Abstract

The shift towards sustainable electric mobility has further increased the efforts in research in advanced materials and integrated component design in electric vehicle (EV) battery systems. This doctoral work examines four interrelated subsystems in the EV battery pack taking into consideration materials and design strategies that improve structural, electrical, as well as environmental performance.

The first investigation (https://doi.org/10.3390/polym17081056) involved modification of lightweight carbon fiber composite (CFRP) using multi-walled carbon nanotubes (MWCNTs) treated with an ionic liquid as an additive process to the structure. Two forms of MWCNTs (Pristine, and nickel coated) were used; each was mixed into the resin in the amount of one to three percent by weight. Before mixing, both types of nanotubes were treated with 5 wt% of ionic liquid dissolved in ethanol to enhance the level of their interaction with the material around them. The sample with 3 wt% of ionic liquid treated pristine MWCNTs exhibited the optimum mechanical response and the closest values for flexural strength, nearly 803 MPa and modulus, at nearly 88 GPa, while its storage modulus was close to 18 GPa. During testing, a slight non-linear response was observed at mid-span deflection, suggesting more effective load transfer across the fiber–matrix interface. The reduced electrical resistance of approximately 29 Ω indicates the formation of conductive networks, confirming the multifunctional potential of the developed laminates.

The second project (https://doi.org/10.1016/j.est.2025.120036) focused on copper busbars role to enhance the safety of energy transmission and storage devices. Electric-vehicle batteries rely on current-carrying components that are expected to be kept safe in situations requiring fast charging and rapid acceleration, which are factors that lead to elevated temperature, increased mechanical loading and the straining of electrical joints. A single digital model was developed to understand these effects in combination of electrical, thermal, magnetic and structural behavior. The model was used with copper busbars that operated from 100 to 500 A and were supported by finite element simulations and experimental measurements. The results showed stable behavior till approx. 200 A, voltage drops between 0.009 and 0.047 V, contact resistance between 12.4 and 18.7 micro-ohms and magnetic fields between 8 and 40 mT, all within the limits stated in IEC 60269-1, IEC 61439-1 and CISPR 25. High current loads (500 A) resulted in localized heat in the vicinity of 273 ◦C, as well as permanent deformation in excess of 1 mm, that indicated demands for thicker sections, integrated cooling and laminated layouts. Three sizes of copper busbars were investigated, and both the simulations and experimental tests proved that all designs fulfilled the structural and working requirements. The work provides an evaluated digital

model associating simulations with physical behavior and potentially helping to determine busbars for safer and more reliable battery system designs for use in future electric vehicles.

The third study (https://doi.org/10.3390/s25216778) examined the performance of reed sensors designed for vibration-prone environments . Reed sensors are used widely in electric vehicles because they can help to enhance safety and operative stability, and the performance is impacted by how they react to magnetic fields during movement and vibration. A set of tests were conducted to determine the switching distances of the sensor when placed in front of five different positions of a cylindrical magnet using a test fixture made with 3D printing. From the analysis it was concluded that the right and slightly upward position of the magnet gave the most favorable result, as the release distance was reduced and the switching was more even. A housing prototype was then produced using Selective Laser Sintering using polybutylene terephthalate and a stainless steel spring was incorporated to increase sensitivity and provide a stable operation. The spring reduced the activation distance to around 2.3 mm, which was up to sixty-percent improvement, and it also made the measurements more repeatable. The results indicate a realistic path for the development of reed sensors that can be used more reliably in challenging automotive applications.

The final investigation was a sustainable approach to creating simple electronic component by forming laser-induced graphene on a layer of paper coated with a thin layer produced from Lignin. The coating mixtures were made with softwood kraft lignin grades EKWZ and SWWZ from Lignoboost AB as a main source of carbon and nine different mixtures were made by varying the amount of 4-hydroxymethylfurfural, urea, propylene glycol and formaldehyde. Each of the additives had a specific function for, assisting removal of water during the heating process, bonding within the coating, flexibility, and making the mixture stable during the processing. When a low-power CO2 laser ran over the coated paper, the surface layer turned into a conductive porous carbon pattern. Optimized mixture and laser settings were able to print patterned tracks with a sheet resistance lower than one hundred ohms per square of material, and the tracks were set into the shapes of an interdigitated array that functioned as small capacitors. The coated paper also remained smooth after processing, and there were no apparent cracks in the smeared regions, which indicates that the method may extract a wider area and more complicated layouts. This approach opens a route to the simple and flexible electronics from natural sources, and may benefit future applications of paper-based sensors, miniaturized energy storage components and inexpensive circuit elements on which environmental impact is of little concern.

The above four investigations are a unified path for developing battery systems with high performance, combined with modular architecture and low environmental. The outcomes indicate a use of lighter structural parts, more stable sensing parts, better current-carrying parts and electronics manufactured out of renewable sources, providing support for current objectives within the electric-vehicle sector. The results also demonstrate how material selection, device architecture, and digital modeling can work together to increase the reliability while being able to reduce the overall footprint of the 3D fabrications for battery systems used in the future.