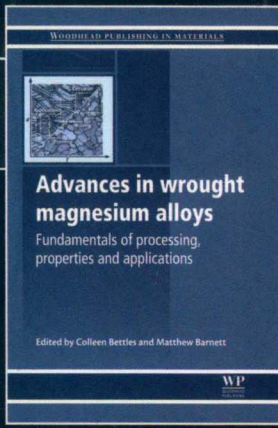




ELSEVIER

国际材料前沿丛书
International Materials Frontier Series



Advances in wrought
magnesium alloys

Fundamentals of processing,
properties and applications

Edited by Colleen Bettles and Matthew Barnett

WP

Colleen Bettles,
Matthew Barnett 编著

变形镁合金研究进展： 加工原理、性能和应用

Advances in Wrought Magnesium Alloys:
Fundamentals of Processing,
Properties and Applications

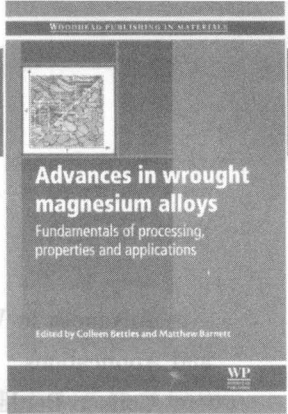
影印版



中南大学出版社
www.csupress.com.cn



国际材料前沿丛书
International Materials Frontier Series

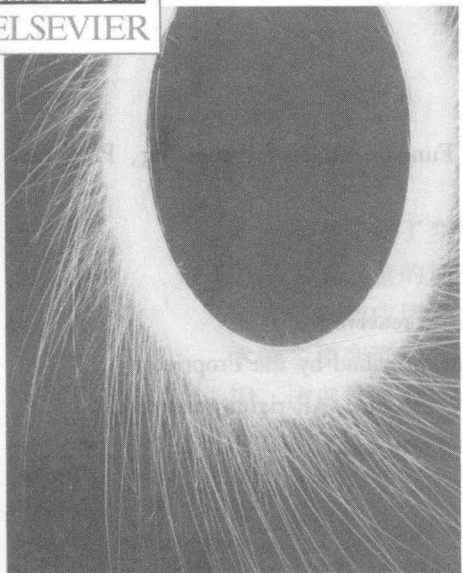


Advances in wrought magnesium alloys

Fundamentals of processing, properties and applications

Edited by Colleen Bettles and Matthew Barnett

WP



内容简介

Colleen Bettles,
Matthew Barnett 编著

变形镁合金研究进展： 加工原理、性能和应用

Advances in Wrought Magnesium Alloys:
Fundamentals of Processing,
Properties and Applications

影印版



中南大学出版社
www.csupress.com.cn

·长沙·

图书在版编目(CIP)数据

变形镁合金研究进展:加工原理、性能和应用:英文 / (澳)科琳·贝特尔(Colleen Bettles), (澳)马修·巴尼特(Matthew Barnett)编著. --长沙:中南大学出版社, 2017. 10

ISBN 978-7-5487-2991-4

I. ①变… II. ①科… ②马… III. ①镁合金—研究—英文 IV. ①TG146.22

中国版本图书馆CIP数据核字(2017)第230377号

变形镁合金研究进展:加工原理、性能和应用
BIANXING MEIHEJIN YANJIU JINZHAN: JIAGONGYUANLI,
XINGNENG HE YINGYONG

Colleen Bettles Matthew Barnett 编著

-
- 责任编辑 史海燕
责任印制 易红卫
出版发行 中南大学出版社
社址:长沙市麓山南路 邮编:410083
发行科电话:0731-88876770 传真:0731-88710482
印 装 长沙超峰印刷有限公司

-
- 开 本 720×1000 1/16 印张 30.25 字数 766千字
版 次 2017年10月第1版 2017年10月第1次印刷
书 号 ISBN 978-7-5487-2991-4
定 价 150.00元
-

图书出现印装问题,请与经销商调换

内容简介

本书介绍了变形镁合金的类型与性能、加工工艺以及应用。总结了镁合金的加工过程对其性能的影响，讨论了可用于开发新一代高性能应用合金的方法，介绍了铸造、挤压、轧制和锻造技术的主要变形行为以及锻造镁合金在汽车和生物医学工程中的应用。该书作者 Colleen Bettles 教授为澳大利亚莫纳什大学轻金属设计优化 ARC 中心副主任，Matthew Barnett 为墨尔本迪肯大学教授。该书为变形镁合金领域的必备参考书，适用于镁合金材料技术、研究人员以及相关本科生、研究生使用。

序

“最早的商用合金含有铝、锌、锰、硅和铈，这些元素仍然是当今绝大多数商用二元和三元合金的主要成分。”1940年W. Buchmann这样写道，当时全世界镁的产量正呈上升趋势。70多年后，这些话大体上还是没有错的。

70多年来，镁的产量波动明显，但最近镁及镁合金在越来越多的主流应用方面已经复苏。传统上，铸造一直是镁合金占主导地位的加工路线，但在过去十年中变形镁合金已在许多结构应用中变得重要。

市场对镁合金的最终性能要求越来越高，而希望价格越来越低。变形镁合金产品的未来将高度依赖巧妙的合金设计(结合化学和镁合金基本变形行为的理解)和优化的二次加工阶段，例如轧制、锻造和挤压。

本书提供了一个独特的机会，让来自众多不同学科的专家同心协力，推动变形镁合金成功实现在非尖端领域的广泛应用。这本书分为3个部分，首先介绍最新发展趋势，我们可能最后会脱离W. Buchmann的观点，接下来探讨变形行为的最重要的基本原理。这些章节是优化加工步骤的基础，且第2部分着重阐述大量不同加工工艺。结论章节讨论未来变形镁合金产品的应用。

我们要感谢本书的所有撰稿人，他们为本书付出了辛勤劳动，作出了专业贡献。我们还要感谢伍德海德出版社的编辑人员，他们提出出版变形镁合金著作的建议并将相关内容汇集，使本书出版成为可能。

Contributor contact details

(* = main contact)

Editors

C. J. Bettles*
ARC Centre of Excellence for
Design in Light Metals
Department of Materials
Engineering
Building 27, Clayton Campus
Monash University
Victoria 3800
Australia
Email: colleen.bettles@monash.edu

M. R. Barnett
ARC Centre of Excellence for
Design in Light Metals
Institute for Frontier Materials
Deakin University
Geelong
Victoria 3217
Australia
Email: matthew.barnett@deakin.edu.au

Chapter 1

M. O. Pegguleryuz
Department of Mining and Materials
Engineering
Wong Building, Rm2m090

McGill University
3610 University Street
Montreal
Quebec H3A 2B2
Canada
Email: mihriban.pekguleryuz@mcgill.ca

Chapter 2

S. R. Agnew
Department of Materials Science
and Engineering
University of Virginia
Charlottesville
Virginia 22904-4745
USA
Email: agnew@virginia.edu

Chapter 3

M. R. Barnett
ARC Centre of Excellence for
Design in Light Metals
Institute for Frontier Materials
Deakin University
Geelong
Victoria 3217
Australia
Email: matthew.barnett@deakin.edu.au

Chapter 4

R. Lapovok* and Y. Estrin
Centre for Advanced Hybrid
Materials
Department of Materials
Engineering
Monash University
Clayton
Victoria 3800
Australia
Email: Rimma.Lapovok@monash.edu

Chapter 5

R. Kaibyshev
Belgorod State University
Pobeda 85
Belgorod 308015
Russia
Email: rustam_kaibyshev@bsu.edu.ru

Chapter 6

J. F. Grandfield
Grandfield Technology Pty Ltd
37 Mattingley Crescent
Brunswick West
Victoria 3055
Australia
Email: grandfieldtechnology@gmail.com

Chapter 7

E. Essadiqi*
CANMET Materials Technology
Laboratory
183 Longwood Road South
Hamilton
Ontario L8P 0A1
Canada
Email: essadiqi@NRCan.gc.ca

I.-H. Pung
Mc Gill University, Canada

M. A. Wells
University of Waterloo, Canada

Chapter 8

A. G. Beer
CAST Cooperative Research Centre
Institute for Frontier Materials
Deakin University
Locked Bag 20000
Geelong
Victoria 3220
Australia
Email: aiden.beer@deakin.edu.au

Chapter 9

W. H. Sillekens*
TNO
P.O. Box 6235
5600 HE Eindhoven
The Netherlands
Email: wim.sillekens@tno.nl

J. Bohlen
Magnesium Innovation Centre
MagIC
Helmholtz-Zentrum Geesthacht
Max-Planck-Str. 1
21502 Geesthacht
Germany
Email: jan.bohlen@hzg.de

Chapter 10

J. Bohlen*, G. Kurz, S. Yi and
D. Letzig
Magnesium Innovation Centre
MagIC

Helmholtz-Zentrum Geesthacht
Max-Planck-Str. 1
21502 Geesthacht
Germany
Email: jan.bohlen@hzg.de

Chapter 11

B.-A. Behrens, I. Pfeiffer*
and J. Knigge
Institute of Forming Technology and
Machines
Leibniz Universität Hannover
An der Universität 2
30823 Garbsen
Germany
Email: pfeiffer@ifum.uni-hannover.de

Chapter 12

A. A. Luo* and A. K. Sachdev
Light Metals for Powertrain and
Structural Subsystems Group
Chemical Sciences & Materials
Systems Lab

General Motors Global Research
and Development
30500 Mound Road
Mail Code 480-106-224
Warren
Michigan 48090-9055
USA
Email: alan.luo@gm.com

Chapter 13

W. H. Sillekens*
TNO
P.O. Box 6235
5600 HE Eindhoven
The Netherlands
Email: wim.sillekens@tno.nl

D. Bormann
Institute of Materials Science
Leibniz Universität Hannover
An der Universität 2
30823 Garbsen
Germany

Introduction

C. BETTLES, Monash University, Australia and
M. BARNETT, Deakin University, Australia

‘Even the earliest of these commercial alloys contained aluminium, zinc, manganese, silicon, as well as cerium, all of which remain today the principal constituents of the majority of commercial binary and ternary alloys’. So wrote W. Buchmann¹ in 1940, when the world-wide production of magnesium was on an upwards trajectory. Those words are still true today, by and large, some 70 years later.

Production tonnages have fluctuated markedly over this time but recently we have seen a resurgence in the use of magnesium and its alloys in an increasing number of mainstream applications. Traditionally, casting has been the dominant processing route, but in the last decade wrought products have found a place in many structural applications.

The final property requirements have been increasing, seemingly in an inverse fashion to pricing requirements. The future of wrought magnesium products will be highly dependent on clever alloy design (combining chemistry and an understanding of the fundamental deformation behaviours of magnesium alloys) and optimisation of the secondary processing stages such as rolling, forging and extrusion.

This book provided a unique opportunity to bring together experts from the many and varied disciplines that are necessary to successfully achieve the widespread adoption of wrought magnesium in non-niche applications. The book is divided broadly into three parts, beginning with an update on alloy trends, showing that we may at last be breaking away from the comment by Buchmann, and following this with chapters discussing the most important fundamental aspects of deformation behaviour. These chapters are the building blocks from which the optimisation of the processing steps can be constructed, and the second part of the book looks at a number of different processing routes. The concluding chapters are used to discuss the applications that will be available to wrought magnesium products in the future.

We would like to thank all the contributors to this book for their hard work and dedication to their particular fields of endeavour. We would also like to thank the editorial staff at Woodhead Publishing for firstly suggesting that wrought

magnesium deserved a book of its own, and secondly for all their efforts in bringing the contents together and making the book possible.

Reference

1. Buchmann, W. (1940). In *The Technology of Magnesium and its Alloys*. Ed: Beck, A. London, FA Hughes.

目 录

作者联系方式 ix

绪论 xiii

第一部分 镁合金的类型与性能

1 变形镁合金的研究和开发 3

1.1 变形镁合金发展概况 3

1.2 变形镁合金发展现状 6

1.3 变形镁合金研究进展 31

1.4 变形镁合金发展趋势 55

1.5 参考文献 59

2 镁合金的变形机制 63

2.1 引言 63

2.2 基面滑移 65

2.3 $\langle a \rangle$ 型位错非基面滑移 72

2.4 $\langle c+a \rangle$ 型位错非基面滑移 78

2.5 形变孪生 83

2.6 动态形变 90

2.7 结论 92

2.8 致谢 93

2.9 参考文献 93

3 孪生及其在变形镁合金中的作用 105

3.1 引言 105

3.2 孪生的基本原理 107

3.3 孪生对力学响应的影响 118

3.4 结构和工艺对孪生的影响 125

3.5 结论 136

3.6 致谢 136

3.7 参考文献 136

4 大塑性变形镁合金的超塑性 144

4.1 引言 144

4.2 热机械加工过程中的微观组织演变 147

4.3 超塑性行为 157

4.4 超塑性变形中的断裂 168

4.5 形变机制与模型 175

4.6 结论 179

4.7 参考文献 179

5 镁合金的动态再结晶 186

5.1 引言 186

5.2 镁合金的动态再结晶机制 187

5.3	原始组织对动态再结晶的影响	207
5.4	不同镁合金中的动态再结晶	211
5.5	大塑性变形过程中的动态再结晶	215
5.6	结论	218
5.7	致谢	219
5.8	参考文献	219

第二部分 镁合金的加工

6	镁合金挤压坯与轧制厚板的直接激冷铸造	229
6.1	引言	229
6.2	热流与流体流	235
6.3	镁合金直接激冷铸造技术与工程学	245
6.4	凝固组织与缺陷形成	249
6.5	结论	261
6.6	参考文献	262
7	镁合金的双辊铸轧	272
7.1	引言	272
7.2	工业前景	274
7.3	双辊铸轧工艺	276
7.4	凝固与带状组织	282
7.5	热力学计算	284
7.6	过程模拟与仿真	292
7.7	结论	300
7.8	参考文献	300

8	提高变形镁合金的可挤压性	304
8.1	引言	304
8.2	变形镁合金的可挤压性	305
8.3	挤压过程中的微观组织变化	309
8.4	镁合金挤压研究进展	319
8.5	结论	321
8.6	参考文献	321
9	镁合金的静液挤压	323
9.1	引言	323
9.2	工艺基础	324
9.3	研究与开发	333
9.4	发展趋势	342
9.5	延伸阅读	343
9.6	结论	343
9.7	参考文献	344
10	镁合金的轧制	346
10.1	引言	346
10.2	镁薄板的发展前景	347
10.3	薄板轧制工艺及其对性能的影响	348
10.4	合金化对薄板性能的影响	354
10.5	镁薄板的可成形性	362
10.6	使能技术与发展趋势	365
10.7	延伸阅读	368
10.8	参考文献	370
11	镁合金的锻造技术	376
11.1	引言	376

Contents

<i>Contributor contact details</i>	<i>ix</i>
<i>Introduction</i>	<i>xiii</i>
Part I Types and properties of magnesium alloys	1
1 Current developments in wrought magnesium alloys	3
M. O. PEKGULERYUZ, McGill University, Canada	
1.1 Introduction: overview of wrought magnesium alloy development	3
1.2 Current developments in magnesium wrought alloys	6
1.3 Progress in wrought magnesium alloys	31
1.4 Future trends in wrought magnesium alloy development	55
1.5 References	59
2 Deformation mechanisms of magnesium alloys	63
S. R. AGNEW, University of Virginia, USA	
2.1 Introduction	63
2.2 Basal slip	65
2.3 Non-basal slip of <a> type dislocations	72
2.4 Non-basal slip of <c+a> type dislocations	78
2.5 Deformation twinning	83
2.6 Dynamic deformation	90
2.7 Conclusions	92
2.8 Acknowledgements	93
2.9 References	93
3 Twinning and its role in wrought magnesium alloys	105
M. R. BARNETT, Deakin University, Australia	
3.1 Introduction	105
3.2 Fundamentals of twinning	107
3.3 The impact of twinning on mechanical response	118
3.4 The impact of structure and processing on twinning	125

vi	Contents	
3.5	Conclusion	136
3.6	Acknowledgements	136
3.7	References	136
4	Superplasticity in magnesium alloys by severe plastic deformation	144
	R. LAPOVOK and Y. ESTRIN, Monash University, Australia	
4.1	Introduction	144
4.2	Microstructure evolution during thermomechanical processing	147
4.3	Superplastic behaviour	157
4.4	Fracture during superplastic deformation	168
4.5	Mechanisms and models	175
4.6	Conclusions	179
4.7	References	179
5	Dynamic recrystallization in magnesium alloys	186
	R. KAIBYSHEV, Belgorod State University, Russia	
5.1	Introduction	186
5.2	Dynamic recrystallization (DRX) mechanisms operating in magnesium alloys	187
5.3	Effect of initial structure on DRX	207
5.4	DRX in different magnesium alloys	211
5.5	DRX during severe plastic deformation	215
5.6	Conclusions	218
5.7	Acknowledgements	219
5.8	References	219
Part II	Processing of magnesium alloys	227
6	Direct chill casting of magnesium extrusion billet and rolling slab	229
	J. F. GRANDFIELD, Grandfield Technology Pty Ltd, Australia	
6.1	Introduction	229
6.2	Heat and fluid flow	235
6.3	Magnesium direct chill (DC) casting technology and engineering	245
6.4	Solidified structures and defect formation	249
6.5	Conclusions	261
6.6	References	262
7	Twin roll casting of magnesium	272
	E. ESSADIQI, CANMET Materials Technology Laboratory, Canada, I.-H. JUNG, McGill University, Canada and M. A. WELLS, University of Waterloo, Canada	
7.1	Introduction	272
7.2	Industrial perspective	274

7.3	Twin roll casting (TRC) process	276
7.4	Solidification and strip microstructure	282
7.5	Thermodynamic calculations	284
7.6	Process modeling and simulation	292
7.7	Conclusions	300
7.8	References	300
8	Enhancing the extrudability of wrought magnesium alloys	304
	A. G. BEER, Deakin University, Australia	
8.1	Introduction	304
8.2	Extrudability of magnesium alloys	305
8.3	Microstructural development during extrusion	309
8.4	Recent extrusion alloy development	319
8.5	Conclusions	321
8.6	References	321
9	Hydrostatic extrusion of magnesium alloys	323
	W. H. SILLEKENS, TNO, The Netherlands and J. BOHLEN, Helmholtz-Zentrum Geesthacht, Germany	
9.1	Introduction	323
9.2	Process basics	324
9.3	Research and development issues	333
9.4	Future trends	342
9.5	Sources of further information	343
9.6	Conclusions	343
9.7	References	344
10	Rolling of magnesium alloys	346
	J. BOHLEN, G. KURZ, S. YI and D. LETZIG, Helmholtz-Zentrum Geesthacht, Germany	
10.1	Introduction	346
10.2	Potential of magnesium sheets	347
10.3	The sheet rolling process and its influence on sheet properties	348
10.4	Alloying effects on sheet properties	354
10.5	Formability of magnesium sheets	362
10.6	Enabling technologies and future trends	365
10.7	Sources of further information	368
10.8	References	370
11	Forging technology for magnesium alloys	376
	B.-A. BEHRENS, I. PFEIFFER and J. KNIGGE, Leibniz Universität Hannover, Germany	
11.1	Introduction	376
11.2	Forging technology	376

11.3	Forging of magnesium alloys	378
11.4	Near-net-shape forming of magnesium alloys	384
11.5	Conclusions	388
11.6	Acknowledgements	389
11.7	References	389
Part III Applications of magnesium alloys		391
12	Applications of magnesium alloys in automotive engineering	393
	A. A. LUO and A. K. SACHDEV, General Motors Global Research and Development, USA	
12.1	Introduction	393
12.2	Materials properties	394
12.3	Alloy development	398
12.4	Manufacturing process development	408
12.5	Automotive applications of magnesium alloys	413
12.6	Future trends	417
12.7	Conclusions	421
12.8	Acknowledgements	421
12.9	References	422
13	Biomedical applications of magnesium alloys	427
	W. H. SILLEKENS, TNO, The Netherlands and D. BORMANN, Leibniz Universität Hannover, Germany	
13.1	Introduction	427
13.2	Functionality of magnesium implants	429
13.3	Cardiovascular implants	440
13.4	Orthopaedic and other implants	445
13.5	Future trends	449
13.6	Sources of further information	451
13.7	Conclusions	452
13.8	References	453
	<i>Index</i>	455