

# **SpringerBriefs in Applied Sciences and Technology**

Manufacturing and Surface Engineering

**Series editor**

Joao Paulo Davim, Aveiro, Portugal

More information about this series at <http://www.springer.com/series/10623>

Konstantinos Salonitis

# Grind Hardening Process

Konstantinos Salonitis  
Manufacturing Department  
School of Aerospace,  
Transport and Manufacturing  
Cranfield University  
Cranfield, UK

ISSN 2191-530X                      ISSN 2191-5318 (electronic)  
SpringerBriefs in Applied Sciences and Technology  
ISBN 978-3-319-19371-7              ISBN 978-3-319-19372-4 (eBook)  
DOI 10.1007/978-3-319-19372-4

Library of Congress Control Number: 2015939989

Springer Cham Heidelberg New York Dordrecht London

© The Author(s) 2015

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

Springer International Publishing AG Switzerland is part of Springer Science+Business Media  
([www.springer.com](http://www.springer.com))

*To my wife Ioanna  
and my daughter Eftychia*

# Preface

Grinding is one of the most important processes in the manufacturing discipline. One of the key goals for successful grinding is controlling the heat transfer in order to ensure that the workpiece material does not undergo any metallurgical changes. However, this problem can also be considered as an opportunity. By controlling the amount of heat that is conducted in the workpiece material, it can result in its surface heat treatment. Grind-hardening process thus is a novel, non-conventional, machining process that can be used for the simultaneous surface hardening and grinding of metallic components.

Grind-hardening process can potentially substitute conventional heat treatment methods by integrating this process in the grinding phase. The key benefit of doing so is the elimination of the need for transportation of the work in progress and the minimization of additional set-ups. The process can be used for selective surface hardening of cylindrical and flat components such as shafts, rail-guides, etc.

The main objective of this book is to present the *Grind-Hardening Process* and the main studies published since it was introduced in the 1990s. Modelling of the various aspects of the process, such as the process forces, temperature profile developed, hardness profiles, residual stresses, etc., are presented in detail. The book is directed to the research community interested in the mathematical modelling and optimization of such a manufacturing process. It is intended to be employed mainly at the postgraduate level.

In the present book, the *Grind-Hardening Process* is introduced and analysed. Chapter 1 compares grind-hardening process to alternative surface modification processes. The state of the art of the grind-hardening process is reviewed and discussed in Chap. 2. The modelling of the process is presented in Chap. 3. In Chap. 4, the energy efficiency issues of the process and its environmental impact is analysed. Finally in Chap. 5, concluding remarks on the grind-hardening process are presented.

Cranfield, UK

Konstantinos Salonitis

# Contents

<b>1 Hybrid Processes for Surface Modification and the Grind-Hardening Process</b> . . . . .	1
1.1 Introduction . . . . .	1
1.2 Principles of Surface Modification. . . . .	2
1.3 Surface Hardening Methods. . . . .	3
1.3.1 Induction Hardening. . . . .	3
1.3.2 High Frequency Resistance Hardening . . . . .	4
1.3.3 Flame Hardening . . . . .	5
1.3.4 Laser Beam Hardening. . . . .	6
1.3.5 Electron Beam Hardening . . . . .	7
1.3.6 Electrolytic Hardening . . . . .	7
1.4 Hybrid Surface Modification Methods. . . . .	8
1.4.1 Grind Hardening. . . . .	8
1.4.2 Hot Stamping . . . . .	9
1.4.3 Cryogenic Deep Rolling and Hardening . . . . .	9
1.4.4 Maturity of Hybrid Processes. . . . .	10
References. . . . .	10
<b>2 Grind-Hardening State-of-the-Art</b> . . . . .	13
2.1 Introduction . . . . .	13
2.2 Grind-Hardening Process Overview. . . . .	14
2.3 Fundamental Mechanisms in Grind Hardening . . . . .	15
2.4 Alternative Process Chains. . . . .	17
2.5 Fundamental Investigations—Feasibility Studies . . . . .	17
2.5.1 Workpiece Material . . . . .	18
2.5.2 Workpiece Geometry . . . . .	21
2.5.3 Grinding Wheel . . . . .	22
2.5.4 Process Parameters. . . . .	23
2.6 Simulation of the Grind-Hardening Process . . . . .	25
2.7 Challenges for Future. . . . .	26
References. . . . .	27

<b>3 Grind-Hardening Process Modelling</b> .....	33
3.1 Introduction .....	33
3.2 Grinding Kinematics—Grinding Wheel Topography .....	34
3.2.1 Static Grains .....	35
3.2.2 Active Grains .....	37
3.3 Process Forces Semi-empirical Modelling .....	39
3.3.1 Sliding Forces .....	39
3.3.2 Cutting Forces .....	42
3.3.3 Model Implementation and Validation .....	43
3.4 Modelling Heat Generation and Partition .....	44
3.4.1 Heat Partition .....	46
3.4.2 Heat Dissipation by the Chips .....	48
3.4.3 Heat Dissipation by the Grinding Wheel .....	48
3.4.4 Heat Entering the Workpiece .....	50
3.4.5 Model Implementation and Validation .....	50
3.5 Modelling of Temperature Distribution .....	51
3.5.1 Modelling of Prismatic Workpiece Geometries .....	52
3.5.2 Modelling of Cylindrical Workpiece Geometries .....	55
3.5.3 Modelling Using Finite Element Analysis .....	58
3.5.4 Model Implementation and Validation .....	59
3.6 Modelling of Metallurgical Changes .....	60
3.6.1 Introduction Surface Heat Treatment Mechanisms .....	60
3.6.2 Austenitization Temperature .....	63
3.6.3 Martensitization Temperature .....	64
3.6.4 Retained Austenite .....	66
3.6.5 Micro-Hardness .....	66
3.6.6 Hardness Penetration Depth .....	67
3.6.7 Model Implementation and Validation .....	68
3.7 Modelling of Residual Stresses .....	71
3.7.1 Modelling Using Finite Element Analysis .....	72
3.7.2 Model Implementation and Validation .....	73
3.8 Integration of Models .....	74
3.8.1 Integrated Model and Database Validation .....	74
References .....	78
<b>4 Energy Efficiency and Environmental Impact Implications of Grind-Hardening Process</b> .....	81
4.1 Introduction .....	81
4.2 Energy Efficiency .....	82
4.3 Environmental Impact Assessment .....	85
4.3.1 Introduction to Life Cycle Assessment .....	85
4.3.2 Technical Framework of Life Cycle Assessment .....	86
4.3.3 Grind-Hardening LCA-Based Environmental Impact Assessment .....	88
References .....	90



<b>5 Concluding Remarks and Outlook</b> .....	93
5.1 Introduction .....	93
5.2 Summary .....	94
5.3 Outlook.....	94
References.....	95