Horst E. Friedrich
Barry L. Mordike
(Eds.)

Magnesium Technology

Metallurgy, Design Data, Applications

Springer

Horst E. Friedrich
Barry L. Mordike
(Eds.)

Magnesium Technology

Metallurgy, Design Data, Applications

Springer

Friedrich · Mordike
Magnesium Technology

Horst E. Friedrich · Barry L. Mordike

Magnesium Technology

Metallurgy, Design Data, Applications

With 590 Figures

Springer

Professor
Dr.-Ing. Horst E. Friedrich
Institut für Fahrzeugkonzepte (FK)
Deutsches Zentrum für Luft- und Raumfahrt (DLR) e.V.
in der Helmholtz-Gemeinschaft
Pfaffenwaldring 38–40
70569 Stuttgart
Germany
e-mail: Horst.Friedrich@dlr.de

Professor
Dr. Barry L. Mordike
Institut für Werkstoffkunde und Werkstofftechnik
TU Clausthal
Agricolastrasse 6
38678 Clausthal-Zellerfeld
Germany
e-mail: barrymordike@hotmail.com

Library of Congress Control Number 2005931991

ISBN-10 3-540-20599-3 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-20599-9 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media
springeronline.com

Printed in Germany

Cover design: deblik Berlin
Typesetting: Fotosatz-Service Köhler GmbH,Würzburg

Printed on acid-free paper 02/3141 xv – 5 4 3 2 1 0

Preface/Foreword

Magnesium was discovered and isolated as a chemical element in 1808 by Sir Humphrey Davy. The problem with its isolation was associated with its reactivity, which has haunted all those interested in using magnesium as components. The applications today must also consider the problems of corrosion. If we consider other properties e.g. elastic rigidity we find that the elastic constants are significantly lower than those of other metals. The yield strength or ultimate tensile strength is also poorer than most constructional metals.

The significant event at the beginning of the twentieth century was aviation and this changed the rules – it was the specific yield strength which was important and indeed much work was undertaken in the two wars to develop magnesium alloys for aviation. Magnesium had come of age and was used extensively in military aircraft during the Second World War. Thereafter, there was a slump in its use and apart from isolated applications was unable to compete with other metals, both from an economic and also technological standpoint.

In the nineteen-nineties a concentrated effort was made to solve many of the problems, which limited the widespread application of magnesium alloys. This effort was essentially global with producers and car manufacturers uniting so that magnesium becomes recognised as a structural material. One group was USA and Canada, another was Australia with CAST, Israel, Norsk Hydro, MEL and Germany. In this book we have authors covering all aspects of magnesium technology. For the first time in 50 years we are able to show which advances in component development have been made possible since the tome by Emley of MEL. The authors come from Germany, USA, Norway, Canada, Israel, Switzerland and the UK and have covered the following topics on a chapter or sub-chapter basis.

There have not been many books on magnesium. The first was Beck's "Magnesium und seine Legierungen", published in the 1930's, which was hurriedly translated into English. This was followed 25 years later by Emley's book, Principles of "Magnesium Technology". This was a comprehensive revue of the state of the art. Since that time there has been the ASM Handbook which provided a useful collation of the properties of magnesium alloys but did not attempt to update Emley.

There are nine chapters in this book. The first chapter covers the history until 1945 and also from 1945 to about 1990. The second chapter covers an extensive survey of 30 pages of various production technologies of magnesium. This is followed by a detailed presentation of the physical metallurgy, physical and mechanical constants, deformation behaviour, strengthening mechanisms, classifi-

cation of alloys, binary and higher phase diagrams, various MEL alloys and highly creep resistant alloys. Chapter 4 is devoted to melting, alloying and refining. Chapter 5 is a contribution by several authors of 70 pages to a detailed description of present day magnesium casting alloys. Chapter 6 covers the technology of magnesium and its alloys. This chapter of 200 pages discusses many aspects e.g. sand casting, casting defects, inspection, identification and elimination of defects. This is followed by a discussion of die casting, also squeeze casting and semi-solid casting with their associated properties. Rolling of magnesium and sheet metal forming is a recent important extension to magnesium technology. Extrusion is also discussed with alloy developments and novel extrusion methods. An important topic in this chapter is magnesium matrix composites. Joining and welding processes are also covered in this chapter. Alternative processes to welding, such as adhesive bonding technology, clinching, riveting, direct screwing, folding, hybrid joining are relatively new methods of joining magnesium. Machining of reinforced and un-reinforced magnesium alloys concludes this chapter.

Chapter 7 is dedicated to corrosion and surface protection and represents a chapter in which significant advances have been made and where some problems have been eliminated. Chapter 8 shows examples of automobile applications in Europe and North America together with concepts of life cycle inventory of vehicles, other applications such as hand tools, sports equipment, electronic equipment and aerospace. Barriers to magnesium are also discussed. In chapter 9 the problem of setting up a secondary recycling strategy for magnesium is discussed.

This book for the first time shows a wide spectrum of applications. Obviously, the automobile applications are particularly important as they could guarantee that a sufficient volume of magnesium is produced; ensuring that unit prices are low. The price competition is keen and there is still much to be achieved with wrought products, in particular.

Significant advances have been made in corrosion protection, joining technologies and recycling.

Horst E. Friedrich Barry L. Mordike

Dr. Horst E. Friedrich

Prof. Dr. H. E. Friedrich studied engineering at the Technical University of Munich. After working in the engineering and consultancy sectors, he took up a senior management position in the aeronautical industry in 1986. He was responsible for new methods of construction and new materials, aircraft engines and optimising product development times. In 1996, Prof. Friedrich joined Volkswagen AG in Wolfsburg as head of vehicle research, where at last he was head of Group research for materials technology and vehicle concepts. He specialised in innovative materials and construction methods, and concept vehicles for future vehicle specifications.

Since March 2004 he is director of the Institute of Vehicle Concepts at the German Aerospace Center in Stuttgart and professor at the University of Stuttgart. The research fields are Alternative Power Trains and Energy Conversion as well as Light Weight Design and Hybrid Construction methods.

Prof. Dr. Friedrich worked as Director of the Board of the International Magnesium Association (IMA) and has a lectureship at the Technical University of Berlin for materials and design in the transportation industry.

Prof. Dr Barry L. Mordike

Barry Mordike studied Physical Metallurgy at Birmingham University and completed his studies with BSc(Hons) Class1 in 1956. He then undertook research for his PhD in the Cavendish Laboratory, Department of Physics, University of Cambridge, completing his PhD in Summer 1959. He then continued research in the Institut für Metallphysik, Universität Göttingen as 'Wissenschaftlicher Assistent' to Prof. Peter Haasen. In September 1966 he took up a post as Senior Lecturer (C4 Professur) in the Department of Metallurgy, University of Liverpool, where he stayed until the end of1976.In Dec 1976 he was appointed to the newly created Chair of Materials Engineering and Technology at the Technical University of Clausthal. He remained at Clausthal until he became Emeritus Professor in October 1999.

Apart from his academic pursuits he created in 1989 a technology transfer company, Zentrum für Funktionswerkstoffe g.G.m.b.H(Clausthal) with the aid of Government funding. This enabled projects to be completed where industrial competence and confidentiality were necessary. In 2002 Prof. V. Neubert took over from him as General Manager.

Initially, his research interests concentrated on fundamental problems such as deformation processes, initiation of fatigue, crystal growth, strengthening mechanisms in metals. He changed his emphasis and developed interests in more applied research. Prior to going to Clausthal he started to work on magnesium alloys (1972), some aspects being supported by MEL (Elektron), Powder Metal-

lurgy (1973) and Laser Technology (1976). At Clausthal, he rapidly built up a considerable research potential and covered a wide range of subjects.

The period 1976 to 1999 will be remembered for its contribution to developing Laser Treatment of Materials, Magnesium 1972 – present day, Powder Metallurgy and Composite Materials, Surface Engineering, in particular, Plasma Immersion Technology.

List of Contributors

Eli Aghion
Department of Materials Engineering, Ben Gurion University of the Negev, P.O.B. 653, Beer Sheva 84105, Israel
e-mail: egyon@bgu.ac.il

Terje Kr. Aune
Advanced Magnesium Technologies Ltd, Level 9, 303 Coronation Drive, Milton, Queensland 4064, Australia

Robert E. Brown
226 Deer Trace, Prattville, Alabama 36067, USA
e-mail: magman6@aol.com

Dieter Brungs
Eversberg, Ober den Eschen 9, 59872 Meschede, Germany

Bernard Closset
Modal Technologies Inc., 8 Chemin de l'Ancien-Tir, 1252 Meinier, Switzerland
e-Mail: closset@deckpoint.ch

Gerald Cole
25800 Romany Way, Franklin, MI 48025-1197, USA
e-mail: geraldcole@peoplepc.com

Günter H. Deinzer
Entwicklung/Werkstoffe AUDI Ingolstadt, Germany
e-mail: guenter.deinzer@audi.de

Berend Denkena
Institut für Fertigungstechnik und Werkzeugmaschinen, Produktionstechnisches Zentrum, Universität Hannover, Schönebecker Allee 2, 30823 Garbsen, Germany
e-mail: denkena@ifw.uni-hannover.de

Hajo Dieringa
GKSS-Forschungszentrum Geesthacht Gmbh, Institut für Werkstoffforschung, Max-Planck-Straße 1, 21502 Geesthacht, Germany
e-mail: hajo.dieringa@gkss.de

Dan Eliezer
Department of Materials Engineering, Ben Gurion University of the Negev, P.O.B. 653, Beer Sheva 84105, Israel
e-mail: deliezer@bgumail.bgu.ac.il

Steve Erickson
e-mail: serickson@iglide.net

Horst E. Friedrich
Institut für Fahrzeugkonzepte (FK), Deutsches Zentrum für Luft- und Raumfahrt (DLR) e.V. in der Helmholtz-Gemeinschaft, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany
e-mail: horst.friedrich@dlr.de

Francis H. Froes
University of Idaho, Institute for Materials and Advanced Processes, College of Engineering, McClure Building, Room 437, Moscow, Idaho 83844-3026, USA
e-mail: imap@uidaho.edu

Gilad Golub
Environmental Services Co. Ltd, Ramat Hovav, P.O. Box 5743, Beer Sheva 84156, Israel

Kurt Harbodt
Reiherstraße 44, 50997 Köln, Germany
e-mail: kharbodt@t-online.de

Otto-Diedrich Hennemann
Fraunhofer Institut, Fertigungstechnik und angewandte Materialforschung, Wiener Straße 12, 28359 Bremen, Germany
e-mail: hen@ifam.fhg.de

Jim Hillis
1027 Riverview Ranch Dr., Brazoria, TX 77422, USA
e-Mail: jehillis@direcway.com

Norbert Hort
GKSS-Forschungszentrum Geesthacht Gmbh, Institut für Werkstoffforschung, Max-Planck-Straße 1, 21502 Geesthacht, Germany
e-mail: norbert.hort@gkss.de

Peter Juchmann
Salzgitter Magnesium-Technologie AG, Eisenhüttenstr. 99, 38239 Salzgitter, Germany
e-mail: juchmann.p@salzgitter-ag.de

Karl Ulrich Kainer
GKSS-Forschungszentrum Geesthacht Gmbh, Institut für Werkstoffforschung, Max-Planck-Straße 1, 21502 Geesthacht, Germany
e-mail: karl.kainer@gkss.de

Catrin Kammer
METALL-Fachzeitschrift für Metallurgie, Kielsche Str. 43B, 38642 Goslar, Germany
e-mail: kammer@t-online.de

Helmut Kaufmann
ARC, Leichtmetallkompetenzzentrum Ranshofen GmbH, Postfach 26, 5282 Ranshofen, Austria
e-mail: helmut.kaufmann@arcs.ac.at

John F. King
19, Brookside Crescent, Greenmount, Bury, BL8 4BG, United Kingdom
e-mail: jking.mel@btopenworld.com

Simon Kleiner
EMPA, Feuerwerkerstr. 39, 3602 Thun, Switzerland
e-mail: simon.kleiner@empa.ch

Sanday Thakar Kumar
Singapore Institute of Manufacturing Technology, Forming Technology Group, 71, Nanyang Drive, Singapore 638075
e-mail: thankur@SIM Tech.a-star.edu.sg

Peter Kurze
AHC-Oberflächentechnik GmbH & Co. KG OGH, Postfach 00 21 49, 50151 Kerpen, Germany
e-mail: info@ahc-surface.com

Pavel Lukáč
Department of Metalphysics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, 12116 Praha 2, Czechia
e-mail: lukac@met.mff.cuni.cz

Andreas Mertz
Am Stockfeld 24, 66539 Neunkirchen, Germany
e-mail: amertz@gmx.net

Gerson Meschut
Wilhelm Böllhof GmbH & Co. KG, Archimedesstraße, 33649 Bielefeld, Germany
e-mail: gmeschut@boellhof.com

Barry L. Mordike
Institut für Werkstoffkunde und Werkstofftechnik, TU Clausthal, Agricolastraße 6, 38678 Clausthal-Zellerfeld, Germany
e-mail: barrymordike@hotmail.com

Mihriban Pekguleryuz
McGill University, Department of Mining and Mettallurgical Engineering, 3610 University Street, Monreal, QC H3A 2B2, Canada
e-mail: mihriban.pekguleryuz@mcgill.ca

Christian Podolsky
Pfalzstr.10, 30173 Hannover, Germany

Michael Rethmeier
Volkswagen AG, Wolfsburg, Germany
e-mail: michael.rethmeier@volkswagen.de

Soenke Schumann
Volkswagen AG, Konzernforschung, Werkstofftechnik/Metalle, Brieffach 1511, 38436 Wolfsburg, Germany
e-mail: soenke.schumann@volkswagen.de

Hans Kurt Tönshoff
Universität Hannover Institute of Production Engineering and Machine Tools(IFW), Schlosswender Straße 5, 30159 Hannover, Germany
e-mail: toenshoff@ ifw.uni-hannover.de

Håkon Westengen
Norsk Hydro ASA, Research Centre Porsgrunn, Forskingsparken Heroya, 3907 Porsgrunn, Norway
e-mail: hakon.westengen@hydro.com

Jens Winkler
Continental AG, Jädekamp 30, 30419 Hannover, Germany
e-mail: jens.winkler@conti.de

Contents