

Engineering Materials

The “Engineering Materials” series provides topical information on innovative, structural and functional materials and composites with applications in optical, electrical, mechanical, civil, aeronautical, medical, bio and nano engineering. The individual volumes are complete, comprehensive monographs covering the structure, properties, manufacturing process and applications of these materials. This multidisciplinary series is devoted to professionals, students and all those interested in the latest developments in the Materials Science field.

More information about this series at <http://www.springer.com/series/4288>

Lorella Ceschini · Arne Dahle
Manoj Gupta · Anders Eric Wollmar Jarfors
S. Jayalakshmi · Alessandro Morri
Fabio Rotundo · Stefania Toschi
R. Arvind Singh

Aluminum and Magnesium Metal Matrix Nanocomposites

Lorella Ceschini
Department of Industrial Engineering (DIN)
Alma Mater Studiorum–University of Bologna
Bologna
Italy

Arne Dahle
School of Engineering
Jönköping University
Jönköping
Sweden

Manoj Gupta
Department of Mechanical Engineering
National University of Singapore
Singapore
Singapore

Anders Eric Wollmar Jarfors
School of Engineering
Jönköping University
Jönköping
Sweden

S. Jayalakshmi
Department of Mechanical Engineering
Bannari Amman Institute of Technology (BIT)
Sathyamangalam, Tamil Nadu
India

Alessandro Morri
Interdepartmental Center for Industrial
Research-Advanced Mechanics and Materials
(CIRI-MAM)
Alma Mater Studiorum–University of Bologna
Bologna
Italy

Fabio Rotundo
Interdepartmental Center for Industrial
Research-Advanced Mechanics and Materials
(CIRI-MAM)
Alma Mater Studiorum–University of Bologna
Bologna
Italy

Stefania Toschi
Department of Industrial Engineering (DIN)
Alma Mater Studiorum–University of Bologna
Bologna
Italy

R. Arvind Singh
Department of Aeronautical Engineering
Bannari Amman Institute of Technology (BIT)
Sathyamangalam, Tamil Nadu
India

This book was advertised with a copyright holder in the name of the author in error, whereas the publisher holds the copyright.

ISSN 1612-1317
Engineering Materials
ISBN 978-981-10-2680-5
DOI 10.1007/978-981-10-2681-2

ISSN 1868-1212 (electronic)
ISBN 978-981-10-2681-2 (eBook)

Library of Congress Control Number: 2016953648

© Springer Nature Singapore Pte Ltd. 2017

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #22-06/08 Gateway East, Singapore 189721, Singapore

Preface

Lightweight materials are getting critically important for weight-saving engineering and biomedical sectors. The use of these materials is getting increasingly important for sustainable planet earth and human comfort. Aluminum and magnesium are two lightweight materials that are of paramount importance for engineers and material selectors. Efforts have been made in past few decades to evolve these two principal elements so that they can cater to a wider spectrum of applications. Composite technology utilizing micron length scale reinforcement was used actively in the past century to realize properties beyond the common alloying technique to enhance certain properties such as elastic modulus, strength, wear and damping response. With the advent of nanotechnology in the late 1990s, researchers worldwide started to use reinforcements at nano-length scale (<100 nm). The resultant nanocomposites exhibited superior combination of properties when compared to micro-composites with significantly reduced weight penalty. In view of significantly different response of elemental matrix in the presence of reinforcement at nano-length scale, it was realized by authors to put together current level of understanding of aluminum and magnesium based nanocomposites. It is hoped that this book will serve as a useful reference for students, teachers, engineers, and researchers to gain understanding of these fascinating materials.

Bologna, Italy

Jönköping, Sweden

Singapore, Singapore

Jönköping, Sweden

Tamil Nadu, India

Bologna, Italy

Bologna, Italy

Bologna, Italy

Tamil Nadu, India

Lorella Ceschini

Arne Dahle

Manoj Gupta

Anders Eric Wollmar Jarfors

S. Jayalakshmi

Alessandro Morri

Fabio Rotundo

Stefania Toschi

R. Arvind Singh

Acknowledgments

Authors would like to take this opportunity to express their heartiest gratitude to all the people who have contributed to and assisted with the publication of this book. We would particularly wish to express our sincere thanks to our families for their constant support and understanding.

Contents

1 Metal Matrix Nanocomposites: An Overview	1
1.1 Metal Matrix Nanocomposites	1
1.2 Strengthening Mechanisms	2
1.2.1 Modelling	4
1.3 Al-Based Nanocomposites	8
1.4 Mg-Based Nanocomposites	10
References	13
2 Ex Situ Production Routes for Metal Matrix Nanocomposites	19
2.1 Liquid State Processes	19
2.2 Solid State Routes	24
2.3 Semi-solid State Processes	28
2.4 Hybrid Methods and Other Routes	30
2.4.1 Other Processes	31
References	33
3 Casting Routes for the Production of Al and Mg Based Nanocomposites	41
3.1 Stir Casting	41
3.1.1 Process Description	41
3.1.2 Al-Based Nanocomposites	42
3.1.3 Mg-Based Nanocomposites	52
3.2 Compcasting	54
3.2.1 Process Description	54
3.2.2 Al-Based Nanocomposites	55
3.2.3 Mg-Based Nanocomposites	59
3.3 Ultrasonic Assisted Casting	61
3.3.1 Process Description	61
3.3.2 Al-Based Nanocomposites	62
3.3.3 Mg-Based Nanocomposites	66

3.4	Disintegrated Melt Deposition (DMD)	76
3.4.1	Process Description	76
3.4.2	Pure Mg-Based Nanocomposites	78
3.4.3	Mg-Alloys Based Nanocomposites	80
	References.	87
4	Mechanical Behavior of Al and Mg Based Nanocomposites.	95
4.1	Al-Based Nanocomposites	95
4.1.1	Room Temperature Mechanical Properties	95
4.1.2	High Temperature Mechanical Properties	118
4.2	Mg-Based Nanocomposites.	118
4.2.1	Room Temperature Mechanical Properties	118
4.2.2	High Temperature Mechanical Properties	129
	References.	131
5	Tribological Characteristics of Al and Mg Nanocomposites.	139
5.1	Al-Based Nanocomposites	139
5.2	Mg-Based Nanocomposites.	147
	References.	150
6	Future Directions.	153
6.1	Industry-Level Translation	153
6.2	Product-Level Translation.	155
6.3	Other Critical Properties to be Investigated	156
6.3.1	Fatigue	156
6.3.2	Corrosion/Oxidation	157
6.4	Recycling Issues.	159
	References.	159
	Concluding Remarks	161
	Index	163

Abbreviations

ADZ	Alumina Depleted Zones
ARB	Accumulative Roll Bonding
BM	Ball Milling
BPR	Ball-to-Powder Ratio
CARB	Cross Accumulative Roll Bonding
CMA	Complex Metallic Alloys
CNF	Carbon Nanofiber
CNT	Carbon Nanotube
CP	Cold Pressing
CRP	Continuous Rheo-conversion Process
CRSS	Critical Resolved Shear Stress
CTE	Coefficient of Thermal Expansion
CYS	Compressive Yield Strength
DMD	Disintegrated Melt Deposition
DRA	Discontinuously Reinforced Aluminium composite
EBS	Electron Backscatter Diffraction
ECAP	Equal Channel Angular Pressing
EDS	Energy Dispersive X-ray Spectroscopy
EM	Elastic Modulus
EPMA	Electron Probe Microscopic Analysis
FESEM	Field Emission Scanning Electron Microscopy
FSP	Friction Stir Processing
GISS	Gas Induced Semi-Solid process
GNP	Graphene Nanoplatelet
HB	Brinell Hardness
HCF	High Cycle Fatigue
HE	Hot Extrusion
HIP	Hot Isostatic Pressing
H-NCM	Hong-Nano Casting Method
HPDC	High Pressure Die Casting

HRTEM	High Resolution Transmission Electron Microscopy
HV	Vickers Hardness
MA	Mechanical Alloying
MMCs	Metal Matrix Composites
MML	Mechanically Mixed Layer
MMNCs	Magnesium Matrix Nanocomposites
MPF	Master Powder Feeding
MW(C)NT	Multi-Walled Carbon Nanotube
NC-US	Non Contact Ultrasonic treatment
ND	Normal Direction
NDZ	Nano-alumina Dispersed Zones
NPs	NanoParticulates or Nanoparticles
NRC	New Rheo Casting process
PCA	Process Control Agent
PM	Powder Metallurgy
RDC	Rheo Die Casting process
RM	Reaction Milling
RSF	Rapid Slurry Forming
SADP	Selected Area Diffraction Pattern
SAED	Selected Area Electron Diffraction
SDAS	Secondary Dendrite Arm Spacing
SEM	Scanning Electron Microscopy
SL	Semisolid-Liquid
SLC	Sub-Liquidus Casting
SLM	Selective Laser Melting
SPS	Spark Plasma Sintering
SS	Semisolid-Semisolid
SSM	Semi-Solid Metal
SSR	Semi-Solid Rheo casting
TEM	Transmission Electron Microscopy
TSRM	Twin Screw Rheo Moulding
TYS	Tensile Yield Strength
UCS	Ultimate Compressive Strength
UFG	Ultra-Fine Grained
US	Ultrasonic treatment
UTS	Ultimate Tensile Strength
vol.%	Volume fraction
wt.%	Weight fraction
XRD	X-Ray Diffraction
YS	Yield Strength