

## **Contents**

| Introduction  |      |
|---|------|
| Tool Steels as Special Alloys   | . 1  |
| Historical Evolution of Iron and Steel  | . 2  |
| Tool Steel History  | . 3  |
| Summary   | . 6  |
| Classification and Selection of Tool Steels   | . /  |
| Classification of Tool Steels   | . 7  |
| Selection of Tool Steels  | 15   |
| Predicting the Performance of Tool Steels   | 15   |
| Performance Selection Factors   | 19   |
| Manufacturing Limitations   | 21   |
| Examples of Tool Steel Selection  | 21   |
| Selection of Steels for Cold-Heading Dies   | 22   |
| Selection of Steels for Coining Dies  | 22   |
| Selection of Steels for Cold-Work Dies and Punches  | 23   |
| Selection of Tool Steels for Cold Forming Hexagon Nuts                                      | 25   |
| Selection of Steels for Cold Extrusion  | 25   |
| Selection of Steels for Snears  Selection of Steels for Die-Forging and Press-Forging Tools | 26   |
| Selection of Steels for Additional Uses   | 27   |
| Manufacture of Tool Steels  | 29   |
| Manutacture of 1001 Steels  | 20   |
| Primary Melting   | 30   |
| Electroslag Remelting   | 33   |
| Primary Breakdown   | 33   |
| Hot and Cold Drawing  | 34   |
| Continuous Casting  | 34   |
| Powder Metallurgy   | 37   |
| Osprey Process  | 40   |
| Tool Steel Alloy Design   | 45   |
| Phases and Phase Diagrams: General Considerations   | 45   |
| Determination of Equilibrium Phase Diagrams   | 40   |
| The Iron-Carbon Phase Diagram: Ferrite, Austenite, and Cementite                            | 41   |
| Alloving Elements: Effects on Ferrite and Austenite Stability                               | 49   |
| Martensite  | 50   |
| Alloy Carbides and Tool Steel Alloy Design  | 55   |
| Principles of Tool Steel Heat Treatment   | 67   |
| Normalizing   | 69   |
| Stress-Relief Heat Treatments   | . 69 |
| Annealing   | .72  |
| Hardening: Introductory Considerations  | . 13 |
| Austenitizing for Hardening   | .74  |
| Austenite Composition, M. Temperatures, and Retained Austenite                              | . 79 |
| Austenite Grain Size and Grain Growth   | . 81 |
| Hardness and Hardenability  | . 82 |
| Diffusion-Controlled Phase Transformations of Austenite                                     | . 87 |
| Transformation Diagrams, Jominy Curves, and Hardenability:                                  | 90   |
| General Considerations  | 00   |
| Transformation Diagrams, Jominy Curves, and Hardenability: Tool Steels                      | 96   |
| Martensite Transformation Ninetics and Stabilization  | 97   |
| Tempering  Practical Aspects of Tool Steel Heat Treatment                                   | 100  |
| Practical Aspects of Tool Steel near freatment  | 100  |
| Salt Bath Furnaces  | 109  |

| Controlled-Atmosphere Furnaces   | 11  | 4   |
|--|-----|-----|
| Vacuum Furnaces  | 114 | 4   |
| Fluidized-Bed Furnaces   | 120 | 0   |
| Water-Hardening Tool Steels  | IZ  | 3   |
| General Processing and Performance Considerations  | 12  | 5   |
| Hardening and Microstructure of Water-Hardening Tool Steels  | 12  | 7   |
| Hardenability of Water-Hardening Tool Steels   | 12  | 9   |
| Tempering of Water-Hardening Tool Steels   | 13  | 0   |
| Low-Alloy Special-Purpose Tool Steels  | 14  |     |
| Low-Alloy Chromium Tool Steels with High Carbon Content  | 14  | 1   |
| Low-Alloy Chromium Tool Steels with Medium Carbon Content  | 14  | 8   |
| Low-Alloy Chromium Tool Steels Containing Nickel   | 15  | 0   |
| Shock-Resisting Tool Steels  | 76  | 5   |
| Alloying Effects of Silicon  | 16  | 5   |
| Shock-Resisting Steels Containing Tungsten   | 16  | 6   |
| Shock-Resisting Tool Steels without Tungsten   | 16  | 9   |
| Oil-Hardening Cold-Work Tool Steels  | 18  | 17  |
| Microstructures  | 18  | 11  |
| Processing Prior to Hardening  | 18  | 2   |
| Hardenability and Hardening  | 18  | 13  |
| Tempering  | 18  | 14  |
| Selection and Applications   | .18 | 6   |
| Air-Hardening, Cold-Work Tool Steels   | 75  | 13  |
| Microstructures  | .19 | 95  |
| Processing Prior to Hardening  | .19 | 95  |
| Hardenability and Hardening  | .19 | 95  |
| Tempering  | .19 | )/  |
| High-Carbon, High-Chromium, Cold-Work Tool Steels  | 20  | 13  |
| Microstructure   | .20 | )3  |
| Processing Prior to Hardening  | .20 | )4  |
| Hardenability and Hardening  | .20 | )5  |
| Tempering  | .20 | 9   |
| Selection and Applications   | .21 | 6   |
| Hot-Work Tool Steels   | ZI  | 19  |
| Chromium Hot-Work Steels   | .22 | 22  |
| Tungsten Hot-Work Steels   | .23 | 34  |
| Molybdenum Hot-Work Steel  | .24 | 10  |
| High Speed Steels  | 2:  | 77  |
| Solidification of High-Speed Steels  | .25 | 53  |
| Hot Work and Annealing   | .25 | 0/  |
| Austenitizing for Hardening of High-Speed Steels   | .25 | 9   |
| Grain Size Control during Austenitizing  | .20 | 202 |
| Cooling Transformations and Hardening  | .20 | 20  |
| Tempering and Hardness of High-Speed Steels  | 2   | 75  |
| Other Property Changes in Tempered High-Speed Steels   | 25  | 82  |
| Summary: Alloying Elements in High-Speed Steels  | 28  | 84  |
| Single-Point Cutting Tools   | 28  | 84  |
| Multipoint Cutting Tools   | .28 | 87  |
| Factors in Selecting High-Speed Tool Steels  | 28  | 89  |
| Mold Steels  | . 2 | 91  |
| Hubbing Grades   | 20  | 92  |
| Machined Cavity Grades   | .29 | 95  |
| Corrosion-Resistant Mold Steels  | 29  | 96  |
| Forging, Annealing, and Stress Relieving   | 29  | 98  |
| Carburizing, Hardening, and Tempering  | 29  | 98  |
| Selection and Applications of Mold Steels  | 3   | 00  |
| CONTROL WITH A PROPERTY OF THE OWNER |     |     |

| Surface Modification of Tool Steel                            | 305   |  |
|---|-------|--|
| Oxide Coatings  | 10000 |  |
| Nitriding   | 000   |  |
| Ion Implantation  |       |  |
| Chemical and Physical Vapor Deposition Processing             | 310   |  |
| CVD and PVD Coating Structure and Performance                 | 313   |  |
| Salt Bath Coating   | 010   |  |
| Laser and Electron Beam Surface Modification                  | 317   |  |
| Boride Coatings   | 320   |  |
| Troubleshooting: Manufacturing and Performance Problems       | 325   |  |
| Fracture and Toughness of Tool Steels: General Considerations | 325   |  |
| Steel Quality and Primary Processing                          | 327   |  |
| Mechanical Design   | 328   |  |
| Heat Treatment Problems                                       | 329   |  |
| Grinding and Finishing of Hardened Tools                      | 338   |  |
| Distortion and Dimensional Change                             | 338   |  |
| Index   |       |  |