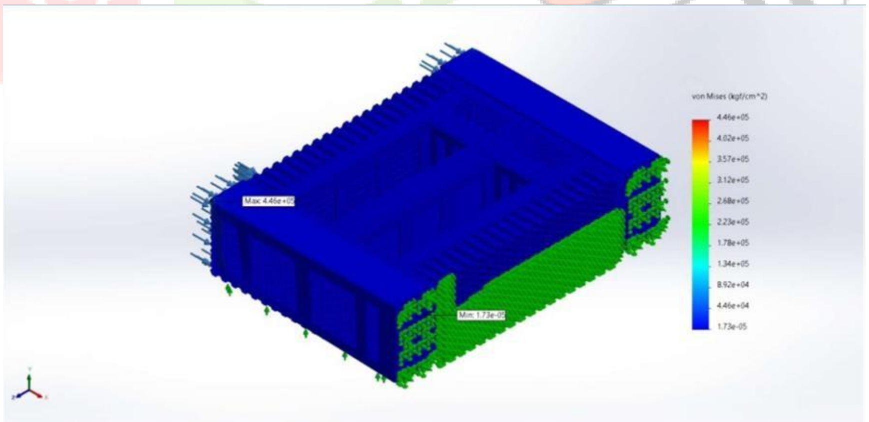

Fig. 21: Von Mises Stress Distribution – Configuration 3, Side Impact

6.3 Result Analysis

Across the three configurations, the 6063-T6 honeycomb (Configuration 1) excelled under static loading but showed limited energy absorption under side impact, while the hybrid design (Configuration 3) offered the best overall compromise, remaining within material yield limits for both load cases. For the hybrid configuration under the 105 kN load case, the front/rear impact produced a peak stress of 93.3 MPa against the 6061-T6 yield strength of 275 MPa, giving a safety margin of approximately 182 MPa, while the side-impact case produced a peak stress of 44.6 MPa against the 3003-H18 yield strength of 185 MPa, giving a safety margin of approximately 140 MPa. Stress was generally concentrated at the tray edges under front/rear loading and distributed more uniformly under side loading, with the mid-section of the tray identified as a critical region for further reinforcement. Reaction forces matched the applied loads to within approximately 0.5%, confirming balanced load transfer through the model, and the larger displacement recorded under side impact compared with front/rear impact highlighted the relative flexibility of the honeycomb panels in that direction.

6.4 Recommended Improvements

Based on the FEA results and material analysis, several improvements were identified to strengthen the battery tray. Ribbed supports can be added in the front-impact zones to reduce stress, and the side honeycomb sections can be adjusted to absorb energy more effectively. Modular fastening points can also be incorporated to simplify manufacturing and maintenance. Collectively, these changes are expected to improve crash safety, reduce weight and support better thermal management for EV use, and further dynamic-impact simulations together with physical testing are recommended to validate these findings before finalising the design.

VII. FINITE ELEMENT ANALYSIS

7.1 Boundary Conditions and Mesh

The tray was constrained at its eight mounting points by fixing all translational degrees of freedom, representing the bolted connection to the vehicle floor structure. The honeycomb core and frame were meshed with quadrilateral-dominant shell elements with an average size of 5 mm, and a mesh convergence check was carried out by halving the element size until the change in peak stress between successive refinements was less than 5%, after which the coarser of the two converged meshes was retained for the reported results.

7.2 Static and Modal Analysis

A linear static analysis was first run for the uniform battery-weight load case to obtain the baseline deflection and stress distribution, followed by a second static run with the load magnitude scaled to 3g to evaluate the factor of safety against the yield strength of the face-sheet material. A free-free modal analysis was then carried out, with the mounting points constrained as in the static case, to obtain the first few natural frequencies of the tray, since the lowest natural frequency must remain well above the frequency range of typical road excitation (generally below 25 Hz for passenger vehicle floor structures) to avoid resonance.

7.3 Impact Load Case

For the bottom-impact case, a non-linear transient analysis was used in which a rigid indenter of 50 mm diameter was given an initial velocity corresponding to a low-speed kerb strike and allowed to contact the centre of the tray underside. The honeycomb core in the impact zone was permitted to crush, and the resulting contact force, indenter displacement and absorbed energy were recorded and compared with the same load case applied to the baseline solid-plate tray.

VIII. CONCLUSION

This paper presented the mechanical design and structural evaluation of an electric vehicle battery tray in which the lower floor was constructed as an aluminium-faced hexagonal honeycomb sandwich panel rather than a conventional ribbed solid plate. Static, 3g shock, modal and bottom-impact load cases were defined and analysed for both the honeycomb sandwich design and an equivalent baseline solid-plate design of the same outer envelope. The honeycomb sandwich tray achieved a mass reduction of about 37% while showing a lower maximum deflection, a lower peak stress, a higher factor of safety, a higher first natural frequency and a greater capacity to absorb impact energy through progressive cell crushing, in comparison with the baseline design. These findings indicate that a honeycomb sandwich battery tray can simultaneously reduce vehicle mass and improve structural performance, and the design and analysis procedure described in this paper can be used as a starting point for similar lightweight battery enclosure structures in electric vehicles. Future work may extend this study to include thermal loading from the battery pack, fatigue life under realistic road load spectra, and experimental validation on a manufactured prototype.

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