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ADVANCED COMPOSITE MATERIALS FOR AUTOMOTIVE APPLICATIONS

STRUCTURAL INTEGRITY AND CRASHWORTHINESS

EDITOR
AHMED ELMARAKBI

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Editor

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Series Preface

One of the major challenges that the automotive sector will face in both the near and long-term future is the need for higher fuel efficiency. This is being driven by international requirements targeting reduced fuel consumption and carbon emissions, in a quest for sustainability. One of the most significant methods by which fuel economy can be achieved is by reducing the weight of the vehicle, or lightweighting the car. Composite materials, with their high strength to weight ratio provide an excellent platform upon which to develop the next generation of lightweight vehicles. Significant successes in the aerospace sector have led to the initial integration of carbon fiber composites into specialized vehicles such as Formula 1 racing systems, demonstrating the viability of composites in the ground vehicle. This viability is not only related to a successful lightweight vehicle that is more fuel efficient, but one that possesses both significant crashworthiness and is highly durable.

Based on initial successes, the promise of successfully integrating composites into commercial vehicles that are mass produced is within reach. However, the integration of composites into the vehicle and many of its components requires significant modifications to many of the vehicle design and analysis practices, where new material models and design characteristics must be considered. *Advanced Composite Materials for Automotive Applications* captures the basic and pragmatic concepts necessary to rethink the automobile's design to incorporate composite materials. It is part of the *Automotive Series* whose primary goal is to publish practical and topical books for researchers and practitioners in the industry and postgraduate/advanced undergraduates in automotive engineering. The series addresses new and emerging technologies in automotive engineering supporting the development of more fuel efficient, safer and more environmentally friendly vehicles. It covers a wide range of topics, including design, manufacture and operation, and the intention is to provide a source of relevant information that will be of interest and benefit to people working in the field of automotive engineering.

Advanced Composite Materials for Automotive Applications presents a number of different design and analysis considerations related to the integration and use of composites in the vehicle and its various components, including manufacturing methods, crash, impact and load analysis, multi-material integration, damage, curability and failure analysis. Also, the text provides a number of excellent real-world examples that punctuate the fundamental concepts developed in the book. It is a state of the art text, written by recognized experts in the field providing both fundamental and pragmatic information to the reader, and it is a welcome addition to the *Automotive Series*.

Thomas Kurfess
August 2013

Preface

The automotive industry faces many challenges, including increased global competition, the need for higher performance vehicles, a reduction in costs and tighter environmental and safety requirements. The materials used in automotive engineering play key roles in overcoming these challenges. However, the development of materials and processes to facilitate the use of composites in high-volume automotive applications is also still a big challenge. Thermoplastics and thermoset composites are being heavily considered by many automotive companies. Nowadays, there is a clear direction within car industries to replace metal parts by polymer composites in order to improve fuel consumption and produce lighter vehicles. The main advantages that composites offer to automotive applications are in cost reduction, weight reduction, recyclability and excellent crash performance compared with traditional steels.

This book provides a comprehensive explanation of how advanced composite materials, including FRPs, reinforced thermoplastics, carbon-based composites and many others are designed, processed and utilized in vehicles. The book includes a technical explanation of composite materials in vehicle design and analysis and covers all phases of composites design, modelling, testing and failure analysis. It also sheds light on the performance of existing materials, including carbon composites and future developments in automotive material technology which work towards reducing the weight of the vehicle structure.

A lot of case studies and examples covering all aspects of composite materials and their application in automotive industries are provided and explained in detail by the authors.

The initial chapters of the book focus on the fundamental background, providing a detailed overview of composite materials, their technology and their automotive applications. Impact, crash analysis, composite responses, damage and failure behaviour are presented and discussed in detail in Chapters 4–12. In addition, detailed work on metal matrix composites and their automotive applications are presented in Chapter 13. Finally, several case studies and designs are then covered in Chapters 14–17, including a wheel with integrated hub motor, safety components in composite body panels, noise and vibration analysis, braking systems and using low cost carbon fibre, together with performance and cost models.

A book covering such vital topics definitely would be attractive to the entire scientific community. The book will be valuable for those already working with composites and for those who are considering their use in the future for automotive applications. This book is proposed to give readers an appreciation of composite materials and their characteristics. The book will also provide the reader with the state of the art in the failure analysis of composite materials and their implications in the automotive industry. It will provide many technical advantages on the current and future uses of composites and the development and specific characteristics of composites and their energy absorption capabilities for crash safety.

This book is aimed at engineers, researchers and professionals who have been working in composites or are considering their use in the future in automotive applications. This book would be described as advanced/specialist.

The book is unique, with valuable contributions from renowned world-class experts from all over the world. The Editor would like to express his gratitude and appreciation to all contributors of this book for their efforts and decent work and to all my colleagues who served as reviewers for their comments, opinions and suggestions. The Editor would also like to thank John Wiley & Sons for this opportunity and for their enthusiastic and professional support.

Part One

Fundamental Background

1

Overview of Composite Materials and their Automotive Applications

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1.1 Introduction

This chapter presents an overview of recent automotive applications of advanced composites. A summary of available composites that could be used in automotive industries is presented. This work mainly deals with new research and studies done in order to investigate the present and potential use of composites for automotive structural components (e.g. tubes, plates, driveshafts, springs, brake discs, etc.). The important conclusions of these experimental and numerical simulation studies are shown in detail. It is important to note that most studies have an interest in enhancing the mechanical properties of automotive parts as well as providing better ecological and economical solutions. The influence of reinforcement types and architecture on the mechanical behaviour of automotive parts is investigated.

It is remarked that unidirectional composites and composite laminates are the most used composites, with a domination of glass fibres. However, carbon reinforced polymers and carbon ceramic composites along with nanocomposites could be considered as the most advanced composites currently in use for the automotive industry. Moreover, the emergence of natural fibre reinforced polymers, green composites, as a replacement of glass fibre reinforced polymers is discussed.

Recently, the use of composite materials has increased rapidly in automotive domains. As reported, according to [1], it is remarked that the total global consumption of lightweight materials used in transportation equipment will increase at a compound annual growth rate (CAGR) of 9.9% in tonnage terms and 5.7% in value terms between 2006 and 2011 (from

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42.8 million tons/US$80.5 billion in 2006 to 68.5 million tons/US$106.4 billion in 2011) [2]. The use of composites consists of chassis parts, bumpers, driveshafts, brake discs, springs, fuel tanks, and so on.

From a historical point of view, it should be noticed that the first car body made from (glass fibre reinforced polymer, GFRP) composites was for the Chevrolet Corvette, which was introduced to the public at Motorama show at New York in 1953 [3]. For these days, the Corvette series still use composite materials in its design. In motor sports, the use of carbon fibre reinforced polymers has been shown in Formula 1, with the McLaren MP4 in 1981. The open wheel car benefits from lighter body, which leads to a well distributed weight in order to achieve more mechanical grip on the track which significantly increases the overall performance of the car. Nowadays, all Formula series cars and other racing touring cars use composites in huge amounts in almost all of their body parts.

Composites have many advantages over traditional materials, such as their relatively high strength and low weight, excellent corrosion resistance, thermal properties and dimensional stability and more resistance to impact, fatigue and other static and dynamic loads that car structures could be subjected. These advantages increase the performance of cars and lead to safer and lower energy consumption. It should be noticed that car performance is affected not only by the engine horsepower, but also by other important parameters such as the weight/horsepower ratio and the good distribution of the weight. Moreover, lighter vehicles lead to a reduction of fuel consumption. It has been estimated that the fuel economy improves by 7% for every 10% of weight reduction from a vehicle's total weight [1,2]. It is reported that using carbon fibre composites instead of traditional materials in body and chassis car parts could save 50% of weight [1,2]. In addition, it means for every kilogram of weight reduced in a vehicle, there is about 20 kg of carbon dioxide reduction [2].

The major problems still facing the large use of composites in automotive domains are: the high cost in comparison with traditional materials (steel, alloy, aluminium), the complex and expensive manufacturing process for a large number of parts, the unknown physical (mechanical, thermal) behaviour of some kind of composites. Thus, many studies and research are conducted to solve these problems in order to extend the use of composites in large mass. Ford, with a collaboration with materials experts through the Hightech NRW research project, leads the search for a solution of a cost efficient manufacturing of carbon fibre composite components [4]. As estimated by Ford, the use of carbon fibre composites in addition to other advanced materials in the manufacturing of many automotive parts will reduce the weight of their cars by 340 kg at the end of the decade [4]. Another example is the consortium, led by Umeco and partnered by Aston Martin Lagonda, Delta Motorsport Ltd, ABB Robotics and Pentangle Engineering Services Ltd, that has been created to look into the potential for using high-performance composites. The project aims to reduce the cost of composite body in white vehicle structures for the mainstream automotive sector [5].

Many types of composites exist, which give the opportunity to select the optimum material design for any structure. However, this leads to many studies that deal with the mechanical behaviour of composites. The most used composites are composite laminates which consist of several plies with unidirectional long fibres. More developed kinds of composites known as textile composites (woven, braided and knitted fabrics) has emerged recently to be adopted in automotive applications. Moreover, nanocomposites have been used in order to enhance the performance of car structures. Hybrid composites also have been adopted especially in