WOODHEAD PUBLISHING REVIEWS
MECHANICAL ENGINEERING

Machining and machine-tools

Research and development

Edited by J. Paulo Davim

WP
WOODHEAD
PUBLISHING

Woodhead Publishing Reviews: Mechanical Engineering

Machining and machine-tools

Research and development

EDITED BY
J. PAULO DAVIM

WP
WOODHEAD
PUBLISHING

Oxford Cambridge Philadelphia New Delhi

Published by Woodhead Publishing Limited, 2013

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 in 2013, 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: 2012954745

Woodhead Publishing ISBN: 978-0-85709-154-3 (print)
ISBN: 978-0-85709-219-9 (online)

Woodhead Publishing Reviews: Mechanical Engineering
ISSN: 2048-0571 (print) and ISSN: 2048-058X (online)

Typeset by Domex e-Data Pvt. Ltd., India
Printed in the UK and USA.

Machining and machine-tools

Woodhead Publishing Reviews:

Mechanical Engineering

Series Editor: Professor J. Paulo Davim,
Department of Mechanical Engineering, University of Aveiro,
Portugal and Head of MACTRIB – Machining and Tribology Research Group
(email: pdavim@ua.pt)

Woodhead Publishing is pleased to publish this major Series of books entitled *Woodhead Publishing Reviews: Mechanical Engineering*. The Series Editor is Professor J. Paulo Davim, Department of Mechanical Engineering, University of Aveiro, Portugal and Head of MACTRIB – Machining and Tribology Research Group.

This research Series publishes refereed, high-quality articles with a special emphasis on research and development in mechanical engineering from a number of perspectives including (but not limited to): machining and machine tools; tribology and surface engineering; materials and manufacturing processes; solid mechanics and structural mechanics; computational mechanics and optimization; mechatronics and robotics; fluid mechanics and heat transfer; renewable energies; biomechanics; micro- and nano-mechanics, etc. We seek authors, editors and contributors from a broad range of areas within the mechanical engineering discipline.

This Series examines current practices and possible future developments within the research field and industry-at-large. It is aimed at an international market of academics, practitioners and professionals working in the area. The books have been specially commissioned from leading authors, with the objective of providing the reader with an authoritative view of current thinking.

New authors: we would be delighted to hear from you if you have an idea for a book. We are interested in both shorter, practically orientated publications (45 000+ words) and longer, theoretical monographs (75 000–100 000 words). Our books can be single, joint or multi-author volumes. If you have an idea for a book, please contact the publishers or Professor J. Paulo Davim, the Series Editor.

Published by Woodhead Publishing Limited, 2013

Dr Glyn Jones
Woodhead Publishing Limited
Email: gjones@chandospublishing.com
www.woodheadpublishing.com

Professor J. Paulo Davim
Department of Mechanical Engineering,
University of Aveiro, Portugal
Email: pdavim@ua.pt
http://www2.mec.ua.pt/machining/pers-davim.htm

Woodhead Publishing Limited: established in 1989, Woodhead Publishing is a leading independent international publisher, publishing in the following main areas: food science, technology and nutrition; materials engineering; welding and metallurgy; textile technology; environmental technology; finance, commodities and investment; and mathematics.

Our ambitious publishing plans for the future will continue to bring you a range of authoritative reference books, professional texts and monographs, all written and produced to the exacting standards that have made Woodhead Publishing one of the UK's fastest growing independent publishers. All of our books are written in direct response to customers' needs by a truly international team of authors, ensuring they are designed for and relevant to a global audience.

Woodhead Publishing books are available worldwide, either direct, via our website, www.woodheadpublishing.com, or through booksellers and an international network of agents and representatives.

Professor J. Paulo Davim received his PhD in Mechanical Engineering from the University of Porto in 1997 and the Aggregation from the University of Coimbra in 2005. Currently, he is Aggregate Professor in the Department of Mechanical Engineering of the University of Aveiro and Head of MACTRIB – Machining and Tribology Research Group. He has more than 25 years of teaching and research experience in manufacturing, materials and mechanical engineering with special emphasis in machining and tribology. He is the Editor of five international journals, and also guest editor, editorial board member, reviewer and scientific advisor for many international journals and conferences. He has also published, as author and co-author, more than 40 book chapters and 350 articles in ISI journals (h-index 25+) and conferences.

Bulk orders: some organizations buy a number of copies of our books. If you are interested in doing this, we would be pleased to discuss a discount. Please email wp@woodheadpublishing.com or telephone +44 (0) 1223 499140.

Published by Woodhead Publishing Limited, 2013

Related titles:

Mechatronics and manufacturing engineering: Research and development
Number 1 in the Woodhead Publishing Reviews: Mechanical Engineering Series
(ISBN 978-0-85709-150-5)
Mechatronics is the blending of mechanical, electronic and computer engineering into an integrated design, and has an increasing impact on engineering processes, particularly on the design, development and operation of manufacturing systems in a wide range of industries. *Mechatronics and manufacturing engineering* is the first in the **Woodhead Publishing Reviews: Mechanical Engineering Series** and presents high quality articles with a special emphasis on research and development in mechatronics and manufacturing engineering. The book is divided into eight chapters, covering implementation of light-scattering instrumentation; planar micromanipulation on microconveyor platforms; basic active and passive joint torque control in a single-axis arm; signal processing for tool condition monitoring; ANN modelling of fractal dimension in machining; predicting forces and damage in drilling of polymer composites; minimising burr size in drilling; and single point incremental forming of polymers.

Materials and surface engineering: Research and development
Number 2 in the Woodhead Publishing Reviews: Mechanical Engineering Series
(ISBN 978-0-85709-151-2)
Materials science is an interdisciplinary field concerned with the micro and nanostructure of materials, and their properties, processing and applications in engineering, technology and industry. *Materials and surface engineering* is the second in the **Woodhead Publishing Reviews: Mechanical Engineering Series**, presenting high quality articles with a special emphasis on research and development in materials and surface engineering and the resultant applications. The book is divided into eight chapters, covering scratch resistance of modified polymethylmethacrylate nanocomposites; nanomechanical properties and nanoscale deformation of engineering materials and alloys; analysis of large-strain microindentation of crystalline polymers; nanocomposite coatings; thermal sprayed Wc-Co coatings; tribological performance of electroless Ni-P coatings, tribological response of materials during sliding; and temperature and stress fields in laser straight cutting of Ti-6Al-4V alloy.

The design and manufacture of medical devices
Number 4 in the Woodhead Publishing Reviews: Mechanical Engineering Series
(ISBN 978-1-907568-72-5)
Medical devices play an important role in the field of medical and health technology, and encompass a wide range of health care products. Directive 2007/47/EC defines a medical device as *any instrument, apparatus, appliance, software, material or other article, whether used alone or in combination, including the software intended by its manufacturer to be used specifically for diagnostic and/or therapeutic purposes and necessary for its proper application, intended by the manufacturer to be used for human beings. The design and manufacture of medical devices*, the fourth in the **Woodhead Reviews: Mechanical Engineering Series**, brings together a range of articles and case studies dealing with medical device R&D. Chapters in the book cover materials used in medical implants, such as Titanium Oxide, polyurethane, and advanced polymers; devices for specific applications such as spinal and craniofacial implants, and other issues related to medical devices, such as precision machining and integrated telemedicine systems.

Details of these and other Woodhead Publishing 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; address: Woodhead Publishing Limited, 80 High Street, Sawston, Cambridge CB22 3HJ, UK)

If you would like to receive information on forthcoming titles, please send your address details to Customer Services, at the address above. Please confirm which subject areas you are interested in.

Published by Woodhead Publishing Limited, 2013

List of abbreviations

3-D	three-dimensional
AE	acoustic emission
BUE	built-up edge
BUL	built-up layer
CBN	cubic boron nitride
CVD	chemical vapor deposition
DA	dimensional accuracy
ECM	electrochemical machining
μECM	micro-electrochemical machining
EDD	electro-discharge drilling
EDM	electrical discharge machining
EDX	energy-dispersive X-ray spectroscopy
FCC	face-centered cubic
FFT	fast Fourier transform
HSM	high-speed machining
HSS	high-speed steel
ISSF	International Stainless Steels Forum
MMC	metal matrix composite

Published by Woodhead Publishing Limited, 2013

MRR	material removal rate
MTL	material transfer layer
MQL	minimum quantity lubrication
PCD	polycrystalline diamond
PTFE	polytetrafluoroethylene
PVD	physical vapor deposition
RMS	root-mean-squared
RSM	response surface methodology
SEM	scanning electron microscopy
STFT	short-time Fourier transform
USM	ultrasonic machining
WC	tungsten carbide
WRW	workpiece removal weight

Published by Woodhead Publishing Limited, 2013

Preface

Machining and machine-tools is an important subject with application in several industries. Parts manufactured by other processes often require further machining operations before the final product is made. Traditional machining is the broad term used to describe removal of material from a workpiece, and covers chip formation operations – turning, milling, drilling and grinding, for example. Recently, the industrial utilization of non-traditional machining processes such as EDM (electrical discharge machining), ECM (electrochemical machining) and USM (ultrasonic machining) has increased. Also, the performance characteristics of machine-tools and the significant development of existing and new processes and machines need to be considered. In Europe, the USA, Japan and countries of emerging economies machine-tools is a sector undergoing great technological evolution.

Machining processes can be applied to work metallic materials, polymers, wood, ceramics, composites, biomaterials, nanomaterials and other specialist materials.

This book aims to provide information on machining and machine-tools for modern industry. Chapter 1 provides an analysis of the evolution of acoustic emission signals for monitoring diamond-coated tool delamination wear in machining. Chapter 2 is dedicated to high-performance machining of austenitic stainless steels.

Published by Woodhead Publishing Limited, 2013

Chapter 2 presents an analysis of forces monitoring in shape grinding processing of complex parts. Chapter 4 covers optimization of minimum quantity lubrication in grinding with CBN (cubic boron nitride) wheels. Chapter 5 is dedicated to EDM, in particular a study on machining characteristics of WC-Co composites.

Chapter 6 provides information on conventional and unconventional hole making in metal matrix composites (MMCs). Chapter 7 describes a laboratory machine for microelectrochemical machining. Finally, Chapter 8 is dedicated to a cam-driven electromagnetic mechanical testing machine.

The book can be used as a research tool for a final undergraduate engineering course or as a topic on machining and machine-tools at the postgraduate level. It can also serve as a useful reference for academics, manufacturing researchers, mechanical, manufacturing, industrial and materials engineers, and professionals in machining and related industries.

I would like to thank Woodhead Publishing for this opportunity and for their enthusiastic and professional support. Finally, I would like to thank all the chapter authors for their input.

J. Paulo Davim
Aveiro, Portugal
November 2012

Published by Woodhead Publishing Limited, 2013

About the contributors

Editor

J. Paulo Davim received his PhD in mechanical engineering from the University of Porto in 1997 and the Aggregation from the University of Coimbra in 2005. He is at present Aggregate Professor in the Department of Mechanical Engineering of the University of Aveiro and Head of MACTRIB – Machining and Tribology Research Group. He has more than 25 years of teaching and research experience in manufacturing, materials and mechanical engineering with special emphasis in machining and tribology. He is the editor of five international journals, and guest editor, editorial board member, reviewer and scientific advisor for many international journals and conferences. He has also published more than 40 book chapters and 350 articles as author and co-author in refereed international journals (more than 170 cited ISI Web of Knowledge, h-index = 25+) and conferences.

Authors

Chapter 1

P. Lu is currently a graduate assistant, pursuing his doctoral degree, in the Mechanical Engineering Department at The University of Alabama (UA). In 1997, he was admitted to Wuhan University of Technology, China, where he received his bachelor's degree in 2001 and master's degree in 2004. To advance his research, Mr Lu entered UA in 2009, and since then, his work has been focused on the analysis of

Published by Woodhead Publishing Limited, 2013

acoustic emission signals for tool condition monitoring, indentation and sliding simulations for diamond-coated carbides, and tool wear of diamond-coated cutting tools. He was awarded a graduate council fellowship from UA in 2011–2012. Mr Lu has conducted joint research at General Motors R&D Center over two summers.

Y. K. Chou is a Professor of Mechanical Engineering at The University Alabama. He received his PhD in Industrial Engineering from Purdue University. Professor Chou's research/teaching interests include design and manufacturing, CAD/CAM, solid mechanics, tribology, metrology and materials. His recent research thrust includes diamond-coated cutting tools, electron beam additive fabrications and nanotechnology-enabled prosthesis supported by the US government and industry. Professor Chou is an active member of ASME, SME and ASM-International. He currently serves as the Chair of the Manufacturing Processes Technical Committee in ASME's Manufacturing Engineering Division; he also serves on the Scientific Committee of North American Manufacturing Research Institute of SME. Professor Chou is a fellow of ASME. He is a registered Professional Engineer in the State of Alabama.

Chapter 2

Ana Isabel Fernández Abia is associate professor of manufacturing engineering at the University of León (Spain). She has been working since 1996 in stainless steel machining, conducting studies on machinability and tool wear in turning operations of these materials. Her PhD degree was reached with work on high-performance turning of austenitic stainless steels. She participates in research projects with companies involved in manufacturing engineering.

Joaquín Barreiro García is associate professor of manufacturing engineering at the University of León (Spain). Prior to joining, he enjoyed two years researching at the University of Cantabria (Spain). His area of expertise is in manufacturing systems and processes, with particular emphasis on metal machining monitoring and inspection systems. He received his PhD degree from Polytechnic University of Madrid in 2001. He is a Fellow Member of SME and was Secretary of the Spanish Society of Manufacturing Engineering from 2006 to 2012.

Luis Norberto López de Lacalle is the head of High Performance Machining research in the Department of Mechanical Engineering of the Faculty of Engineering of Bilbao. He was born in 1964, finishing his engineering studies in 1988. His PhD was awarded in 1993 following work on reliability updating using experimental measurements of natural frequencies of mechanical systems. He then began research into the milling and turning of titanium and nickel alloys, using high-pressure coolant-assisted systems in turning and drilling operations. Other important projects were the Introduction of High Speed Machining in Die and Mould Basque Companies. His current research is looking at five-axis machining and simulation of ball-end milling operations using semi-empirical models. He is the author of more than 90 journal articles on machining issues.

Chapter 3

Antoniomaria Di Ilio graduated in Mechanical Engineering in 1977 at the University of Rome and began his academic career at the University of Naples, undertaking research in the field of composite materials. He has been professor of manufacturing technology at the University of L'Aquila since 1989, where he is Director of the Degree Course in

Engineering Management. He is the author of more than 90 scientific papers concerning the manufacturing technologies of metals and advanced materials, with traditional as well as non-traditional methods. In particular, he has performed research on grinding and drilling of composite materials as well as in the field of laser technologies. In 2012 he was appointed Associate Member of the International Academy for Production Engineering (CIRP).

Chapter 4

Eduardo Carlos Bianchi is a Professor in the Department of Mechanical Engineering, School of Engineering, University Estadual Paulista (Unesp), Bauru Campus. He graduated in Mechanical Engineering at Unesp-Bauru, and obtained his Master of Science and PhD degrees in Mechanical Engineering at the University of Sao Paulo (USP), in the areas of Manufacturing Processes and Abrasive Machining. He is a founder and Senior Member of the Grinding Research Group, leading the Laboratory of Abrasive Machining (LUA). He teaches undergraduate and graduate courses, mostly in Manufacturing Technology and Abrasive Machining Processes. He is a member of the Manufacturing committee of the Brazilian Society of Mechanical Sciences and Engineering (ABCM), and member of the Brazilian Association of Technical Standards (ABNT). He has advised on seven masters dissertations and three doctoral theses, and has published more than 100 papers in national and international journals.

Anselmo Eduardo Diniz graduated in Mechanical Engineering in 1982 from the University of Campinas (UNICAMP), Brazil. He received his doctorate from UNICAMP in 1989. In 1990–1991 he undertook postdoctoral studies at the University of California at Berkeley (CA-USA) under the

supervision of Prof. David Dornfeld. He has been a professor of the Mechanical Engineering course of UNICAMP since 1983, teaching courses in the area of Manufacturing, mainly in Metal Cutting. Since 1990 he has been teaching graduate courses. He has advised 34 master dissertations and 13 doctoral theses. He is the author of 36 papers published in journals cited in the ISI Web of Knowledge database and more than 100 conference papers. He also works as referee for several international journals. From 2006 to 2010 he was the director of the College of Mechanical Engineering of UNICAMP.

Paulo R. Aguiar is a Professor in the Department of Electrical Engineering, School of Engineering, Unesp, Bauru Campus. He was a postdoctoral fellow at the University of Connecticut, USA, during 1998–1999, in the area of Manufacturing Processes. After receiving a Master of Science and PhD in Electrical Engineering from Sao Paulo University, USP (Electrical Machine, Power Systems and Manufacturing Processes), Dr Aguiar took the position of Associate Professor in 2003 at Unesp-Bauru, through a public examination. He has lectured on numerous courses in the areas of Control Systems, Electrical Machines and Manufacturing Processes. He received an Electrical Engineering degree in 1988 at Unesp-Bauru. He has been supported by private industry, and state and federal research agencies since graduating. He is a founder and Senior Member of the Grinding Research Group, leading the Laboratory of Abrasive Machining (LUA) and the Data Acquisition and Signal Processing Laboratory (LADAPS) at Unesp.

Rubens Chinali Canarim is a Mechanical Engineer at the Department of Mechanical Engineering, School of Engineering, University Estadual Paulista (Unesp), Bauru Campus. He is a graduate student in Mechanical Engineering

Published by Woodhead Publishing Limited, 2013

under the supervision of Prof. Dr Eduardo Carlos Bianchi, and is a member of the Grinding Research Group. He has also worked as Substitute Professor at Unesp, teaching courses in Fluid Mechanics and Heat and Mass Transfer.

Chapter 5

K. Palanikumar received his PhD in Mechanical Engineering from Anna University, Chennai, India. He is currently Professor and Principal in Sri Sai Ram Institute of Technology, Chennai, Tamilnadu, India. He has published more than 75 international journal articles and more than 100 national journal and conference articles. He is on the Review Board of many international journals in Materials and Manufacturing. He is on the Editorial Board of two international journals. His current research interest includes machining of composite materials, welding of metals and alloys, total quality management and computer-integrated manufacturing.

J. Paulo Davim, as above.

Chapter 6

Inderdeep Singh is Assistant Professor at the Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee. He received his PhD degree from the Indian Institute of Technology (IIT), Delhi. His research work won an award from the Foundation for Innovation and Technology Transfer (FITT) as the 'Best Industry Relevant PhD Thesis of the Academic Year 2004–2005' at IIT Delhi. He is involved in research and development work in the field of machining of composite materials. He has guided two PhD theses and is currently supervising six PhD scholars. He has also supervised 20 postgraduate students towards successful completion of their dissertation work. He has to his credit 100 research publications in international and national journals and conference proceedings.

Published by Woodhead Publishing Limited, 2013