

Abstract

With the world's increasing tendency toward electrification, this research begins by comparing the lifecycle carbon footprints of internal combustion engine vehicles (ICEVs) and electric vehicles (EVs). This comparison underscores the significant environmental advantages of EVs, particularly their lower greenhouse gas emissions, especially when powered by renewable energy sources. Acknowledging the necessity for ongoing advancements in sustainable technologies, this dissertation then delves into advanced solutions for enhancing energy absorption and thermal management in structural and automotive applications. Specifically, it investigates the potential of thin-walled aluminum tubes filled with Phase Change Material (PCM) to provide superior performance in these areas, contributing to the development of safer and more efficient vehicular and structural designs.

Recognizing the superiority of EVs over ICEVs in reducing carbon emissions, the focus then shifts to addressing specific issues associated with EVs, notably the safety and efficiency of their batteries. The research investigates the carbon footprint across the entire lifecycle of vehicles, covering raw material production, manufacturing, transportation, operation, and decommissioning, and emphasizes the impact of regional electricity generation mixes on EV emissions.

Having established the environmental benefits of EVs, the dissertation scrutinizes the challenges posed by EV batteries, particularly their energy absorption and thermal management. To resolve these issues, the research proposes an integrated method using thin-walled aluminum tubes filled with PCM. This innovative approach aims to enhance both energy absorption and heat dissipation, addressing critical safety and performance concerns associated with EV batteries.

The second study delves into the energy absorption capacity of these PCM-filled tubes. By employing systematic case design (SCD) and finite element (FE) methods, the research investigates how geometrical parameters such as thickness, diameter, and orifice size influence the specific energy absorption (SE) of the tubes. The experimental and numerical results reveal that PCM-filled tubes outperform hollow tubes in energy absorption due to the dissipation of energy as PCM is squeezed through the orifices. An empirical formulation is derived to predict energy

absorption with over 95% accuracy, validated against experimental data. This study provides reliable guidelines for the design of energy absorbers under lateral compression, using a hemi-cylindrical indenter and validated FE models developed with commercial software (LS-Dyna).

Building on the insights from energy absorption, the third study addresses structural integrity and thermal management in EV battery systems. PCM-filled aluminum tubes are integrated into battery thermal management systems (BTMS) to enhance structural integrity and thermal regulation under mechanical stress and high discharge rates. The combined experimental and simulation results show that PCM-filled tubes significantly improve both mechanical resilience and thermal stability. The PCM effectively absorbs impact energy and reduces peak temperature rise during high discharge rates, mitigating the risk of thermal runaway and enhancing battery safety. By building upon previous studies, the research achieves the highest thermal conductivity of PCM by combining it with expanded graphite. This optimized PCM composite effectively reduces peak temperature rise during high discharge rates, mitigating the risk of thermal runaway and enhancing battery safety. The results demonstrate that this configuration can lower peak temperature rise by up to 18°C during 2C discharge rates.

The research provides a holistic view of the dual functionality of PCM-filled tubular structures in enhancing both crashworthiness and thermal regulation. The lifecycle analysis in the first study establishes the environmental context and underscores the necessity of advanced materials and designs for sustainable automotive technologies. The second study's detailed exploration of energy absorption mechanisms lays the groundwork for practical applications in crashworthiness, while the third study's focus on thermal management extends these benefits to battery safety and performance as well as their mechanical response under dynamic loading. This integrated approach highlights the multifaceted advantages of PCM-filled structures, making them highly suitable for modern engineering challenges in both automotive and structural applications.

In conclusion, by providing empirical and analytical models, the research offers valuable guidance for designing energy absorbers and thermal management systems, contributing to the broader goals of sustainability and environmental protection in transportation and structural engineering. The integration of PCM in thin-walled aluminum tubes represents a promising approach to addressing critical issues in energy efficiency and safety, paving the way for future

advancements in the field. The findings underscore the potential for PCM-filled structures to play a crucial role in reducing the carbon footprint of vehicles, enhancing safety, and improving the overall sustainability of transportation systems.