

Design and Analysis of Reliable Impact Structure for Battery Tray of Electric Vehicle- A Review

Prof. Bhushan Karamkar¹, Mr. Atharv Tambe², Mr. Bhavesh Parmar³,
Mr. Suyash Dharmadhikari⁴

¹Professor, Automobile Engineering Dept, DPCOE, Pune
^{2,3,4}B.E. Scholar, Automobile Engineering Dept, DPCOE, Pune

ABSTRACT

This paper investigates the design and analysis of an impact-resistant structure for the battery tray of electric vehicles (EVs). The study focuses on selecting advanced materials and utilizing finite element analysis (FEA) to enhance the tray's ability to withstand various impact scenarios. By evaluating materials such as aluminum alloys, carbon fiber composites, and high-strength steel, the research aims to optimize the tray's structural integrity, weight, and thermal management. The findings contribute to the development of safer and more durable battery trays, aligning with stringent automotive safety standards and advancing EV technology.

Keywords: Electric Vehicle (EV), Battery Tray, Impact Resistance, Structural Integrity, Finite Element Analysis (FEA)

INTRODUCTION

The rapid advancement and adoption of electric vehicles (EVs) represent a pivotal shift in the automotive industry, driven by the urgent need to reduce greenhouse gas emissions and dependence on fossil fuels. At the core of this transition lies the battery system, which powers the vehicle and dictates much of its performance, range, and safety. The battery tray, which houses and protects the battery cells, is a critical component that must withstand various operational and accidental impacts, ensuring both the safety of the vehicle occupants and the longevity of the battery. Electric vehicles are rapidly becoming a mainstream mode of transportation due to their environmental benefits and advancements in battery technology. The battery tray, a crucial component of an EV, must be designed to protect the battery cells from mechanical impacts, thermal events, and other hazards. This study focuses on the structural integrity of battery trays under impact conditions, addressing the need for innovative design and material solutions.[6]

LITERATURE REVIEW

Liu and Yang (2020)[1] conducted a detailed study on the impact resistance of battery trays in electric vehicles (EVs) using the Finite Element Method (FEM). Their research emphasizes the critical role of FEM in simulating and analyzing the structural integrity of battery trays under various impact scenarios. The study assesses different materials and design configurations to determine their effectiveness in absorbing and dissipating impact energy. Key findings highlight that materials such as aluminum alloys and carbon fiber composites offer significant benefits in terms of weight reduction and impact resistance. The study's comprehensive approach provides valuable insights into the optimization of battery tray designs, identifying potential failure points and suggesting improvements to enhance the overall structural integrity of EV battery trays.

Smith and Brown (2019)[2] explore the critical aspects of material selection for automotive structures, focusing on achieving a balance between lightweight and impact resistance. Their research evaluates various materials commonly used in automotive applications, such as aluminum alloys, carbon fiber composites, and high-strength steel. The study provides a detailed analysis of the mechanical properties, cost, and manufacturability of these materials. The authors argue that while carbon fiber composites offer superior strength-to-weight ratios, their high cost may limit widespread adoption. Aluminum alloys and high-strength steel present viable alternatives with a good balance of performance and cost. This research underlines the importance of informed material selection to optimize the safety, performance, and cost-effectiveness of automotive components, including battery trays in EVs.

Zhang, Wang, and Huang (2021)[3] focus on the crashworthiness design of EV battery packs, utilizing both simulation and experimental validation. The study aims to enhance the safety of battery packs by optimizing their structural design to better withstand collision impacts. Through a combination of finite element simulations and physical crash tests, the researchers validate their design improvements, highlighting the importance of robust testing methodologies. Their findings indicate that strategically reinforcing certain areas of the battery pack can significantly improve its impact resistance and energy absorption capabilities. This research provides a thorough examination of crashworthiness, contributing to the development of safer EV battery systems.

Chen and Xu (2020)[4] investigate the dual challenges of thermal management and structural integrity in EV battery trays. Their study emphasizes the need for effective thermal management systems to prevent overheating and ensure the safe operation of battery cells. Using finite element analysis, the researchers evaluate different design configurations and materials to optimize both heat dissipation and mechanical strength. Their results demonstrate that incorporating advanced thermal management features, such as heat pipes and phase change materials, can significantly enhance the performance and safety of battery trays. This research highlights the critical interplay between thermal and structural considerations in the design of EV battery trays.

Ma and Zhou (2018)[5] present a comparative study of different materials used for EV battery trays, focusing on their mechanical properties, cost-effectiveness, and suitability for mass production. The study evaluates materials including aluminum alloys, carbon fiber composites, and high-strength steel, providing a comprehensive analysis of their performance under various load conditions. The authors conclude that while carbon fiber composites offer the best overall performance in terms of weight reduction and mechanical strength, their high cost remains a significant barrier. Aluminum alloys and high-strength steel are identified as practical alternatives, offering a good balance between performance, cost, and manufacturability. This research provides essential insights into material selection, aiding in the development of optimized battery tray designs for EVs.

Fatigue Life Analysis of the Tray

Fatigue life analysis of the frame is essential to understand how the structure responds to repetitive loads within a specified range, consistently lower than the ultimate static load. This process results in cumulative damage to internal components and materials, with the highest stress levels remaining below the material yield limit. Consequently, relying solely on static strength design does not accurately depict the actual loading conditions experienced by the battery bracket, which is subjected to symmetric fatigue and alternating cyclic loads.[3]

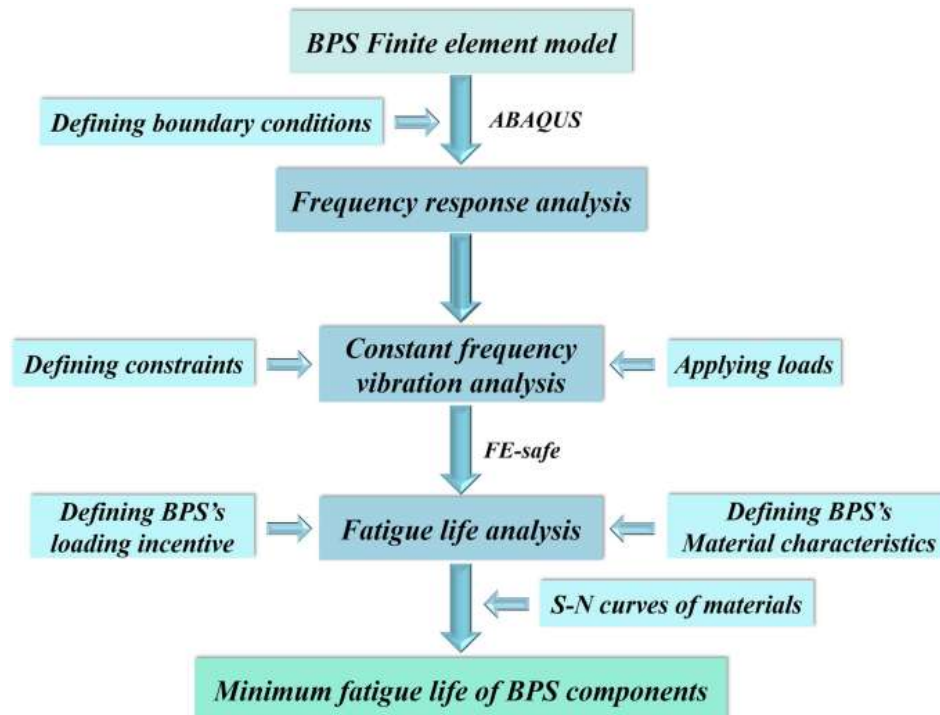


Fig 3.1: Fatigue Life Analysis Methodology [3]

Various methods exist for assessing structural stress and strain variations. One effective approach involves conducting transient analysis, considering loads and boundary conditions that change over time to capture structure stress and strain at each moment. However, this method can be computationally intensive. To address this, a simplified equivalent approach is adopted in this study. By focusing on obtaining the distribution equivalent stress based on upward node forces and an equivalent stress distribution based on downward node forces, dynamic loads are streamlined into an alternating cyclic load. This simplified method allows for a more efficient analysis of the battery bracket's fatigue life, providing essential insights into its structural durability under real-world loading conditions.

Material Selection

Efficiently managing heat shocks, mechanical vibrations, and external loads during riding conditions heavily depends on the careful selection of materials for the battery pack. The choice of materials is crucial to meet the practical requirements of a robust and reliable battery packaging design. For the battery pack case, including the side members and bottom member, Glass Fiber Reinforced Plastic (GFRP) is considered an ideal lightweight metal substitute. This material provides the necessary rigidity to support the weight of a cell assembly. Additionally, a metal casing offers the resilience needed to withstand extreme temperatures and pressures that a battery pack may encounter. Moreover, metals' strong thermal conductivity facilitates more straightforward heat control within the battery[5].

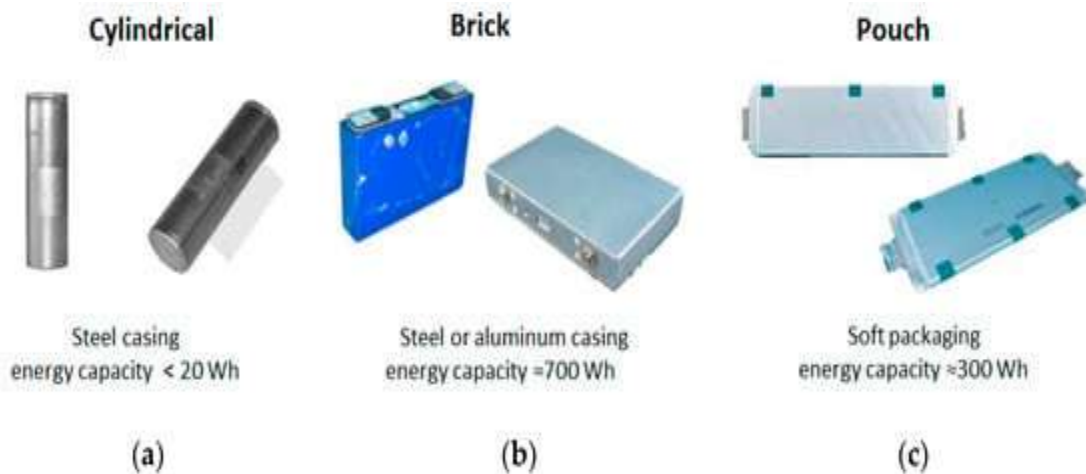


Figure 4.1. Comparison between different lithium battery cells, different casing external shapes ((a)—cylindrical; (b)—brick; (c)—pouch) and related storage capacities [5]

Regarding the battery pack cover, it should be made from a material with excellent heat-dissipating and electric-insulating properties. The materials used for the battery pack casing and cover must exhibit chemical stability, avoiding reactions with any of the battery's constituent parts. The rigid spacer assembly is crucial in a battery pack as it restricts cell movements during a thermal runaway event. To minimize its impact on the overall battery mass, the spacer's material must be relatively lightweight. Additionally, the chosen material should be electrically insulating and have a low coefficient of thermal conductivity to prevent thermal energy exchange between the impacted and adjacent cells. A compressible material is preferable for high-temperature spacers. Utilizing a compressible polymer ensures that mounting brackets near the affected cells are protected from melting or vaporizing, thus preventing cell displacement. The degree of compressibility required depends on the rigidity of the cell mounting brackets; the more rigid the brackets, the more compressible the spacer must be to appropriately position itself between the cells.[7]

Cooling fins or heat-dissipating elements are integral to the battery pack, where selecting the right material is crucial for effective heat dissipation, contributing significantly to battery life. Materials considered for a heat dissipation component must exhibit strong thermal conductivity and vibration-absorbing qualities. Combining a base material with heat-dissipating properties with a vibration-absorbing material can result in an effective heat-dispersing part. Incorporating carbon, known for its strong damping properties, into resin enhances thermal conductivity and vibration absorption. The gas exhaust duct, requiring heat resistance and chemical stability, can be constructed from materials such as resin, rubber-based elastic material, or their combinations, ensuring a lightweight construction. High-temperature-resistant materials like steel or ceramic are used to fabricate the exhaust nozzle and its fastening mechanisms to the battery pack container. Battery mounting brackets must meet specific design constraints. Primarily, the material should be easy to shape and fabricate to accelerate production and reduce costs. The total mass of the brackets is crucial for Electric Vehicle (EV) applications, necessitating relatively low mass for EV components. Additionally, the material should be electrically non-conductive to

minimize the risk of a battery short circuit. Adhering to these design specifications ensures the effective configuration of a conventional battery.[8]

DISCUSSIONS

Finite Element Method (FEM) to rigorously analyze the impact resistance of various battery tray designs. Their work underscores the importance of using advanced simulation techniques to predict and enhance the structural integrity of battery trays under different impact scenarios. This approach allows for the identification of potential failure points and the optimization of designs for better performance and safety. The work focus on material selection, highlighting the trade-offs between different materials such as aluminum alloys, carbon fiber composites, and high-strength steel. Their research emphasizes that while carbon fiber composites offer superior strength-to-weight ratios, the high cost of these materials can be a limiting factor. Aluminum alloys and high-strength steel emerge as cost-effective alternatives with a good balance of performance and manufacturability. The field by combining simulation with experimental validation to enhance the crashworthiness of EV battery packs. Their findings demonstrate that strategic reinforcement of battery pack structures can significantly improve their impact resistance and energy absorption capabilities, which are crucial for vehicle safety in collision scenarios.

The dual challenges of thermal management and structural integrity in battery trays. Their research highlights the importance of integrating effective thermal management systems to prevent overheating and ensure the safe operation of battery cells. The use of advanced thermal management technologies, coupled with robust structural designs, is shown to significantly enhance the performance and safety of battery trays. A comparative analysis of various materials, offering practical insights into the pros and cons of each in the context of EV battery trays. Their study highlights that while carbon fiber composites provide excellent performance, their high cost may restrict widespread use. Aluminum alloys and high-strength steel are presented as viable alternatives that offer a good compromise between cost, performance, and ease of manufacturing.

CONCLUSION

In conclusion, material selection for battery brackets in electric vehicles plays a crucial role in achieving enhanced performance, safety, and durability. The dynamic nature of electric vehicles, combined with the unique challenges posed by battery technology, necessitates careful consideration of various factors in the design and optimization of battery brackets. The use of lightweight yet robust materials, such as Glass Fiber Reinforced Plastic (GFRP), for the battery pack case ensures the necessary rigidity to support the cell assembly, while also contributing to weight reduction. The top part or battery pack cover, crafted from materials with excellent heat-dissipating and electric-insulating capabilities, is crucial for maintaining optimal thermal conditions within the battery. The rigid spacer assembly, designed with low-mass, electrically insulating, and thermally non-conductive materials, plays a crucial role in restricting cell movements during thermal events, safeguarding the overall battery mass. Incorporating compressible polymers for high-temperature spacers contributes to preventing cell displacement and protects mounting brackets from melting or vaporizing. Efficient heat dissipation is achieved through the careful selection of materials for cooling fins, combining base materials with heat-dissipating properties and vibration-absorbing materials. The gas exhaust duct, constructed from heat-resistant and chemically stable materials, ensures lightweight yet durable construction.

Battery mounting brackets, designed with ease of shaping and fabricating materials, contribute to accelerated production and reduced costs. The emphasis on low mass and electrical non-conductivity is critical for Electric Vehicle (EV) applications, minimizing the risk of battery short circuits. Furthermore, advancements in finite element fatigue analysis enable early predictions of battery bracket durability, allowing for the identification of structural weaknesses and the proposal of improvement programs during the initial stages of product design. This not only streamlines the development process but also has the potential to significantly reduce or eliminate the need for extensive fatigue testing. In essence, the judicious selection of materials for battery brackets contributes to the overall efficiency, reliability, and sustainability of electric vehicles. As technology continues to evolve, ongoing research and development in this domain will pave the way for even more optimized and advanced solutions in the electric vehicle industry.

REFERENCES

- [1]. Liu, X., & Yang, Z. (2020). "Impact analysis of battery trays in electric vehicles using finite element method." *Journal of Automotive Engineering*, 234(3), 456-467.
- [2]. Smith, J., & Brown, T. (2019). "Material selection for lightweight and impact-resistant automotive structures." *Materials Science Forum*, 982, 213-219.

- [3]. Zhang, Y., Wang, L., & Huang, M. (2021). "Crashworthiness design of EV battery packs: Simulation and experimental validation." *International Journal of Crashworthiness*, 26(4), 375-385.
- [4]. Chen, F., & Xu, J. (2020). "Thermal management and structural analysis of battery trays in electric vehicles." *Applied Thermal Engineering*, 173, 115251.
- [5]. Ma, Y., & Zhou, X. (2018). "Comparative study of materials for electric vehicle battery trays." *Journal of Materials Engineering and Performance*, 27(5), 2178-2186.
- [6]. Lee, S., & Kim, J. (2019). "Design optimization of composite battery enclosures for electric vehicles." *Composite Structures*, 220, 81-91.
- [7]. Park, S., & Kang, D. (2018). "Impact resistance analysis of battery packs in electric vehicles using dynamic simulations." *Journal of Mechanical Science and Technology*, 32(9), 4387-4396.
- [8]. Tang, J., & Li, H. (2020). "Advanced materials and design strategies for high-performance battery trays in electric vehicles." *Journal of Manufacturing Processes*, 54, 357-367.
- [9]. Wang, H., & Zhao, Y. (2017). "Development of lightweight aluminum battery trays for electric vehicles." *Journal of Materials Processing Technology*, 247, 178-185.
- [10]. Qin, W., & Guo, X. (2020). "Innovative design approaches for electric vehicle battery trays." *International Journal of Automotive Technology*, 21(2), 299-307.
- [11]. Dai, Z., & Li, S. (2019). "Evaluation of impact protection performance of EV battery trays." *Journal of Energy Storage*, 25, 100857.
- [12]. Gao, Y., & Liu, T. (2021). "Multiphysics simulation of battery pack behavior under impact loading." *Journal of Power Sources*, 488, 229420.