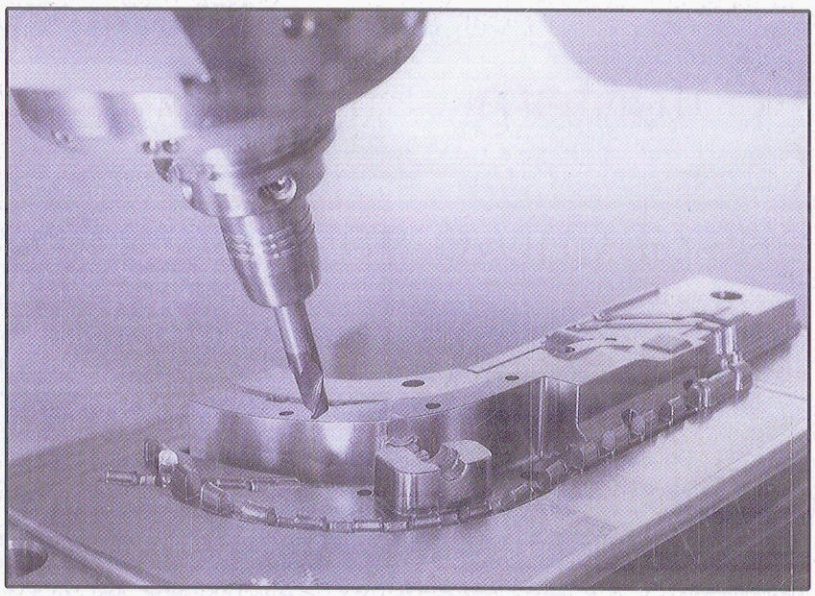
ELSEVIER

Advanced Machining Processes of Metallic Materials

Theory, Modelling and Applications



Wit Grzesik

CONTENTS

Preface *xi*
Nomenclature *xiii*

1. Introduction **1**

References 3

2. Metal Cutting Operations and Terminology **5**

2.1 Classification of Machining Processes 5
2.2 Kinematics of Cutting Process and Cutting Parameters 10
2.3 Geometry of Cutting Tools 12
References 15

3. Trends in Metal Cutting Theory and Practice **17**

3.1 Evolution of Manufacturing Methods and Systems 17
3.2 Driven Factors in Modern Machining Technology 20
3.3 The Future of Manufacturing 25
References 26

4. Cutting Tool Materials **27**

4.1 Classification and Properties of Cutting Tool Materials 27
4.2 High Speed Steels and Cast-Cobalt Alloys 30
4.3 Sintered Tungsten Carbides 31
4.4 Ceramics 34
4.5 Superhard Materials 36
4.6 Cutting Tool Coatings 39
4.7 Rules for Applications of Cutting Tool Coatings 46
References 48

5. Modelling and Simulation of Machining Processes and Operations **49**

5.1 The Role of Modelling in Modern Production Systems 49
5.2 Classification of Models for Machining Processes 51
5.3 Modelling Techniques for Machining Processes 54
5.4 Data Needed for Modelling of Machining Processes 61
References 66

6. Orthogonal and Oblique Cutting Mechanics **69**

6.1 Geometrical and Kinematical Characterization 69
6.2 Forces in the Cutting Zone 71
6.3 Cutting Energy 75

6.4 Stresses on the Shear Plane 77
6.5 Plastic Deformation in the Cutting Zone 79
References 83

7. Chip Formation and Control 85

7.1 Chip Classification 85
7.2 Chip Formation Mechanisms 89
7.3 Modelling of Chip Formation 95
7.4 Chip Flow 101
7.5 Chip Breaking 105
References 112

8. Cutting Vibrations 115

8.1 Classification of Cutting Vibrations and their Sources 115
8.2 Forced Vibrations in Milling Operations 116
8.3 Mechanisms of Self-excitation in Metal Cutting 118
8.4 Stability of Chatter 120
8.5 Methods for Improving Machine Tool Stability 122
References 125

9. Heat in Metal Cutting 127

9.1 Heat Sources in Metal Cutting and Cutting Temperature 127
9.2 Heat Flow and Distribution in the Cutting Zone 128
9.3 Prediction and Modelling of Temperatures in the Cutting Zone 131
9.3.1 Calculation of temperature rise due to plastic deformation in the PDZ 131
9.3.2 Calculation of average and maximum interface temperatures 132
9.3.3 FEM and FDA prediction of cutting temperature 133
9.4 Measurements of Temperatures in the Cutting Zone 136
References 139

10. Cutting Fluids 141

10.1 Basic Categories of Cutting Fluids 141
10.2 Functions and Action of Cutting Fluids 143
10.3 Application of Cutting Fluids and Other Cooling/Lubrication Media 144
10.4 Maintenance and Disposal of Cutting Fluids 146
References 148

11. Tribology of Metal Cutting 149

11.1 Tribological Characterization of the Cutting Zone 149
11.2 Distribution of Stresses in the Tool/Chip Interface 152
11.3 Characterization of Friction at the Tool/Chip Interface 156
11.4 Measurements and Predictions of Contact Stresses and Friction 158
References 160

12. Tool Wear and Damage 163

12.1 Types of Tool Wear 163
12.2 Physical Mechanisms of Tool Wear 167
12.3 Tool Life 169
12.4 Modelling of Tool Wear 172
12.5 Advanced Method of Tool Wear Identification and Measurement 176
References 180

13. Machinability of Engineering Materials 183

13.1 Definition and Machinability Criteria 183
13.2 Machinability Rating 186
13.3 Machinability Data Systems 188
13.4 Survey of Machinability of Engineering Materials 189
13.4.1 Carbon/unalloyed steels 189
13.4.2 Alloyed steels 190
13.4.3 Stainless steels 190
13.4.4 Cast irons 191
13.4.5 Titanium and its alloys 192
13.4.6 Nickel-based alloys 194
13.4.7 Lightweight materials 194
13.4.8 Magnesium alloys 195
13.4.9 Composite materials 195
13.4.10 Refractory metals 196
References 196

14. Machining Economics and Optimization 199

14.1 Machining Economics 199
14.2 Optimizing Cutting Speed and Feed Based on Tool-life Equation 202
14.3 Advanced Methods of Optimization 204
References 212

15. Advanced Machining Processes 213

15.1 High Speed Machining 213
15.1.1 Definition of basic features of HSM 213
15.1.2 Physical aspects of HSM 215
15.1.3 HSM technology and appliances 219
15.1.4 Basic applications of HSM technology 221
15.1.5 Machining of monolithic parts 224
References 226
15.2 Dry and Semi-dry Machining 226
15.2.1 The way to dry machining 226
15.2.2 Dry machine tools and equipment 229
15.2.3 Dry machining operations 233
15.2.4 Introduction of near-dry machining 236

15.2.5 MQL media and mixture supplying systems 237
15.2.6 Near-dry machine tools and machining operations 241
References 244
15.3 Hard Part Machining 245
15.3.1 Definition of basic feature of hard part machining (HM) 245
15.3.2 Physical aspects of hard machining 246
15.3.3 Applications of HM technology 251
15.3.4 Surface finish produced by HPM 253
References 258
15.4 High Performance and High Efficiency Machining 259
15.4.1 Basic aspects of high performance and high efficiency machining 259
15.4.2 Machine tools and tooling 262
15.4.3 Simplifying machining operations 267
References 278
15.5 Multitasking and One-pass Machining 278
15.5.1 Background of multitasking machining 278
15.5.2 Multitasking machines and tooling 280
15.5.3 One-pass machining 285
References 289
15.6 Ultrasonically Assisted and Thermally Assisted Machining 289
15.6.1 Ultrasonically assisted machining and ultrasonic vibration cutting 289
15.6.2 Laser-assisted machining 293
15.6.3 Plasma-assisted machining 296
References 298

16. Micro-machining 301

16.1 Definition and Miniaturization 301
16.2 A Survey of Micro-machining Processes 303
16.3 Micro-machines and Equipment 306
16.4 Examples of Micro-machining Products 315
16.5 Tooling and Fixturing for Micro-machining 320
16.6 Metrology for Micro-machining Processes and Products 326
References 329

17. Nanomanufacturing/Nanotechnology 331

17.1 Definition and State of the Art of Nanomanufacturing 331
17.2 Ultra-precision Machines and Nano-scale Machining Operations 334
17.3 Examples of Nano-products 343
17.4 Nanometrology 350
References 352

18. Sensor-assisted Machining 355

18.1 Sensors and System Architecture 355
18.2 Practical Examples of Monitoring Systems for Metal Cutting Applications 363

18.3 Touch-trigger Probing and Laser Measuring Systems 372
18.4 Sensor-guided and Intelligent/Smart Tools 379
References 382

19. Virtual/Digital and Internet-based Machining 385

19.1 Overview of the Manufacturing Evolution 385
19.2 Digital/Virtual Manufacturing 389
19.3 Internet-based Manufacturing 396
References 404

20. Surface Integrity 405

20.1 Superficial Layer and Surface Integrity 405
20.2 Surface Roughness Evaluation 410
20.3 Surface Roughness Measurements 416
20.4 Properties of Subsurface Layer 420
References 425

21. Troubleshooting in Machining 427

21.1 Problems in Machining Operations 427
21.2 Practical Examples of Troubleshooting 428
References 433

Index *435*