MACHINING OF STAINLESS STEELS AND SUPER ALLOYS

MACHINING OF STAINLESS STEELS AND SUPER ALLOYS

TRADITIONAL AND NONTRADITIONAL TECHNIQUES

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Knowledge is a treasure, but
Practice is the key of it
Fuller

Dedicated
To my little angles

Youssef J., Nour, Anorine, Fayrouz, and Youssra
With lot of love

Contents

Preface

The term machining covers a large collection of manufacturing methods for shaping parts by removing a portion from workpiece material, so as to obtain a finished product. Machining is used to convert forgings, castings, welded, and sintered products into desired shapes, sized, and finished to fulfill design requirements. Compared to other manufacturing techniques, machining is characterized by its versatility and capability of achieving the highest accuracy and surface quality in the most economical way.

The development of new tool materials opened a new era for the machining industry in which a parallel development in machine tools took place. In the last century, nontraditional machining techniques offered alternative methods for machining parts of complex shapes in extra-hard and tougher exotic materials that were difficult to machine by traditional methods.

In highly developed industrial countries, the yearly cost associated with metal removal has been estimated at about 10% of the gross national production. For this reason, rational approach and minor improvements in productivity of material removal processes are of major importance in high volume production.

During recent decades, engineering materials have been greatly developed. Materials such as hardened steels, stainless steels, super alloys, carbides, ceramics, and fiber-reinforced composite materials are frequently used in modern industry. The cutting speed and material removal rate when machining such materials using traditional methods such as turning, milling, grinding, and so on, tend to be falling. Sometimes, it is difficult to machine hard materials to certain shapes using these traditional methods. By adopting a unified program, and utilizing the results of basic and applied research, it will become possible in the very near future to process many of these engineering materials that were formerly considered difficult-to-cut using traditional or nontraditional methods.

This book mainly covers the machining technologies applicable for stainless steels and super alloys, which represent two of the main difficult-to-cut materials frequently used in modern industrial applications. The treatment of its topics starts from traditional machining processes, and extends to the most recent technologies of nontraditional and hybrid machining techniques. The book may therefore be regarded as a reference text for both senior undergraduate and postgraduate students enrolled in manufacturing, materials, and mechanical engineering programs. The book covers elective courses of manufacturing technology taught in engineering institutions all over the world. Additionally, the book can be used by students in other disciplines concerned with design and manufacturing such as automotive, aerospace engineering, and gas turbine plants. Besides being a reference, this book offers broadly based fundamental information for selecting the appropriate machining parameters and tooling, developing successful machining strategies in both traditional and nontraditional machining processes. It focuses on scientific and practical developments affecting the present and future of machining processes for stainless steels and super-alloys.

The instructor may tailor the course to adapt specific needs of students. Moreover, I hope that engineers and senior technologists working in the fields of machining technology, too, will find many useful ideas and thoughts in this book, if not in their specialty then in the ever-broadening fields of alternative and competitive processes and materials.

The book has two main aims: first to deal with the characteristics of stainless steels and super alloys that have been proved to be useful as engineering materials for many applications; second, it explains how and why these materials differ in machining performance and machining methods used, which represent important topics addressed in this book.

The book is written in nine chapters describing the machining possibilities of stainless steels and super alloys. These materials may be machined either traditionally, or nontraditionally, considering economical, and ecological measures. Traditional machining operations such as turning, milling, drilling, reaming, broaching, and grinding are generally used, whenever possible. Sometimes, it is no longer possible to find suitable tool materials that are sufficiently hard to cut these materials at economical speeds; then the use of nontraditional machining represents the solution. Nontraditional machining processes, such as jet machining, abrasive flow machining, electrochemical machining, laser beam machining, and so on, are capable of machining these alloys precisely, irrespective of their hardness and strength.

Outline of the Book

Writing such a book is a difficult task, since it is dealing with two complex materials (stainless steels and super alloys); each is composed of many alloys which are required to be machined using two different machining techniques (traditional and nontraditional machining processes). Moreover, being a book of such a small size, its material should be carefully selected to clearly express and highlight the different topics dealt with. Although its is intended to be as thorough and insightful as possible, the book provides mathematical modeling and equations only as needed to enhance the basic understanding of the material at hand. I have been selective in citing literature that seems to supports points of view closest to the fact in each problem considered. Ideas and experimental results have been considered from a sufficient number of sources that I have tried to clearly acknowledge through the book. Individuals desiring additional information on specific items of the book are directed to various references at the end of each chapter.

The table below gives at a glance how the chapters of the book have been organized to realize its objectives. Moreover, the topics covered by individual chapters of the book are briefly described below.

Book chapters	Topics dealt with •			
	TM	NTM	SSs	SAs
CH1	•	•	•	•
CH2	—	—	•	—
CH3	—	—	—	•
CH4	•	—	•	•
CH5	•	—	•	—
CH6	•	—	—	•
CH7	—	•	—	—
CH8	—	•	•	•
CH9	•	•	•	•

Chapter titles: see table of contents, TM: traditional machining, NTM: nontraditional machining, SSs: stainless steels, and SAs: super alloys.

Chapter 1 introduces stainless steels and super alloys as an important category of Difficult-to-Cut Materials. Historical background of stainless steels and super alloys, as well as their applications, are presented. The machining processes are then classified into traditional and nontraditional machining processes. Finally, the machining variables of a machining process are defined.

Chapters 2 and ***3*** consider the types and classifications of SSs and SAs according to the AISI- and the UNS-designation systems. In ***Chapter 2***, the effect of alloying on the properties of SSs has been presented, then the SSs are grouped into their different categories. In ***Chapter 3***, SAs are similarly classified into Ni-, Fe-, and Co-base alloys. It is self-evident that to perform any machining process correctly, the material properties must be known. The mechanical and thermal characteristics of SSs and SAs have been briefly presented, and their chemical compositions have been provided. Finally, their industrial applications have been highlighted.

Chapters 4–6 deal with the traditional methods of machining stainless steels and super alloys. Three issues related to traditional machining of stainless steels and super alloys are to be dealt with in ***Chapter 4***. These are machinability, cutting tools, and cutting fluids. After the basic machinability of TM has been considered, methods of enhancement of machinability of stainless steels and super alloys are presented. Then, tool materials such as high speed steels (HSSs), satellites, UCON, coated and carbides, ceramics, and cermets that are used for economical machining of difficult-to-cut material such as stainless steels and super alloys are presented. More recently developed tool materials such as polycrystalline cubic boron nitride (PCBN), and polycrystalline synthetic diamond (PCD) are also provided. Many tables listing the composition and properties of tool material are given. Finally, suitable cutting fluids for machining both stainless steels and super alloys have been suggested. ***Chapter 5*** covers traditional machining processes of stainless steels. The machinability of free-machining and enhanced stainless alloys as compared to the nonfree-machining alloys are investigated. A proposed 10-level machinability chart is developed to rank important grades of stainless steels. Traditional machining processes of stainless steels are then presented. The relevant machining parameters are tabulated. ***Chapter 6*** covers traditional machining processes of super alloys. The traditional machining of these important alloys are presented similarly to their treatment in ***Chapter 5***. Relevant machining parameters are tabulated and tooling and cutting fluids for traditional techniques of super alloys are considered.

Chapters 7–8 deal with nontraditional machining methods. ***Chapter 7*** provides a survey of nontraditional machining processes, in which the basics of nontraditional machining operations, such as jet machining, ultrasonic machining, electrochemical machining, electric discharge machining, laser beam machining, and so on, are considered. Furthermore, the capabilities, advantages and limitations of each process are presented. ***Chapter 8*** describes briefly, as based on available data in literature, specialized company information, and handbooks, some of the nontraditional machining processes which have been applied successfully to stainless steels and super alloys.

Chapter 9 deals with current and recent developments regarding both traditional and nontraditional machining of stainless steels and super alloys. This chapter relies mainly on notable academic publications and recent conference proceedings, to fill the gap of the advanced knowledge between industry and the latest and frequently cited research documents. The main objective of these researches was the enhancement of the productivity of traditional and nontraditional machining of stainless steels and super alloys by increasing machinability through many strategies.

At the end of the book, review questions are provided to make the students aware of the importance of relevant topics.

Prerequisite Knowledge

The student should have acquired the following as prerequisite courses:

- Manufacturing technology
- Fundamentals of machining processes
- Material science
- Heat treatment of metals and alloys

Features of the Book

The book provides the following features:

1. It provides a description for machining technologies of stainless steels, and super alloys in today's industrial applications.
2. It presents stainless steels, and super alloys, described and classified in a tabulated form (84) and illustrations (114).
3. The bibliography at the end of each chapter contains books and periodicals that serve as thoroughly updated references to the reader.
4. It provides rational selection of cutting tools along with recommended cutting fluids for traditional machining of stainless steels, and super-alloys.
5. It presents important guidelines for machining stainless steels and super-alloys.
6. It covers the most recent machining technologies that are not covered in other books.
7. It provides up-to-date and recent developments regarding both traditional and nontraditional machining of stainless steels and super alloys as based on notable academic publications and recent conference proceeding.

8. It covers the basics as well as the most recent advances in manufacturing technology.
9. It offers for the first time one easy-to-use reference for traditional and nontraditional machining stainless steels and super alloys.

Finally, I have done my best to eliminate all possible errors. I do not expect complete success in this regard and would appreciate being informed of errors which still persist. Individual questions or comments may be directed to me personally at youssef_helmi@yahoo.com.

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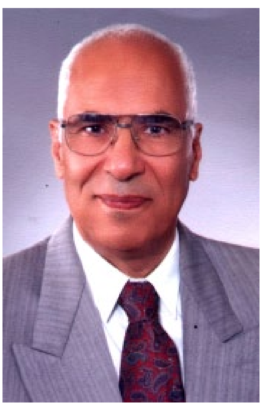
November 2015

About the Author



Professor Helmi A.A. Youssef, born in August 1938 in Alexandria, Egypt, acquired his B.Sc. Honors degree in Production Engineering from Alexandria University in 1960. He then completed his scientific building in the Carolo-Welhelmina, TH Braunschweig in Germany during 1961–1967. In June 1964 he acquired his Dipl.-Ing degree; then in December 1967, completed his Dr.-Ing degree in the domain of Non-traditional Machining. In 1968, he returned to Alexandria University, Production Engineering Department as an assistant professor. In 1973 he was promoted to associate, and in 1978 to full professor. In 1995–1998, Professor Youssef was chairman of the Production Engineering Department, Alexandria University. Since 1989, he has been a member of the scientific committee for promotion of professors in Egyptian universities. Between 1975 and 1995, Professor Youssef was a visiting professor in El-Fateh University in Tripoli, the Technical University in Baghdad, King Saud University (KSU) in Riyadh, and Beirut Arab University (BAU) in Beirut. He established laboratories and supervised many PhD and MSc theses. Professor Youssef has organized and participated in many international conferences. He has published many scientific papers in specialized journals. He authored many books in his fields of specialization, two of which are single authored. One book, co-authored on Machining Technology, was published in 2008 by CRC, USA. Another co-authored book, *Manufacturing Technology*, was also published by CRC in 2011. Currently, he is emeritus professor in PED, Alexandria University. His work at the university involves developing courses and conducting research in the areas of metal cutting and nontraditional machining.

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Nomenclature

Symbol	Definition	Unit
*A*c	Uncut chip cross-sectional area	mm^2
C	Capacitance	μF
C	Taylor constant	—
c	Acoustic speed in horn material	m/s
c	Electrolyte specific heat	cal/kg·°C
c_1	Specific heat of WP material	N m/kg·°C
C_d	Coefficient of thermal diffusivity = $k_t/\rho.\ c_1$	m^2/s
D	Workpiece diameter	mm
df	Electron beam focusing diameter	mm
dg	Abrasive grain diameter	µm
du	Chemical undercut	mm
E	Young's modulus	MPa
Ed	Energy of individual discharge	J
EF	Etch factor	—
F	Force	N
F	Faraday's constant = 96 487	A·s/mol
f	Feed rate	mm/rev
f r	Natural frequency (resonant frequency)	Hz
Fa	Axial force	N
Fc	Main cutting force	N
fe	Frequency of exciting vibration	Hz
Ff	Feed force	N
Fr	Radial force	N
h	Undeformed chip thickness	mm
H	Thermal energy	cal
hc	Chip thickness	mm
hg	Frontal gap thickness in EDM	µm

Symbol	Definition	Unit
I	Machining current	A
I	Plasma current	A
ib	Electron beam current	A
i_b	Electron beam current	A
ic	Charging current	A
id	Discharging current	A
Ip	Pre-magnetizing current	A
ks	Specific cutting energy	N/mm^2
k_t	Thermal conductivity	N/s·°C
Li	Electron beam energy	A·s
m	Mass of anodic dissolution of work material	g
m_e	Electrolyte mass flow in time t	kg
n	Taylor exponent	—
N	Atomic weight of work material	g/mol
n, N	Spindle rotational speed	rpm
N/n	EC-equivalent of work material	g/mol
P	Laser power	W
P_e	Power of electron beam	N m/s
pt	Stagnant pressure	MPa
q	Electrolyte flow rate	m^3/s
R	Resultant cutting force	N
R	Radius	mm
R	Resistance	Ω
rn	Tool nose radius	mm
RT	Machinability rating as based on the tool life	—
RV	Machinability rating as based on the cutting speed	—
T	Tool life	min
t	Depth of cut	mm
t	Time	s
t	Depth of cut in CH-Milling	µm
t	Plate thickness	m
T	Drilling torque	N·m
t_1	plate thickness	m
T_b	Boiling temperature of electrolyte	°C
tc	Charging time	µs
td	Discharging time	µs
Te	Chemical etch depth	mm
te	Etching time	min
Ti	Inlet temperature of electrolyte	°C
ti	Pulse duration	µs
To	Initial bulk temperature	K
Ts	Surface temperature	K
u	Undercut in CH-Milling	µm
v	Cutting speed	m/min
Vb	Electron beam accelerating voltage	kV