WOODHEAD PUBLISHING IN MATERIALS

Advanced materials in automotive engineering

Edited by Jason Rowe

WP
WOODHEAD PUBLISHING

Advanced materials in automotive engineering

Edited by

Jason Rowe

WOODHEAD PUBLISHING

Oxford Cambridge Philadelphia New Delhi

Advanced materials in automotive engineering

Related titles:

Diesel engine system design
(ISBN 978-1-84569-715-0)
Diesel engine system design links everything diesel engineers need to know about engine performance and system design in order for them to master all the essential topics quickly and to solve practical design problems. Based on the author's unique experience in the field, it enables engineers to come up with an appropriate specification at an early stage in the product development cycle.

Tailor welded blanks for advanced manufacturing
(ISBN 978-1-84569-704-4)
Tailor welded blanks are sheets made from different strengths and thicknesses of steel pre-welded together being pressed and shaped into the final component. They produce high-quality components with the right grade and thickness of steel where they are most needed, providing significant savings in weight and processing costs in such industries as automotive engineering. Part I reviews processing issues in product design, production methods, weld integrity and deformation. Part II discusses applications in areas such as automotive and aerospace engineering.

Handbook of metal injection molding
(ISBN 978-0-85709-066-9)
Metal injection molding (MIM) is an important technology for the manufacture of small and intricate components with a high level of precision. MIM components are used in sectors such as automotive and biomedical engineering as well as microelectronics. This book is an authoritative guide to the technology and its applications. The book reviews key processing technologies, quality issues and MIM processing of a range of metals.

Details of these and other Woodhead Publishing materials books can be obtained by:

- visiting our web site at www.woodheadpublishing.com
- contacting Customer Services (e-mail: sales@woodheadpublishing.com; fax: +44 (0) 1223 832819; tel.: +44 (0) 1223 499140 ext. 130; address: Woodhead Publishing Limited, 80 High Street, Sawston, Cambridge CB22 3HJ, UK)
- contacting our US office (e-mail: usmarketing@woodheadpublishing.com; tel.: (215) 928 9112; address: Woodhead Publishing, 1518 Walnut Street, Suite 1100, Philadelphia, PA 19102-3406, USA)

If you would like e-versions of our content, please visit our online platform: www.woodheadpublishingonline.com. Please recommend it to your librarian so that everyone in your institution can benefit from the wealth of content on the site.

Published by Woodhead Publishing Limited,
80 High Street, Sawston, Cambridge CB22 3HJ, UK
www.woodheadpublishing.com
www.woodheadpublishingonline.com

Woodhead Publishing, 1518 Walnut Street, Suite 1100, Philadelphia,
PA 19102-3406, USA

Woodhead Publishing India Private Limited, G-2, Vardaan House,
7/28 Ansari Road, Daryaganj, New Delhi – 110002, India
www.woodheadpublishingindia.com

First published 2012, Woodhead Publishing Limited

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library.

Library of Congress Control Number: 2012931665

ISBN 978-1-84569-561-3 (print)
ISBN 978-0-85709-546-6 (online)

The publisher's policy is to use permanent paper from mills that operate a sustainable forestry policy, and which has been manufactured from pulp which is processed using acid-free and elemental chlorine-free practices. Furthermore, the publisher ensures that the text paper and cover board used have met acceptable environmental accreditation standards.

Typeset by Replika Press Pvt Ltd, India
Printed by Lightning Source

Contents

Contributor contact details

(* = main contact)

Editor and Chapter 1

J. Rowe

E-mail: rowejmc@gmail.com

Chapter 2

P. K. Mallick
Department of Mechanical Engineering
University of Michigan – Dearborn
4901 Evergreen Road
Dearborn, MI 48128
USA

E-mail: pkm@umich.edu

Chapter 3

Nick den Uijl* and Louisa Carless
Tata Steel RD&T
P.O. Box 10.000
1970 CA Ijmuiden
The Netherlands

E-mail: nick.den-uijl@tatasteel.com; louisa.carless@tatasteel.com

Chapter 4

Y. Okitsu*
Honda R&D Co. Ltd
4930 Shimotakanezawa
Haga-machi, Haga-gun
Tochigi 321-3393
Japan

E-mail: yoshitaka_okitsu@n.t.rd.honda.co.jp

N. Tsuji
Department of Materials Science and Engineering
Graduate School of Engineering
Kyoto University
Yoshida-Honmachi, Sakyo-ku
Kyoto 606-8501
Japan

E-mail: nobuhiro.tsuji@ky5.ecs.kyoto-u.ac.jp

Chapter 5

M. Bloeck
Novelis Switzerland SA
Research and Development Centre Sierre
CH – 3960 Sierre
Switzerland

E-mail: margarete.bloeck@novelis.com

Chapter 6

F. Casarotto*, A. J. Franke and R. Franke
Rheinfelden Alloys GmbH & Co. KG
Friedrichstrasse 80
79618 Rheinfelden
Germany

E-mail: fcasarotto@rheinfelden-alloys.eu; franke@alurheinfelden.com; rfranke@rheinfelden-alloys.eu

Chapter 7

B. R. Powell*
Materials Battery Group
Electrochemical Energy Research Lab
Mail Code 480-102-000
General Motors Global Research and Development Center
30500 Mound Road
Warren, MI 48090-9055
USA

E-mail: bob.r.powell@gm.com

A.A. Luo
Light Metals for Powertrain and Structural Subsystems Group Chemical Sciences and Materials Systems Lab
Mail Code 480-106-212
General Motors Global Research and Development Center
30500 Mound Road
Warren, MI 48090-9055
USA

E-mail: alan.luo@gm.com

P. E. Krajewski
Front and Rear Closures Group
Mail Code 480-210-2Y9
General Motors Global Vehicle Engineering
30001 Van Dyke Road
Warren, MI 48090-9020
USA

E-mail: paul.e.krajewski@gm.com

Chapter 8

P. Mitschang* and K. Hildebrandt
Department of Manufacturing Science
Institut für Verbundwerkstoffe GmbH
Erwin-Schrödinger-Strasse, Geb. 58
67663 Kaiserslautern
Germany

E-mail: peter.mitschang@ivw.uni-kl.de

Chapter 9

P. Urban* and R. Wohlecker
Forschungsgesellschaft Kraftfahrwesen mbH Aachen
Steinbachstrasse 7
52074 Aachen
Germany

E-mail: urban@fka.de; wohlecker@fka.de

Chapter 10

T. Bein*, J. Bös, D. Mayer and T. Melz
Fraunhofer Institute for Structural Durability and System Reliability LBF
Bartningstrasse 47
64289 Darmstadt
Germany

E-mail: thilo.bein@lbf.fraunhofer.de

Chapter 11

K. Kirwan* and B. M. Wood
WMG
International Manufacturing Centre
University of Warwick
Coventry CV4 7AL
UK

E-mail: Kerry.Kirwan@warwick.ac.uk; b.m.wood@warwick.ac.uk

Chapter 12

J. A. Poulis* and F.M. De Wit
Delft University of Technology
Building 62
Kluyverweg 1
2629HS Delft
The Netherlands

E-mail: J.A.Poulis@tudelft.nl; F.M.deWit@tudelft.nl

1
Introduction: advanced materials and vehicle lightweighting

J. ROWE, Automotive Consultant Engineer, UK

The UK automotive industry is a large and critical sector within the UK economy. It accounts for 820,000 jobs, exports finished goods worth £8.9bn annually and adds value of £10 billion to the UK economy each year [1]. However, the UK automotive industry is currently facing great challenges as road transport released 132 million tonnes CO_2 in 2008, accounting for 19% of the total UK annual CO_2 emission. Furthermore, its global competitiveness is threatened by the emerging new economic powers, such as China and India. In addition, the UK government is committed to reduce CO_2 significantly by 2050 and the EU requires 95% recovery and reuse of ELVs (end of life vehicles) by 2015. A solution to these challenges comes from the development and manufacture of LCVs (low carbon vehicles), and this is clearly presented in the vision of the UK automotive industry set by the NAIGT [1].

Vehicle lightweighting is an effective approach to improve fuel economy and reduce CO_2 emissions. CO_2 emission per km driven is linearly related to vehicle curb weight [2]. Studies have shown that every 10% reduction in vehicle weight can result in 3.5% improvement in fuel efficiency (on the New European Drive Cycle (NEDC)) [3]. In terms of greenhouse effect, this means that every 100kg weight reduction results in CO_2 reduction of about 3.5gCO_2/km driven for the entire vehicle life [3]. In addition to such primary benefits, vehicle lightweighting reduces the power required for acceleration and braking, which provides the opportunity to employ smaller engines, and smaller transmissions and braking systems. These savings have been termed secondary weight reduction in the literature and would allow a CO_2 reduction of up to 8.5gCO_2/km [3]. Furthermore, if appropriate technologies are used, vehicle weight reduction can be achieved independent of size, functionality and class of vehicle. It is important to point out that similar benefits of mass reduction can be demonstrated for hybrid vehicles (HVs) and electric vehicles (EVs).

Approaches to vehicle mass reduction include deployment of advanced materials and mass-optimised vehicle design. One of the major systems of the vehicle is the body (body-in-white, or BIW) that represents about one-quarter of the overall vehicle mass and is the core structure and frame of the vehicle. The body is so fundamental to the vehicle that sometimes it is the only portion of the vehicle that is researched, designed and analysed in mass reduction technology studies [2]. Over many years there has been a fundamental material shift from wood, cast iron and steel to high strength steel (HSS), advanced high strength steel (AHSS), aluminium, magnesium and polymer matrix composites (PMCs). Between 1995 and 2007, the use of aluminium increased by 23%, PMCs by 25% and magnesium by 127% [2]. Further vehicle mass reduction can be achieved by mass-optimised design technology. Mass-optimisation from a whole vehicle perspective opens up the possibility for much larger vehicle mass reduction. For example, secondary mass reduction is possible since reducing the mass of one vehicle part can lead to further reductions elsewhere due to reduced requirements of the powertrain, suspension and body structure to support and propel the various systems. New and more holistic approaches that include integrated vehicle system design, secondary mass effects, multi-materials concepts and new manufacturing processes are expected to contribute to vehicle mass optimisation for much greater potential mass reduction [4]. As reviewed by Lutsey [2], there have been 26 major R&D programmes worldwide on vehicle mass reduction. Compared to a steel structure, the HSS intensive body structure by the Auto Steel Partnership achieved 20–30% mass reduction [5], the Al intensive body structures of the Jaguar XJ, Audi A8 and A2 achieved 30–40% mass reduction (e.g. [6]) and a multi-material body structure featuring more Al (37%), Mg (30%) and PMCs (21%) by the Lotus High Development Programme achieved 42% mass reduction [4]. It is clear that although a single material approach can achieve substantial mass reduction the greatest potential comes from an integrated multi-material approach that exploits the mass and functional properties of Al, Mg, PMCs and AHSS. Despite the greater use of the higher cost advanced materials, mass-optimised vehicle designs could have a minimal or moderate cost impact on new vehicles [2] if a holistical whole vehicle design approach is used. For instance, the Lotus High Development Programme demonstrated a 30% whole vehicle mass reduction could be achieved with only a 5% increase in cost, whilst the VW-led Super Light Car achieved a 35% body mass reduction for a cost of less than €8 for every kilogram of mass reduction. The combination of a multi-material concept and a mass-optimised whole vehicle design approach can achieve significant mass reduction with a minimal or moderate cost impact on vehicle structure and it is most likely that the future materials for LCVs are an optimised combination of Al, Mg, PMCs and AHSS.

Closed-loop recycling of advanced automotive materials, however, has been missing from nearly all the LCV programmes worldwide, which have concentrated on the reduction of CO_2 emission during the use phase of vehicles produced from primary advanced materials. The production energy of all primary automotive materials is always much greater than that of their secondary (recycled) counterparts [7]. For instance, production of 1kg primary Al from the primary route costs 45kWh electricity and releases 12kg

CO_2, whilst 1kg recycled Al only costs only 5% of that energy and 5% CO_2 emission [8]. Detailed life cycle analysis (LCA) has shown that a primary Al intensive car can only achieve energy saving after more than 20,000 km driven compared with its steel counterpart, while a secondary Al intensive car will save energy from the very beginning of vehicle life [9]. If all the automotive materials can be effectively recycled in a closed-loop through advanced materials development and novel manufacturing technologies, the energy savings and cost reduction for the vehicle structure will be considerably more significant.

The vision of automotive manufacturers is that future LCVs are achieved by a combination of multi-material concepts with mass-optimised design approaches through the deployment of advanced low carbon input materials, efficient low carbon manufacturing processes and closed-loop recycling of ELVs. Advanced materials will include Al, Mg and PMCs, which are all supplied from a recycled source. A holistic and systematic mass-optimised design approach will be used throughout the vehicle (including chassis, trim, etc.) not only for mass reduction and optimised performance during vehicle life but also for facilitating reuse, remanufacture and closed-loop recycling at the end of vehicle life. Novel manufacturing processes will be used to reduce materials waste and energy consumption, shorten manufacturing steps and facilitate parts integration and ELV recycling. Fully closed-loop ELV recycling will be facilitated by new materials development, novel design approaches, advanced manufacturing processes and efficient disassembly technologies, all of which will be effectively guided by a full life cycle analysis.

The themes described above have been taken from the TARF-LCV 2011 (Towards Affordable, Closed-Loop Recyclable Future Low Carbon Vehicles Structures) programme submission (reproduced with the kind permission of Professor Zhongyun Fan, Chair of Metallurgy at Brunel University), and are developed within the following chapters of this book using contributions from leading experts from both academia and industry.

1.1 References

[1] NAIGT: *An Independent Report on the Future of the Automotive Industry in the UK*, 2009.

[2] N. Lutsey: UCD-ITS-RR-10-10, University of California, Davis, May 2010.

[3] M. Goede: SLC Project December 2003 and May 2008, VW.

[4] Lotus Engineering Inc: An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Programme, March 2010.

[5] Auto Steel Partnership (ASP): Future Generation of Passenger Compartment, December 2007.

[6] S. Birch: Jaguar Remakes XJ, http://www.sae.org/mags/sve/7547, March 2010.

[7] S. K. Das: in *Materials, Design and Manufacturing for Lightweight Vehicles*, CRC Press, New York, 2010, pp. 309–331.

[8] J. A. S. Green: Aluminium Recycling and Processing, ASM International, Materials Park, Ohio, USA, 2007, p. 67.

[9] T. Inaba: in *Automotive Engineering – Lightweight, Functional and Novel Materials*, Taylor and Francis, 2008, pp. 19–27.

2
Advanced materials for automotive applications: an overview

P. K. MALLICK, University of Michigan – Dearborn, USA

Abstract: With increasing demand on fuel economy improvement and emission control, there is great deal of interest in using advanced materials to produce lightweight vehicles. The advanced materials include advanced high strength steels, non-ferrous alloys, such as aluminum, magnesium and titanium alloys, and a variety of composites, including carbon fiber composites, metal matrix composites and nanocomposites. This chapter provides an overview of these materials and their current applications and potential applications in future automobiles.

Key words: advanced materials, advanced steels, aluminum alloys, magnesium alloys, titanium alloys, stainless steels, cast iron, composites, glazing materials.

2.1 Introduction

Vehicle weight reduction through material substitution is one of the key elements in the overall strategy for fuel economy improvement and emission control. While the principal material in current vehicles is plain carbon steels, there is now a great deal of interest in replacing them with advanced high strength steels, light non-ferrous alloys, such as aluminum, magnesium and titanium alloys, and a variety of composites, including carbon fiber composites, metal matrix composites and nanocomposites. This chapter is a broad overview of these materials and their applications in the automobiles.

2.1.1 Materials scenario

Plain carbon steel and cast iron were the workhorse materials in the automotive industry prior to 1970s. As shown in Table 2.1, even today steel is used in much larger quantities than any other material; however, high strength steels and advanced high strength steels, on account of their significantly higher strength, are now replacing plain carbon steels in several body structure and chassis applications. As a result, the amount of high strength and advanced high strength steels has increased in recent years, while the amount of plain carbon steels has decreased (Table 2.2). There is also an increasing use of aluminum alloys and polymer matrix composites. For example, the use of aluminum alloys in North American automobiles has increased from 2% of