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Advances in Sustainable Machining and Manufacturing Processes

Edited by
Kishor Kumar Gajrani
Arbind Prasad
Ashwani Kumar

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This book is dedicated to all mechanical,
production, manufacturing,
and aerospace engineers

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Preface

Humans impact the environment in numerous ways. Human civilization needs a healthy environment to ensure the survival of our planet. The balance between environment and technology is the need of today's world. Technology has made our life comfortable, but our environment is paying price. Nowadays, it has been realized that a healthy environment is the necessity of humans' and this planet's survival. Therefore, efforts are increasing toward adapting green and sustainable technology to reduce detrimental environmental impacts.

Sustainable machining and manufacturing processes are the need of today's world. Among various manufacturing processes, machining is one of the widely used. Hence, it has to be made sustainable. The chapters in this book are categorized under two broad sections: (1) sustainable machining and (2) manufacturing processes. Part I, includes the work of numerous researchers as a review of modeling and experimental work. Chapter 1 discusses challenges in machining advanced materials using conventional and nonconventional machining processes. Chapter 2 covers the challenges and probable opportunities during machining by advanced ceramic materials. Chapter 3 discusses various ways to characterize and evaluate eco-friendly cutting fluids. Chapter 4 covers dry machining using advanced textured cutting tools. Chapter 5 discusses advances in one of the important techniques of near-dry machining, namely, minimum quantity lubrication, its need, its significance, and economics and environmentally friendly ways for machining. Chapter 6 covers the application of nanofluids as cutting fluids during machining. Chapter 7 discusses using nanofluids for machining in the era of Industry 4.0 and its effect on environmental sustainability. Chapter 8 explores the use of ionic liquids as a potential sustainable green lubricant for machining in the era of Industry 4.0. The structure of various ionic liquids, their relative machining performance, and their overall environmentally sustainable aspects are covered. Chapter 9 discusses sustainable electrical-discharge machining and using sustainable dielectric while maintaining similar accuracy and precision during the process. Chapter 10 covers the effects of water jet pressure, flow rate, standoff distance, and abrasive grit size on depth of penetration, cutting rate, surface roughness, taper cut ratio, and top kerf width during sustainable abrasive jet machining. Chapter 11 explores the use of artificial neural networks to successfully predict various responses, such as surface roughness, cutting force, and tool wear, during machining. Chapter 12 discusses the machining and vibration behavior of Ti-TiB composites processed through powder metallurgy techniques. In Chapter 13, the numerical analysis of machining forces and shear angle during dry hard turning of AISI 4640 steel using Al_2O_3-coated tungsten-based cemented carbide cutting inserts is conducted to predict cutting force and shear angle. Chapter 14 explores the machining performance evaluation of titanium biomaterial alloys in computer numerical control turning using a cubic boron nitride tool insert.

Part II of this book discusses sustainability aspects in various manufacturing processes. Chapter 15 discusses the use of Industrial Internet of Things in manufacturing, various communication protocols, data management techniques, and software design models focusing on the Fourth Industrial Revolution. Chapter 16 explores the ways to improve forming characteristics in incremental sheet forming. The chapter aims to highlight and systematically review the recent strategies related to numerical techniques, such as finite element analyses, computer-aided design, tool path development, experimental setups, and hybrid techniques that have been proved to increase the quality of the formed ISF parts. Chapter 17 covers the similarities and differences in deformation mechanisms of polymers, metals, and their composites in dieless forming operations. Chapter 18 discusses the sustainable polishing of directed energy deposition–based cladding using micro-transferred arc.

This book will work as a reference book for researchers, practicing machine shop engineers, and managers. This book can also be used as a textbook for the postgraduate level and as an elective course book for the undergraduate level. *Advances in Sustainable Machining and Manufacturing Processes* provides a foundational link to more specialized research work in the domain of sustainable manufacturing.

Dr. Kishor Kumar Gajrani
Dr. Arbind Prasad
Dr. Ashwani Kumar

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Editors

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Introduction

The ever-increasing trends of upcoming technology also lead to many concerns related to the environment, society, and economics in every field of engineering. Sustainability in any organization implies that something can be sustained indefinitely. Recently, governments and world leaders have been advocating for green and sustainable manufacturing initiatives. To support and promote such initiatives, researchers, scientists, engineers, and academic institutions have a responsibility to introduce educational programs related to sustainable manufacturing to prepare the future generation. Sustainable machining and manufacturing processes are a need of today's world. *Sustainable machining* is defined as the creation of products by cutting material that uses processes that are environmentally friendly, economically sound, and safe for employees, consumers, and communities, as well as can conserve energy.

To introduce these multidimensional machining and manufacturing processes into industries, as well as into the curriculum of future generations of researchers and engineers, is the ambition behind this book. This goal can be balanced by developing adequate economic, environmental, and social criteria, with analysis of their independencies and application of that analysis for guiding technological innovation in respective economic, environmental, and societal frameworks.

This book provides a lucid way for readers to understand the advances in sustainable techniques for machining and manufacturing applications. The book consists of 18 chapters dedicated to the advances in sustainable machining and manufacturing processes. The chapters discuss the challenges faced when machining advanced materials, the use of eco-friendly cutting fluids, and how they affect the machined component characteristics and our environment. This book also covers topics such as dry and near-dry machining, machining with advanced textured cutting tools, minimum quantity lubrication, nanofluids and ionic fluids in the era of Industry 4.0, sustainable electrical-discharge machining, abrasive jet machining, and artificial neural network–based machining. This book includes machining and vibration behavior of composites and finite element analysis during machining with advanced ceramic coated carbide tools. Furthermore, the use of the Industrial Internet of Things in manufacturing, sheet forming, and deformation mechanism, as well as sustainable polishing using micro-plasma transferred arc, is discussed.

This book addresses the challenges and solutions for sustainable machining and manufacturing processes. It discusses prevailing trends and suggests research findings for industries to move toward sustainable development by improving economic and social perspectives, as well as reducing the detrimental effects to the environment. Overall, the aim of this book is to catalogue the latest achievements in the modern machining and manufacturing industry that can be helpful for future generations.

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Part I

Sustainable Machining

1 Challenges in Machining of Advanced Materials

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CONTENTS

1.1 INTRODUCTION

The fuel efficiency and performance improvement in the aerospace application has led to the development of advanced materials, namely, from steel to nickel to titanium alloys; materials with lower density, for example, aluminum to carbon fiber composites; and ceramic and metal matrix composites (CMCs and MMCs, respectively), which are restituting part of elevated temperature alloys subject to engine application en route to the end of the 20th century [1].

Advanced structural materials can be defined as complex shapes or materials combinations to attain properties linking to functionality, for example, smart materials. These are materials designed for good mechanical, electrical, or thermal properties; high-efficiency energy conversion; materials with embedded sending systems for reliability and safety; and smart materials vehicles and large space structures are subject to a high-strength-per-mass ratio [2]. Researchers studied the design and fabrication of specific structures to enhance materials property three-dimensional (3D) printed structures, such as curved [3], honeycomb [4], cell shapes [5] or hexachirales [6].

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The thermal, mechanical and electrical properties, which also enhance the performance of polymer matrix composites, make carbon nanotubes (CNTs) attractive for industry use. However, identifying prospective applications for space use is a challenge for these materials [7]. On one hand, the chief challenges formed by today's establishments involve comprehending and assimilating the rapidly advancing technological machining methods fabricated by industry. The integration and application of these advances prepare the industry for the next set of leading technical improvements. The present work focuses on a vast area of machining techniques and their challenges faced by advanced materials.

1.2 MACHINING PROCESS AND MATERIALS

1.2.1 CUTTING TOOL

Advanced materials, such as superalloys, are a challenge for machining due to their inherent high hardness, low thermal conductivity, and great resistance to shearing. However, they require elevated cutting temperatures and high cutting forces to avoid severe tool wear [8].

The major tools employed in the fabrication of Ni-based superalloys are ceramic, carbide tools, and polycrystalline cubic boron nitride (PCBN). The latter is commonly used due to its superior machining capabilities for "difficult to cut" materials [9]. The PCBN is designed without a chip breaker, which is a flat rake, resulting in more resistance to breaking the chip during the cutting process. However, its shortcomings are that the surface of the workpiece is effortlessly damaged by the chip winding workpiece [9]. It was suggested that applying high-pressure cooling may overcome these drawbacks [10–11], while the importance of tool failure is attributed to analyzing the damage of tool material [12].

1.2.2 MATERIAL SELECTION

Advanced ceramic materials, for example, are clustered into two groups, that is, (1) conductive—such as the typical zirconium diboride (ZrB_2), metal nitrides (TiN/ZrN), boron carbide (B_4C), titanium diboride (TiB_2), and other similar materials—and (2) nonconductive silicon nitride (Si_3N_4), alumina (Al_2O_3), zirconia (ZrO_2), and silicon carbide (SiC). However, adding advanced ceramic materials or conductive particles to the latter, such as B_4C, TiC, Si, CaO, TiB_2, Si_3N_4 + TiC, Si_3N_4 + TiN, ZrO_2 + Cao, Al_2O_3 + TiC, ZrO_2 + Y_2O_3 + TiN, and Al_2O_3 + TiN, makes them conductive advanced materials [13–14]. However, the conventional machining shortcomings of advanced ceramic materials are attributable to their elevated hardness and brittleness [13]. Additionally, their processing/manufacturing performance is not cost-effective, particularly the expense incurred during the polishing stage [13]. Therefore, the surface of advanced materials may suffer damage during machining, resulting in stress concentration and cracks, thus affecting the mechanical strength of components [14].

Ceramic phases, that is, Al_2O_3/Al_2O_3 or SiC/SiC, in the same structure of CMCs mitigate the aggregate residual stresses emanating from the manufacturing process. Further, the coefficient of thermal expansion (CTE) mismatch and processing temperature affects the residual stresses amid matrix and fibers, characterized by X-ray diffraction (XRD), Raman spectroscopy, or micro-hardness tests [15].

1.2.3 TYPES OF MACHINING TECHNIQUES

Many machining techniques effectuated unrelenting tool wear associated with longer cutting time, the high cutting force resulting in higher machining cost, thus bearing machining challenges of advanced materials [12]. Furthermore, when processing advanced ceramics, for example, by abrasive machining and grinding, the product components experience plastic deformation and considerable residual stress, friable layers, and surface cracks [16, 17]. Table 1.1 outlines some machining techniques, both conventional and nonconventional.

The susceptible factors in the performance of electrical-discharge machining (EDM) are a low material removal rate (MRR) and high tool wear, which may be conquered by other advantages when compared with other nonconventional techniques [18].

On one hand, dry machining is conducted without the facilitation of cutting fluids. This process has gained widespread over the past years and is increasingly used by manufacturers that fabricate products with metals [19]. However, the technique exhibits drawbacks, such as (1) equipped for materials workpiece and machining approaches, which do not yield favorable results; (2) elevated temperatures at the tool–workpiece interface on the cutting edge; (3) the tool heating up due to the amplified temperature and losing its hardness [19]; (4) the surface integrity and dimensional accuracy of the workpiece are altered [20]; and (5) only materials that pose good machinability can be employed for dry machining [21].

1.3 TOOL WEAR/LIFE SPAN AND COMMERCIAL METAL CUTTING

Some advanced materials, such as the $40CrNi_2Si_2MoVA$ (300 M) steel, employed in aerospace because of its good strength, fracture toughness, elevated transverse plasticity, good corrosion resistance, and fatigue performance have their inherent drawbacks. The 300 M steel suffers poor thermal conductivity, resulting in a large cutting force and an elevated temperature, difficult chip control, and easy tool wear during the cutting process [30]. However, Zhang et al. [31] used cryogenic minimum quantity of lubricant (CMQL) technology to analyze the varying tool wear lubricants and cutting force amid high-speed turning of 300 M steel. The results indicated that this method reduced tool wear and prolonged tool life by the reduction of cutting force, cutting temperature at the knifepoint and friction amid the tool and workpiece. Furthermore, the authors studied the genetic algorithm under CMQL conditions which optimized cutting parameters and presented theoretical attribution for tool wear control at high-speed cutting 300 M steel. The ultimate tool wear prediction is demonstrated in Equation 1.1:

$$VB = 0.0362 v^{0.1054} f^{0.0567} a_p^{0.0119}, \tag{1.1}$$

TABLE 1.1
Feature/Operation of Ceramic Metal Matrix Composites on the Machining Techniques

Machining Techniques	Information Machined	Challenges	Concluding Remarks	References
Conventional				
Orthogonal cutting	• Defined cutting edges • Fiber-reinforced orientations, i.e. parallel, across, and transverse	Ductile and brittle behavior transpire due to ceramic machining at small uncut chip thickness leading to grain fracture and slip-plane mechanisms	Roughness/coarseness of machined surface is susceptible to microcracking mechanisms of the particles, leading to residual stress as the scratch load increases	[22]
Milling	• Surface finish – roughness and morphology	Observed ductile to brittle transition in the matrix during machining. Fiber removal due to pullout mechanism.	Concluded that surface roughness increased at a penetration depth of >4 μm, resulting in larger grooves due to brittle fracture	[23]
Drilling	The tool rotates along its axis	Entry and exit delaminations are induced machining damage due to high thrust forces employed-conventional drilling (CD)	Rotary ultrasonic machining (RUM) had an average reduced thrust force (~10%–15%), resulting in less significant exit delamination than CD	[24]
Grinding	Favored finishing operation for hard/brittle materials to achieve dimensional accuracies	Three grinding methods showed different results performed on C/Si materials CG provided a surface roughness (Ra) ~2–4 times lower than IG, while the UAG produced much higher values of Ra, as a result of the induced impact on the abrasive grains -caused cracks to propagate	Grinding holes >1-mm diameter are useful for successful machining of slots and surface finish employing the typical conventional mechanical techniques using cubic boron nitride and diamond tools	[25]
Nonconventional				
Abrasive waterjet (AWJ)	Cut and shape hard metals	Reduced surface quality at the jet exit because of kerf taper angle effect and brittle fracture removal due to loss of energy of the jet	The technique can be effective in machining slots, holes, and through cuts in Al_2O_3/Al_2O_3 and SiC/SiC CMCs, provided the operating parameters are optimized	[26]
Pulsed laser ablating (PLA)	Hole making in ultra-hard materials	The main drawback is heat-affected zone (HAZ)	Minimization of thermal damage, the PLA is recommended provided the pulse duration is enhanced, i.e., milli-, nano-, pico-, or femtosecond laser ablation.	[27, 28]
Electrical-discharge machining (EDM)	Cuts and holes in electrically conductive materials difficult to cut	Temperature built up due to process sparks, affecting the machined surface resulting in residual stress levels amid the fibers and matrix.	Debris removal is important to prevent damage to the workpiece. Additionally, deep flushing and tool vibration enhanced surface quality.	[29]

where *VB* is the amount of flank wear and v, f, and a_p are the cutting speed, feed, and depth of cutting, respectively. However, if the influence of a factor is not significant on the dependent variable, then the coefficient of the factor should be zero, that is, *bi* = 0, utilizing a *t* test as shown in Equation 1.2:

$$ti = \frac{bi / \sqrt{cii}}{\sqrt{Q/(n-m-1)}}, i = 1,2,\ldots\ldots, m. \tag{1.2}$$

The tool wear coefficient level as determined by Zhang et al. [31] was 0.05(α = 0.05), and $t(\alpha/2)$ $(n - p - 1)$, and the ultimate results showed that $t0.025(n - p - 1)$ = 2.22814. This indicated the significant effect of the cutting speed on the forecast value, with subsequent feed, and the depth of cutting.

To achieve economic tool life with subsequent surface conditions, cutting parameters must be carefully chosen. For example, on powder metal Ni alloys [32], these are generally

- Strain <0.01 mm,
- Surface roughness <0.8 µm,
- Nonparent material required,
- No redeposited material or layer, and
- No light contrast amorphous or recast layer.

For the cutting process completion, cutting strategies, namely, cutting parameters and tool geometries, must be properly analyzed. Wear evaluation is subject to an assessment conducted on cutting tools that are worn displaying wear features. In particular, flank wear and chipping of cutting edges cannot be utilized to measure tool wear according to ISO 3685 standard [32]. However, Abele et al. [33] employed statistical experiments/five-axis milling that involved a merger between the flank or tip and the cutting tool radius. Key process variables to consider using this method are axial depth of cut, cutting speed or feed rate, and to predict tool wear behavior.

A lot of research in the cutting process covers tool wear of tungsten carbide and carbide tools, but little has been covered on polycrystalline cubic boron nitride (PCBN) tool wear under high-pressure cooling. This was described by [34], that the workpiece deploys increased pressure on the tool flank, while its contact area is small, resulting in the flank being worn out. However, the flank face cutting area poses challenges because of insufficient coolant while the wear is escalating affecting the machined surface integrity. A study by Wu et al. [34] demonstrated the wear morphology and profile of the PCBN tool. Conversely, the wear model from the study provided a source to cutting superalloys subjected to cooling at high pressures to minimize machining and tool wear. The model was also subsequently reciprocal to cutting parameters, cutting time, and cooling pressure.

1.4 MACHINABILITY

Machinability of materials is clearly expressed as the effortless practice of materials removal (chips) by cutting tool edge, employing conventional machining operations to yield a suitable cost-effective surface quality [35].

The machinability of NiTi shape memory alloy (SMA) is a challenge due to the existence of intermetallics, resulting in strain hardening effects and poor surface texture [36]. Two varying approaches to machine NiTi SMAs have been adopted by Kong et al. [37], the results indicated that abrasive water jet machining was superior to plain water jet machining regarding a more controlled depth and surface texture. Likewise, Frotscher et al. [38] outlined that abrasive water jet machining was an appropriate machining process compared to the micromachining process, which was able to decrease the thermal effect and cutting time of the machining process. Some other unconventional machining processes such as the wire-electrical-discharge machining (WEDM), laser beam and EDM could be utilized for machining the NiTi alloys but have drawbacks, such as heat-affected zone, microvoids, and recast layer. To overcome these drawbacks, Manjaiah et al. [39] consolidated the parameters of the water jet machining to improve surface roughness and the kerf angle of the composites. It was concluded that the reinforcement of the composite in wt.% improved the integrity of the surface machined by clearing particles from the surface matrix [39]. Table 1.2 shows the conducted machinability studies of some of the advanced materials.

1.5 MACHINING PROCESS SELECTION

Machining process selection and technologies have become demanding for advanced materials. The prerequisites to consider are precision machining and reduced surface roughness (quality), large material removal rate (productivity), decreased tool wear (tool cost). The study reported by Feucht et al. [45] indicated the ultrasonic technology influence and the integrated machining of hard-to-machine advanced materials. Table 1.3 lists the summary of some of the simulated model approaches used for cutting mechanisms.

1.5.1 Challenges Related to Machining

Prerequisites in the CMC structures affected by the machining process are elevated tensile or compressive residual stresses, processing temperature, and CTE mismatch [50]. On one hand, the machining of CMCs is challenging because of their (1) brittle behavior, (2) high hardness, (3) heterogeneous structure composed (matrix, fibers, porosities), and (4) orthotropic mechanical and thermal behavior [50].

1.5.2 Practical Aspects and Developments

Contemporarily, manufacturing industries are harnessing the utilization of limited quantity lubrication and dry machining, ascribed to their ecological and economic conveniences. The minimum quantity lubrication (MQL) assisted machining is used

TABLE 1.2
Machinability Studies on Some of the Advanced Materials

Approach	Material	Application	Type of Electrode/ Cutting Fluids	Remarks	Reference
Electric discharge machining (EDM)	Ti-6Al-4V	Biomedical, automotive, and aerospace	Graphite, aluminum, copper, and brass	Discharge current elevated values cause coarser surface integrity. Unlike other electrodes, graphite resulted in high surface roughness, particularly at elevated discharge current values	[40]
High-pressure cooling (HPC)	Inconel 718	Nuclear reactors, pumps, spacecraft, gas turbines, and rocket motors	Vegetable oil–based	The utility of cutting oils viz. their environmental, economic, and societal pillars combined with the surface texture of tools of the HPC method can enhance the high-speed machinability and productivity of superalloys.	[41]
Wire electrical discharge (WED)	AA2024/Al_2O_3/BN hybrid composite	Automobile, structural and aerospace industries	Molybdenum	From the optimization method, it was concluded that the pulse on-time makes a significant impact on the desired performance measures during machinability of the composite	[42]
Wire electrical discharge (WED)	Hybrid metal matrix composite (HMMC): Al LM6 as matrix, silicon carbide, and dunite added as reinforcements	Military components, automotive, and aerospace	Brass	The machinability analysis on performance has shown that pulse ON duration is the prevalent variable for achieving the performance measures desired.	[43]
Wire electrical discharge (WED)	Al/$AlCoCrFeNiMo_{0.5}$ MMC	Engineering materials for automotive industry	0.25 mm diameter copper wire	The surface roughness, KW, and MRR were minimal. The lower effectiveness range because of reinforcement over the MMCs machinability is a positive indicator for the contemporary utilization of the novel material.	[44]

KW = kerf width, MRR = material removal rate.

TABLE 1.3
Simulated Model Approaches Used for Cutting Mechanisms

Machining Approach	Theoretical Model	Type of Material	Process Parameters	Remarks	Author
PCBN turning	Adaptive genetic algorithm	GH4169 superalloy	Initial population size, i.e., m, P_c, P_m	Surface roughness during the turning process can be estimated, and the maximum error amid measured and predicted value is 0.107	[46]
Femtosecond laser processing	COMSOL software	Diamond microgrooves	Inlet velocity and size cross-section shape with a depth of 1000 microns	It was concluded that rectangular microgrooves have good heat dissipation compared to triangular and trapezoidal structures	[47]
PCBN tooling	Chip breaking model	GH4169 superalloy	$f = 0.15$ mm/r, $ap = 0.4$ mm, $v_c = 160$ m/min	Bending moment increases, and the crimp radius decreases, leading to a reduction of feed rate and depth of cutting during the high-pressure cooling process. Ultimately, the breaking performance of the chip is improved	[8]
CNC machining	Stereoscopic/spherical geometry method (SGM), and Projection method (PM)	For advanced materials	Position angle θ and orientation angle ϕ of drilling and milling modular fixture	The procedure and principle of solving spatial angle in the modular fixture by SGM, and PM was well executed	[48]
Intelligent machining combined with sensor-based control systems	Interactive search method (ISM), multi-objective genetic algorithm (MOGA), and genetic algorithms (GA)	AISI 1064 steel	Cutting speed, depth of cut, and feed rate	The results showed that ISM exhibited optimal outcomes in the field of manipulation of machining processes parameters	[49]
Abrasive water jet cutting	SPH algorithm and Lagrange model numerical simulation	Q235, X60, X80 and 304 stainless steels	Pressure 40 Mpa, target distance 5 mm, and 80 mesh garnet abrasive	The erosion effect was experienced during cutting due to stress and friction, impact deformation, resulting in the depth of cutting increasing with an increase in cutting pressure.	[18]

where f is the cutting force, ap is the cutting depth, and v_c is the deflection.

in auto parts, for example. It has been used in the crankshaft (drilling oil holes) and the block, which is typically a challenging approach as a result of diameter and large length [19].

A new novel concept of energy efficiency grade evaluation (EEGE) has been formulated by Ma et al. [51]. This approach is developed in various stages: (1) the enlisting of the inherent energy efficiency (IEE), (2) the advancement of quantitative approach in machining systems, and (3) creation of IEE evaluating indicator system from both the inherent specific energy (ISE) and inherent energy utilization. The EEGE method is a new tool for analyzing the energy efficiency of the machining system. However, future works objectives should be on establishing fundamental databases and interval threshold standards and discovering the application of the EEGE method to configure high-energy-efficiency machining systems [51].

Nanomachining technology using electron beam processing was studied by [52]. The structure of the self-organized surface of the nanomaterials was etched by engaging varying etching speeds, forces, depths, and probe cyclic times; however, the proportionality amid the etching depth and force, while the self-organized nanomaterials are progressively raised. The author indicated that selection of suitable parameters is a possibility to produce a linear structure with a width of approximately 60 nm and a depth of approximately 8 nm on the self-organized surface of the nanomaterial and a dotlike structure with a point spacing and height of 70 nm and 4 nm, respectively.

One of the complex systems is intelligent manufacturing systems in whereby enhancement approaches are combined with sensor-based control systems. Researchers have ascertained the viability of sensors transmitting networks with each other during the cutting operation. However, the objective was to devise a procedure that qualifies a CNC lathe spindle and smart feed drive to react to variations in signals fed to them from a series of external sensors, able to detect disturbances throughout the cutting process. Regrettably, no prototype was developed for this proposed system. Instead, this was achieved via a simulation of lathes created to substantiate logic and coding of the sensory communication network [53].

On the other hand, advanced engineering structures with embedded sensors form the basis of progressing attempts in structural health monitoring (SHM) systems [54]. However, there are certain dependencies not required for SHM designers which are treated as noises in the signals created by sensors. Some of these dependencies that affect sensing properties are (1) mechanical and thermal loading, (2) signal processing method, (3) integration configuration between material and surface-bonded, (4) fabrication process utilized for integration, and (5) base metal properties [54]. Albeit, piezoelectric materials offer high durability, providing good sensing mechanisms. Optical sensors, although costly, are efficient in quantifying strain and temperature simultaneously, resulting in overall superior performance. Generally, sensor fabrication is a countless in situ quantification of SHM variables but attributed to laboratory applications, for example, characterization and identification of complex structures in terms of deformation and failure mechanisms. Additionally, the emergence of multimaterial three-dimensional (3D) printing methods eases the integration of sensor materials into 3D printed composites. Consecutively, contributing greater understanding of the deformation interfacial mechanisms of composite materials used in the architecture industry [54].

1.6 CONCLUSION

Advanced materials for current and future aerospace applications, for example, are invented to withstand conditions such as environmental damage (oxidation and corrosion), creep strain, dwell crack growth, elevated temperature yield stress, and microstructure stability, exclusive of rises in cost and density. However, advanced materials, such as the advanced Ni alloys, solicit enhanced process of machining to acquire modified materials mechanical properties, including cost improvement outcome.

Tool failure mechanism research study as part of the challenges faced during machining is prevalent in the comprehension of tool structure and applications. Recently, tool failure exploration included both the macro problems of tool failure and microcrack propagation within the material before the appearance of tool surface crack defects. However, the intense cutting process outlining the damage mechanism of the carbide tool was explored, namely, (1) crack initiation, (2) crack propagation, (3) damage accumulation, and (4) tool breakage.

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