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BODY AND SAFETY, CHASSIS, MANUFACTURING, MATERIALS AND RECYCLING

Effective Mechanical Properties of an Innovative Module-Free Li-Ion Battery Pack Integrated with Honeycomb Cells and Optimum Design for Enhanced Crash Energy Absorption

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Abstract
To create advanced lithium-ion battery packs (BP) that are both lightweight and durable in crashes, an innovative honeycomb BP design has been developed. This design involves inserting cylindrical lithium-ion battery cells into a honeycomb cell core, eliminating the need for traditional modules. To reduce the weight of BP, collision analyses using the finite element method (FEM) are conducted with various thickness-to-length ratios for the honeycomb cell structures. A new mathematical formula is developed to calculate the energy absorption rate per unit volume and compared with the FEM results. Based on the formula, the optimal thickness-to-length ratio is determined. Furthermore, a new method to capture effective mechanical properties for the integrated battery cells with honeycomb cells is developed using the optimal thickness ratios and a modified rule of mixture. To enhance the collision safety of the honeycomb BP, its dimensions have been optimized by performing transient FE analyses while colliding with a rigid pillar on its one edge. A weight reduction of approximately 23.7% has been achieved.

Keywords Honeycomb batteries · Crash energy · Effective mechanical properties · Design optimization · Lithium ions

1 Introduction

The battery system of an electric vehicle is composed of cells, modules, and packs. A battery cell is the basic unit of a lithium-ion battery (LIB) and is made of anode, cathode, separator, and electrolyte. A module is an assembly of a certain number of battery cells to protect them from external loads and impacts. A battery pack is the final form of the battery system in an electric vehicle (EV), made by combining modules with cooling, control, and protection systems. The largest weight component in an EV is the battery pack at the current state of EV technology. However, driving performance and capacity are determined by the number of cells inside the battery pack and the weight of the body, so keeping the battery pack light and freeing up space for additional cells is a critical issue.

In the event of a vehicle-to-vehicle collision, the battery pack and surrounding reinforcement structure should be designed to absorb the impact energy, preventing damage to the battery cells that could lead to a fire. Recently, new concepts such as cell-to-pack or module-less battery packs are being researched to reduce weight and free up additional space to accommodate more cells.

Honeycomb has very good structural performance against impact loads, making it a good candidate for dual functionality as a battery pack and module. To date, many studies (Gibson & Ashby, 1997; Hu & Yu, 2010) have been conducted on honeycomb structural and mechanical properties. A novel thin-walled honeycomb structure for Li-ion battery packaging (Shuai et al., 2020) has been proposed, featuring a reinforcing grid for enhanced strength, reduced weight to enhance energy density, improved battery protection, and EV safety, with efficient optimization using a space mapping algorithm. An impact analysis involving a moving rigid pole was conducted to assess the packaging efficiency and crashworthiness of empty battery packs in rectangular, hexagonal, and trapezoidal shapes (Uerlich et al., 2020). Out of the three shapes considered, the hexagonal shape exhibited

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