

Lightweight Materials for Electric Vehicles

Sustainable Materials, Production Process,
and Modeling Techniques



EDITED BY

R. Suresh, C. Durga Prasad, Satish Kumar, K.N. Bharath,
and Ajith G. Joshi



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Lightweight Materials for Electric Vehicles

Lightweight Materials for Electric Vehicles serves as a comprehensive guide to the seamless integration of sustainable materials, advanced manufacturing techniques, and innovative solutions to tackle industry challenges. It underscores the pivotal role of academia in equipping the next generation of engineers with expertise in electric vehicle (EV) technologies. The book provides an in-depth exploration of the latest advancements in lightweight materials for EVs, focusing on their properties, applications, processing methods, and the challenges they present.

Furthermore, it examines emerging trends such as artificial intelligence-driven design, additive manufacturing, and the adoption of circular economy principles in automotive materials engineering. By addressing the evolving complexities of material selection and manufacturing, the book offers valuable insights into the future of EV innovation, extending its relevance to sectors beyond automotive, including aeronautics and aerospace.

Through case studies and research findings, the book also provides practical implementation strategies and actionable recommendations, while reinforcing the critical role of academia in driving progress and innovation in this transformative field.

Features:

- Discusses contemporary issues and challenges in the selection criteria of materials for EVs.
- Explores various materials employed for EV batteries, such as lithium-ion, nickel-metal hydride, and solid-state batteries.
- Overviews the use of lightweight materials, such as aluminum, carbon fiber-reinforced polymers, and magnesium alloys, in EV bodies.
- Reviews different types of materials, their sustainability, feasibility of usage, and challenges.
- Presents case studies on the application of different materials in EVs.

This book is an essential resource for practitioners, research scholars, academicians, and students involved in the study and development of materials for EVs.

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The *Emerging Materials and Technologies* series is devoted to highlighting publications centered on emerging advanced materials and novel technologies. Attention is paid to those newly discovered or applied materials with potential to solve pressing societal problems and improve quality of life, corresponding to environmental protection, medicine, communications, energy, transportation, advanced manufacturing, and related areas.

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Preface

The automotive industry is experiencing a paradigm shift, as the transition toward electric mobility becomes not only a technological ambition but an environmental necessity. In this rapidly evolving landscape, the materials that shape our vehicles are as important as the energy that powers them. As electric vehicles (EVs) and hybrid EVs (HEVs) continue to rise in prominence, the demand for lightweight, high-performance, and sustainable materials has reached an all-time high.

This book, *Lightweight Materials and Processing Technologies for Electric Vehicles*, arrives at a critical moment. It provides a thorough and well-structured exploration of the materials and manufacturing innovations that are defining the future of mobility. From lightweight alloys to composite materials, from additive manufacturing to nanomaterials for energy storage, the authors have compiled a comprehensive and timely resource that addresses both the promise and the complexity of next-generation vehicle materials.

What sets this book apart is its balance between foundational knowledge and advanced research. The discussions on material preparation, mechanical behavior, wear resistance, and fabrication challenges are not only academically rigorous but also deeply relevant to real-world engineering problems. Whether you're a student entering the field, a researcher pushing the boundaries of materials science, or an industry professional solving practical design challenges, this book offers valuable insights.

The editors commend the authors for their thoughtful contributions to this dynamic and critical area of research. As we collectively advance toward cleaner, smarter, and more efficient transportation systems, resources like this will serve as essential guides for innovation and collaboration.

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Introduction

*R. Suresh, C. Durga Prasad, Satish Kumar, K.N. Bharath, and
Ajith G. Joshi*

The growing demand for energy-efficient and high-performance electric vehicles (EVs) has led to an increased focus on lightweight materials that enhance vehicle efficiency, durability, and sustainability. Lightweight alloys and composite materials have become essential in EV manufacturing due to their superior mechanical properties, machinability, and resistance to wear and corrosion. However, the processing and fabrication of these materials present significant challenges, including their heterogeneity and the abrasive nature of composite reinforcements.

This book explores the latest advancements in lightweight materials and processing technologies, with a particular emphasis on their application in EVs and hybrid EVs (HEVs). It covers critical aspects such as material preparation techniques, mechanical and physical properties, and manufacturing challenges. Additionally, it highlights emerging trends in additive manufacturing, nanomaterials for battery applications, and computational modeling for EV components. Designed as a comprehensive resource, this book serves as a valuable reference for undergraduate and post-graduate students, researchers, academicians, and professionals in the fields of materials science, automotive engineering, and EV manufacturing. By addressing the evolving needs of the industry, this book contributes to the ongoing development of innovative materials and technologies that drive the future of sustainable transportation.

Seeking to promote research on the selection and implementation of lightweight materials and processing technologies for EVs, the book *Lightweight Materials for Electric Vehicles* is divided into 18 chapters. Chapter 1 introduces the development of advanced lightweight materials, composites reinforced with particles, natural and synthetic fibers, aimed at replacing heavier materials while maintaining strength and safety. It explores material properties, processing methods, artificial intelligence (AI)-driven design, and emerging innovations. Additionally, the chapter discusses key challenges such as machinability, corrosion resistance, and recyclability, emphasizing additive manufacturing (AM) and circular economy principles. These advancements have broader applications beyond EV technologies.

Chapter 2 explores advancements in epoxy-enhanced bamboo nanocomposites, emphasizing their synthesis, structure, and applications. Bamboo's high strength-to-weight ratio and sustainability make it an ideal reinforcement, while epoxy resins enhance mechanical and chemical properties. The chapter covers nanofiller integration, preparation techniques, and structural characterization methods like Fourier transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM), X-ray diffraction (XRD), and transmission electron microscopy (TEM). It discusses thermal stability, viscoelastic properties, and applications in automotive, aerospace, and construction. Challenges such as scalability, cost, and sustainable processing are also examined to improve commercial viability.

Chapter 3 presents a comprehensive overview of EV battery technologies, emphasizing innovations in energy storage and management systems essential for the future of sustainable transportation. The rapid growth of EVs represents a significant step toward an eco-friendly future, addressing the environmental challenges posed by traditional automobiles. Battery technology plays a crucial role in enhancing EV performance, with lithium-ion batteries (LIB) being the preferred choice due to their high energy density and long life cycle. However, emerging battery technologies,

such as lithium-metal and solid-state batteries, present promising alternatives with significantly higher energy storage potential. A robust battery management system (BMS) is vital for ensuring battery efficiency, safety, and longevity, with advancements incorporating Internet of Things (IoT) and AI-driven solutions.

The rapid evolution of energy storage technology has made the development of advanced nanomaterials for next-generation batteries a necessity. Chapter 4 explores how nanomaterials, with their unique properties, such as high surface area, enhanced electron transport, and tunable electrochemical characteristics, can significantly improve battery performance. It examines their role in lithium-ion, sodium-ion, and solid-state batteries, addressing key challenges like energy density, cycle stability, and safety. Additionally, the chapter highlights innovations in nanomaterial-based batteries, including two-dimensional (2D) materials, quantum dots, and metal-organic frameworks (MOFs), and their potential to revolutionize large-scale energy storage, EVs, and portable devices. Ensuring the scalability and sustainability of nanomaterials for widespread battery applications remains a crucial focus for the future.

The growing adoption of EVs requires advanced, lightweight BMSs for improved performance and safety. Chapter 5 explores innovative materials like polymer composites, MOFs, and nanomaterials that enhance energy density and thermal management. It also highlights bio-based polymers and recyclable composites for sustainability while maintaining durability. Case studies and AI-driven modeling provide insights into next-generation BMS design for EVs.

The advancement of EVs and HEVs demands innovative manufacturing solutions for improved performance and sustainability. AM plays a crucial role by enabling lightweight, complex, and durable components. Chapter 6 explores the integration of thermal spray coatings (TSCs) with AM to enhance wear resistance, corrosion protection, and energy efficiency in EV/HEV systems. By combining AM and TSC, manufacturers can optimize key vehicle parts, contributing to sustainable and high-performance automotive designs.

Chapter 7 delves into the growing significance of polymeric heat exchangers (PHEs) in thermal management systems, particularly for LIBs in EVs. It highlights the innovative designs, efficiency, and versatility of PHEs, showcasing their advantages over traditional metallic counterparts. By exploring computational and experimental analyses, along with current research, the chapter provides a comprehensive overview of PHE applications and advancements, emphasizing their role in fostering sustainable and high-performance technologies.

Chapter 8 presents the evolution of EVs, which has been driven by advancements in lightweight materials, improving performance and efficiency. This study explores the use of biomaterials, eco-friendly composites, and fire-retardant polymers in EVs and HEVs. By analyzing their impact on vehicle dynamics, energy consumption, and safety, along with their life cycle and recyclability, this research highlights the role of sustainable materials in the future of automotive design. With the rise of EVs and HEVs, the demand for durable and sustainable tribological materials is increasing. Chapter 9 delves into advanced materials such as biodegradable polymers, recycled metals, and self-lubricating coatings that enhance wear resistance, efficiency, and environmental sustainability. By reducing friction, improving recyclability, and minimizing carbon footprints, these materials play a crucial role in the evolution of greener automotive technologies. Additionally, the chapter discusses how innovations in sustainable tribology contribute to lightweight, high-performance vehicle components, supporting the industry's transition toward cleaner energy solutions.

Chapter 10 explores the concept of remaining useful life (RUL) prediction, which is critical for optimizing performance and ensuring safety in LIBs used in EVs, energy storage, and consumer electronics. Traditional RUL prediction methods face challenges in interpretability and computational efficiency. To address this, we propose a hybrid deep learning framework that integrates one-dimensional convolution neural networks (1D CNNs) with attention mechanisms while also evaluating alternative models like support vector machine (SVM), long short-term memory (LSTM),

and Transformers. Feature selection is enhanced using SelectKBest with mutual information regression (MIR), and model performance is assessed through mean squared error (MSE), mean absolute error (MAE), and root mean squared error (RMSE). This approach enhances generalization and efficiency, making it highly relevant for industries relying on battery-powered systems.

The automotive industry is under growing pressure to adopt sustainable materials, with natural fiber composites emerging as a lightweight and eco-friendly alternative, particularly for EVs. Chapter 11 describes their sustainability, property enhancements through chemical treatments, and economic viability. It also discusses challenges and compares them with glass fiber composites to assess their potential in automotive applications. Finally, key insights and recommendations are provided to guide future research and industry adoption.

Chapter 12 explores 2D carbon-based polymer nanocomposites, highlighting their enhanced mechanical and thermal properties through interface engineering. By incorporating nanomaterials like graphene, carbon nanotubes (CNTs), and carbon nanofibers (CNFs) with functional agents such as 3-aminopropyltriethoxysilane (APTES) and dopamine, these composites improve performance in automotive applications. This review examines recent advancements in nanoparticle–matrix interactions, load-transfer mechanisms, and reinforcement strategies.

Chapter 13 presents the role of EVs and HEVs in achieving carbon neutrality and addressing the climate crisis. It highlights the importance of advancements in battery technology and BMSs for the future of electric mobility. The chapter traces the evolution of battery materials from lead-acid to lithium-ion, metal-air, and flow batteries driving progress in energy storage. Additionally, it examines emerging materials like zinc manganese oxide, lithium tungsten, and lithium-sulfur batteries, which offer fast charging, affordability, and sustainability, shaping the future of electrification.

With the growing demand for sustainable energy solutions, perovskite materials have emerged as promising candidates for next-generation battery technologies. Their unique properties, including high ionic conductivity, tunable band gaps, and excellent electrochemical stability, enhance battery efficiency, and lifespan. Chapter 14 explores advancements in perovskite-based batteries while addressing key innovations, challenges, and future prospects for high-performance energy storage solutions.

AI and machine learning (ML) are transforming material processing by enhancing efficiency, precision, and sustainability. Chapter 15 explores how AI and ML optimize techniques like casting, welding, machining, and additive manufacturing through predictive modeling and real-time control. By integrating AI-driven analytics and the IoT, these advancements minimize costs, reduce waste, and improve manufacturing processes, offering valuable insights for researchers and industry professionals.

Chapter 16 explores the use of magnetorheological elastomers (MREs) in vibration isolation systems for EVs. Unlike magnetorheological fluids (MRFs), MREs offer long-term stability by preventing sedimentation and leakage. Using a blocked transfer stiffness approach, the study evaluates MREs' dynamic performance under torsional vibrations. Results show that increasing the magnetic field enhances stiffness and damping, improving ride comfort and noise reduction. MREs' adaptability makes them ideal for next-generation EV vibration isolation systems.

Chapter 17 explores the critical role of BMSs in ensuring the safety, efficiency, and longevity of EV energy storage. While advances in lithium-ion, solid-state, and sodium-ion batteries drive innovation, challenges persist in thermal management, charge cycles, and safety. Emerging materials such as solid electrolytes, nanomaterials, and phase-change materials (PCMs) enhance BMS performance. Integrating these advancements with sensor technology and AI can further improve efficiency and sustainability. This chapter examines how materials science innovations are shaping the future of EV batteries.

The rapid shift toward EVs is revolutionizing the automotive industry, driving advanced developments in materials for enhanced performance and sustainability. Among these innovations, advanced polymers and composites play a pivotal role in reducing weight, improving energy

efficiency, and optimizing thermal management. Their integration not only extends driving range but also enhances safety and structural integrity. Chapter 18 explores the crucial contributions of advanced polymers and composites in shaping the future of EVs and HEVs, addressing both their potential and the challenges that lie ahead.

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Chapter

Advanced Composites and Sustainable Materials for Lightweight Electric Vehicle Components

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ABSTRACT

Electric vehicles (EVs) have changed drastically recently—lightweight materials have helped them to evolve forward. Light materials such as carbon fiber-reinforced polymers (CFRPs) and glass fiber composites offer great strength and low weight. This chapter examines biomaterials, eco-friendly materials, along with fire-retardant polymers in EVs and hybrid electric vehicles (HEVs). New materials combine the low weight of common polymers with properties from biomaterials that increase strength, reduce weight, and enhance fire resistance. The authors analyze the effects on car dynamics, energy needs, and range, all while meeting safety regulations. The research also follows the full life cycle of those materials, from sourcing and producing them to recycling, showing their role in a circular economy.

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