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Green Tribology

Emerging Technologies and Applications

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Contents

Preface

Green tribology includes a focus on innovative lubricants, materials, surfaces and machining to reduce friction and wear for environmental conservation and sustainability. With the themes of "Emerging Technologies and Applications in Green Tribology," the book creates a platform for sharing knowledge emerging in the field of green tribology. The book chapters bring together the research expertise of the large international tribology community impacting the field of green tribology. The book focuses on the role of mathematics, chemistry, physics, materials and mechanical engineering in recent advancements and developments in green tribology. The scope of the book includes recent developments and the future outlook of the emerging technologies and applications in green tribology. An overview of the recent developments in green tribology in the areas of green lubricants, green composites, texture surfaces and green machining are presented. The chapters highlight the key findings on current trends and future developments of environmentally friendly (green) lubricants, tribological performance improvement with the advances in green/eco-friendly materials, superior tribological characteristics of textured/bio-inspired surfaces and minimum quantity lubrication. The ongoing trends and future prospects in green tribology are discussed. Wide themes in green tribology are addressed in this book in the interest of tribologists.

Editors

T.V.V.L.N. Rao received his PhD in Tribology of Fluid Film Bearings from the Indian Institute of Technology, Delhi, in 2000, and his MTech in Mechanical Manufacturing Technology from the National Institute of Technology (formerly known as Regional Engineering College) Calicut in 1994. Rao's current research interests are in bearings, lubrication and tribology. He has authored (and co-authored) over 120 publications to date. He has secured (as PI and Co-PI) several research grants from the Ministry of Higher Education, Malaysia, and a research grant from The Sumitomo Foundation, Japan. Rao is a member of the Editorial Board (2022) in Tribology and Lubrication Technology (TLT). He is a Guest Associate Editor in the *Journal of Engineering Tribology*, *Industrial Lubrication and Tribology*, *Tribology – Materials, Surfaces and Interfaces*, and *Arabian Journal for Science and Engineering*. Rao is an executive member (2015–2021) of the Malaysian Tribology Society. He is a member of the Society of Tribologists and Lubrication Engineers, Malaysian Tribology Society and Tribology Society of India. Rao is currently Professor in the Department of Mechanical Engineering at Madanapalle Institute of Technology and Science. Prior to joining MITS, he served as Research Associate Professor at SRMIST (2017–2020), Visiting Faculty at LNMIIT (2016–2017), Associate Professor at Universiti Teknologi PETRONAS (2010–2016), and Assistant Professor in BITS Pilani at Pilani (2000–2004, 2007–2010) and Dubai (2004–2007) campuses.

Salmiah Binti Kasolang is currently the Rector of Universiti Teknologi MARA (UiTM) Pulau Pinang Branch. Her research interest is in tribology specifically in hydrodynamic lubrication. She graduated from the University of Wisconsin–Madison in 1992 and later pursued her master's degree in Manufacturing System Engineering at Universiti Putra Malaysia UPM. She did her PhD at the University of Sheffield under the supervision of Professor Rob Dwyer-Joyce. She has administrative experience for 10 years as the Deputy Dean (7 years from 2009 to 2015) and Dean (3 years from 2015 to 2017). She is actively leading a tribology research group in UiTM with more than 100 indexed publications. Her engagement with MYTRIBOS has enabled her to link up with other tribologists in Malaysia. Currently, she is the President of the Malaysian Tribology Society (MYTRIBOS). She is also the President of the Society of Mechanical Engineering Liveliness SOMEL that promotes many aspects of engineering, including but not limited to education, research, industry-community engagement, engineering art, and engineering life style.

Guoxin Xie received his doctoral degree at Tsinghua University, China, in 2010, majoring in Mechanical Engineering. After that, he spent two years at State Key Laboratory of Tribology, Tsinghua University, China, for postdoctoral research. From 2012 to 2014, he worked at the Royal Institute of Technology, Sweden, for another two years of postdoctoral research. Since 2014, he has worked at Tsinghua University as a Tenured Associate Professor. His research interests include solid lubrication, electric contact lubrication, thin film lubrication, etc. He has published more than 80 referred papers in international journals. He won several important academic awards, such as Chinese Thousands of Young Talents, the Excellent Doctoral Dissertation Award of China, and Ragnar Holm Plaque from KTH, Sweden. He is currently Associate Editor of FRICTION, and he will be the Director of the Young Committee of Chinese Tribology Institution.

Jitendra Kumar Katiyar is presently working as a Research Assistant Professor in the Department of Mechanical Engineering, SRM Institute of Science and Technology Kattankulathur Chennai, India. His research interests include tribology of carbon materials, polymer composites, self-lubricating polymers, lubrication tribology, modern manufacturing techniques, and coatings for advanced technologies. He obtained his bachelor's degree from UPTU Lucknow with Honors in 2007. He obtained his master's degree from the Indian Institute of Technology Kanpur, India, in 2010 and his PhD from the same institution in 2017. He is a life member of the Tribology Society of India, Malaysian Society of Tribology, Institute of Engineers, India, and the Indian Society for Technical Education (ISTE), etc. He has authored/co-authored/published more than 25 articles in reputed journals, 30+ articles in international/national conferences, and 12+ book chapters, and he has two books published, *Automotive Tribology and Tribology in Materials and Application* by Springer and *Engineering Thermodynamics* for the undergraduate level by Khanna Publication. He has served as a guest editor for a special issue in *Tribology Materials, Surfaces and Interfaces*, *Journal of Engineering Tribology Part J*, *Arabian Journal for Science and Engineering*, and *Industrial Lubrication and Tribology*. He is also an active reviewer in various reputed journals related to materials and tribology. He has delivered more than 30+ invited talks on various research fields related to tribology, composite materials, surface engineering, and machining. He has received research grants from various government organizations such as MHRD and SERB. He has organized 5+ FDP/Short Term Courses in tribology and the International Tribology Research Symposium.

Ahmad Majdi Abdul Rani received his PhD in Mechanical and Manufacturing Engineering from Loughborough University, UK, his MSc in Industrial Engineering, and his BSc in Manufacturing from Northern Illinois University, USA. His research interests are in biomedical engineering, mechanical and manufacturing engineering, and tribology. He has supervised and is currently supervising more than 20 postgraduate (PhD and MSc) students. He recently received the Leadership in Innovation Fellowship – Newton Award, UK. He has secured 3 patents and won more than 15 gold awards in exhibitions such as ITEX, MaGRIs (MOSTI), MARS, PENCIPTA, IME, SPDEC, CoRIC, etc. He has authored over 150 publications to date. He has secured (as PI and Co-PI) several research grants from the Ministry of Higher Education, Malaysia (FRGS, PRGS, ERGS, MyBrain) and Universiti Teknologi PETRONAS (YUTP, I-GEN, STIRF). He has been associated with the Department of Mechanical Engineering at Universiti Teknologi PETRONAS since 1998. He was Head of the Department of Mechanical Engineering at Universiti Teknologi PETRONAS from 2009–2011.

Contributors

Adnan Ahmed
Mechanical Engineering Department
University of Engineering and Technology
Peshawar, Pakistan

Tauseef Ahmed
Mechanical Engineering Department
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia

Mohammad Azad Alam
Mechanical Engineering Department
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia

Arslan Ahmed
Department of Mechanical Engineering
COMSATS University Islamabad Sahiwal Campus
Islamabad, Pakistan

Mohammad Azeem
Mechanical Engineering Department
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia

Sayed Khadija Bari
Bio Fuels Division
CSIR – Indian Institute of Petroleum
Dehradun, India

Skylab P. Bhore
Rotor Dynamics and Vibration Diagnostics Lab
Department of Mechanical Engineering
Motilal Nehru National Institute of Technology
Allahabad, India

H. Chen
Department of Mechanical Engineering
Tsinghua University
Beijing, China

Sangeeta Das
Department of Mechanical Engineering
Girijananda Chowdhury Institute of Management and Technology
Guwahati, India

Shubhajit Das
Department of Mechanical Engineering
National Institute of Technology
Yupia, India

I.M. Rizwanul Fattah
School of Information, Systems and Modelling
Faculty of Engineering and Information Technology
University of Technology
Sydney, Australia

H.J. Gong
Department of Mechanical Engineering
Tsinghua University
Beijing, China

Rajeev Nayan Gupta
Department of Mechanical Engineering
National Institute of Technology
Silchar, India

A.P. Harsha
Department of Mechanical Engineering
Indian Institute of Technology (Banaras Hindu University)
Varanasi, India

Nilesh D. Hingawe
Rotor Dynamics and Vibration Diagnostics Lab
Department of Mechanical Engineering
Motilal Nehru National Institute of Technology
Allahabad, India

Mian Imran
Department of Mechanical Engineering
Institute of Space Technology
Islamabad, Pakistan

Z.J. Ji
Department of Mechanical Engineering
Qinghai University
Xining, China

M.A. Kalam
Department of Mechanical Engineering
Faculty of Engineering
University of Malaya
Kuala Lumpur, Malaysia

Salmiah Binti Kasolang
Universiti Teknologi MARA
Shah Alam, Malaysia

Jitendra Kumar Katiyar
Department of Mechanical Engineering
SRM Institute of Science and Technology
Kattankulathur, India

Hafiz Usman Khalid
Mechanical Engineering Department
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia

Mohammad Rehan Khan
College of Electrical and Mechanical Engineering
National University of Science and Technology
Islamabad, Pakistan

M.Y. Li
Department of Mechanical Engineering
Tsinghua University
Beijing, China

Y.B. Li
Department of Mechanical Engineering
Tsinghua University
Beijing, China

Abdul Munir Hidayat Syah Lubis
Department of Mechanical Engineering
Universiti Teknikal Malaysia
Melaka, Malaysia

Ponnekanti Nagendramma
Bio Fuels Division
CSIR – Indian Institute of Petroleum
Dehradun, India

Norhuda Hidayah Nordin
Department of Manufacturing and Materials Engineering
Kuliyyah of Engineering
International Islamic University Malaysia
Selangor, Malaysia

Tej Pratap
Department of Mechanical Engineering
Motilal Nehru National Institute of Technology
Allahabad, India

Ahmad Majdi Abdul Rani
Department of Mechanical Engineering
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia

T.V.V.L.N. Rao
Department of Mechanical Engineering
Madanapalle Institute of Technology and Science
Madanapalle, India

Anjan Ray
Analytical Sciences Division
CSIR – Indian Institute of Petroleum
Dehradun, India

Ali Raza
Department of Mechanical Engineering
COMSATS University Islamabad
Sahiwal Campus
Islamabad, Pakistan

Y.L. Ren
Department of Mechanical Engineering
Tsinghua University
Beijing, China

M.J.M. Ridzuan
School of Mechatronic Engineering
International Islamic University
Malaysia Perlis
Perlis, Malaysia

Neha Sharma
Academy of Scientific and Innovative
Research (AcSIR) and Tribology and
Combustion Division
CSIR – Indian Institute of Petroleum
Dehradun, India

L.N. Si
Department of Mechanical Engineering
North China University of Technology
Beijing, China

N.A. Sukindar
Department of Manufacturing and
Materials Engineering
International Islamic University
Malaysia
Selangor, Malaysia

Mohd Hafis Sulaiman
Department of Manufacturing and
Materials Engineering
Kuliyyah of Engineering
International Islamic University
Malaysia
Selangor, Malaysia

X.H. Sun
Department of Mechanical Engineering
Tsinghua University
Beijing, China

Gananath D. Thakre
Tribology and Combustion Division
CSIR – Indian Institute of Petroleum
Dehradun, India

Guoxin Xie
Department of Mechanical Engineering
Tsinghua University
Beijing, China

H.H. Ya
Mechanical Engineering Department
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia

L. Zhang
Department of Mechanical Engineering
Tsinghua University
Beijing, China

Leong Zhaoyuan
Department of Materials Science and
Engineering
Faculty of Engineering
The University of Sheffield
Sheffield, United Kingdom

1 Recent Developments in Green Tribology

T.V.V.L.N. Rao
Madanapalle Institute of Technology & Science
Madanapalle, India

Salmiah Binti Kasolang
Universiti Teknologi MARA
Shah Alam, Malaysia

Guoxin Xie
Tsinghua University
Beijing, China

Jitendra Kumar Katiyar
SRM Institute of Science and Technology
Kattankulathur, India

Ahmad Majdi Abdul Rani
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia

CONTENTS

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1.1 INTRODUCTION

Green tribology encompasses friction, wear and lubrication principles of tribology of surfaces under relative motion impacting environment and biology. The recently highlighted perspectives and challenges in green tribology are in the areas of biomimetic surfaces, materials, and green lubricants [1]. Recently, the potential of green nano-tribology has been analysed and a path towards efficient, innovative and sustainable green nano-tribology has been established [2]. The basic concepts in green nano-tribology identified are (nano-) surfaces, (nano-) agents, and (nano-) processes. More recent progress in green tribology is directed towards eco-friendly materials, bio-based ceramics, water based fluids, bio-lubricants, and fibre-reinforced composites [3].

Growing interests around energy and environment have generated worldwide attention for efficient and cleaner systems towards sustainability [4]. Sustainable development thinking in green tribology design elucidates the significance of understanding tribology from an environmental viewpoint [5]. Recent advances in green tribology in lubricants, composites, surfaces and machining cause friction and wear reduction leading to sustainable development.

An overview of the recent developments in green tribology presented in Figure 1.1 is in the areas of green lubricants, green composites, textured surfaces and green machining.

1.2 GREEN LUBRICANTS

Bio-based lubricants have been acknowledged to play a significant role in overcoming environmental pollution and hazards. Bio-based lubricants are renewable and biodegradable and are a favourable alternative for numerous applications with superior lubricant properties [6]. Nevertheless, prior chemical alteration is essential to rise above the low temperature properties and oxidative stability. The appropriate base oil and additive formulations are required for development of bio-based lubricants to exceed the performance of conventional lubricants. Synthetic and vegetable oil-based esters extend the ideal choice in developing environment friendly lubricant products [7]. In recent times, intelligent materials and structures for lubrication with properties of bionic functions emulating the living systems have stimulated immense interest [8]. Functional lubricating materials with the feedback mechanism have the ability to control lubrication.

The desired lubricants in nano-technology applications require functioning at severe operating conditions. Ionic liquids have excellent thermal and electrical

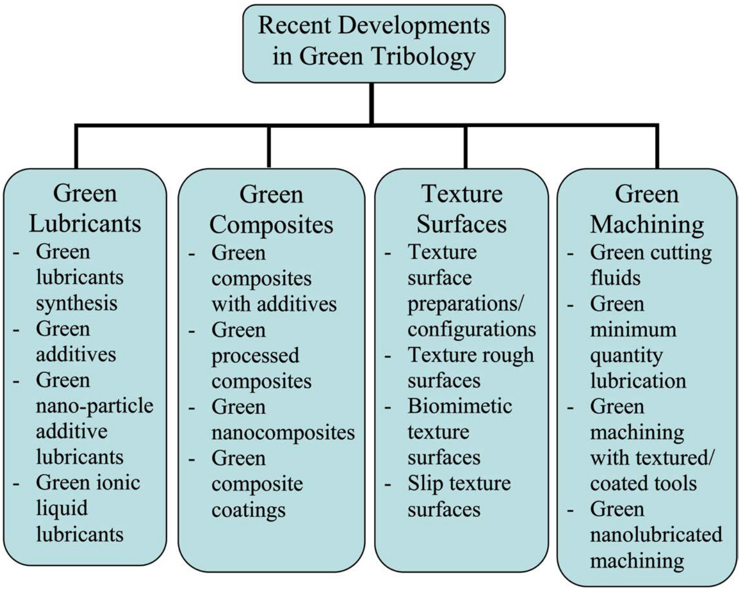

FIGURE 1.1 An overview of recent developments in green tribology

conductivity and have been explored as green lubricants as they do not emit volatile organic compounds [9]) Sustainable bio-based ionic liquid (IL) lubricants are environmentally friendly and have overcome the shortcomings related to conventional bio-lubricants. The outcome of adjusting cation–anion combinations is investigated in bio-based ionic liquids to understand their tribological performance and industrial viability [10]. Cation–anion combinations with the presence of large alkyl cation chain length and large aromatic anion ring size in bio-based ionic liquids can effectively provide friction and wear reduction. Ionic liquids as sustainable and environmentally friendly lubricants have an excellent potential to replace the conventional lubricants. Tailor-made advanced ionic liquid lubricants will play a vital role in augmenting tribological properties of sliding interfaces [11]. The sustainability of bio-based ionic liquid (IL) lubricants as an alternative to conventional bio-lubricants has also been confirmed in tribological tests. Phosphonium-based ionic liquids are further appropriate for tribological applications as these ionic liquids can be tailored rendering sustainability to the applications [12].

Recent developments in green tribology on lubricants are presented in Table 1.1.

1.2.1 Green Lubricants Synthesis

Bio-based lubricants blended from renewable and biodegradable resources have enormous possibility to replace conventional lubricants. Epoxidised palm stearin methyl ester bio-based lubricants demonstrated reduced friction coefficients and wear scar diameter [13]. The green concept demands lubricants to be from biodegradable resources and environmentally friendly. Synthesised biodegradable esters

TABLE 1.1
Recent Developments in Green Tribologyon Lubricants

Green Lubricants	Authors
Bio-lubricants potential for a range of applications	[6]
Biodegradable synthetic ester base stocks for new lubricants formulation	[7]
Novel micro-/nano-composites (containers) lubricating technologies	[8]
Ionic liquids as lubricants	[9]
Bio-based ionic liquids lubricants	[10]
Ionic liquids as sustainable lubricants	[11]
Ionic liquids as lubricants properties	[12]

were investigated for their physico-chemical properties, lubricity, biodegradability and toxicity characteristics [14]. The characterised biodegradable esters were found to have good potential for use in industrial applications. The shortcomings of bio-based lubricants restrict their tribological applications. The cold flow properties of the coconut oil have been improved with free movement of the fatty acid esters but the tribological properties are diminished compared to conventional coconut oil [15]. Oleate ester obtained from the transesterification process between oleic acid and alcohols results in minimum coefficient of friction and wear-scar diameter [16].

However, additives are used to improve the friction- and wear-reducing properties. Glycerol aqueous blends, with lower friction coefficient, have a great possibility as environmentally friendly lubricants in several applications [17]. The viscosity of glycerol in all lubrication regimes can be enriched by adding water. A canola oil and boric acid lubricant mixture demonstrated excellent potential in industrial sheet metal-forming applications [18]. The tribological properties are enhanced (reduced friction coefficient and wear) using commercialised palm oil mixed with zinc dioctyldithiophosphate (ZnDoDP) and zinc diamyldithiocarbamate (ZDDC) [19].

Recent developments in green tribology on bio-based lubricants synthesis are presented in Table 1.2.

1.2.2 Green Additives

Usually, the biodegradable castor oil-based formulations as lubricating greases offer the friction coefficient in a tribological contact subject to the class of thickener agents utilised. Biodegradable castor oil-based formulations containing cellulose or chitin derivatives as thickener agents generate higher values of the friction coefficient compared to those attained with the lithium greases in a tribological contact depending on the thickener agents [20]. Leaf surface waxes extracted from plants as biodegradable additives can effectually advance the friction and wear reduction

TABLE 1.2
Recent Developments in Green Tribology on Bio-Based Lubricants Synthesis

Green Lubricants Synthesis	Authors
Palm stearin methyl ester in an epoxidation reaction	[13]
Biodegradable esters	[14]
Fatty acids into esters by the process of alkali esterification	[15]
Oleate ester bio-based lubricant	[16]
Glycerol as a green lubricant	[17]
Canola oil and boric acid powder green lubricant	[18]
Commercialised palm oil mixed with zinc dioctyldithiophosphate (ZnDoDP) and zinc diamyldithiocarbamate (ZDDC)	[19]

accomplishments as leaf surface waxes form a protective film on the worn surface in the tribological contact [21].

Recent developments in green tribology on green additives are presented in Table 1.3.

1.2.3 Green Nano-particle Additive Lubricants

There is an increasing demand to use bio-lubricants in new base formulations as they are biodegradable, non-toxic and environmentally friendly. Biodegradable castor oil-based formulations containing calcium–copper–titanate and zinc dialkyldithiophosphate nano-particles have shown an improvement in the friction, wear and extreme-pressure reduction accomplishments in a tribological contact [22]. Renewable bio-oil with graphene oxide sheets as additives show a prospect of improvement in tribological iron/steel contacts [23]. The optimal concentrations of graphene oxide sheets with smaller sizes in bio-oil form an entire lubricant film on the tribological interfaces which results in lower friction coefficient and wear. However, higher concentrations of graphene oxide sheets in bio-oil form significant aggregation on the tribological interfaces which results in higher friction coefficient and wear. The optimal concentrations of MoS_2 nano-particles in castor oil reduce the asperity contact on the tribological interfaces which results in lower friction coefficient and adhesive wear [24]. However, higher concentrations of MoS_2 nano-particle in castor oil form agglomeration on the tribological interfaces which results in higher friction coefficient and wear due to abrasive wear. Water-based lubricant with an optimum concentration

TABLE 1.3
Recent Developments in Green Tribology on Additives

Green Additives	Authors
Biodegradable castor oil and biogenic thickeners formulations	[20]
Green additive of leaf-surface wax	[21]

of hexagonal boron nitride nano-additives shows improvement with friction and wear reduction of tribological contacts [25]. The recommended lubrication mechanisms of water-based lubricant with hexagonal boron nitride nano-additives in a mixed lubrication regime are mending, rolling and polishing effects. However, increasing concentrations of hexagonal boron nitride nano-additives in water-based lubricant leads to significant agglomeration on the tribological interfaces which results in higher friction. Rice bran oil with turmeric oil and halloysite nano-clay additives is recommended as a bio-lubricant due to the curcumin in turmeric oil, which has shown good anti-oxidant behaviour [26]. Coconut oil is a promising lubricant in sustainable manufacturing as the use of coconut oil as a lubricant reduces the friction coefficient and wear rate [27]. Furthermore, the tribological performance of coconut oil can be improved with the addition of hexagonal boron nitride (h-BN) powder nano-particles resulting in further reduction of friction coefficient and wear rate.

Recent developments in green tribology on nano-particle additive lubricants are presented in Table 1.4.

1.2.4 Green Ionic Liquid Lubricants

Ionic liquids usually display biodegradability and are opted for good potential to be used as lubricants or lubricant additives. The effect of external electric fields on the increase in the film thickness of ionic liquid films confined within a nano-space due to the shorter alkyl side chain is more noticeable [28]. It is believed that the charged anions and cationic head groups are arranged near electrified walls to form ordered layers, and short alkyl side chains at the interfaces are lined up alongside the direction of external electric fields owing to induced dipoles. Halide-free ionic liquids involving two types of anions and four types of cations as additives in glycerol yield highly biodegradable polar lubricants [29]. Friction and wear reduction is achieved by a sizable amount for methyl sulphates for all temperatures, which display strong anion domination. The ionic liquids ammonium- and pyrrolidinium-based cations combined with methylsulphate, methylsulphonate have been investigated as lubricant additives for their aquatic low-toxicity [30]. The choline amino acid ionic liquids exhibit good physicochemical and tribological characteristics with outstanding environmentally friendly characteristics of biodegradability and low toxicity against

TABLE 1.4
Recent Developments in Green Tribology on Nano-Particle Additive Lubricants

Green Nano-Particle Additive Lubricants	Authors
Castor oil with calcium–copper–titanate and zinc dialkyldithiophosphate nano-particles	[22]
Bio-oil with graphene oxide sheets	[23]
Castor oil with MoS_2 nano-particles	[24]
Water-based lubricant with hexagonal boron nitride nano-additives	[25]
Rice bran oil with turmeric oil and halloysite nano-clay additives	[26]
Coconut oil with hexagonal boron nitride (h-BN) powder nano-particles	[27]

aquatic organisms [31]. Synthesised polyol ester is blended with environmentally friendly ionic liquids derived from aspartic acid and glutamic acid to be used as lubricant additives [32]. The polyol ester ionic liquids form blends compatible as lubricant additives, resulting in friction- and wear-reducing performance characteristics between the contact interfaces. The fatty acid ionic liquids are designed and synthesised by quaternary ammonium cations with bio-based fatty acid anions which prevent metal–to-metal contact and further friction and wear reduction [33]. The lubrication mechanism of fatty acid ionic liquids reveals effectual physical adsorption and tribochemical reaction films formed on the sliding interfaces due to the polarity of the fatty acid anions and the aliphatic tails. Environmentally friendly ricinoleic acid-based ionic liquid is used as a multifunctional lubricant additive in glycerol solution due to its remarkable anticorrosion and lubricating properties [34]. The lubrication mechanism of the ricinoleic acid-based ionic liquid is accredited to the stable adsorbed layers and tribofilms on the contact surface avoiding wear and corrosion. Tribological characteristics of trimethylolpropane trioleate with phosphorus-type ionic liquid additives on the reduction in friction coefficient and wear have been evaluated [35]. In situ MoS_2 quantum dots (less than 10 nm) in green ionic liquids displayed lasting dispersion stabilities with enhanced lubricating properties owing to thin film formation [36]. Eco-friendly nano-particles have demonstrated an ideal performance in enhancing the friction and wear characteristics in sliding interfaces. The carbon dots enriched with the big organic cations from the ionic liquids have been demonstrated to be the ideal candidate as additives in synthesised nano-lubricants for friction coefficient and wear reduction [37]. The layered boric acid nano-particle is a promising green lubricant additive due to its biodegradability and improvement in scuffing load capacity [38]. An adsorption layer as well as boron tribofilm is formed on the contact surfaces to improve lubrication performance.

Recent developments in green tribology on ionic liquid lubricants are presented in Table 1.5.

TABLE 1.5
Recent Developments in Green Tribology on Ionic Liquid Lubricants

Green Ionic Liquid Lubricants	Authors
External electric fields effect on ionic liquid films confined within a nano-space	[28]
Halide-free ionic liquids involving two types of anions and four types of cations as additives in glycerol	[29]
Ammonium- and pyrrolidinium-based cations combined with methylsulphate, methylsulphonate	[30]
Choline amino acid ionic liquids from choline cations and amino acid anions	[31]
Ionic liquids as bio-lubricant additives for polyol ester	[32]
Fatty acid ionic liquids by using quaternary ammonium cations with bio-based fatty acid anions	[33]
Ricinoleic acid-based ionic liquid as a lubricant additive in glycerol solution	[34]
Trimethylolpropane trioleate with phosphorus-type ionic liquid	[35]
In situ MoS_2 quantum dots (less than 10 nm) in green ionic liquids	[36]
Metal-free and eco-friendly carbon-based ionic liquid nano-particles as additives in lubricants	[37]
Layered boric acid nano-particle as a promising green lubricant	[38]

1.3 GREEN COMPOSITES

Green tribology emphasises environmental adaptability with an improved tribological performance. The environmental compatibility, efficiency and durability of composites are the key requirements for utilisation in demanding tribological systems. Natural fibre-reinforced polymer composites have emerged in tribological applications due to their sustainable environmentally friendly aspects and cost-effective economic potential [39]. The enhanced tribological properties (friction and wear performance) are mainly influenced by the treatment and orientation fibres. Natural fibre composites are explored in tribology from friction materials to friction modifiers [40]. The fibre composite failures are due to fibre/matrix debonding, cracks in matrix, fibre fragmentation and debris formation. The hybridisation of the natural fibre composites with transfer film formation is vital to ensure enhanced tribological and mechanical properties. Core–shell (micro-/nano-) particles, with diverse composition and synergy, are widely used in tribology due to improved friction and wear performance [41]. The friction- and wear-enhancing characteristics of core–shell (micro-/nano-) particles are attained by optimizing the shell material coated on the abrasive surface. Two-dimensional (2D) nano-material-based composites are developed incorporating 2D nano-materials in a composite for potentially enhanced tribological and mechanical properties [42]. Advanced 2D nano-composites can act as excellent reinforcements as they possess ultralow friction, high elasticity modulus, and high strength. Thermoplastic polymer multiscale composite materials with high performance are used to address the tribological challenges [43]. High performance polymers such as polyetheretherketone (PEEK) and aromatic thermosetting polyester (ATSP) are used in bulk and as coatings for challenging tribological applications with superior performance [44]. The superior performance demonstrated by high performance polymers is due to the capability to form a transfer film on the surface. Advanced polymeric coatings are classified as tribological, superhydrophobic and self-healing [45]. The tribological coatings exhibit low friction with excellent wear resistance, the superhydrophobic coatings prevent wetting due to their surface structure with low surface energy and the self-healing coatings recover their functionality after damage. Polymer composite coatings with tailored properties (mechanical and tribological) reduce friction and wear. Functional fillers extend the service life and enhance the mechanical and tribological characteristics of the coatings [46]. Fillers provide low friction by promoting the formation of transfer films or liquid shear films. The polymer composite coating adhesion between the coating and substrate adhesion can be enhanced through treatment (mechanical, chemical and energy) of the substrate.

Recent developments in green tribology on composites are presented in Table 1.6.

1.3.1 Green Composites with Additives

The bio-based polymer composite has been developed using porous composites with self-lubricating properties [47]. The bio-based polymer composite using acrylic resin and short wood fibres led to a decrease in the coefficient of friction for applications in bearings. Sour-weed natural fibre reinforced with polyester matrix reinforced with

TABLE 1.6
Recent Developments in Green Tribology on Composites

Green Composites	Authors
Tribology of natural fibre-reinforced composites	[39]
Tribology of hybrid natural fibre composites	[40]
Synthesis methods and the tribology of core–shell (micro-/nano-) particles	[41]
Tribology of 2D nano-material reinforcements	[42]
Tribology of multiscale thermoplastic polymer composites	[43]
Tribology of high performance bulk polymers and coatings	[44]
Tribology of advanced polymeric coatings	[45]
Tribology of polymer matrices and composite coatings with functional fillers	[46]

optimum fibre's size resulted in enhanced tensile strength, impact strength, hardness and specific wear rate [48]. Hemp fibre reinforced with kevlar/carbon epoxy composites brought about noteworthy improvement of the mechanical and wear resistance properties [49].

Recent developments in green tribology on green composites with additives are presented in Table 1.7.

1.3.2 Green Processed Composites

The long fibre size of kenaf fibres and varying size proportions of an oil palm empty fruit bunch have significant influence on the specific wear rate of the epoxy composites [50]. Copper is an exceptional ingredient of friction materials but is a hazard for an aquatic environment [51]. Metal-free friction materials developed from hydrated calcium silicate as copper replacement are successful with a tribological properties characterisation. The phase transformation of the surface transfer layer is essential for controlling the mechanism of friction and wear properties of an activated carbon composite derived from palm kernel. The surface transfer layer is effective for producing low friction and wear only at limited applied loads [52]. The predominant wear mechanisms of kenaf/epoxy composite are identified as micro-cracking and fibre debonding [53].

TABLE 1.7
Recent Developments in Green Tribology on Composites with Additives

Green Composites with Additives	Authors
Bio-based composites of acrylic resin and short wood fibres	[47]
Sour-weed natural fibre reinforced with polyester matrix	[48]
Hemp fibre reinforced with kevlar/carbon epoxy composites	[49]

TABLE 1.8
Recent Developments in Green Tribology on Processed Composites

Green Processed Composites	Authors
Kenaf and oil palm empty fruit bunch epoxy composites	[50]
Metal-free brake pads for copper replacement	[51]
Activated carbon composite derived from palm kernel	[52]
Kenaf/epoxy composite friction material	[53]

Recent developments in green tribology on processed composites are presented in Table 1.8.

1.3.3 Green Nano-Composites

Bio-based composites are vital from energy and environment perspectives. Nano-modified epoxy polymers produced from adding nano-silica to the epoxy polymer resulted in improved tensile strength based on the degree of dispersion of the spherical nano-silica particles in the epoxy matrix [54]. Bio-based epoxy composites with cellulose nano-fibres showed improved tribological and mechanical properties compared to untreated conventional composites [55]. Cellulose nano-fibre bio-based epoxy composites form a uniform tribolayer which reduces the direct contact of contact surfaces and thus provides friction- and wear-reducing properties of the composites. The "metal-reservoir" nano-composite coating for lower viscosity oils exhibited lower friction based on the controlled the boundary films due to transition metal carbides stability [56]. The corrosion- and wear-resistant nano-composite coatings through the electrical discharge method effectively reduced the coefficient of friction [57]. Graphene synthesised from fruit cover plastic waste and oil palm fibre is an ideal source of solid carbon for graphene synthesis. Synthesised graphene substantially reduces the friction coefficient and wear rate on contact surfaces even at higher sliding speeds [58].

Recent developments in green tribology on nano-composites are presented in Table 1.9.

TABLE 1.9
Recent Developments in Green Tribology on Nano-Composites

Green Nano-Composites	Authors
Epoxy polymer with nano-silica	[54]
Bio-based epoxy composites with the plant-derived cellulose nano-fibre	[55]
Metal-reservoir nano-composite coatings	[56]
Nano-composite coatings through electrical discharge method	[57]
Graphene from fruit cover plastic waste (FCPW) and oil palm fibre (OPF)	[58]

TABLE 1.10
Recent Developments in Green Tribology on Composite Coatings

Green Composite Coatings	Authors
Hybrid of core-shell structure for epoxy composite coatings	[59]
Silk fibroin and titanates nano-composite coatings	[60]

1.3.4 Green Composite Coatings

The epoxy core-shell (CNF/MoS_2) structure is a promising reinforced composite coating which is attributed to the synergy of the core-shell (CNF/MoS_2) along with good interfacial adhesion of the reinforced structure (CNF/MoS_2) with the epoxy matrix [59]. The epoxy core-shell (CNF/MoS_2) composite coatings have superior friction- and wear-reducing properties compared with other reinforced composite coatings. The nano-mechanical characterisation of spin-coated biocompatible silk-based nano-composite coatings showed higher hardness and elastic modulus compared to previous silk coats [60]. The scratch resistance of a composite coating is improved with adding titanates nano-sheets.

Recent developments in green tribology for composite coatings are presented in Table 1.10.

1.4 TEXTURED SURFACES

Surface texturing has emerged as a potentially viable option to make contribution to surface engineering for the accomplishment of green tribology. Surface texturing has a potential to influence tribological contacts performance with significant improvement in load capacity and reduction in friction and wear. The benefits of surface texturing for improving the tribological contacts performance are being widely explored in recent times.

Laser Surface Texturing (LST) is the most advanced technique for surface texturing of micro-dimples at large numbers [61]. The micro-dimples can serve in cases of full or mixed lubrication (micro-bearing), starved lubrication (micro-reservoir), or in either lubricated or dry sliding (micro-debris trap). Laser surfaces texturing using the laser beam machining process is increasingly utilised due to its contribution to friction and wear reduction [62]. Texturing methods suited particularly for surfaces with contact areas larger than the texture width under either hydrodynamic or starved lubrication are maskless electrochemical texturing and etching [63].

Nano-scale surface texturing is a way to increase the tribological performance of micro-electro-mechanical systems (MEMs) and nano-scale technology significantly [64]. Nano-scale surface texturing will allow for precise control of the lubricant behaviour changes as the geometry of the texture is decreased toward the nano-scale. Both the load support and friction force decrease with the decreasing scale of the texture, and overall the effective coefficient of friction decreases. Surface texture functionality is ensured by correct optimisation of its geometrical parameters and therefore an appropriate choice of fabrication techniques is essential for each application [65]. The optimisation of surface texture geometrical parameters is essential for performance improvement of bearing sliders [66] and tribo contacts [67]. The geometrical parameters in surface texturing have been effectively used to improve tribological performance of sliding surfaces [68]. Optimisation of surface texture geometrical parameters is essential for each application to have improvements in the performance of sliding contacts. To accomplish the design of surface textures, a comprehensive study of texture design parameters (position, orientation, aspect ratio and texture density) is essential [69]. Surface texture design effects influence the mechanism of friction and wear reduction under dry contact and lubrication (boundary, mixed, elastohydrodynamic and hydrodynamic) conditions [70].

Surface texturing has gained a great deal of attention since precise texture design parameters will help to reduce friction and wear of sliding surfaces. The optimal design guidelines of surface textures in terms of texture design parameters will help to reduce friction and wear of sliding components [71]. Parallel bearing surfaces provide significant improvement in load capacity and reduction in the coefficient of friction with partial slip texturing patterns [72].

Recent developments in green tribology on texture surfaces are presented in Table 1.11.

1.4.1 Textured Surface Configurations

Surface textures and topography may significantly influence the tribological performance of contact surfaces. The need for further improvement of the performance of counterformal lubricating contact surfaces requires that surface topography and

TABLE 1.11
Recent Developments in Green Tribology on Textured Surfaces

Textured Surfaces	Authors
Potential of laser surface texturing in lubricated contacts	[61]
Laser surface texturing for reduction of friction and wear	[62]
Texturing methods for tribological applications with low cost and rapid texturing speed	[63]
Scale-dependent nano-scale surface textures lubrication theory	[64]
Texture manufacturing techniques classification	[65]
Surface texturing developments and optimisation in bearing sliders	[66]
Surface textures at the concentrated surface contacts	[67]
Surface texturing for piston cylinder assembly and mechanical seals	[68]
Texture modelling techniques classification	[69]
Potential of laser surface texturing in conformal and non-conformal lubrication	[70]
Surface texturing developments in machine elements	[71]
Partial slip texturing patterns in bearings	[72]

textures are optimised [73]. The virtual texturing is a tool to optimise the geometric surface texture pattern designs for the tribological performance improvement of contact surfaces. Appropriate dimple dimensions improve the friction characteristics of journal bearings particularly for low-viscous oils [74]. The lubrication produced in the dimpled space is the principal mechanism for step-up of performance in mixed lubrication regime. The dimple internal structure has an overwhelming impact on the load capacity [75]. Cylindrical dimples of the rectangular profile produce larger load capacity than those with triangular profile due to the pressure rise from the converging step profile.

An increasing interest is aimed at the analytical and numerical solutions of the textured lubricated contacts. Parametric analysis of the slider bearing in terms of texture dimensions reveals that the performance characteristics are independent of the number of cells [76]. Suitable preparation of textured surfaces with distinctive shapes and at unique locations is an efficient method to improve the performance of bearings [77]. The spherical textures or micro-groove surfaces of the journal bearing reduce the friction coefficient [78]. The textured journal bearing provides improved stability of the non-recessed hybrid journal bearing lubricated with non-Newtonian power-law fluids [79]. Laser surface texturing is a viable option for enhancing tribological characteristics. In the laser surface texturing of palm kernel-activated carbon epoxy composite, the friction coefficient decreased with increasing dimple diameter [80]. Partial textured micro-dimple geometries at proper location yield enhanced stability of journal bearings [81]. The dimples geometry and location are important due to their role in improving the tribological performance of sliding machine components. The turning operations are used for fabrication of dimples based on the process capabilities and cost under the green machining environment [82]. Optimal free-form and dimple textures in mechanical seals yield lower leakage and coefficient of friction [83]. The generalised elliptical dimple textures in high speed gas face seal yield improved sealing characteristics (lower leakage) compared with conventional elliptical dimple textures [84]. The textures have significant influence on the bearing characteristics. Partial textures yield maximum performance improvement in load capacity of the meso-scale air journal bearing [85]. Textured surface profile design helps to improve the tribological characteristics and increases the life span of the surfaces in relative motion. The textured surface with a triangle profile design yields the maximum load capacity and the minimum friction coefficient compared to other texture bottom profiles [86]. Surface velocities and the texture aspect ratio are the significant parameters based on load capacity improvement and friction coefficient reduction. Texture density has the least significant influence on the bearing performance characteristics.

Recent developments in green tribology on textured surface configurations are presented in Table 1.12.

1.4.2 Textured Rough Surfaces

Surface texturing of sliding surfaces is a way to transit to the hydrodynamic regime of lubrication. Spiral-groove surface textures of sliding surfaces enable

TABLE 1.12
Recent Developments in Green Tribology on Textured Surface Configurations

Textured Surface Configurations	Authors
Virtual dimple design exploration on the mixed lubrication characteristics for a counterformal contact	[73]
Stribeck curve of dimpled bearings using machining and chemical etching	[74]
Dimples internal profile structure on bearing lubrication effectiveness	[75]
Partially textured parallel bearing surfaces analysis for optimum parameters using analytical solution	[76]
Texture location effect in journal bearings using numerical solution	[77]
Texturing or grooving location effect in journal bearings	[78]
Textured surface analysis of non-recessed hybrid journal bearing	[79]
Laser surface texture effects on palm kernel activated carbon epoxy composite.	[80]
Partial micro-dimple geometries at different locations on the journal bearings	[81]
Dimples fabrication on a cylindrical surface using turning operation	[82]
Optimal free-form and dimple textures in mechanical seals	[83]
Ellipse dimple texture of gas face seal	[84]
Texture geometry and position on the performance of meso-scale air journal bearing	[85]
Square textured profiles on parallel slider bearing performance	[86]

the transition to the hydrodynamic regime of thick film lubrication [87]. The surface roughness of sliding surfaces produced the transition from the hydrodynamic regime of thick film lubrication to a mixed regime of lubrication at higher rotational speeds. Surface roughness effects may be ignored under the hydrodynamic regime of lubrication [88]. The surface roughness effects may also be ignored for the optimum texture parameters at minimum friction coefficient under the hydrodynamic regime of lubrication determined. Half-section dimples in the leading edge of the hybrid thrust pad bearing surface are beneficial in enhancing load capacity and reducing power losses [89]. Dimpled surfaces having transverse micro-roughness improve the dynamic characteristics of hybrid thrust pad bearings. The surface roughness pattern and standard deviation of asperity height have significant effects on the transient startup characteristics of the bearing [90]. The lubrication model of surface texture coupled with a non-Gaussian roughness distribution of cylinder liner surface has been analysed [91]. The surface texture coupled with a small negative skewness surface in cylinder liner improves the lubrication performance. There have been efforts recently to control friction and wear using surface texturing combined with surface topography modification. The mixed lubrication model of surface texture coupled with non-Gaussian roughness distribution considering the effects of skewness and kurtosis has been analysed [92]. The optimal surface texture coupled with skewness and kurtosis parameters influences the mixed lubrication performance.

Recent developments in green tribology on textured rough surfaces are presented in Table 1.13.

TABLE 1.13
Recent Developments in Green Tribology on Textured Rough Surfaces

Textured Rough Surfaces	Authors
Nano-texturing performance on hydrodynamic lubrication	[87]
Roughness and texture numerical investigations under asperity contact	[88]
Optimised micro-rough dimple hybrid thrust pad bearing	[89]
Mixed/hydrodynamic transient regime lubrication modelling in journal bearing considering surface roughness effects	[90]
Non-Gaussian roughness and surface textures distribution on cylinder liner	[91]
Mixed film lubrication modelling rough-textured interfaces	[92]

1.4.3 Biomimetic/Tailored Textured Surfaces

Biomimetic and/or tailored texturing of surfaces accomplishes the expectation of superior performance of tribological components. The biomimetic dragonfly wing micro-spike structure influences the friction reduction and whirling orbit stability in journal bearings [93]. Friction reduction and whirling orbit stability are due to the generation of micro-bubbles by the spikes which contract the oil film distribution and expand the gas-phase distribution. Biomimetics embraces ideas from nature and emulates it towards all-inclusive nano-structured design of structures and products for technological applications. Surface roughness has the greatest influence on oleophilicity behaviour in the case of pistia-motivated surfaces [94]. The tribological performance of sliding contacts with textures is improved by depositing an amorphous hydrogenated diamond-like carbon (DLC) coating [95]. The beneficial effects of amorphous hydrogenated diamond-like carbon (DLC)-coated textures are at an optimum texture diameter/depth as deep dimples weaken the benefits of coated textures in non-conformal contact under boundary/starved lubrication. Tailored texturing may lead to enhanced and impressive results of lubricated tribopair contacts. The design of tailored (anisotropic and non-uniform) texturing maximizing the load of the thrust pad largely affects the friction characteristics of the contact [96]. Tailored surface texturing shows friction characteristics are clearly sensitive to the relative sliding motion of the tribopair. The fabricated patterns (single and multi-scale) on shaft surface show greatly reduced coefficients of friction at smaller rotational speeds compared to the smooth surface [97]. Reduced coefficients of friction at smaller rotational speeds on the patterned shaft surface are due to the transition from a mixed to a hydrodynamic regime of lubrication. Multi-scale surface patterns offer excellent potential to control friction and guide the lubricant along the surface [98]. Multi-scale surface patterns demonstrated the strongest influences on the lubricant spreading along the surface. Multi-scale surface texturing is a promising technique to improve the tribological characteristics of meso-scale air bearing systems.

Recent developments in green tribology on textured rough surfaces are presented in Table 1.14.

TABLE 1.14
Recent Developments in Green Tribology on Biomimetic/Tailored Textured Surfaces

Biomimetic/tailored Textured Surfaces	Authors
Biomimetic dragonfly wing micro-spike structure on journal bearing	[93]
Pistia stratiotes-motivated surface roughness for oleophilicity	[94]
Amorphous hydrogenated diamond-like carbon (DLC)-coated surface textures	[95]
Surface micro-structural modifications on a thrust bearing	[96]
Multi-scale patterns by roller-coining and/or lasers on the journal bearings	[97]
Optimised multi-scale patterns on the journal bearings	[98]

1.4.4 Slip Textured Surfaces

Slip conditions in conjunction with texturing result in tribological performance enhancements in sliding contacts. Tribological performance enhancements in bearings are influenced by pressure and shear stress variation. The pressure distribution increases while the shear stress distribution decreases overall in the partial slip textured/grooved bearing compared to the conventional bearing [99]. A partial slip textured/grooved bearing with constant film thickness (parallel slider or concentric journal) results in significant enhancement in characteristics compared to the conventional bearing. The textured/slippage combined pattern has a favourable influence by increasing load and decreasing friction in slider bearings [100]. The textured/slippage combined pattern has a much lower coefficient of friction compared to a conventional (non-textured) surface. The textured/slippage combined pattern even with a negligible gap ratio (parallel gap) has a favourable influence on the lubrication behaviour by increasing load and decreasing friction in slider bearings [101]. The gap ratio in a textured/slippage combined pattern appears to promote the lower coefficient of friction compared to the slip pattern on the surface. Optimal slip parameters are calculated utilising the two-component slip model in a journal bearing with a range of eccentricity ratios [102]. The performance of the journal bearing evaluated for load and friction coefficient yields the location of the slip zone at the convergent region of the film. The slip zone in the circumferential direction should begin in the convergent region and end close to the minimum film thickness position, while the slip zone in the axial direction should be maximum, for improvement in bearing performance.

Recent developments in green tribology on slip textured surfaces are presented in Table 1.15.

1.5 GREEN MACHINING

Machining operations for various industrial applications have greatly increased with the increase in demand. With the rise of eco-awareness, sustainable machining for various industrial applications achieves environmental conservation. Sustainable machining involves enhancement in machining performance with green cutting

TABLE 1.15
Recent Developments in Green Tribology on Slip Textured Surfaces

Slip Textured Surfaces	Authors
Slider and journal partial slip textured/grooved bearing analysis	[99]
Slippage/textured combined pattern with optimum parameters in MEMS applications	[100]
Slip texture zones with optimum parameters in slider bearing	[101]
Slip zones with optimum partial extent in hydrodynamic journal bearing	[102]

fluids [103], green minimum quantity lubrication [104], green machining with textured/coated tools and green nano-lubricated machining [105].

Recent developments in green tribology on machining are presented in Table 1.16.

1.5.1 Green Cutting Fluids

Sustainable machining involves enhancement in machining performance with green cutting fluids, and therefore, the manufacturer tends to substitute mineral oil for environmentally friendly bio-based oil. The developments of green cutting fluids from environmentally friendly bio-based oil have brought about remarkable changes in the growing machining industry. Green cutting fluids give a positive impact on the environment and act as a cooling and lubrication agent in the machining process. The machining performance of modified jatropha oil (MJO) significantly improves lubricating effect compared to substitute synthetic ester (SE) as a machining lubricant [106]. Machining performance using green cutting fluids formulated with non-toxic emulsifiers and natural additives meets the specifications of commercial formulations [107]. Green cutting fluids synthesis from bio-based oils is a good basis for development of non-toxic eco-friendly products for sustainable machining.

Recent developments in green tribology on cutting fluids are presented in Table 1.17.

1.5.2 Green Minimum Quantity Lubrication

As the global demand for cutting fluids continues to rise in the manufacturing industry, the development of greener, more sustainable cutting fluids and approaches are highly desired. Recent trends in machining show an increasing of demand for the eco-friendly approaches in order to eliminate the health, energy and environmental issues caused by the application of conventional cutting fluids. Conventional

TABLE 1.16
Recent Developments in Green Tribology on Machining

Green Machining	Authors
Green metal-forming lubrication on the adhesion theory	[103]
Potential MQL advancements in terms of sustainability and machining performances	[104]
Sustainable machining using vegetable oil-based nano-fluids and the future prospects	[105]

TABLE 1.17
Recent Developments in Green Tribology on Cutting Fluids

Green Cutting Fluids	Authors
Bio-based modified jatropha oil (MJO) developed by transesterification of jatropha methyl ester (JME) to trimethylolpropane (TMP)	[106]
Sustainable and biodegradable cutting fluid prepared by combining non-toxic emulsifiers and natural additives	[107]

machining cannot fit the principles of green manufacturing in terms of health, energy and environmental issues and hence eco-friendly approaches such as minimum quantity lubrication (MQL) need to be implemented.

Minimum quantity lubrication (MQL) using nano-fluids significantly enhances the machinability, cooling and lubricating properties of base MQL [108]. Minimum quantity lubrication (MQL) using palm oil-based alumina nano-fluids resulted in the formation of an effective surface protecting film on the machined surface which influenced the tool wear under the mechanism of adhesion and abrasion [109]. Minimum quantity lubrication (MQL) using palm oil-based nano-fluids with graphene nano-platelets (GNPs) could lessen the specific cutting energy compared to commercial lubricants because of reduction in the cutting force and improvement in the surface quality [110]. Conventional cutting fluids contaminated by bacteria, fungi and biocide contents are costly to dispose of and potentially harmful to the environment [111]. MQL machining with microbial-based cutting fluids containing microalgae species results in cutting forces, tool wear, surface finish and dimensional accuracy comparable to conventional cutting fluids. The MQL approach extends tool life with the maximum volume of material removal compared to machining with cryogenic CO_2 coolant [112]. The cryogenic CO_2 coolant lowers the tool wear rate due to effectiveness in lubrication compared to the cooling effect. The cryogenic CO_2 cooling approach is introduced for efficient lubricating and cooling performance.

Recent developments in green tribology on minimum quantity lubrication are presented in Table 1.18.

TABLE 1.18
Recent Developments in Green Tribology on Minimum Quantity Lubrication

Green Minimum Quantity Lubrication	Authors
Minimum quantity lubrication (MQL) using canola oil-based diamond nano-fluids	[108]
Minimum quantity lubrication (MQL) using alumina-enhanced palm oil medium	[109]
Minimum quantity lubrication (MQL) using palm oil-based nano-fluids with graphene nano-platelets (GNPs)	[110]
Small Quantity Lubrication (SQL) using microbial-based cutting fluids containing a microalgae species	[111]
Sustainable techniques using MQL on machinability of Inconel 718	[112]

1.5.3 Green Machining with Textured/Coated Tools

Green machining with textured/coated tools is desirable with high quality products in both metal cutting and forming industries. In metal cutting industries it is desired to obtain longer tool life and better surface quality, whereas in metal forming industries it is desired to obtain reduced die wear and improved surface finish.

The goals of green machining for high quality products with a cost effective process are achieved with a poly crystalline cubic boron nitride cutting tool under dry machining conditions [113]. Surface texturing is mainly used to improve cutting tool performance in green machining operations. Textures improve cutting performance by reducing the friction force, cutting forces and cutting temperature. Surface textures enhance lubricant availability at the contact point, reduce the contact area of tool-chip, reduce the crater/flank wear and trap the wear debris [114]. Micro-textured/dimpled surfaces lower the friction coefficient, reduce the thrust force and torque and minimise the chip clogging and chip evacuation force [115]. Micro-texturing of the drill tool improves cutting performance by minimizing frictional forces at the contact interfaces, and thereby the energy loss while machining Ti-6Al-4V. The surface coating is also used to improve cutting tool performance in green machining operations. The influence of tool life on the optimal coating properties is determined by the wear morphology of the crater [116].

Recent developments in green tribology on machining with textured/coated tools are presented in Table 1.19.

1.5.4 Green Nano-Lubricated Machining

The eco-friendly green nano-cutting fluids have the potential to improve machining performance. Green machining nano-fluids formulated using coconut oil dispersed with nano-graphene resulted in reduced machining forces, tool wear and temperatures, and improved surface finish [117]. The hot chrome steel rolling service life can be effectively improved using water-based nano-TiO_2 lubricants with significant reduction in coefficient of friction and wear [118]. Reduced coefficient of friction and wear of nano-TiO_2 water-based lubricants is due to the semisolid film and solid layer formation mechanisms. Green nano-particles are explored as lubricant additives due to improvement in tribological performance in metal forming applications. The improved lubrication provided by eco-friendly lubricant additives in a polymeric

TABLE 1.19
Recent Developments in Green Tribology on Machining with Textured/Coated Tools

Green Machining with Textured/Coated Tools	Authors
Green machining with poly crystalline cubic boron nitride cutting tool in dry machining	[113]
Surface micro-nano-texture effects on cutting tool performance	[114]
Sustainable machining with surface micro-texture drill tools for the machining of Ti-6Al-4V	[115]
Sustainable machining with coated tools for the machining of 316L stainless steel	[116]

TABLE 1.20
Recent Developments in Green Tribology on Nano-Lubricated Machining

Green Nano-Lubricated Machining	Authors
Green machining nano-fluids formulated by nano-graphene particles in coconut and canola oil	[117]
Environmentally friendly water-based nano-TiO_2 lubricants	[118]
Halloysite clay nanotubes (HNTs) as green lubricant additives	[119]

lubricant results in longer tool life and lower energy consumption for metal-forming applications [119]. Halloysite clay nano-tubes (HNTs) are attractive as natural green lubricant additives as they increased the scuffing load and surface finish and lowered wear loss and coefficient of friction due to the formation of a tribofilm.

Future outlooks in green tribology on nano-lubricated machining are presented in Table 1.20.

1.6 CONCLUSION

This chapter highlights the significance of green tribology in tribological systems for sustainable development. This chapter reviews the recent developments based on the literature on green lubricants, green composites, textured surfaces and green machining. The significant progresses in green tribology on noteworthy improvements in lubrication enrichment, friction and wear reduction are elaborated. Further outlooks render continual sustainable development with advances in green tribology.

REFERENCES

1. M. Nosonovsky and B. Bhushan. Green Tribology: Biomimetics, Energy Conservation and Sustainability, 2012, Springer, Germany.
2. I. C. Gebeshuber. Green nanotribology, Proc. Inst. Mech. Eng. C J. Mech. Eng. Sci., 226, 2, 2012, 347–358.
3. J. P. Davim. Progress in Green Tribology: Green and Conventional Techniques, 2017, De Gruyter, Germany.
4. K. Holmberg and A. Erdemir. The impact of tribology on energy use and CO_2 emission globally and in combustion engine and electric cars, Trib. Int., 135, 2019, 389–396.
5. M. Hadfield and C. Ciantar. Sustainable development thinking in tribology design, Tribol. Int. Eng. Ser., 48, 2005, 457–464.
6. A.Z. Syahir, N.W.M. Zulkifli, H.H. Masjuki, M.A. Kalam, Abdullah Alabdulkarem, M. Gulzar, L.S. Khuong and M.H. Harith. A review on bio-based lubricants and their applications, J. Cleaner Prod., 168, 2017, 997–1016.
7. P. Nagendramma and S. Kaul. Development of ecofriendly/biodegradable lubricants: An overview, Renew. Sustain. En. Rev., 16, 1, 2012, 764–774.
8. H. Gong, C. Yu, L. Zhang, G. Xie, D. Guo and J. Luo. Intelligent lubricating materials: A review, Comp. Part B: Eng., 202, 2020, 108450.
9. M. Palacio and B. Bhushan. A review of ionic liquids for green molecular lubrication in nanotechnology, Tribol. Lett., 40, 2010, 247–268.
10. C. J. Reeves, A. Siddaiah and P. L. Menezes. Friction and wear behavior of environmentally friendly ionic liquids for sustainability of biolubricants, J. Tribol., 141, 5, 2019, 051604.

11. S.A.S. Amiril, E.A. Rahim and S. Syahrullail. A review on ionic liquids as sustainable lubricants in manufacturing and engineering: Recent research, performance, and applications, J. Cleaner Prod., 168, 2017, 1571–1589.
12. T. Naveed, R. Zahid, R. A. Mufti, M. Waqas and M. T. Hanif. A review on tribological performance of ionic liquids as additives to bio lubricants, P. I. Mech. Eng. J.-J. Eng., 2020, https://doi.org/10.1177/1350650120973805.
13. A. N. Afifah, S. Syahrullail, N. I. W. Azlee and A. M. Rohah. Synthesis and tribological studies of epoxidized palm stearin methyl ester as a green lubricant, J. Cleaner Prod., 280, Part 1, 2021, 124320.
14. P. Nagendramma, B. M. Shukla and D. K. Adhikari. Synthesis, characterization and tribological evaluation of new generation materials for aluminum cold rolling oils, Lubricants, 4, 3, 2016, 23.
15. K. J. Babu, A. S. Kynadi, M. L. Joy and K. P. Nair. Enhancement of cold flow property of coconut oil by alkali esterification process and development of a bio-lubricant oil, P. I. Mech. Eng. J.-J. Eng., 232,3, 2018, 307–314.
16. Z. M. Zulfattah, N. W. M. Zulkifli, H. H. Masjuki, M. H. Harith, A. Z. Syahir, I. Norain, M. N. A. M. Yusoff, M. Jamshaid and A. Arslan. Friction and wear performance of oleate-based esters with two-, three-, and four-branched molecular structure in pure form and mixture, J. Tribol., 143, 1, 2021, 011901.
17. Y. Shi, I. Minami, M. Grahn, M. Björling and R. Larsson. Boundary and elastohydrodynamic lubrication studies of glycerol aqueous solutions as green lubricants, Tribol. Int., 69, 2014, 39–45.
18. M. A. Kabir, C. Fred Higgs, III and M. R. Lovell. A pin-on-disk experimental study on a green particulate-fluid lubricant, J. Tribol., 2008, 130, 4, 041801.
19. M.A. M. Alias, M. F. B. Abdollah, and H. Amiruddin. Lubricant and tribological properties of zinc compound in palm oil, Ind. Lub. Tribol., 71, 10, 2019, 1177–1185.
20. R. Sánchez, M. Fiedler, E. Kuhn and J. M. Franco. Tribological characterization of green lubricating greases formulated with castor oil and different biogenic thickener agents: a comparative experimental study, Ind. Lub. Tribol., 63, 6, 2011, 446–452.
21. Y. Xia, W. Zhang, Z. Cao and X. Feng. A comparative study on tribological properties of leaf-surface waxes extracted from coastal and inland plants, Ind. Lub. Tribol., 71, 4, 2019, 586–593.
22. R. N. Gupta and A. P. Harsha. Synthesis, characterization, and tribological studies of calcium–copper–titanate nanoparticles as a biolubricant additive, J. Tribol., 139, 2, 2017, 021801.
23. D. Wu, Y. Xu, L. Yao, T. You and X. Hu. Tribological behaviour of graphene oxide sheets as lubricating additives in bio-oil, Ind. Lubr. Tribol., 70, 8, 2018, 1396–1401.
24. R. Yu, J. Liu and Y. Zhou. Experimental study on tribological property of MoS_2 nanoparticle in castor oil, J. Tribol., 141, 10, 2019, 102001.
25. M. F. B. Abdollah, H. Amiruddin, M. Alif Azmi and N. A. M. Tahir. Lubrication mechanisms of hexagonal boron nitride nano-additives water-based lubricant for steel–steel contact, P. I. Mech. Eng. J.-J. Eng., 2020, https://doi.org/10.1177/1350650120940173.
26. E. Sneha, V. S. Sarath, S. Rani and K. B. Kumar. Effect of turmeric oil and halloysite nano clay as anti-oxidant and anti-wear additives in rice bran oil, P. I. Mech. Eng. J.-J. Eng., 2020, https://doi.org/10.1177/1350650120945074.
27. B. Sagbas. Tribological performance of peek with green lubricant enhanced by nano hexagonal boron nitride powder, Ind. Lub. Tribol., 72, 2, 2018, 203–210.
28. G. Xie, J. Luo, D. Guo and S. Liu. Nanoconfined ionic liquids under electric fields, Appl. Phys. Lett., 96, 2010, 043112.
29. M. Kronberger, V. Pejaković, C. Gabler and M. Kalin. How anion and cation species influence the tribology of a green lubricant based on ionic liquids, P. I. Mech. Eng. J.-J. Eng., 226, 11, 2012, 933–951.

30. S. Stolte, S. Steudte, O. Areitioaurtena, F. Pagano, J. Thöming, P. Stepnowski and A. Igartua. Ionic liquids as lubricants or lubrication additives: An ecotoxicity and biodegradability assessment, Chemosphere, 89, 9, 2012, 1135–1141.
31. S. Zhang, L. Ma, P. Wen, X. Ye, R. Dong, W. Sun, M. Fan, D. Yang, F. Zhou and W. Liu. The ecotoxicity and tribological properties of choline amino acid ionic liquid lubricants, Tribol. Int., 121, 2018, 435–441.
32. P. Nagendramma, P. K. Khatri, G. D. Thakre and S. L. Jain. Lubrication capabilities of amino acid based ionic liquids as green bio-lubricant additives, J. Mol. Liq., 244, 2017, 219–225.
33. M. Fan, L. Ma, C. Zhang, Z. Wang, J. Ruan, M. Han, Y. Ren, C. Zhang, D. Yang, F. Zhou and W. Liu. Biobased green lubricants: Physicochemical, tribological and toxicological properties of fatty acid ionic liquids, Tribol. Trans., 61, 2, 2018, 195–206.
34. D. Zheng, X. Wang, M. Zhang Z. Liu and C. Ju. Anticorrosion and lubricating properties of a fully green lubricant, Tribol. Int., 130, 2019, 324–333.
35. A. Z. Syahir, M. H. Harith, N. W. M. Zulkifli, H. H. Masjuki, M. A. Kalam, M. N. A. M. Yusoff, Z. M. Zulfattah and T. M. Ibrahim. Compatibility of ionic liquid with glycerol monooleate and molybdenum dithiocarbamate as additives in bio-based lubricant, J. Tribol., 142, 6, 2020, 061901.
36. C. Ju, D. Zheng, Q. Zhao, et al. Tribological properties of green ILs containing MoS_2 quantum dots with one-step preparation. Tribol. Lett. 68, 2020, 79.
37. C. Chimeno-Trinchet, M. E. Pacheco, A. Fernández-González, M. E. Díaz-García and R. Badía-Laíño. New metal-free nanolubricants based on carbon-dots with outstanding antiwear performance, J. Ind. Eng. Chem., 87, 2020, 152–161.
38. H. Wu, S. Yin, L. Wang, Y. Du, Y. Yang, J. Shi and H. Wang. Investigation on the robust adsorption mechanism of alkyl-functional boric acid nanoparticles as high performance green lubricant additives, Tribology International, 157, May 2021, 106909.
39. E. Omrani, P. L. Menezes and P. K. Rohatgi. State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world, Eng. Sci. Tech. Int. J., 19, 2, 2016, 717–736.
40. S. Karthikeyan, N. Rajini, M. Jawaid, J. T. Winowlin Jappes, M. T. H. Thariq, S. Siengchin and J. Sukumaran. A review on tribological properties of natural fiber based sustainable hybrid composite, P. I. Mech. Eng. J.-J. Eng., 231, 12, 2017, 1616–1634.
41. H. Chen, L. Zhang, M. Li and G. Xie. Synthesis of core–shell micro/nanoparticles and their tribological application: A review, Materials, 13, 20, 2020, 4590.
42. Z. Ji, L. Zhang, G. Xie et al. Mechanical and tribological properties of nanocomposites incorporated with two-dimensional materials. Friction, 8, 2020, 813–846.
43. P. Saravanan and N. Emami. Chapter 13 – Sustainable tribology: Processing and characterization of multiscale thermoplastic composites within hydropower applications, Tribol. Polym. Compos. Charact. Prop. Appl., Elsevier Series on Tribology and Surface Engineering, 2021, 241–277.
44. E. E. Nunez, R. Gheisari and A. A. Polycarpou. Tribology review of blended bulk polymers and their coatings for high-load bearing applications, Tribol. Int., 129, 2019, 92–111.
45. P. Lan, E. E. Nunez and A. A. Polycarpou. Advanced polymeric coatings and their applications: Green tribology, Encycl. Renewable Sustainable Mater., 4, 2020, 345–358.
46. Y. Ren, L. Zhang, G. Xie et al. A review on tribology of polymer composite coatings. Friction, 9, 2021, 429–470.
47. E. I. Akpan, B. Wetzel and K. Friedrich, A fully biobased tribology material based on acrylic resin and short wood fibres, Tribol. Int., 120, 2018, 381–390.
48. V. K. Patel, S. Chauhan and J. K. Katiyar. Physico-mechanical and wear properties of novel sustainable sour-weed fiber reinforced polyester composites, Mater. Res. Express, 5, 4, 2018, 045310.

49. A. S. Negi, J. K. Katiyar, S. Kumar, N. Kumar and V. K. Patel. Physicomechanical and abrasive wear properties of hemp/kevlar/carbon reinforced hybrid epoxy composites, Mat. Res. Exp., 6, 11, 2019, 115304.
50. M. A. A. Bakar, A. H. Abdul, S. Kasolang and M. A. Ahmad. Specific wear rate of kenaf epoxy composite and oil palm empty fruit bunch (OPEFB) epoxy composite in dry sliding, J. Tekn., 58, 2012, 85–88.
51. V. Mahale, J. Bijwe and S. Sinha. Efforts towards green friction materials, Tribol. Int., 136, August 2019, 196–206.
52. D. N. F. Mahmud, M. F. B. Abdollah, N. A. B. Masripan, N. Tamaldin and H. Amiruddin. Frictional wear stability mechanisms of an activated carbon composite derived from palm kernel by phase transformation study, Ind. Lub. Tribol., 69, 6, 2017, 945–951.
53. A. Mustafa, M. F. B. Abdollah, H. Amiruddin, F. F. Shuhimi and N. Muhammad. Optimization of friction properties of kenaf polymer composite as an alternative friction material, Ind. Lub. Tribol., 69, 2, 2017, 259–266.
54. A. Jumahat, C. Soutis, S. A. Abdullah and S. Kasolang. Tensile properties of nanosilica/epoxy nanocomposites, Proc. Eng., 41, 2012, 1634–1640.
55. B. Barari, E. Omrani, A. D. Moghadam, P. L. Menezes, K. M. Pillai and P. K. Rohatgi. Mechanical, physical and tribological characterization of nano-cellulose fibers reinforced bio-epoxy composites: An attempt to fabricate and scale the 'Green' composite, Carb. Polym., 147, 2016, 282–293.
56. X. Wei, G. Zhang and L. Wang. "Metal-reservoir" carbon-based nanocomposite coating for green tribology. Tribol. Lett., 59, 2015, 34.
57. I. Taheridoustabad, M. Khosravi and Y. Yaghoubinezhad. Fabrication of GO/RGO/TiC/TiB2 nanocomposite coating on Ti–6Al–4V alloy using electrical discharge coating and exploring its tribological properties, Tribol. Int., 156, 2021, 106860.
58. N. A. M. Tahir, M. F. B. Abdollah, N. Tamaldin, M. R. B. M. Zin and H. Amiruddin. Effect of hydrogen on graphene growth from solid waste products by chemical vapour deposition: friction coefficient properties, Ind. Lub. Tribol., 72, 2, 2018, 181–188.
59. B. Chen, Y. Jia, M. Zhang, H. Liang, X. Li, J. Yang, F. Yan and C. Li. Tribological properties of epoxy lubricating composite coatings reinforced with core-shell structure of CNF/MoS_2 hybrid, Comp. Part A Appl. Sci. Manuf., 122, 2019, 85–95.
60. J. A. Arseculаratne, E. Colusso, E. D. Gaspera, A. Martucci and M. J. Hoffman. Nanomechanical and tribological characterization of silk and silk-titanate composite coatings, Tribol. Int., 146, 2020, 106195.
61. I. Etsion. State of the art in laser surface texturing, J. Tribol., 127, 1, 2005 248–253.
62. A. F. S. Baharin, M. J. Ghazali and J. A. Wahab. Laser surface texturing and its contribution to friction and wear reduction: a brief review, Ind. Lub. Tribol., 68, 1, 2016, 57–66.
63. H. L. Costa and I. M. Hutchings. Some innovative surface texturing techniques for tribological purposes. P. I. Mech. Eng. J.-J. Eng., 229, 4, 2015, 429–448.
64. R. L. Jackson. A scale dependent simulation of liquid lubricated textured surfaces, J. Tribol., 132, 2, 2010, 022001.
65. D. G. Coblas, A. Fatu, A. Maoui and M. Hajjam. Manufacturing textured surfaces: State of art and recent developments, P. I. Mech. Eng. J.-J. Eng., 229, 1, 2015, 3–29.
66. T. Ibatan, M. S. Uddin and M. A. K. Chowdhury. Recent development on surface texturing in enhancing tribological performance of bearing sliders. Surf. Coat Tech., 272, 2015, 102–120.
67. U. Sudeep, N. Tandon and R. K. Pandey. Performance of lubricated rolling/sliding concentrated contacts with surface textures: A review, J. Tribol., 137, 3, 2015, 031501.
68. A. Ahmed, H. H. Masjuki, M. Varman, M. A. Kalam, M. Habibullah and K. A. H. Al Mahmud. An overview of geometrical parameters of surface texturing for piston/cylinder assembly and mechanical seals, Meccanica, 51, 2016, 9–23.

69. D. Gropper, L. Wang and T. J. Harvey. Hydrodynamic lubrication of textured surfaces: A review of modeling techniques and key findings. Tribol. Int., 94, 2016, pp. 509–529.
70. C. Gachot, A. Rosenkranz, S. M. Hsu and H. L. Costa. A critical assessment of surface texturing for friction and wear improvement, Wear, 372, 2017, 21–41.
71. A. Rosenkranz, P. G. Grützmacher, C. Gachot and H. L. Costa. Surface texturing in machine elements – a critical discussion for rolling and sliding contacts, Adv. Eng. Mat., 21, 8, 2019, 1900194.
72. A. Senatore and T. V. V. L. N. Rao. Partial slip texture slider and journal bearing lubricated with Newtonian fluids: A review. J. Tribol., 140, 4, 2018, 040801-1-20.
73. Q. J. Wang and D. Zhu. Virtual texturing: Modeling the performance of lubricated contacts of engineered surfaces, J. Tribol., 127, 4, 2005, 722–728.
74. X. Lu, and M. M. Khonsari. An experimental investigation of dimple effect on the stribeck curve of journal bearings. Tribol. Lett., 27, 2007, 169.
75. C. Shen and M. M. Khonsari. Effect of dimple's internal structure on hydrodynamic lubrication. Tribol. Lett., 52, 2013, 415–430.
76. M. D. Pascovici, T. Cicone, M. Fillon and M. B. Dobrica. Analytical investigation of a partially textured parallel slider, P. I. Mech. Eng. J.-J. Eng., 223, 2, 2009, 151–158.
77. N. Tala-Ighil, M. Fillon and P. Maspeyrot. Effect of textured area on the performances of a hydrodynamic journal bearing, Tribol. Int., 44, 3, 2011, 211–219.
78. S. Kango, R. K. Sharma and R. K. Pandey. Comparative analysis of textured and grooved hydrodynamic journal bearing, P. I. Mech. Eng. J.-J. Eng., 228, 1, 2014, 82–95.
79. C. B. Khatri and S. C. Sharma. Influence of textured surface on the performance of non-recessed hybrid journal bearing operating with non-Newtonian lubricant, Tribol. Int., 95, 2016, 221–235.
80. M. Mohmad, M. F. B. Abdollah, N. Tamaldin and H. Amiruddin. The effect of dimple size on the tribological performances of a laser surface textured palm kernel activated carbon-epoxy composite, Ind. Lub. Tribol., 69, 5, 2017, 768–774.
81. S. Matele and K. N. Pandey. Effect of surface texturing on the dynamic characteristics of hydrodynamic journal bearing comprising concepts of green tribology, P. I. Mech. Eng. J.-J. Eng., 232, 11, 2018, 1365–1376.
82. J. A. Ghani, M. N. A. M. Dali, H. A. Rahman, C. H. C. Haron, W. M. F. Wan Mahmood, M. R. M. Rasani and M. Z. Nuawi. Analysis of dimple structure fabricated using turning process and subsequent reduction in friction, Wear, 426–427, Part B, 2019, 1280–1285.
83. X. Wang, M. Khonsari, S. Li, Q. Dai and X. Wang. Experimental verification of textured mechanical seal designed using multi-objective optimization, Ind. Lub. Tribol., 71, 6, 2019,766–771.
84. K. Guiyue, L. Xinghu, W. Yan, L. Mouyou, Z. Kanran and M. Mingfei. Parameter study and shape optimisation of a generalised ellipse dimple-textured face seal, Lub. Sci., 32, 1, 2020, 10–20.
85. N. D. Hingawe and S. P. Bhore. Tribological performance of a surface textured meso scale air bearing, Ind. Lub. Tribol., 72, 5, 2019, 599–609.
86. N. D. Hingawe and S. P. Bhore. Multi-objective optimization of the design parameters of texture bottom profiles in a parallel slider, Friction, 8, 4, 2020, 726–745.
87. T. Hirayama, H. Shiotani, K. Yamada, N. Yamashita, T. Matsuoka, H. Sawada and K. Kawahara. Hydrodynamic performance produced by nanotexturing in submicrometer clearance with surface roughness, J. Tribol., 137, 1, 2015, 011704.
88. C. Ma, Y. Duan, B. Yu, J. Sun and Q. Tu. The comprehensive effect of surface texture and roughness under hydrodynamic and mixed lubrication conditions. P. I. Mech. Eng. J.-J. Eng., 231, 10, 2017, 1307–1319.
89. V. Kumar and S. C. Sharma. Influence of dimple geometry and micro-roughness orientation on performance of textured hybrid thrust pad bearing. Meccanica, 53, 2018, 3579–3606.

Recent Developments in Green Tribology

M. Nosonovsky and B. Bhushan . Green Tribology: Biomimetics, Energy Conservation and Sustainability, 2012, Springer, Germany.

I. C. Gebeshuber . Green nanotribology, Proc. Inst. Mech. Eng. C J. Mech. Eng. Sci., 226, 2, 2012, 347–358.

J. P. Davim . Progress in Green Tribology: Green and Conventional Techniques, 2017, De Gruyter, Germany.

K. Holmberg and A. Erdemir . The impact of tribology on energy use and CO2 emission globally and in combustion engine and electric cars, Trib. Int., 135, 2019, 389–396.

M. Hadfield and C. Ciantar . Sustainable development thinking in tribology design, Tribol. Int. Eng. Ser., 48, 2005, 457–464.

A.Z. Syahir , N.W.M. Zulkifli , H.H. Masjuki , M.A. Kalam , Abdullah Alabdulkarem , M. Gulzar , L.S. Khuong and M.H. Harith . A review on bio-based lubricants and their applications, J. Cleaner Prod., 168, 2017, 997–1016.

P. Nagendramma and S. Kaul . Development of ecofriendly/biodegradable lubricants: An overview, Renew. Sustain. En. Rev., 16, 1, 2012, 764–774.

H. Gong , C. Yu , L. Zhang , G. Xie , D. Guo and J. Luo . Intelligent lubricating materials: A review, Comp. Part B: Eng., 202, 2020, 108450.

M. Palacio and B. Bhushan . A review of ionic liquids for green molecular lubrication in nanotechnology, Tribol. Lett., 40, 2010, 247–268.

C. J. Reeves , A. Siddaiah and P. L. Menezes . Friction and wear behavior of environmentally friendly ionic liquids for sustainability of biolubricants, J. Tribol., 141, 5, 2019, 051604.

S.A.S. Amiril , E.A. Rahim and S. Syahrullail . A review on ionic liquids as sustainable lubricants in manufacturing and engineering: Recent research, performance, and applications, J. Cleaner Prod., 168, 2017, 1571–1589.

T. Naveed , R. Zahid , R. A. Mufti , M. Waqas and M. T. Hanif . A review on tribological performance of ionic liquids as additives to bio lubricants, P. I. Mech. Eng. J.-J. Eng., 2020, https://doi.org/10.1177/1350650120973805.

A. N. Afifah , S. Syahrullail , N. I. W. Azlee and A. M. Rohah . Synthesis and tribological studies of epoxidized palm stearin methyl ester as a green lubricant, J. Cleaner Prod., 280, Part 1, 2021, 124320.

P. Nagendramma , B. M. Shukla and D. K. Adhikari . Synthesis, characterization and tribological evaluation of new generation materials for aluminum cold rolling oils, Lubricants, 4, 3, 2016, 23.

K. J. Babu , A. S. Kynadi , M. L. Joy and K. P. Nair . Enhancement of cold flow property of coconut oil by alkali esterification process and development of a bio-lubricant oil, P. I. Mech. Eng. J.-J. Eng., 232,3, 2018, 307–314.

Z. M. Zulfattah , N. W. M. Zulkifli , H. H. Masjuki , M. H. Harith , A. Z. Syahir , I. Norain , M. N. A. M. Yusoff , M. Jamshaid and A. Arslan . Friction and wear performance of oleate-based esters with two-, three-, and four-branched molecular structure in pure form and mixture, J. Tribol., 143, 1, 2021, 011901.

Y. Shi , I. Minami , M. Grahn , M. Björling and R. Larsson . Boundary and elastohydrodynamic lubrication studies of glycerol aqueous solutions as green lubricants, Tribol. Int., 69, 2014, 39–45.

M. A. Kabir , C. Fred Higgs, III and M. R. Lovell . A pin-on-disk experimental study on a green particulate-fluid lubricant, J. Tribol., 2008, 130, 4, 041801.

M.A. M. Alias , M. F. B. Abdollah , and H. Amiruddin . Lubricant and tribological properties of zinc compound in palm oil, Ind. Lub. Tribol., 71, 10, 2019, 1177–1185.

R. Sánchez , M. Fiedler , E. Kuhn and J. M. Franco . Tribological characterization of green lubricating greases formulated with castor oil and different biogenic thickener agents: a comparative experimental study, Ind. Lub. Tribol., 63, 6, 2011, 446–452.

Y. Xia , W. Zhang , Z. Cao and X. Feng . A comparative study on tribological properties of leaf-surface waxes extracted from coastal and inland plants, Ind. Lub. Tribol., 71, 4, 2019, 586–593.

R. N. Gupta and A. P. Harsha . Synthesis, characterization, and tribological studies of calcium–copper–titanate nanoparticles as a biolubricant additive, J. Tribol., 139, 2, 2017, 021801.

D. Wu , Y. Xu , L. Yao , T. You and X. Hu . Tribological behaviour of graphene oxide sheets as lubricating additives in bio-oil, Ind. Lubr. Tribol., 70, 8, 2018, 1396–1401.

R. Yu , J. Liu and Y. Zhou . Experimental study on tribological property of MoS2 nanoparticle in castor oil, J. Tribol., 141, 10, 2019, 102001.
M. F. B. Abdollah , H. Amiruddin , M. Alif Azmi and N. A. M. Tahir . Lubrication mechanisms of hexagonal boron nitride nano-additives water-based lubricant for steel–steel contact, P. I. Mech. Eng. J.-J. Eng., 2020, https://doi.org/10.1177/1350650120940173.
E. Sneha , V. S. Sarath , S. Rani and K. B. Kumar . Effect of turmeric oil and halloysite nano clay as anti-oxidant and anti-wear additives in rice bran oil, P. I. Mech. Eng. J.-J. Eng., 2020, https://doi.org/10.1177/1350650120945074.
B. Sagbas . Tribological performance of peek with green lubricant enhanced by nano hexagonal boron nitride powder, Ind. Lub. Tribol., 72, 2, 2018, 203–210.
G. Xie , J. Luo , D. Guo and S. Liu . Nanoconfined ionic liquids under electric fields, Appl. Phys. Lett., 96, 2010, 043112.
M. Kronberger , V. Pejaković , C. Gabler and M. Kalin . How anion and cation species influence the tribology of a green lubricant based on ionic liquids, P. I. Mech. Eng. J.-J. Eng., 226, 11, 2012, 933–951.
S. Stolte , S. Steudte , O. Areitioaurtena , F. Pagano , J. Thöming , P. Stepnowski and A. Igartua . Ionic liquids as lubricants or lubrication additives: An ecotoxicity and biodegradability assessment, Chemosphere, 89, 9, 2012, 1135–1141.
S. Zhang , L. Ma , P. Wen , X. Ye , R. Dong , W. Sun , M. Fan , D. Yang , F. Zhou and W. Liu . The ecotoxicity and tribological properties of choline amino acid ionic liquid lubricants, Tribol. Int., 121, 2018, 435–441.
P. Nagendramma , P. K. Khatri , G. D. Thakre and S. L. Jain . Lubrication capabilities of amino acid based ionic liquids as green bio-lubricant additives, J. Mol. Liq., 244, 2017, 219–225.
M. Fan , L. Ma , C. Zhang , Z. Wang , J. Ruan , M. Han , Y. Ren , C. Zhang , D. Yang , F. Zhou and W. Liu . Biobased green lubricants: Physicochemical, tribological and toxicological properties of fatty acid ionic liquids, Tribol. Trans., 61, 2, 2018, 195–206.
D. Zheng , X. Wang , M. Zhang Z. Liu and C. Ju . Anticorrosion and lubricating properties of a fully green lubricant, Tribol. Int., 130, 2019, 324–333.
A. Z. Syahir , M. H. Harith , N. W. M. Zulkifli , H. H. Masjuki , M. A. Kalam , M. N. A. M. Yusoff , Z. M. Zulfattah and T. M. Ibrahim . Compatibility of ionic liquid with glycerol monooleate and molybdenum dithiocarbamate as additives in bio-based lubricant, J. Tribol., 142, 6, 2020, 061901.
C. Ju , D. Zheng , Q. Zhao , et al. Tribological properties of green ILs containing MoS2 quantum dots with one-step preparation. Tribol. Lett. 68, 2020, 79.
C. Chimeno-Trinchet , M. E. Pacheco , A. Fernández-González , M. E. Díaz-García and R. Badía-Laíño . New metal-free nanolubricants based on carbon-dots with outstanding antiwear performance, J. Ind. Eng. Chem., 87, 2020, 152–161.
H. Wu , S. Yin , L. Wang , Y. Du , Y. Yang , J. Shi and H. Wang . Investigation on the robust adsorption mechanism of alkyl-functional boric acid nanoparticles as high performance green lubricant additives, Tribology International, 157, May 2021, 106909.
E. Omrani , P. L. Menezes and P. K. Rohatgi . State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world, Eng. Sci. Tech. Int. J., 19, 2, 2016, 717–736.
S. Karthikeyan , N. Rajini , M. Jawaid , J. T. Winowlin Jappes , M. T. H. Thariq , S. Siengchin and J. Sukumaran . A review on tribological properties of natural fiber based sustainable hybrid composite, P. I. Mech. Eng. J.-J. Eng., 231, 12, 2017, 1616–1634.
H. Chen , L. Zhang , M. Li and G. Xie . Synthesis of core–shell micro/nanoparticles and their tribological application: A review, Materials, 13, 20, 2020, 4590.
Z. Ji , L. Zhang , G. Xie et al. Mechanical and tribological properties of nanocomposites incorporated with two-dimensional materials. Friction, 8, 2020, 813–846.
P. Saravanan and N. Emami . Chapter 13 – Sustainable tribology: Processing and characterization of multiscale thermoplastic composites within hydropower applications, Tribol. Polym. Compos. Charact. Prop. Appl., Elsevier Series on Tribology and Surface Engineering, 2021, 241–277.
E. E. Nunez , R. Gheisari and A. A. Polycarpou . Tribology review of blended bulk polymers and their coatings for high-load bearing applications, Tribol. Int., 129, 2019, 92–111.
P. Lan , E. E. Nunez and A. A. Polycarpou . Advanced polymeric coatings and their applications: Green tribology, Encycl. Renewable Sustainable Mater., 4, 2020, 345–358.

Y. Ren , L. Zhang , G. Xie et al. A review on tribology of polymer composite coatings. Friction, 9, 2021, 429–470.
E. I. Akpan , B. Wetzel and K. Friedrich , A fully biobased tribology material based on acrylic resin and short wood fibres, Tribol. Int., 120, 2018, 381–390.
V. K. Patel , S. Chauhan and J. K. Katiyar . Physico-mechanical and wear properties of novel sustainable sour-weed fiber reinforced polyester composites, Mater. Res. Express, 5, 4, 2018, 045310.
A. S. Negi , J. K. Katiyar , S. Kumar , N. Kumar and V. K. Patel . Physicomechanical and abrasive wear properties of hemp/kevlar/carbon reinforced hybrid epoxy composites, Mat. Res. Exp., 6, 11, 2019, 115304.
M. A. A. Bakar , A. H. Abdul , S. Kasolang and M. A. Ahmad . Specific wear rate of kenaf epoxy composite and oil palm empty fruit bunch (OPEFB) epoxy composite in dry sliding, J. Tekn., 58, 2012, 85–88.
V. Mahale , J. Bijwe and S. Sinha . Efforts towards green friction materials, Tribol. Int., 136, August 2019, 196–206.
D. N. F. Mahmud , M. F. B. Abdollah , N. A. B. Masripan , N. Tamaldin and H. Amiruddin . Frictional wear stability mechanisms of an activated carbon composite derived from palm kernel by phase transformation study, Ind. Lub. Tribol., 69, 6, 2017, 945–951.
A. Mustafa , M. F. B. Abdollah , H. Amiruddin , F. F. Shuhimi and N. Muhammad . Optimization of friction properties of kenaf polymer composite as an alternative friction material, Ind. Lub. Tribol., 69, 2, 2017, 259–266.
A. Jumahat , C. Soutis , S. A. Abdullah and S. Kasolang . Tensile properties of nanosilica/epoxy nanocomposites, Proc. Eng., 41, 2012, 1634–1640.
B. Barari , E. Omrani , A. D. Moghadam , P. L. Menezes , K. M. Pillai and P. K. Rohatgi . Mechanical, physical and tribological characterization of nano-cellulose fibers reinforced bio-epoxy composites: An attempt to fabricate and scale the ‘Green’ composite, Carb. Polym., 147, 2016, 282–293.
X. Wei , G. Zhang and L. Wang . “Metal-reservoir” carbon-based nanocomposite coating for green tribology. Tribol. Lett., 59, 2015, 34.
I. Taheridoustabad , M. Khosravi and Y. Yaghoubinezhad . Fabrication of GO/RGO/TiC/TiB2 nanocomposite coating on Ti–6Al–4V alloy using electrical discharge coating and exploring its tribological properties, Tribol. Int., 156, 2021, 106860.
N. A. M. Tahir , M. F. B. Abdollah , N. Tamaldin , M. R. B. M. Zin and H. Amiruddin . Effect of hydrogen on graphene growth from solid waste products by chemical vapour deposition: friction coefficient properties, Ind. Lub. Tribol., 72, 2, 2018, 181–188.
B. Chen , Y. Jia , M. Zhang , H. Liang , X. Li , J. Yang , F. Yan and C. Li . Tribological properties of epoxy lubricating composite coatings reinforced with core-shell structure of CNF/MoS2 hybrid, Comp. Part A Appl. Sci. Manuf., 122, 2019, 85–95.
J. A. Arsecularatne , E. Colusso , E. D. Gaspera , A. Martucci and M. J. Hoffman . Nanomechanical and tribological characterization of silk and silk-titanate composite coatings, Tribol. Int., 146, 2020, 106195.
I. Etsion . State of the art in laser surface texturing, J. Tribol., 127, 1, 2005 248–253.
A. F. S. Baharin , M. J. Ghazali and J. A. Wahab . Laser surface texturing and its contribution to friction and wear reduction: a brief review, Ind. Lub. Tribol., 68, 1, 2016, 57–66.
H. L. Costa and I. M. Hutchings . Some innovative surface texturing techniques for tribological purposes. P. I. Mech. Eng. J.-J. Eng., 229, 4, 2015, 429–448.
R. L. Jackson . A scale dependent simulation of liquid lubricated textured surfaces, J. Tribol., 132, 2, 2010, 022001.
D. G. Coblas , A. Fatu , A. Maoui and M. Hajjam . Manufacturing textured surfaces: State of art and recent developments, P. I. Mech. Eng. J.-J. Eng., 229, 1, 2015, 3–29.
T. Ibatan , M. S. Uddin and M. A. K. Chowdhury . Recent development on surface texturing in enhancing tribological performance of bearing sliders. Surf. Coat Tech., 272, 2015, 102–120.
U. Sudeep , N. Tandon and R. K. Pandey . Performance of lubricated rolling/sliding concentrated contacts with surface textures: A review, J. Tribol., 137, 3, 2015, 031501.
A. Ahmed , H. H. Masjuki , M. Varman , M. A. Kalam , M. Habibullah and K. A. H. Al Mahmud . An overview of geometrical parameters of surface texturing for piston/cylinder assembly and mechanical seals, Meccanica, 51, 2016, 9–23.

D. Gropper , L. Wang and T. J. Harvey . Hydrodynamic lubrication of textured surfaces: A review of modeling techniques and key findings. Tribol. Int., 94, 2016, pp. 509–529.
C. Gachot , A. Rosenkranz , S. M. Hsu and H. L. Costa . A critical assessment of surface texturing for friction and wear improvement, Wear, 372, 2017, 21–41.
A. Rosenkranz , P. G. Grützmacher , C. Gachot and H. L. Costa . Surface texturing in machine elements − a critical discussion for rolling and sliding contacts, Adv. Eng. Mat., 21, 8, 2019, 1900194.
A. Senatore and T.V.V.L.N. Rao . Partial slip texture slider and journal bearing lubricated with Newtonian fluids: A review. J. Tribol., 140, 4, 2018, 040801-1-20.
Q. J. Wang and D. Zhu . Virtual texturing: Modeling the performance of lubricated contacts of engineered surfaces, J. Tribol., 127, 4, 2005, 722–728.
X. Lu , and M. M. Khonsari . An experimental investigation of dimple effect on the stribeck curve of journal bearings. Tribol. Lett., 27, 2007, 169.
C. Shen and M. M. Khonsari . Effect of dimple's internal structure on hydrodynamic lubrication. Tribol. Lett., 52, 2013, 415–430.
M. D. Pascovici , T. Cicone , M. Fillon and M. B. Dobrica . Analytical investigation of a partially textured parallel slider, P. I. Mech. Eng. J.-J. Eng., 223, 2, 2009, 151–158.
N. Tala-Ighil , M. Fillon and P. Maspeyrot . Effect of textured area on the performances of a hydrodynamic journal bearing, Tribol. Int., 44, 3, 2011, 211–219.
S. Kango , R. K. Sharma and R. K. Pandey . Comparative analysis of textured and grooved hydrodynamic journal bearing, P. I. Mech. Eng. J.-J. Eng., 228, 1, 2014, 82–95.
C. B. Khatri and S. C. Sharma . Influence of textured surface on the performance of non-recessed hybrid journal bearing operating with non-Newtonian lubricant, Tribol. Int., 95, 2016, 221–235.
M. Mohmad , M. F. B. Abdollah , N. Tamaldin and H. Amiruddin . The effect of dimple size on the tribological performances of a laser surface textured palm kernel activated carbon-epoxy composite, Ind. Lub. Tribol., 69, 5, 2017, 768–774.
S. Matele and K. N. Pandey . Effect of surface texturing on the dynamic characteristics of hydrodynamic journal bearing comprising concepts of green tribology, P. I. Mech. Eng. J.-J. Eng., 232, 11, 2018, 1365–1376.
J. A. Ghani , M. N. A. M. Dali , H. A. Rahman , C. H. C. Haron , W. M. F. Wan Mahmood , M. R. M. Rasani and M. Z. Nuawi . Analysis of dimple structure fabricated using turning process and subsequent reduction in friction, Wear, 426–427, Part B, 2019, 1280–1285.
X. Wang , M. Khonsari , S. Li , Q. Dai and X. Wang . Experimental verification of textured mechanical seal designed using multi-objective optimization, Ind. Lub. Tribol., 71, 6, 2019,766–771.
K. Guiyue , L. Xinghu , W. Yan , L. Mouyou , Z. Kanran and M. Mingfei . Parameter study and shape optimisation of a generalised ellipse dimple-textured face seal, Lub. Sci., 32, 1, 2020, 10–20.
N. D. Hingawe and S. P. Bhore . Tribological performance of a surface textured meso scale air bearing, Ind. Lub. Tribol., 72, 5, 2019, 599–609.
N. D. Hingawe and S. P. Bhore . Multi-objective optimization of the design parameters of texture bottom profiles in a parallel slider, Friction, 8, 4, 2020, 726–745.
T. Hirayama , H. Shiotani , K. Yamada , N. Yamashita , T. Matsuoka , H. Sawada and K. Kawahara . Hydrodynamic performance produced by nanotexturing in submicrometer clearance with surface roughness, J. Tribol., 137, 1, 2015, 011704.
C. Ma , Y. Duan , B. Yu , J. Sun and Q. Tu . The comprehensive effect of surface texture and roughness under hydrodynamic and mixed lubrication conditions. P. I. Mech. Eng. J.-J. Eng., 231, 10, 2017, 1307–1319.
V. Kumar and S. C. Sharma . Influence of dimple geometry and micro-roughness orientation on performance of textured hybrid thrust pad bearing. Meccanica, 53, 2018, 3579–3606.
S. Cui , L. Gu , M. Fillon , L. Wang and C. Zhang . The effects of surface roughness on the transient characteristics of hydrodynamic cylindrical bearings during startup, Tribol. Int., 128, 2018, 421–428.
B. Yin , H. Zhou , B. Xu and H. Jia . The influence of roughness distribution characteristic on the lubrication performance of textured cylinder liners, Ind. Lub. Tribol., 71, 3, 2019, 486–493.
C. Gu , X. Meng , S. Wang and X. Ding . Study on the mutual influence of surface roughness and texture features of rough-textured surfaces on the tribological properties. P. I. Mech. Eng.

J.-J. Eng., 2020, https://doi.org/10.1177/1350650120940211.
K. Furukawa , M. Ochiai , H. Hashimoto and S. Kotani . Bearing characteristic of journal bearing applied biomimetics, Tribol. Int., 150, 2020, 106345.
N. A. Latif , S. Kasolang , M. A. Ahmad and M. A. A. Bakar . Effect of oleophilicity on Pistia inspired surface roughness, J. Mech. Eng., 8, 2019, 105–116.
A. Arslan , H. H. Masjuki , M. Varman , M. A. Kalam , M. M. Quazi , K. A. H. Al Mahmud , M. Gulzar and M. Habibullah . Effects of texture diameter and depth on the tribological performance of DLC coating under lubricated sliding condition, Appl. Surf. Sci., 356, 2015, 1135–1149.
A. Ancona , G. S. Joshi , A. Volpe , M. Scaraggi , P. M. Lugarà and G. Carbone . Non-uniform laser surface texturing of an un-tapered square pad for tribological applications. Lubricants, 5, 4, 2017, 41.
P. G. Grützmacher , A. Rosenkranz , A. Szurdak , F. König , G. Jacobs , G. Hirt and F. Mücklich . From lab to application – improved frictional performance of journal bearings induced by single-and multi-scale surface patterns, Tribol. Int., 127, 2018, 500–508.
P. G. Grützmacher , A. Rosenkranz , A. Szurdak , M. Grüber , C. Gachot , G. Hirt and F. Mücklich . Multi-scale surface patterning – an approach to control friction and lubricant migration in lubricated systems, Ind. Lub. Tribol., 71, 8, 2019, 1007–1016.
T.V.V.L.N. Rao . Analysis of single-grooved slider and journal bearing with partial slip surface, J. Tribol., 132, 1, 2010, 014501.
M. Tauviqirrahman , R. Ismail , J. Jamari and D. J. Schipper . Combined effect of texturing and boundary slippage in lubricated sliding contacts, Tribol. Int., 66, 2013, 274–281.
S. Susilowati , M. Tauviqirrahman , J. Jamari and A. P. Bayuseno . Numerical investigation of the combined effects of slip and texture on tribological performance of bearing, Tribol.– Mat. Surf. Inter., 10, 2, 2016, 86–89.
S. Cui , C. Zhang , M. Fillon and L. Gu . Optimization performance of plain journal bearings with partial wall slip, Tribol. Int., 145, 2020, 106137.
Z. G. Wang . Tribological approaches for green metal forming, J. Mat. Proc. Tech., 151, 1–3, 2004, 223–227.
N. N. Nor Hamran , J. A. Ghani , R. Ramli and C. H. Che Haron . A review on recent development of minimum quantity lubrication for sustainable machining, J. Clean. Prod., 268, 2020, 122165.
K. C. Wickramasinghe , H. Sasahara , E. A. Rahim and G. I. P. Perera . Green metalworking fluids for sustainable machining applications: A review, J. Clean. Prod., 257, 2020, 120552.
N. Talib and E.A. Rahim . Performance evaluation of chemically modified crude jatropha oil as a bio-based metalworking fluids for machining process, Proc. CIRP, 26, 2015, 346–350.
P. S. Suvin , P. Gupta , J.-H. Horng and S. V. Kailas . Evaluation of a comprehensive non-toxic, biodegradable and sustainable cutting fluid developed from coconut oil, P. I. Mech. Eng. J.-J. Eng., 2020, https://doi.org/10.1177/1350650120975518.
S. Yuan , X. Hou , L. Wang et al. Experimental investigation on the compatibility of nanoparticles with vegetable oils for nanofluid minimum quantity lubrication machining. Tribol. Lett. 66, 2018, 106.
B. Sen , M. K. Gupta , M. Mia , U. K. Mandal and S. P. Mondal . Wear behaviour of TiAlN coated solid carbide end-mill under alumina enriched minimum quantity palm oil-based lubricating condition, Tribol. Int., 148, 2020, 106310.
A. M. M. Ibrahim , W. Li , H. Xiao , Z. Zeng , Y. Ren and M. S. Alsoufi . Energy conservation and environmental sustainability during grinding operation of Ti–6Al–4V alloys via eco-friendly oil/graphene nano additive and minimum quantity lubrication, Tribol. Int., 150, 2020, 106387.
R. Teti , D. M. D’Addona and T. Segreto . Microbial-based cutting fluids as bio-integration manufacturing solution for green and sustainable machining, CIRP J. Manuf. Sci. Tech., 32, 2021, 16–25.
N. H. Abdul Halim , C. H. Che Haron and J. Abdul Ghani . Sustainable machining of hardened inconel 718: A comparative study, Int. J. Precis. Eng. Manuf., 21, 2020, 1375–1387.
S. Sivarajan and R. Padmanabhan . Green machining and forming by the use of surface coated tools, Proc. Eng., 97, 2014, 15–21.
A. Arslan , H. H. Masjuki , M. A. Kalam , M. Varman , R. A. Mufti , M. H. Mosarof , L. S. Khuong and M. M. Quazi . Surface texture manufacturing techniques and tribological effect of surface texturing on cutting tool performance: A review, Crit. Rev. Sol. State Mat. Sci., 41, 6, 2016,

447–481.
S. Niketh and G.L. Samuel . Surface texturing for tribology enhancement and its application on drill tool for the sustainable machining of titanium alloy, J. Clean. Prod., 167, 2017, 253–270.
Z. Lai , C. Wang , L. Zheng , W. Huang , J. Yang , G. Guo and W. Xiong . Adaptability of AlTiN-based coated tools with green cutting technologies in sustainable machining of 316L stainless steel, Tribol. Int., 148, 2020, 106300.
R. Padmini , P. V. Krishna , S. Mahith and S. Kumar . Influence of green nanocutting fluids on machining performance using minimum quantity lubrication technique, Mat. Today: Proc., 18, Part 3, 2019, 1435–1449.
H. Wu , F. Jia , J. Zhao , S. Huang , L. Wang , S. Jiao , H. Huang and Z. Jiang . Effect of water-based nanolubricant containing nano-TiO2 on friction and wear behaviour of chrome steel at ambient and elevated temperatures, Wear, 426–427, Part A, 2019, 792–804.
L. Peña-Parás , D.o Maldonado-Cortés , P. García , M. Irigoyen , J. Taha-Tijerina and J. Guerra . Tribological performance of halloysite clay nanotubes as green lubricant additives, Wear, 376–377, Part A, 2017, 885–892.

Bio-Based Lubricant in the Presence of Additives

Evans, C. (1978). Strategy for Energy Conservation through Tribology. American Society of Mechanical Engineers, New York, 1977. Energy Policy, 6(2), 170–171.
Blau, P. J. (1997). Fifty Years of Research on the Wear of Metals. Tribology International, 30(5), 321–331.
Holmberg, K. , Andersson, P. , & Erdemir, A. (2012). Global Energy Consumption due to Friction in Passenger Cars. Tribology International, 47, 221–234.
Tung, S. C. , & McMillan, M. L. (2004). Automotive Tribology Overview of Current Advances and Challenges for the Future. Tribology International, 37(7), 517–536.
Baek, J. S. , Groll, E. A. , & Lawless, P. B. (2005). Piston-Cylinder Work Producing Expansion Device in a Transcritical Carbon Dioxide Cycle. Part I: Experimental Investigation. International Journal of Refrigeration, 28(2), 141–151.
Tan, Y.-C. , & Ripin, Z. M. (2011). Frictional Behavior of Piston Rings of Small Utility Two-Stroke Engine Under Secondary Motion of Piston. Tribology International, 44(5), 592–602.
Tan, Y.-C. , & Ripin, Z. M. (2014). Technique to Determine Instantaneous Piston Skirt Friction During Piston Slap. Tribology International, 74, 145–153.
Nakada, M. (1994). Trends in Engine Technology and Tribology. Tribology International, 27(1), 3–8.
Allmaier, H. , Priestner, C. , Reich, F. M. , Priebsch, H. H. , Forstner, C. , & Novotny-Farkas, F. (2012). Predicting Friction Reliably and Accurately in Journal Bearings: The Importance of Extensive Oil-Models. Tribology International, 48, 93–101.
Iwai, Y. , Yoneda, H. , & Honda, T. (1995). Sliding Wear Behavior of SiC Whisker-Reinforced Aluminum Composite. Wear, 181, 594–602.
Gopalakrishnan, S. , & Murugan, N. (2012). Production and Wear Characterisation of AA 6061 Matrix Titanium Carbide Particulate Reinforced Composite by Enhanced Stir Casting Method. Composites Part B: Engineering, 43(2), 302–308.
Kumar, S. , Chakraborty, M. , Sarma, V. S. , & Murty, B. S. (2008). Tensile and Wear Behaviour of in situ Al–7Si/TiB2 Particulate Composites. Wear, 265(1–2), 134–142.
Rajan, H. B. M. , Ramabalan, S. , Dinaharan, I. , & Vijay, S. J. (2014). Effect of TiB2 Content and Temperature on Sliding Wear Behavior of AA7075/TiB2 in situ Aluminum Cast Composites. Archives of Civil and Mechanical Engineering, 14(1), 72–79.
Miller, A. L. , Stipe, C. B. , Habjan, M. C. , & Ahlstrand, G. G. (2007). Role of Lubrication Oil in Particulate Emissions from a Hydrogen-Powered Internal Combustion Engine. Environmental Science & Technology, 41(19), 6828–6835.
Ssempebwa, J. C. , & Carpenter, D. O. (2009). The Generation, Use and Disposal of Waste Crankcase Oil in Developing Countries: A Case for Kampala District, Uganda. Journal of Hazardous Materials, 161(2–3), 835–841.
Asadauskas, S. , Perez, J. M. , & Duda, J. L. (1996). Oxidative Stability and Antiwear Properties of High Oleic Vegetable Oils. Lubrication Engineering, 52(12), 877–882.

Nagendramma, P. , & Kaul, S. (2012). Development of Ecofriendly/Biodegradable Lubricants: An Overview. Renewable and Sustainable Energy Reviews, 16(1), 764–774.
Quinchia, L. A. , Delgado, M. A. , Reddyhoff, T. , Gallegos, C. , & Spikes, H. A. (2014). Tribological Studies of Potential Vegetable Oil-Based Lubricants Containing Environmentally Friendly Viscosity Modifiers. Tribology International, 69, 110–117.
Shahabuddin, M. , Masjuki, H. H. , Kalam, M. A. , Bhuiya, M. M. K. , & Mehat, H. (2013). Comparative Tribological Investigation of Bio-lubricant Formulated from a Non-edible Oil Source (Jatropha Oil). Industrial Crops and Products, 47, 323–330.
Padhi, S. K. , & Singh, R. K. (2011). Non-edible Oils as the Potential Source for the Production of Biodiesel in India: A Review. Journal of Chemical and Pharmaceutical Research, 3(2), 39–49.
Ong, H. C. , Mahlia, T. M. I. , Masjuki, H. H. , & Norhasyima, R. S. (2011). Comparison of Palm Oil, *Jatropha curcas* and *Calophyllum inophyllum* for Biodiesel: A Review. Renewable and Sustainable Energy Reviews, 15(8), 3501–3515.
Sharma, R. V. , & Dalai, A. K. (2013). Synthesis of Bio-lubricant from Epoxy Canola Oil Using Sulfated Ti-SBA-15 Catalyst. Applied Catalysis B: Environmental, 142, 604–614.
Gulzar, M. , Masjuki, H. H. , Kalam, M. A. , Varman, M. , Zulkifli, N. W. M. , Mufti, R. A. , & Zahid, R. (2016). Tribological Performance of Nanoparticles as Lubricating Oil Additives. Journal of Nanoparticle Research, 18(8), 223.
Watanabe, S. , Noshiro, J. , & Miyake, S. (2004). Tribological Characteristics of WS2/MoS2 Solid Lubricating Multilayer Films. Surface and Coatings Technology, 183(2–3), 347–351. https://doi.org/10.1016/j.surfcoat.2003.09.063
Kim, H. J. , Shin, D. G. , & Kim, D. E. (2016). Frictional Behavior Between Silicon and Steel Coated with Graphene Oxide in Dry Sliding and Water Lubrication Conditions. International Journal of Precision Engineering and Manufacturing – Green Technology, 3(1), 91–97. https://doi.org/10.1007/s40684-016-0012-8
Donnet, C. , & Erdemir, A. (2004). Historical Developments and New Trends in Tribological and Solid Lubricant Coatings. Surface and Coatings Technology, 180, 76–84.
Barnes, A. M. , Bartle, K. D. , & Thibon, V. R. A. (2001). A Review of Zinc dialkyl dithiophosphates (ZDDPS): Characterisation and Role in the Lubricating Oil. Tribology International, 34(6), 389–395.
Tung, S. C. , & Totten, G. E. (2012). Automotive lubricants and testing. ASTM International.
Bartz, W. J. (1978). Tribology, Lubricants and Lubrication Engineering—A Review. Wear, 49(1), 1–18.
Hutton, J. F. (1973). The Rheology of Petroleum-based Lubricating Oils and Greases: A Review. The Rheology of Lubricants, 16.
Gangopadhyay, A. (2017). A Review of Automotive Engine Friction Reduction Opportunities Through Technologies Related to tribology. Transactions of the Indian Institute of Metals, 70(2), 527–535. https://doi.org/10.1007/s12666-016-1001-x
Stachowiak, G. , & Batchelor, A. W. (2013). Engineering tribology. Butterworth-Heinemann.
Nabil, M. F. , Azmi, W. H. , Hamid, K. A. , Mamat, R. , & Hagos, F. Y. (2017). An Experimental Study on the Thermal Conductivity and Dynamic Viscosity of TiO2–SiO2 Nanofluids in Water: Ethylene Glycol Mixture. International Communications in Heat and Mass Transfer, 86, 181–189.
Komatsuzaki, S. , & Ito, R. (1975). Flow Properties of Lubricating Greases at High-Temperature. 1. Apparent Viscosity at High-Temperature. Journal of Japan Society of Lubrication Engineers, 20(2), 97–105.
Bartz, W. J. (1976). About the influence of viscosity index improvers on the cold flow properties of engine oils. TRIBOLOGY International, 9(1), 13–20. https://doi.org/10.1016/0301-679X(76)90064-5.
Bart, Jan C. J. , Gucciardi, E. , & Cavallaro, S. (2012). Biolubricants: science and technology. Elsevier.
Pillon, L. Z. (2016). Surface activity of petroleum derived lubricants (Vol. 127). CRC Press.
Bart, J C J , Gucciardi, E. , & Cavallaro, S. (2013). *Lubricants: Properties and characteristics* . Biolubricants. Woodhead Publishing Series in Energy, 24, 73.
Kodali, D. R. (2002). High Performance Ester Lubricants from Natural Oils. Industrial Lubrication and Tribology.
Anand, A. , Haq, M. I. U. , Vohra, K. , Raina, A. , & Wani, M. F. (2017). Role of Green Tribology in Sustainability of Mechanical Systems: A State of the Art Survey. Materials Today:

Proceedings, 4(2), 3659–3665.
Hamrock, B. J. (1994). Fundamentals of fluid film lubrication. McGraw-Hill. Inc., Hightstown, NJ, 8520.
Rudnick, L. R. (2013). Synthetics, mineral oils, and bio-based lubricants: chemistry and technology. CRC Press
Quinchia, L. A. , Delgado, M. A. , Franco, J. M. , Spikes, H. A. , & Gallegos, C. (2012). Low-Temperature Flow Behaviour of Vegetable Oil-based Lubricants. Industrial Crops and Products, 37(1), 383–388.
Crawford, J. , Psaila, A. , & Orszulik, S. T. (1997). Miscellaneous additives and vegetable oils. In Chemistry and technology of lubricants (pp. 181–202). Springer.
McNutt, J. (2016). Development of Biolubricants from Vegetable Oils via Chemical Modification. Journal of Industrial and Engineering Chemistry, 36, 1–12.
Reeves, C. J. , Menezes, P. L. , Jen, T.-C. , & Lovell, M. R. (2015). The Influence of Fatty Acids on Tribological and Thermal Properties of Natural Oils as Sustainable Biolubricants. Tribology International, 90, 123–134.
Syahir, A. Z. , Zulkifli, N. W. M. , Masjuki, H. H. , Kalam, M. A. , Alabdulkarem, A. , Gulzar, M. , Khuong, L. S. , & Harith, M. H. (2017). A Review on Bio-based Lubricants and their Applications. Journal of Cleaner Production, 168, 997–1016.
Salimon, J. , Salih, N. , & Yousif, E. (2012). Industrial Development and Applications of Plant Oils and their Biobased Oleochemicals. Arabian Journal of Chemistry, 5(2), 135–145.
Bovington, C. H. (2010). Friction, wear and the role of additives in controlling them. In Chemistry and technology of lubricants (pp. 77–105). Springer.
Peña-Parás, L. , Maldonado-Cortés, D. , Kharissova, O. V. , Saldívar, K. I. , Contreras, L. , Arquieta, P. , & Castaños, B. (2019). Novel Carbon Nanotori Additives for Lubricants with Superior Anti-wear and Extreme Pressure Properties. Tribology International, 131, 488–495.
Khrushchev, M. M. , & Babichev, M. A. (1953). Resistance to abrasive wear and the hardness of metals (Vol. 15). US Atomic Energy Commission, Technical Information Service.
Rabinowicz, E. , & Mutis, A. (1965). Effect of Abrasive Particle Size on Wear. Wear, 8(5), 381–390.
Zhang, Z. , Zhang, L. , & Mai, Y.-W. (1997). Modeling Steady Wear of Steel/Al2O3 Al Particle Reinforced Composite System. Wear, 211(2), 147–150.
Archard, J. (1953). Contact and Rubbing of Flat Surfaces. Journal of Applied Physics, 24(8), 981–988.
Suh, N. P. (1973). The Delamination Theory of Wear. Wear, 25(1), 111–124. https://doi.org/10.1016/0043-1648(73)90125-7
Sin, H. , Saka, N. , & Suh, N. P. (1979). Abrasive Wear Mechanisms and the Grit Size Effect. Wear, 55(1), 163–190. https://doi.org/10.1016/0043-1648(79)90188-1
Spikes, H. (2004). The History and Mechanisms of ZDDP. Tribology Letters, 17(3), 469–489.
Mortier, R. M. , Orszulik, S. T. , & Fox, M. F. (2010). Chemistry and technology of lubricants (Vol. 107115). Springer.
Dienwiebel, M. , & Pöhlmann, K. (2007). Nanoscale Evolution of Sliding Metal Surfaces During Running-in. Tribology Letters, 27(3), 255–260.
Azman, N. F. , Samion, S. , Moen, M. A. A. , Hamid, M. K. A. , & Musa, M. N. (2019). The Anti-wear and Extreme Pressure Performance of CuO and Graphite Nanoparticles as an Additive in Palm Oil. International Journal of Structural Integrity. 10(5), 714–725.
Sajeeb, A. , & Rajendrakumar, P. K. (2019). Experimental Studies on Viscosity and Tribological Characteristics of Blends of Vegetable Oils with CuO Nanoparticles as Additive. Micro & Nano Letters, 14(11), 1121–1125.
Lu, Z. , Cao, Z. , Hu, E. , Hu, K. , & Hu, X. (2019). Preparation and Tribological Properties of WS2 and WS2/TiO2 Nanoparticles. Tribology International, 130, 308–316.
Gulzar, M. , Masjuki, H. H. , Varman, M. , Kalam, M. A. , Mufti, R. A. , Zulkifli, N. W. M. , Yunus, R. , & Zahid, R. (2015). Improving the AW/EP Ability of Chemically Modified Palm Oil by Adding CuO and MoS2 Nanoparticles. Tribology International, 88, 271–279.
Arumugam, S. , & Sriram, G. (2013). Preliminary Study of Nano- and Microscale TiO2 Additives on Tribological Behavior of Chemically Modified Rapeseed Oil. Tribology Transactions, 56(5), 797–805.
Katiyar, J. K. , Bhaumik, S. , Ashok, A. , & Sharma, A. K. (2018). Physiochemical Properties of Hexagonal Boron Nitride Blended Coconut Oil. Proceedings of TRIBOINDIA-2018 – An

International Conference on Tribology, Available at SSRN: https://ssrn.com/abstract=3321035 or http://dx.doi.org/10.2139/ssrn.3321035

Zaarour, M. , El Siblani, H. , Arnault, N. , Boullay, P. , & Mintova, S. (2019). Zeolite Nanocrystals Protect the Performance of Organic Additives and Adsorb Acid Compounds During Lubricants Oxidation. Materials, 12(17), 2830.

Sabarinath, S. , Rajendrakumar, P. K. , & Prabhakaran Nair, K. (2019). Evaluation of Tribological Properties of Sesame Oil as Biolubricant with SiO2 Nanoparticles and Imidazolium-Based Ionic Liquid as Hybrid Additives. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 233(9), 1306–1317.

Khorshidnia, H. , & Shirneshan, A. (2019). Investigating the Tribological Behavior of Diesel-Biodiesel Blends with Nanoparticle Additives Under Short-term Tests. ADMT Journal, 12(3), 19–24.

Philip, J. T. , Koshy, C. P. , Mathew, M. D. , & Kuriachen, B. (2019). Tribological Characteristic Evaluation of Coconut Oil Dispersed with Surfactant Modified Ceria-Zirconia Hybrid Nanoparticles. Tribology-Materials, Surfaces & Interfaces, 13(4), 197–214.

V. Kotturu, C. M. V. , Srinivas, V. , Vandana, V. , Chebattina, K. R. R. , & Seetha Rama Rao, Y. (2019). Investigation of Tribological Properties and Engine Performance of Polyol Ester–based Bio-lubricant: Commercial Motorbike Engine Oil Blends. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 234(5), 1304–1317.

Alghani, W. , Ab Karim, M. S. , Bagheri, S. , Amran, N. A. M. , & Gulzar, M. (2019). Enhancing the Tribological Behavior of Lubricating Oil by Adding TiO2, Graphene, and TiO2/Graphene Nanoparticles. Tribology Transactions, 62(3), 452–463.

Zadoshenko, E. G. , Burlakova, V. E. , & Novikova, A. A. (2020). Effect of Nickel Nanopowder on Lubrication Behaviour of Low-Temperature Grease in Steel-Steel Tribosystem. Tribology-Materials, Surfaces & Interfaces, 14(1), 51–58.

Gulzar, M. , Masjuki, H. H. , Kalam, M. A. , Varman, M. , Zulkifli, N. W. M. , Mufti, R. A. , Zahid, R. , & Yunus, R. (2017). Dispersion Stability and Tribological Characteristics of TiO2/SiO2 Nanocomposite-Enriched Biobased Lubricant. Tribology Transactions, 60(4), 670–680.

Srivyas, P. D. , & Charoo, M. S. (2019). Graphene: An effective lubricant for tribological applications. Lecture Notes in Mechanical Engineering. https://doi.org/10.1007/978-981-13-6469-3_22

Shinde, V. , & Soni, S. (2018). Effect of Lubricants with Nanoparticles on Performance of Hydrodynamic Journal Bearing. Proceedings of TRIBOINDIA-2018, An International Conference on Tribology, Available at SSRN: https://ssrn.com/abstract=3320357 or http://dx.doi.org/10.2139/ssrn.3320357

Jazaa, Y. , Lan, T. , Padalkar, S. , & Louis, S. (2018). The Effect of Agglomeration Reduction on the Tribological Behavior of WS 2 and MoS 2 Nanoparticle. Lubricants, 6(4), 106. https://doi.org/10.3390/lubricants6040106

Kannan, K. T. , & Rameshbabu, S. (2018). Tribological Properties of Modified Jojoba Oil as Probable Base Stoke of Engine Lubricant. Journal of Mechanical Science and Technology, 32(4), 1739–1747. https://doi.org/10.1007/s12206-018-0330-6

Pillay, D. S. , Azwadi, N. , & Sidik, C. (2017). Tribological Properties of Biodegradable Nano-Lubricant. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 33(1), 1–13.

Baskar, S. , Sriram, G. , & Arumugam, S. (2016b). Tribological Analysis of a Hydrodynamic Journal Bearing Under the Influence of Synthetic and Biolubricants. Tribology Transactions, 60(3), 428–436. https://doi.org/10.1080/10402004.2016.1176285

Vista, L. B. , Reeves, C. J. , Menezes, P. L. , Lovell, M. R. , & Jen, T. (2014). The Effect of Particulate Additives on the Tribological Performance of Bio-based and Ionic Liquid-based Lubricants for Energy Conservation and Sustainability Track. *Proceedings of the 2014 STLE Annual Meeting & Exhibition Disney's Contemporary Resort. M.* 2–4.

Baskar, S. , Sriram, G. , & Arumugam, S. (2016a). The Use of D-optimal Design for Modeling and Analyzing the Tribological Characteristics of Journal Bearing Materials Lubricated by Nano-based Biolubricants. Tribology Transactions, 59(1), 44–54. https://doi.org/10.1080/10402004.2015.1063179

Sa, S. , Azman, N. , Wahidah, N. , Zulki, M. , Masjuki, H. , & Gulzar, M. (2016). Study of tribological properties of lubricating oil blend added with graphene nanoplatelets. Journal of Materials Research, 31(13)

Reeves, C. J. , Menezes, P. L. , Lovell, M. R. , & Jen, T.-C. (2015). The Influence of Surface Roughness and Particulate Size on the Tribological Performance of Bio-Based Multi-Functional Hybrid Lubricants. Tribology International, 88, 40–55.

Qu, J. , Bansal, D. G. , Yu, B. , Howe, J. Y. , Luo, H. , Dai, S. , Li, H. , Blau, P. J. , Bunting, B. G. , & Mordukhovich, G. (2012). Antiwear Performance and Mechanism of an Oil-Miscible Ionic Liquid as a Lubricant Additive. ACS Applied Materials & Interfaces, 4(2), 997–1002.

Singh, J. , Anand, G. , Kumar, D. , & Tandon, N. (2016). Graphene Based Composite Grease for Elastohydrodynamic Lubricated Point Contact. IOP Conference Series: Materials Science and Engineering, 149(1), 12195.

Kenig, S. , Wagner, H. , Zak, A. , Moshkovith, A. , Rapoport, L. , & Tenne, R. (2011). The Mechanical and Tribological Properties of Epoxy Nanocomposites with WS2 Nanotubes. Sensors & Transducers, 12, 53–65.

Srinivas, V. , Manikanta, P. V. , Satish, V. , & Valluripally, D. (2014). Physicochemical Properties of Motor Oil Dispersed with WS2 and MoS2 Nano Particles. *International Mechanical Engineering Congress*.

Bogunovic, L. , Zuenkeler, S. , Toensing, K. , & Anselmetti, D. (2015). An Oil-Based Lubrication System Based on Nanoparticular TiO2 with Superior Friction and Wear Properties. Tribology Letters, 59(2), 29.

Tribological Investigations of Sustainable Bio-Based Lubricants for Industrial Applications

C. Lea , Energy savings through use of advanced biodegradable lubricants, Industrial Lubrication and Tribology 59 (2007) 132–136.

P. Dašić , F. Franek , E. Assenova , M. Radovanovic , International standardization and organizations in the field of tribology, Industrial Lubrication and Tribology 55(6) (2003) 287–291.

P. H. Jost , Tribology micro and macro economics: A road to economic savings. World Tribology Congress III, Washington, DC, Tribology & Lubrication Technology 61(10) (2005) 18–22.

G. Karmakar , P. Ghosh , B. Sharma , Chemically modifying vegetable oils to prepare green lubricants, Lubricants 5 (2017) 44.

R. Singh , S.K. Padhi , Characterization of jatropha oil for the preparation of biodiesel, Natural Product Radiance 8 (2009) 127–132.

A.B. Chhetri , M.S. Tango , S.M. Budge , K.C. Watts , M.R. Islam , Non-edible plant oils as new sources for biodiesel production, International Journal of Molecular Sciences 9 (2008) 169–180.

A. Murugesan , C. Umarani , T. Chinnusamy , M. Krishnan , R. Subramanian , N. Neduzchezhain , Production and analysis of biodiesel from non-edible oils—A review, Renewable and Sustainable Energy Reviews 13 (2009) 825–834.

F. Klocke , A. Schulz , K. Gerschwiler , Saubere Fertigungstechnologien–Ein Wettbewerbsvorteil von morgen, *Aachener Perspektiven*, VDI, Düsselorf (1996).

F. Ma , M.A. Hanna , Biodiesel production: A review, Bioresource Technology 70 (1999) 1–15.

L. Meher , D.V. Sagar , S. Naik , Technical aspects of biodiesel production by transesterification—A review, Renewable and Sustainable Energy Reviews 10 (2006) 248–268.

B. Fabiano , A. Reverberi , A. Del Borghi , V. Dovì , Biodiesel production via transesterification: Process safety insights from kinetic modelling, Theoretical Foundations of Chemical Engineering 46 (2012) 673–680.

S. Arumugam , G. Sriram , Effect of bio-lubricant, and biodiesel-contaminated lubricant on tribological behaviour of cylinder liner–piston ring combination, Tribology Transactions 55 (2012) 438–445.

W. Castro , D.E. Weller , K. Cheenkachorn , J.M. Perez , The effect of the chemical structure of base fluids on antiwear effectiveness of additives, Tribology International 38 (2005) 321–326.

M.T. Siniawski , N. Saniei , J. Pfaendtner , Tribological degradation of two vegetable-based lubricants at elevated temperatures, Lubrication Science 24 (2007) 167–179.

S. Boyde , Green lubricants. Environmental benefits and impacts of lubrication. Green Chemistry 4(4) (2002) 293–307.

T. Ushikusa , T. Maruyama , I. Nhya , M. Okada , Pyrolysis behaviours and thermostability of polyglycerols and polyglycerol fatty acid esters, Journal of the Japan Oil Chemists' Society 39 (1990) 314–320, 5.
D. Dermawan , Polyglycerol esters of oleic acid – estolide as renewable lubicating oil base stock, *Regional symposium of Chemical Engineering* , Singapore (2006).
B. De Meulenaer , B. Vanhoutte , A. Huyghebaert , Development of a chromatographic method to determine the degree of polymerization of polyglycerols and polyglycerol fatty acid esters, Chromatographia 51 (2000) 49–51.
J.B. Rodríguez , The food additive polyglycerol polyricinoleate (E-476): Structure, applications, and production methods, ISRN Chemical Engineering (2013) Article ID124767: 21.
K.S. Shikhaliev , N.V. Stolpovskaya , M.Y. Krysin , A.V. Zorina , V. Lyapun , F.I. Denis Zubkov , K.Y. Yankina , Production and emulsifying effect of polyglycerol and fatty acid esters with varying degrees of esterification, Journal of the American Oil Chemists' Society 93 (2016) 1429–1440.
V.K. Babayan , R.T. McIntyre . Preparation and properties of some polyglycerol esters of short and medium-chain length fatty acids, Technical 48 (1968) 307–309.
C.S. Miner , N.N. Dalton , Chemical Properties and Derivatives of Glycerine, Reinhold Publication Corp., New York, Printed in USA (1953) 4–21.
P. Nagendramma , Development of eco-friendly/biodegradable synthetic (polyol & complex) ester lube base stocks. Thesis. Srinagar, India: HNB Garhwal Central University (2004).
P. Nagendramma and S. Kaul , Development of eco-friendly/biodegradable lubricants: An overview, Renewable and Sustainable Energy Reviews 16 (2012) 764–774.
https://www.inovyn.com, products, organic chlorine derivatives. (2019).
P. Nagendramma , S. Goyal , A. Ray , J. Singh , N. Atrey , Studies on the sustainability of vegetable oil as a biocompatible multipurpose green lubes and additives, Indian Journal of Chemical Technology 26 (2019) 454–457.
E. Mirci , A. Patrut , Synthetic adipic complex tetra esters as eco-friendly lubricants, Lubrication Science 25 (2013) 339–350.
P. Nagendramma , Study of pentaerythritol tetraoleate ester as industrial gear oil, Lubrication Science 23 (2011) 355–362.
Daniel Wayne Lemke , Processes for preparing linear Polyglycerols and polyglycerol esters US6620904B2 United States (2003).
J. Nowicki , J. Mosio-Mosiewski , Esterification of fatty acids with C8–C9 alcohols over selected sulfonic heterogeneous catalysts. Polish Journal of Chemical Technology Tech, 15 (2013) 42–47.
J. McNutt , S. H. Quan , Development of biolubricants from vegetable oils via chemical modification, Journal of Industrial and Engineering Chemistry 36 (2016) 1–34.
F.S. Yan , W. He , Q. Jia , Q. Wang , S. Xia , P. Ma , Prediction of ionic liquids viscosity at variable temperatures and pressures, Chemical Engineering Science 184 (2018) 134–140.
T. Housel , Synthetic esters: Engineered to perform, Machinery Lubrication Magazine, (2014) 1–10.
A. N. Raof , R. Yunus , U. Rashid , N. Azis , Z. Yaakub , Effects of molecular structure on the physical, chemical, and electrical properties of ester-based transformer insulating liquids, Journal of the American Oil Chemists' Society 96 (2019) 607–616.
M. H. Ghatee , M. Zare , F. Moosavi , A. R. Zolghadr , Temperature-dependent density and viscosity of ionic liquids 1-alkyl-3-methylimidazolium iodides: Experiment and molecular dynamics simulation, Journal of Chemical & Engineering Data 55(9) (2010) 3084–3088.
A. Wolak , Changes in lubricant properties of used synthetic oils based on the total acid number, Measurement and Control 51(3–4) (2018) 65–72.
P. Nagendramma , B.M. Shukla , D.K. Adhikari , Synthesis, characterization and tribological evaluation of new generation materials for aluminum cold rolling oils, Lubricants 4 (2016) 23.
R. Nutiu , M. Maties , M. Nutiu , Correlation between structure and physical and rheological properties in the class of neopentanepolyol esters used as lubricating oils, Journal of Synthetic Lubrication 7(2) (1990) 145–154.
F. J. Flider , Polyglycerol esters as functional fluids and functional fluid modifiers, US5380469A United States (1993).
N. E. Rothfuss , M. D. Petters , Influence of functional groups on the viscosity of organic aerosol, Environmental Science & Technology 51(1) (2016) 271–279.

G. Bahlakeh , B. Ramezanzadeh , A detailed molecular dynamics simulation and experimental investigation on the interfacial bonding mechanism of an epoxy adhesive on carbon steel sheets decorated with a novel cerium-lanthanum nanofilm, ACS Applied Materials & Interfaces 9 (2017) 17536–17551.
M. Osama , A. Singh , R. Walvekar , M. Khalid , T. C. S. M. Gupta , W. W. Gupta , Recent developments and performance review of metalworking fluids, Tribology International 114 (2017) 389–401.
M. Anna, Gradkowski , Antiwear action of mineral lubricants modified by conventional and unconventional additives, Tribology 27 (2007) 177–180.
A. R. Macrae , R. C. Hammond , Present and future applications of lipases, Biotechnology and Genetic Engineering Reviews 3 (1982) 1093–1217.
J.M. Wyatt , The microbial degradation of two-stroke oils. Ph.D. Thesis. University of Kent at Canterbury, U.K. (1983).
C.E. Cerniglia , Microbial transformation of aromatic hydrocarbons. In: Atlas RM (Ed.) Petroleum Microbiology Macmillan Publishing Co., New York, (1984) 98–128.
ASTM-D-5864-95 , Standard Test Method for Determining Aerobic Aquatic Biodegradation of Lubricants or Their Components, American National Standards Institute, New York, NY (1996).
A. Emmanuel , K. O. Obahiagbon , M. Orijesu , Biodegradation of vegetable oils: A review article, Scientific Research and Essays 4(6) (2009) 543–548.
K. Van Miert , Methods for the determination of ecotoxicity, C3—Algal inhibition test, Official Journal of the European Communities 383A (1993) 179–185.

Nano-Technology-Driven Interventions in Bio-Lubricant's Tribology for Sustainability

Hamrock BJ , Schmid SR , Jacobson BO . Fundamentals of fluid film lubrication, 2nd edition, 2004, Marcel Dekker, New York.
Pop L , Puşcaş C , Bandur G , Vlase G , Nuţiu R. Basestock oils for lubricants from mixtures of corn oil and synthetic diesters. Journal of the American Oil Chemists' Society, 2008, 85(1), 71–76.
Griffin J , Fantini A-M. Organization of the Petroleum Exporting Countries. OPEC World Oil Outlook, October 2017. Helferstorferstrasse 17 A-1010 Vienna, Austria.
Bartz WJ . Lubricants and the environment, Tribology International, 1998, 31(1–3), 35–47.
Abdalla HS , Patel S. The performance and oxidation stability of sustainable metalworking fluid derived from vegetable extracts. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 2006, 220(12), 2027–2040.
Gnanasekaran D , Chavidi V.P. Chapter 2: Biodegradable, renewable, and eco-friendly vegetable oil: Lubricants, Vegetable oil based bio-lubricants and transformer fluids, 2018, 29–47, Springer, Singapore. https://doi.org/10.1007/978-981-10-4870-8_2.
Rafiq M , Lv YZ , Zhou Y , Ma KB , Wang W , Li CR , Wang Q. Use of vegetable oils as transformer oils–a review. Renewable and Sustainable Energy Reviews, 2015, 52, 308–324.
Rizvi S.Q.A. Chapter 13: Lubricants and the environment, A comprehensive review of lubricant chemistry, technology, selection, and design, 2009, 579–600. MNL11473M, ASTM International, West Conshohocken, PA.
Anand ON , Chhibber V.K. Vegetable oil derivatives: environment-friendly lubricants and fuels. Journal of Synthetic Lubrication, 2006, 23, 91–107.
Kumar BS , Padmanabhan G , Krishna P.V. Performance assessment of vegetable oil based cutting fluids with extreme pressure additive in machining. Journal of Advanced Research in Materials Science, 2016, 19(1), 1–13.
Kashyap A , Harsha A.P. Tribological studies on chemically modified rapeseed oil with CuO and CeO2 nanoparticles. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 2016, 230(12), 1562–1571.
Rastogi RB , Maurya JL , Jaiswal V. Low sulfur, phosphorus and metal free antiwear additives: Synergistic action of salicylaldehyde *N*(4)-phenylthiosemicarbazones and its different derivatives with Vanlube 289 additive, Wear, 2013, 297 (1–2), 849–859.

Jahanmir S , Beltzer M. Effect of additive molecular structure on friction coefficient and adsorption. Transactions of the ASME, Journal of Tribology, 1986, 108, 109–116.
Jain AK , Suhane A. Research approach & prospects of non edible vegetable oil as a potential resource for biolubricant – a review. Advanced Engineering and Applied Sciences: An International Journal, 2012, 1(1), 23–32.
Wu X , Zhang X , Yang S , Chen H , Wang D. The study of epoxidized rapeseed oil used as a potential biodegradable lubricant. Journal of the American Oil Chemists' Society, 2000, 77(5), 561–563.
Doll KM , Sharma B.K. Physical properties study on partially bio-based lubricant blends: Thermally modified soybean oil with popular commercial esters. International Journal of Sustainable Engineering, 2012, 5(1), 33–37.
Castro W , Perez JM , Erhan SZ , Caputo F. A study of the oxidation and wear properties of vegetable oils: Soybean oil without additives. Journal of the American Oil Chemists' Society, 2006, 83(1), 47–52.
Mannekote JK , Kailas S.V. Experimental investigation of coconut and palm oils as lubricants in four-stroke engine. Tribology Online, 2011, 6, 76–82.
Campanella A , Rustoy E , Baldessari A , Baltanás M.A. Lubricants from chemically modified vegetable oils. Bioresource Technology, 2010, 101(1), 245–254.
Bisht RPS , Sivasankaran GA , Bhatia V.K. Additive properties of jojoba oil for lubricating oil formulations, Wear, 1993, 161(1), 193–197.
Biresaw G , Bantchev G. Effect of chemical structure on film-forming properties of seed oils. Journal of Synthetic Lubrication, 2008, 25(4), 159–183.
Hsien WLY . Towards green lubrication in machining – Utilization of vegetable oil as bio-lubricant and additive. Springer Briefs in Green Chemistry for Sustainability, 2014, 7–17. DOI 10.1007/978-981-287-266-1_2.
Shahnazar S , Bagheri S , Hamid SBA . Enhancing lubricant properties by nanoparticle additives. International Journal of Hydrogen Energy, 2016, 41(4), 3153–3170.
Aleksandar RAC , Aleksandar Vencl . Ecological and technical aspects of the waste oils influence on environment. The Annals of University "Dunărea De Jos" of Galaţi fascicle VIII, Tribology, 2012, 18(1), 5–11.
Aluyor EO , Obahiagbon KO , Ori-Jesu M. Biodegradation of vegetable oils: A review. Scientific Research and Essays, 2009, 4(6), 543–548.
Nwobi BE , Ofoegbu OO , Adesina O.B. Extraction of qualitative assessment of African sweet orange seed oil. African Journal of Food Agriculture Nutrition and Development, 2006, 6(2), 1–11.
Shashidhara YM , Jayaram S.R. Vegetable oil as a potential cutting fluid--An evolution. Tribology International, 2010, 43(5–6), 1073–1081.
Fox NJ , Stachowiak G.W. Vegetable oil-based lubricants – A review of oxidation, Tribology International, 2007, 40(7), 1035–1046.
Mongkolwongrojn M , Arunmetta P. Theoretical characteristics of hydrodynamic journal bearings lubricated with soybean-based oil. Journal of Synthetic Lubrication, 2002, 19(3), 213–228.
Orsavova J , Misurcova L , Ambrozova JV , Vicha R , Mlcek J. Fatty acids composition of vegetable oils and its contribution to dietary energy intake and dependence of cardiovascular mortality on dietary intake of fatty acids. International Journal of Molecular Science, 2015, 16(6), 12871–12890.
Reeves CJ , Menezes P.L. Evaluation of boron nitride particles on the tribological performance of avocado and canola oil for energy conservation and sustainability. International Journal of Advanced Manufacturing Technology, 2017, 89(9), 3475–3486.
Asadauskas S , Erhan S.Z. Thin film test to investigate liquid oxypolymerization of nonvolatile analyses: Assessment of vegetable oils and biodegradable lubricants. Journal of American Oil Chemists' Society, 2001, 78(10), 1029–1035.
Quinchia LA , Delgado MA , Reddyhoff T , Gallegos C , Spikes H.A. Tribological studies of potential vegetable oil based lubricants containing environmentally friendly viscosity modifiers. Tribology International, 2014, 69, 110–117.
Luna FMT , Rocha BS , Rola Jr. EM , Albuquerque MCG , Azevedo DCS , Cavalcante Jr C.L. Assessment of biodegradability and oxidation stability of mineral, vegetable and synthetic oil samples. Industrial Crops and Products, 2011, 33(3), 579–583.

Joseph PV , Saxena D , Sharma D.K. Study of some non-edible vegetable oils of Indian origin for lubricant application. Journal of Synthetic Lubrication, 2007, 24, 181–197.
Krishna Reddy KSV , Kabra N , Kunchum U , Vijayakumar T. Experimental investigation on usage of palm oil as a lubricant to substitute mineral oil in CI engines. Chinese Journal of Engineering, 2014, Article ID 643521, 2014, 1–5. DOI:10.1155/2014/643521.
Norhaizan ME , Hosseini S , Gangadaran S , Lee ST , Kapourchali FR and Moghadasian M.H. Palm oil: Features and applications. Lipid Technology, 2013, 25(2), 39–42.
Choi US , Ahn BG , Kwon OK , Chun Y.J. Tribological behavior of some antiwear additives in vegetable oils. Tribology International 1997, 30(9), 677–683.
Popa V-M , Gruia A , Raba D-N , Dumbrava D , Moldovan C , Bordean D , Mateescu C. Fatty acids composition and oil characteristics of linseed (LinumUsitatissimum L.) from Romania, Journal of Agroalimentary Processes and Technologies, 2012, 18 (2), 136–140.
Siniawski MT , Saniei N , Adhikari B , Doezema L.A. Influence of fatty acid composition on the tribological performance of two vegetable-based lubricants. Journal of Synthetic Lubrication, 2007, 24, 101–110.
Pramanik K. Properties and use of jatrophacurcas oil and diesel fuel blends in compression ignition engine. Renewable Energy, 2003, 28(2), 239–248.
Schuchardt U , Sercheli R , Vargas R.M. , Transesterification of vegetable oils: A review, Journal of the Brazilian Chemical Society, 1998, 9, 199–210.
Saurabh T , Patnaik M , Bhagt SL , Renge V.C. Epoxidation of vegetable oils: A review. International Journal of Advanced Engineering Technology, 2011, 2(4), 491–501.
Cahoon EB , Kinney A.J. Production of vegetable oils with novel properties: Using genomic tools to probe and manipulate fatty acid metabolism. European Journal of Lipid Science and Technology, 2005, 107(4), 239–243.
McKeon T.A. Chapter 1: Genetic modification of seed oils for industrial applications, Industrial uses of vegetable oils, 2005, USDA, ARS, WRRC, Albany, CA. https://doi.org/10.1201/9781439822388.ch1.
Adhvaryu A , Erhan S.Z. Epoxidized soyabean oil as a potential source of high temperature lubricants. Industrial Crops and Products, 2002, 15(3), 247–254.
Jayadas NH , Nair KP , Ajithkumar G. Tribological evaluation of coconut oil as an environment-friendly lubricant. Tribology International, 2007, 40(2), 350–354.
Dmitrieva TV , Sirovatka LA , Bortnitskii V.I. Composites based on rapeseed oil and functional additives. TrenieIznos, 2001, 22(6), 693–698.
Castro W , Weller DE , Cheenkachorn K , Perez J.M. The effect of chemical structure of basefluids on antiwear effectiveness of additives. Tribology International, 2005, 38(3), 321–326.
Spikes H. Low- and zero-sulphated ash, phosphorus and sulphur anti-wear additives for engine oils. Lubrication Science, 2008, 20(2), 103–136.
Gallopoulos N.E. Thermal decomposition of metal dialkyldithiophosphate oil blends. ASLE Transactions, 1964, 7, 55–63.
Born M , Hipeaux JC , Marchand P , Parc G. Relationship between chemical structure and effectiveness of some metallic dialkyl and diaryldithiophosphates in different lubricated mechanisms. Lubrication Science, 1992, 4, 93–116.
Allum KG , Forbes E.S. The load-carrying properties of metal dialkyldithiophosphates: The effect of chemical structure. Proceedings of the Institution of Mechanical Engineering: Conference Proceedings, 1968, 183, 7–14.
Rowe CN , Dickert Jr. J.J. The relation of antiwear function to thermal stability and structure for metal O,O-dialkylphosphorodithioates. ASLE Transactions, 1967, 10(1), 85–90.
Sanin PI , Shepeleva ES , Ulyanova AV , Kleimenov B.V. The effect of synthetic additives in lubricating oil on wear under friction. Wear, 1960, 3(3), 200–218.
Farrington BB , Clayton J.O. Compounded mineral oil. US Patent 2228658, 1941.
Sakurai T , Sato K. Chemical reactivity and load carrying capacity of lubricating oils containing organic phosphorus compounds. ASLE Transactions, 1970, 13(4), 252–261.
Didziulis SV , Fleischauer P.D. Chemistry of the extreme-pressure lubricant additive lead naphthenate on steel surfaces. Langmuir, 1991, 7(12), 2981–2990.
Choudhary RB , Pande P.P. Lubrication potential of boron compounds: an overview. Lubrication Science, 2002, 14(2), 211–222.
Liu W , Xue Q , Zhang X , Wang H. Effect of molecular structure of organic borates on their friction and wear properties. Lubrication Science, 1993, 6(1), 41–49.

Kapadia R , Glyde R , Wu Y. In situ observation of phosphorous and non-phosphorous antiwear films using a mini traction machine with spacer layer image mapping. Tribology International, 2007, 40(10–12), 1667–1679.

Jaiswal V , Kalyani, Rastogi RB , Kumar R. Tribological studies of some SAPS-free Schiff bases derived from 4-aminoantipyrine and aromatic aldehydes and their synergistic interaction with borate ester. Journal of Materials Chemistry A, 2014, 2(27), 10424–10434.

Rastogi RB , Maurya JL , Jaiswal V. Zero SAPs and ash free antiwear additives: Schiff bases of salicylaldehyde with 1, 2-phenylenediamine, 1, 4-phenylenediamine, and 4, 4′-diaminodiphenylenemethane and their synergistic interactions with borate ester. Tribology Transactions, 2013, 56(4), 592–606.

Greenall A , Neville A , Morina A , Sutton M. Investigation of the interactions between a novel, organic anti-wear additive, ZDDP and overbased calcium sulphonate. Tribology International, 2012, 46(1), 52–61.

Khan M S , Sisodia M S , Gupta S , Feroskhan M , Kannan S , Krishnasamy K. Measurement of tribological properties of Cu and Ag blended coconut oil nanofluids for metal cutting. Engineering Science and Technology, an International Journal, 2019, 22(6), 1187–1192.

Rajubhai VH , Singh Y , Suthar K. , Surana A.R. Friction and wear behavior of Al-7% Si alloy pin under pongamia oil with copper nanoparticles as additives. Materials Today Proceeding, 2019, 25, 695–698.

Abad MD , Sánchez-López J.C. Tribological properties of surface-modified Pd nanoparticles for electrical contacts. Wear, 2013, 297, 943–951.

Le VN , Lin J-W. Tribological properties of aluminum nanoparticles as additives in an aqueous glycerol solution. Applied Science, 2017, 7(1), 80, 1–15.

Zhang S , Hu L , Feng D , Wang H. Anti-wear and friction-reduction mechanism of Sn and Fe nanoparticles as additives of multialkylatedcyclopentanes under vacuum condition. Vacuum, 2013, 87, 75–80.

Wang A , Chen L , Xu F , Yan Z. In situ synthesis of copper nanoparticles within ionic liquid-in-vegetable oil microemulsions and their direct use as high efficient nanolubricants. RSC Advances, 2014, 4, 45251–45257.

Maliar T , Achanta S , Cesiulis H , Drees D. Tribological behaviour of mineral and rapeseed oils containing iron particles. Industrial Lubrication and Tribology, 2015, 67(4), 308–314.

Battez AH , Rico JEF , Arias AN , Rodriguez JLV , Rodriguez RC , Fernandez J.M.D. The tribological behaviour of ZnO nanoparticles as an additive to PAO6. Wear, 2006, 261(3–4), 256–263.

Battez AH , González R , Felgueroso D , Fernández JE , Fernández M R , García MA , Peñuelas I. Wear prevention behaviour of nanoparticle suspension under extreme pressure conditions. Wear, 2007, 263(7–12), 1568–1574.

Thottackkad MV , Rajendrakumar PK , Prabhakaran NK , Tribological analysis of surfactant modified nanolubricants containing CeO2 nanoparticles. Tribology-Materials, Surfaces & Interfaces, 2014, 8(3), 125–130.

Sajeeb A , Rajendrakumar P.K. Tribological assessment of vegetable oil based CeO2/CuO hybrid nano-lubricant. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 2020, 234(12), 1940–1956.

Thottackkad MV , Perikinalil RK , Kumarapillai P.N. Experimental evaluation on the tribological properties of coconut oil by the addition of CuO nanoparticles. International Journal of Precision Engineering and Manufacturing, 2012, 13(1), 111–116.

Alves SM , Barros BS , Trajano MF , Ribeiro KSB , Moura E. Tribological behavior of vegetable oil-based lubricants with nanoparticles of oxides in boundary lubrication conditions. Tribology International, 2013, 65, 28–36.

Shaari MZ , Roselina NRN , Kasolang S , Hyie KM , Murad MC , Abu Bakar M.A. Investigation of tribological properties of palm oil biolubricant modified nanoparticles. Jurnal Teknolgi, 2015, 76, 69–73.

Zulkifli NWM , Kalam MA , Masjuki HH , Yunus R. Experimental analysis of tribological properties of biolubricant with nanoparticle additive. Procedia Engineering, 2013, 68, 152–157.

Ingole S , Charanpahari A , Kakade A , Umare SS , Bhatt DV , Menghani J. Tribological behavior of nano TiO2 as an additive in base oil. Wear, 2013, 301(1–2), 776–785.

Luo T , Wei X , Huang X , Huang L , Yang F. Tribological properties of Al2O3 nanoparticles as lubricating oil additives. Ceramics International, 2014, 40(5), 7143–7149.

Bhaumik S , Kamaraj M , Paleu V. Tribological analyses of a new optimized gearbox biodegradable lubricant blended with reduced graphene oxide nanoparticles. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 2020, 1–15. DOI: 10.1177/1350650120925590.
Gupta RN , Harsha AP , Singh S. Tribological study on rapeseed oil with nano-additives in close contact sliding situation. Applied Nanoscience, 2018, 8(4), 567–580.
Dubey MK , Bijwe J , Ramakumar S.S.V. PTFE based nano-lubricants. Wear, 2013, 306(1–2), 80–88.
Song H , Wang Z , Yang J. Tribological properties of graphene oxide and carbon spheres as lubrication additives. Applied Physics A, 2016, 122, 933/1–9.
Kiong KSS , Yusup S , Soon CV , Arpin T , Samion S , Kamil R.N.M. Tribological investigation of graphene as lubricant additive in vegetable oil. Journal of Physical Science, 2017, 28, 257–267.
Kannan KT , Rameshbabu S. Tribological behavior of modified jojoba oil with graphene nanoparticle as additive in SAE20W40 oil using pin on disc tribometer. Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 2017, 39, 1842–1848.
Su Y , Gong L , Chen D. An investigation on tribological properties and lubrication mechanism of graphite nanoparticles as vegetable based oil additive. Journal of Nanomaterials, 2015, 2015, 1–7.
Cornelio JAC , Cuervo PA , Hoyos-Palacio LM , Lara-Romero J , Toro A. Tribological properties of carbon nanotubes as lubricant additive in oil and water for a wheel–rail system. Journal of Materials Research and Technology, 2016, 5(1), 68–76.
Opia AC , Kameil AHM , Daud ZHC , Mamah SC , Izmi MI , Rahim A.B. Tribological properties enhancement through organic carbon nanotubes as nanoparticle additives in boundary lubrication conditions. JurnalTribologi, 2020, 27, 116–131.
Abd HS , Abdulmunem AR , Jabal MH , Samin PM , Rahman H.A. Working features evaluation of the diesel engine lubricated with blends of renewable corn oil and carbon nanotubes. Journal of Mechanical Engineering Research and Developments, 2020, 43(2), 384–395.
Kiu SSK , Yusup S , Chok VS , Taufiq A , Kamil RNM , Syahrullail S , Chin B.L.F. Comparison on tribological properties of vegetable oil upon addition of carbon based nanoparticles. IOP Conf. Series: Materials Science and Engineering, 2017, 206, 012043, doi:10.1088/1757-899X/206/1/012043.
Ranjan N , Shende RC , Kamaraj M , Ramaprabhu S. Utilization of TiO_2/gC_3N_4 nanoadditive to boost oxidative properties of vegetable oil for tribological application. Friction, 2021, 9, 273–287.
Dong JX , Hu Z.S. A study of the anti-wear and friction-reducing properties of the lubricant additive, nanometer zinc borate. Tribology International, 1998, 31(5), 219–223.
Sunqing Q , Junxiu D , Guoxu C. Tribological properties of CeF_3 nanoparticles as additives in lubricating oils. Wear, 1999, 230, 35–38.
Liu W , Chen S. An investigation of the tribological behaviour of surface-modified ZnS nanoparticles in liquid paraffin. Wear, 2000, 238, 120–124.
Rapoport L , Leshchinsky V , Lapsker I , Volovik Y , Nepomnyashchy O , Lvovsky M , Popovitz-Biro R , Feldman Y , Tenne R. Tribological properties of WS_2 nanoparticles under mixed lubrication. Wear, 2003, 255, 785–793.
Joly-Pottuz L , Dassenoy F , Martin JM , Vrbanic D , Mrzel A , Mihailovic D , Vogel W , Montagnac G. Tribological properties of Mo–S–I nanowires as additive in oil. Tribology Letters, 2005, 18(3), 385–393.
Yu HL , Xu Y , Shi PJ , Wang HM , Zhao Y , Xu BS , Bai Z.M. Tribological behaviors of surface-coated serpentine ultrafine powders as lubricant additive. Tribology International, 2010, 43, 667–675.
Lingtong K , Hua H , Tianyou W , Dinghai H , Jianjian F. Synthesis and surface modification of the nanoscale cerium borate as lubricant additive. Journal of Rare Earths, 2011, 29(11), 1095–1099.
Rudenko P , Bandyopadhyay A. Talc as friction reducing additive to lubricating oil. Applied Surface Science, 2013, 276, 383–389.
Srinivas V , Thakur RN , Jain A.K. Antiwear, antifriction and extreme pressure properties of motor bike engine oil dispersed with molybdenum disulfide nanoparticles. Tribology Transactions, 2017, 60(1), 12–19.

Charoo M S , Wani M.F. Tribological properties of h-BN nanoparticles as lubricant additive on cylinder liner and piston ring. Lubrication Science, 2017, 29, 241–254.
Weertman J.R. Hall-Petch strengthening in nanocrystalline metals. Material Science and Engineering A, 1993, 166(1–2), 161–167.
Yamakov V , Wolf D , Phillpot SR , Mukherjee AK , Gleiter H. Deformation mechanism map for nanocrystalline metals by molecular-dynamics simulation. Nature Materials, 2004, 3, 43–47.
Narayanunni V , Kheireddin BA , Akbulut M. Influence of surface topography on frictional properties of Cu surfaces under different lubrication conditions: Comparison of dry, base oil, and ZnS nanowire-based lubrication system. Tribology International, 2011, 44, 1720–1725.
Akbulut M. Nanoparticle-based lubrication systems. Journal of Powder Metallurgy and Mining, 2012, 1, 1–3.
Kotia A , Chowdary K , Srivastava I , Ghosh SK , Ali M.K.A. Carbon nanomaterials as friction modifiers in automotive engines: Recent progress and perspectives. Journal of Molecular Liquids, 2020, 310, 113200.
Wang X , Xu X , Choi S.U.S. Thermal conductivity of nanoparticle-fluid mixture. Journal of Thermophysics and Heat Transfer, 1999, 13(4), 474–480.
Taha-Tijerina J , Peña-Paras L , Narayanan TN , Garza L , Lapray C , Gonzalez J , Palacios E , Molina D , García A , Maldonado D , Ajayan P.M. Multifunctional nanofluids with 2D nanosheets for thermal and tribological management. Wear, 2013, 302, 1241–1248.
Lee K , Hwang Y , Cheong S , Choi Y , Kwon L , Lee J , Kim S.H. Understanding the role of nanoparticles in nano-oil lubrication. Tribology Letters, 2009, 35, 127–131.
Ghaednia H , Jackson R.L. The effect of nanoparticles on the real area of contact, friction, and wear. Transactions of ASME, Journal of Tribology, 2013, 135, 041603.
Liu G , Li X , Qin B , Xing D , Guo Y , Fan R. Investigation of the mending effect and mechanism of copper nano-particles on a tribologically stressed surface. Tribology Letters, 2004, 17, 961–966.
Tao X , Jiazheng Z , Kang X. The ball-bearing effect of diamond nanoparticles as an oil additive. Journal of Physics D: Applied Physics, 1996, 29, 2932–2937.
Jaiswal V , Rastogi RB , Kumar R , Singh L , Mandal K.D. Tribological studies of stearic acid-modified CaCu2.9Zn0.1Ti4O12 nanoparticles as effective zero SAPS antiwear lubricant additives in paraffin oil. Journal of Materials Chemistry A, 2014, 2, 375–386.
Wäsche R , Hartelt M , Hodoroaba V-D. Analysis of nanoscale wear particles from lubricated steel-steel contacts. Tribology Letters 2015, 58(3), Article number 49, 1–10.
Dai W , Kheireddin B , Gao H , Liang H. Roles of nanoparticles in oil lubrication. Tribology International, 2016, 102, 88–98.
Chou C-C , Lee S-H. Tribological behavior of nanodiamond-dispersed lubricants on carbon steels and aluminum alloy. Wear, 2010, 269, 757–762.

Tribology of Polymer Composites with Green Nano-Materials

Holmberg K , Andersson P , Erdemir A. Global energy consumption due to friction in passenger cars. Tribol Int 47: 221–234 (2012).
Gong H J , Yu C C , Zhang L , Xie G X , Guo D , Luo J B . Intelligent lubricating materials: A review. Compos. B Eng 202: 108450 (2020).
Perry SS , Tysoe W.T. Frontiers of fundamental tribological research. Tribol Lett 19(3): 151–161 (2005).
Wu S , Li J , Zhang G , Yao Y , Li G , Sun R , Wong C. Ultrafast self-healing nanocomposites via infrared laser and their application in flexible electronics. ACS Appl Mater Interfaces 9(3):3040–3049 (2017).
Petrova P N , Fedorov A L . Polytetrafluoroethylene-based polymer composites with increased wear resistance in dry friction. Russ Eng Res 30: 895–899 (2010).
Podsiadlo P , Kaushik A K , Arruda E M , Waas A M , Shim B S , Xu J D , Nandivada H , Pumplin B G , Lahann J , Ramamoorthy A , Kotov N. Ultrastrong and stiff layered polymer nanocomposites. Science 318(5847): 80–83 (2008).
Panin S V , Duc Anh N , Kornienko L A , Ivanova L R , Ovechkin B B . Comparison on efficiency of solid-lubricant fillers for polyetheretherketone-based composites. AIP Conf Proc 2051:

020232 (2018).
Peng S G , Zhang L , Xie G X , Guo Y , Si L N , Luo J B . Friction and wear behavior of PTFE coatings modified with poly (methyl methacrylate). Compos. B Eng 172: 316–322 (2019).
Donnet C , Erdemir A. Solid lubricant coatings: Recent developments and future trends. Tribol Lett 17(3): 389–397 (2004).
Ren Y L , Zhang L , Xie G X , Li Z B , Chen H , Gong H J , Xu W H , Guo D , Luo J B . A review on tribology of polymer composite coatings. Friction 9: 429–470 (2021).
Ji Z J , Zhang L , Xie G X , Xu W H , Guo D , Luo J B , Prakash B. Mechanical and tribological properties of nanocomposites incorporated with two-dimensional materials. Friction 8(5): 813–846 (2020).
Chen H , Zhang L , Li M Y , Xie G X . Synthesis of core–shell micro/nanoparticles and their tribological application: a review. Materials 13(20): 4590 (2020).
Wang H , Zhang S , Wang G , Yang S , Zhu Y. Tribological behaviors of hierarchical porous PEEK composites with mesoporous titanium oxide whisker. Wear 297(1): 736–741 (2013).
Huang X , Wu J , Lu X , Feng X , Shi Y. Tribological properties of porous PEEK composites containing ionic liquid under dry friction condition. Lubricants 5(2): 19 (2017).
Zhu Y , Lin S , Wang H , Liu D. Study on the tribological properties of porous sweating PEEK composites under ionic liquid lubricated condition. J Appl Polym Sci 131(21): 1284–1287 (2014).
Wang J , Zhao H , Huang W , Wang X. Investigation of porous polyimide lubricant retainers to improve the performance of rolling bearings under conditions of starved lubrication. Wear 380–381: 52–58 (2017).
Zhang G L , Xie G X , Si L N , Wen S Z , Guo D. Ultralow friction self-lubricating nanocomposites with mesoporous metal-organic frameworks as smart nanocontainers for lubricants. ACS Appl Mater Inter 9(43): 38146–38152 (2017).
Guo Q B , Lau K T , Zheng B F , Rong M Z , Zhang M Q . Imparting ultra-low friction and wear rate to epoxy by the incorporation of microencapsulated lubricant? Macromol Mater Eng 294(1): 20–24 (2009).
Khun N W , Zhang H , Yang J , Liu E. Mechanical and tribological properties of epoxy matrix composites modified with microencapsulated mixture of wax lubricant and multi-walled carbon nanotubes. Friction 1(4):341–349 (2013).
Zhang L , Xie G X , Wu S , Peng S G , Zhang X Q , Guo D , Wen S Z , Luo J B . Ultralow friction polymer composites incorporated with monodispersed oil microcapsules. Friction 9(1): 29–40 (2019).
Yang M , Zhu X , Ren G , Men X , Guo F , Li P , Zhang Z. Tribological behaviors of polyurethane composite coatings filled with ionic liquid core/silica gel shell microcapsules. Tribol Lett 58(1): 9 (2015).
Bandeira P , Monteiro J , Baptista AM , Magalhães F.D. Tribological performance of PTFE-based coating modified with microencapsulated [HMIM][NTf2] ionic liquid. Tribol Lett 59(1): 13 (2015).
Li H , Wang Q , Wang H , Cui Y , Zhu Y , Wang B. Fabrication of thermally stable polysulfone microcapsules containing [EMIm][NTf2] ionic liquid for enhancement of in situ self-lubrication effect of epoxy. Macromol Mater Eng 301(12): 1473–1481 (2016).
Imani A , Zhang H , Owais M , Zhao J , Chu P , Yang J , Zhang Z. Wear and friction of epoxy based nanocomposites with silica nanoparticles and wax-containing microcapsules. Compos Part A Appl Sci Manuf 107: 607–615 (2018).
Guo Q B , Lau K T , Rong M Z , Zhang M Q . Optimization of tribological and mechanical properties of epoxy through hybrid filling. Wear 269(1–2): 13–20 (2010).
Khun N W , Zhang H , Yue C Y , Yang J L . Self-lubricating and wear resistant epoxy composites incorporated with microencapsulated wax. J Appl Mech 81(7): (2014).
Gong H J , Song Y , Li G L , Xie G , Luo J B . A highly tough and ultralow friction resin nanocomposite with crosslinkable polymer-encapsulated nanoparticles. Compos B Eng 197:108157 (2020).
Zhang X , Wang P , Sun D , Li X , An J , Yu T , Yang E-H , Yang J. Dynamic plastic deformation and failure mechanisms of individual microcapsule and its polymeric composites. J Mech Phys Solids 139: 103933 (2020).
Shchukin D , Mohwald H. A coat of many functions. Science 341(6153): 1458–1459 (2013).

Tang G G , Zhang J , Liu C C , Zhang D , Wang Y Q , Tang H , Li C. Synthesis and tribological properties of flower-like MoS2 microspheres. Ceram Int 40: 11575–11580 (2014).
Yang Z R , Guo Z W , Yuan C Q . Effects of MoS2 microcapsulation on the tribological properties of a composite material in a water-lubricant condition. Wear 432: 102919 (2019).
Chen B B , Jia Y H , Zhang M J , Liang H Y , Li X , Yang J , Yan F , Li C. Tribological properties of epoxy lubricating composite coatings reinforced with core-shell structure of CNF/MoS2 hybrid. Compos Part A Appl Sci Manuf 122: 85–95 (2019).
Wu G Y , Xu C H , Xiao G C , Yi M D , Chen Z Q , Chen H. An advanced self-lubricating ceramic composite with the addition of core-shell structured h-BN@Ni powders. Int J Refract Met Hard Mater 72: 276–285 (2018).
Wang H Y , Lei Y , Liu D J , Wang C , Zhu Y J , Zhu J H . Investigation of the tribological properties: Core-shell structured magnetic Ni@NiO nanoparticles reinforced epoxy nanocomposites. Tribol Int 83: 139–145 (2015).
Fan C L , Li H L , Jin L , Zhang M J , Xiao L H , Li M , Ao Y. Improving tribological properties of phenolic resin/carbon fiber composites using m-Si3N4@PANI core-shell particles. J Appl Polym Sci 136: 47785 (2019).
Zhang J S , Yang S F , Chen Z X , Wyszomirska M , Zhao J W , Jiang Z Y . Microstructure and tribological behavior of alumina composites reinforced with SiC-graphene core-shell nanoparticles. Tribol Int 131: 94–101 (2019).
Yoo, S C , Kang B , Van Trinh P , Doan D P , Soon H H . Enhanced mechanical and wear properties of Al6061 alloy nanocomposite reinforced by CNT-template-grown core-shell CNT/SiC nanotubes. Sci Rep 10: 12896 (2020).
Lian W Q , Mai Y J , Wang J , Zhang L Y , Liu C S , Jie X H . Fabrication of graphene oxide-Ti3AlC2 synergistically reinforced copper matrix composites with enhanced tribological performance. Ceram Int 45: 18592–18598 (2019).
Xiong K Y , Wang Y , Tang B , Yi M , Wu Z Z , Wu X F . Review of activated carbon fiber. Synth. Fiber 49(10): 15–19 (2020).
Yuan N , Wang Y Z , Duan J K , Wang Y , Shi D D , Wu X F . Review of high performance fiber reinforced concrete composites. Synth Fiber 49(11): 52–56 (2020).
Liu A Y , Liu J C , Xu J L , Zhang J Q , Xing W F , Zhang H Y , Liu F B , Wang D Y , Li S H , Chen Y W . Research progress of carbon nanotube/carbon fiber composites. Eng Plast Appl 48(8): 158–162 (2020).
Li X M , Xu X C , Yu W , Gu Y J , Shi Y , Cheng R M , Chen Y W . Conductivity of carbon nanotubes/polyacetylene composites. Acta Comp Sin 23 (5): 70–74 (2006).
Sathishkumar T P , Satheeshkumar S , Naveen J. Glass fiber-reinforced polymer composites–a review. J Reinf Plast Compos 33(13): 1258–1275 (2014).
Adekomaya O , Adama K , Naveen J. Glass-fiber reinforced composites: The effect of fiber loading and orientation on tensile and impact strength. Nigerian J Technol 36(3): 782–787 (2017).
Harizi W , Chaki S , Bourse M, Ourak . Mechanical damage assessment of glass fiber-reinforced polymer composites using passive infrared thermography. Compos B Eng 59: 74–79 (2014).
Vyas S , Goli E , Zhang X , Geubelle P H . Manufacturing of unidirectional glass-fiber-reinforced composites via frontal polymerization: A numerical study. Compos Sci Technol 184: 107832 (2019).
Balachandar M , Ramnath Vijaya B , Jagadeeshwar P , Yokesh R. Mechanical behaviour of natural and glass fiber reinforced with polymer matrix composite. Mater Today Proc 16(2): 1297–1303 (2019).
Smaranika N , Nayak R K , Panigrahi I , Sahoo A K . Tribo-mechanical responses of glass fiber reinforced polymer hybrid nanocomposites. Mater Today Proc 18(7): 4042–4047 (2019).
Beckford S , Mathurin L , Chen J Y , Fleming R A , Zou M. The effects of polydopamine coated Cu nanoparticles on the tribological properties of polydopamine/PTFE coatings. Tribol Int 103: 87–94 (2016).
Pryamitsyn V , Ganesan V. Origins of linear viscoelastic behavior of polymer-nanoparticle composites. Macromolecules 39(2): 844–856 (2006).
Mujtaba A , Keller M , Ilisch S , Radusch H J , Beiner M , Thurn-Albrecht T , Saalwächter K. Detection of surface-immobilized components and their role in viscoelastic reinforcement of rubber-silica nanocomposites. ACS Macro Lett 3(5): 481–485 (2014).

Chen Q , Gong S S , Moll J , Zhao D , Kumar S K , Colby R H . Mechanical reinforcement of polymer nanocomposites from percolation of a nanoparticle network. ACS Macro Lett 4(4): 398–402 (2015).
Papon A , Montes H , Lequeux F , Oberdisse J , Saalwächter K , Guy L. Solid particles in an elastomer matrix: Impact of colloid dispersion and polymer mobility modification on the mechanical properties. Soft Matter 8(15): 4090–4096 (2012).
Papageorgiou D G , Li Z L , Liu M F , Kinloch I A , Young R J . Mechanisms of mechanical reinforcement by graphene and carbon nanotubes in polymer nanocomposites. Nanoscale 12(4): 2228–2267 (2020).
Samad M A , Sinha S K . Nanocomposite UHMWPE-CNT polymer coatings for boundary lubrication on aluminium substrates. Tribol Lett 38(3): 301–311 (2010).
Chih A , Ansón-Casaos A , Puértolas J A . Frictional and mechanical behaviour of graphene/UHMWPE composite coatings. Tribol Int 116: 295–302 (2017).
Ning H B , Lu N , Hassen A A , Chawla K , Selim M , Pillay S . A review of long fibre thermoplastic (LFT) composites. Int Mater Rev 65(3): 164–188 (2020).
Maillard D , Kumar S K , Fragneaud B , Kysar J W , Rungta A , Benicewicz B C , Deng H , Brinson L C , Douglas J F . Mechanical properties of thin glassy polymer films filled with spherical polymer-grafted nanoparticles. Nano Lett 12(8): 3909–3914 (2012).
Mortazavian S , Fatemi A. Effects of fiber orientation and anisotropy on tensile strength and elastic modulus of short fiber reinforced polymer composites. Compos B Eng 72: 116–129 (2015).
Zhang B , Jia L H , Tian M , Ning N Y , Zhang L Q , Wang W C . Surface and interface modification of aramid fiber and its reinforcement for polymer composites: A review. Eur Polym J 14: 110352 (2021).
Seretis G V , Manolakos D E , Provatidis C G . On the stainless steel flakes reinforcement of polymer matrix particulate composites. Compos B Eng 162: 80–88 (2019).
Shubham S K , Purohit R , Yadav P S , Rana R S . Study of nano-fillers embedded in polymer matrix composites to enhance its properties – A review. Mater Today Proc 26 (2): 3024–3029 (2020).
Li X , Kang H L , Shen J X . Effects of graft locations on dispersion behavior of polymer-grafted nanorods: A molecular dynamics simulation study. Polymer 211: 123077 (2020).
Broughton W R , Koukoulas T , Woolliams P. Assessment of nanoparticle loading and dispersion in polymeric materials using oscillatory photon correlation spectroscopy. Polym Test 49: 107–114 (2016).
Cheng S W , Bocharova V , Belianinov A , Xiong S M , Kisliuk A , Somnath S , Holt A P , Ovchinnikova O S , Jesse S , Martin H , Etampawala T , Dadmun M , Sokolov A P . Unraveling the mechanism of nanoscale mechanical reinforcement in glassy polymer nanocomposites. Nano Lett 16(6): 3630–3637 (2016).
Okumura T , Sonobe K , Ohashi A , Watanabe H , Watanabe K , Oyamada H , Aramaki M , Ougizawa T. Synthesis of polyamide-hydroxyapatite nanocomposites. Polym Eng Sci 60(7): 1699–1711 (2020).
Scotti R , Conzatti L , D'Arienzo M , Di Credico B , Giannini L , Hanel T , Stagnaro P , Susanna A , Tadiello L , Morazzoni F. Shape controlled spherical (0D) and rod-like (1D) silica nanoparticles in silica/styrene butadiene rubber nanocomposites: Role of the particle morphology on the filler reinforcing effect. Polymer 55(6): 1497–1506 (2014).
Pradhan S , Lach R , Le H H , Grellmann W , Radusch H J , Adhikari R. Effect of filler dimensionality on mechanical properties of nanofiller reinforced polyolefin elastomers. Int Sch Res Not 2013: 284504 (2013).
Nadiv R , Shachar G , Peretz-Damari S , Varenik M , Levy I , Buzaglo M , Ruse E , Regev O. Performance of nano-carbon loaded polymer composites: Dimensionality matters. Carbon 126: 410–418 (2018).
Thirumurugan R , Gnanasekar N. Influence of finite element model, load-sharing and load distribution on crack propagation path in spur gear drive. Eng Fail Anal 110: 104383 (2020).
Emdadi A , Zaeem M A . Phase-field modeling of crack propagation in polycrystalline materials. Comput Mater Sci 186: 110057 (2021).
Bhandari N L , Lach R , Grellmann W , Adhikari R. Depth-dependent indentation microhardness studies of different polymer nanocomposites. Macromol Symp 315(1): 44–51 (2012).

Opelt C V , Becker D , Lepienski C M , Coelho L A F . Reinforcement and toughening mechanisms in polymer nanocomposites--Carbon nanotubes and aluminum oxide. Compos B Eng 75: 119–126 (2015).
Boåsen M , Dahlberg C F O , Efsing P , Faleskog J. A weakest link model for multiple mechanism brittle fracture—Model development and application. J Mech Phys Solids 147: 104224 (2021).
Fu S Y , Sun Z , Pei H , Li Y Q , Hu N. Some basic aspects of polymer nanocomposites: A critical review. Nano Mater Sci 1 (1): 2–13 (2019).
Vasoya M , Unni A B , Leblond J B , Lazarus V , Ponson L. Finite size and geometrical non-linear effects during crack pinning by heterogeneities: An analytical and experimental study. J Mech Phys Solids 89: 211–230 (2016).
Patinet S , Alzate L , Barthel E , Dalmas D , Vandembroucq D , Lazarus V. Finite size and geometrical non-linear effects during crack pinning by heterogeneities: An analytical and experimental study. J Mech Phys Solids 61(2): 311–324 (2013).
Narducci F , Pinho S T . Exploiting nacre-inspired crack deflection mechanisms in CFRP via micro-structural design. Compos Sci Technol 153: 178–189 (2017).
Bonfoh N , Lipinski P. Ductile damage micromodeling by particles' debonding in metal matrix composites. Int J Mech Sci 49(2): 151–160 (2007).
Veluri B , Jensen H M . Steady-state propagation of interface corner crack. Int J Solids Struct 50(10): 1613–1620 (2013).
Steffensen S , Kibsgaard R L , Jensen H M . Debonding of particles in thin films. Int J Solids Struct 51 (15-16): 2850–2856 (2014).
Wei Y Z , Wang G S , Wu Y , Yue Y H , Wu J T , Lu C , Guo L. Bioinspired design and assembly of platelet reinforced polymer films with enhanced absorption properties. J Mater Chem A 2(15): 5516–5524 (2014).
He Y , Farokhzadeh K , Edrisy A. Characterization of thermal, mechanical and tribological properties of fluoropolymer composite coatings. J Mater Eng Perform 26(6): 2520–2534 (2017).
Su C , Xue F , Li T S , Xin Y S , Wang M M . Study on the tribological properties of carbon fabric/polyimide composites filled with SiC nanoparticles. J Macromol Sci Part B 55(6): 627–641 (2016).
Luo W , Qi Liu , Li Y , Zhou S T , Zou H W , Liang M. Enhanced mechanical and tribological properties in polyphenylene sulfide/polytetrafluoroethylene composites reinforced by short carbon fiber. Compos B Eng 91: 579–588 (2016).
Nie P , Min C Y , Song H J , Chen X H , Zhang Z Z , Zhao K L . Preparation and tribological properties of polyimide/carboxyl functionalized multi-walled carbon nanotube nanocomposite films under seawater lubrication. Tribol Lett 58: 7(2015).
Stankovich S , Dikin D A , Dommett G H B , Kohlhaas K M , Zimney E J , Stach E A , Piner R D , Nguyen S B T , Ruoff R S . Graphene-based composite materials. Nature 442(7100): 282–286 (2006).
Ramanathan T , Abdala A A , Stankovich S , Dikin D A , Herrera-Alonso M , Piner R D , Adamson D H , Schniepp H C , Chen X , Ruoff R S , Nguyen S T , Aksay I A , Prud'Homme R K , Brinson L C . Functionalized graphene sheets for polymer nanocomposites. Nat Nanotechnol 3: 327–331 (2008).
Huang X , Qi X Y , Boey F , Zhang H. Graphene-based composites. Chem Soc Rev 41(2): 666–686 (2012).
Kim S , Wang H T , Lee Y M . 2D nanosheets and their composite membranes for water, gas, and ion separation. Angew Chem Int Ed Engl 58(49): 17512–17527 (2019).
Li X , Sun M , Shan C X , Chen Q , Wei X L . Mechanical properties of 2D materials studied by in situ microscopy techniques. Adv Mater Interfaces 5(5): 1701246 (2018).
Baig Z , Mamat O , Mustapha M. Recent progress on the dispersion and the strengthening effect of carbon nanotubes and graphene-reinforced metal nanocomposites: A review. Crit Rev Solid State Mater Sci 43(1): 1–46 (2018).
Wang W , Xie G X , Luo J B . Black phosphorus as a new lubricant. Friction 6(1): 116–142 (2018).
Naguib M , Kurtoglu M , Presser V , Lu J , Niu J J , Heon M , Hultman L , Gogotsi Y , Barsoum M W . Two-dimensional nanocrystals produced by exfoliation of Ti3AlC2 . Adv Mater 23(37): 4248–4253 (2011).

Halim J , Kota S , Lukatskaya M R , Naguib M , Zhao M Q , Moon E J , Pitock J , Nanda J , May S J , Gogotsi Y , Barsoum M. Synthesis and characterization of 2D molybdenum carbide (MXene). Adv Funct Mater 26(18): 3118–3127 (2016).

Hong Ng V M , Huang H , Zhou K , Lee P S , Que W X , Xu J Z , Kong L B . Recent progress in layered transition metal carbides and/or nitrides (MXenes) and their composites: Synthesis and applications. J Mater Chem A 5(7): 3039–3068 (2017).

Dai W Y , Shao F , Szczerbiński J , McCaffrey R , Zenobi R , Jin Y H , Schlüter A D , Zhang W. Synthesis of a two-dimensional covalent organic monolayer through dynamic imine chemistry at the air/water interface. Angew Chem Int Ed Engl 55(1): 213–217 (2016).

Liu L C , Zhou M , Jin L , Li L C , Mo Y T , Su G S , Li X , Zhu H W , Tian Y. Recent advances in friction and lubrication of graphene and other 2D materials: Mechanisms and applications. Friction 7(3): 199–216 (2019).

Li D , Kaner R B . Graphene-based materials. Science 320(5880): 1170–1171 (2008).

Kim H , Abdala A A , Macosko C W . Graphene/polymer nanocomposites. Macromolecules 43(16): 6515–6530 (2010).

Bartolucci S F , Paras J , Rafiee M A , Rafiee J , Lee S , Kapoor D , Koratkar N. Graphene–aluminum nanocomposites. Mater Sci Eng A 528(27): 7933–7937 (2011).

Papageorgiou D G , Kinloch I A , Young R J . Mechanical properties of graphene and graphene-based nanocomposites. Prog Mater Sci 90: 75–127 (2017).

Chieng B W , Ibrahim N A , W Yunus W M Z , Hussein M Z , Giita Silverajah V S . Graphene nanoplatelets as novel reinforcement filler in poly(lactic acid)/epoxidized palm oil green nanocomposites: Mechanical properties. Int J Mol Sci 13(9): 10920–10934 (2012).

El Achaby M , Arrakhiz F E , Vaudreuil S , El Kacem Qaiss A , Bousmina M , Fassi-Fehri O. Mechanical, thermal, and rheological properties of graphene-based polypropylene nanocomposites prepared by melt mixing. Polym Compos 33(5): 733–744 (2012).

Ni Y , Chen L , Teng K , Shi J , Qian X M , Xu Z W , Tian X , Hu C S , Ma M J . Superior mechanical properties of epoxy composites reinforced by 3D interconnected graphene skeleton. ACS Appl Mater Interfaces 7(21): 11583–11591 (2015).

Lee B , Koo M Y , Jin S H , Kim K T , Hong S H . Simultaneous strengthening and toughening of reduced graphene oxide/alumina composites fabricated by molecular-level mixing process. Carbon 78: 212–219 (2014).

Ye H Z , Liu X Y , Hong H P . Fabrication of metal matrix composites by metal injection molding—A review. J Mater Process Technol 200(1–3): 12–24 (2008).

Song Y , He G Y , Wang Y G , Chen Y. Tribological behavior of boron nitride nanoplatelet reinforced Ni3Al intermetallic matrix composite fabricated by selective laser melting. Mater Design 165: 107579 (2019).

Hwang J , Yoon T , Jin S H , Lee J , Kim T S , Hong S H , Jeon S. Enhanced mechanical properties of graphene/copper nanocomposites using a molecular-level mixing process. Adv Mater 25(46): 6724–6729 (2013).

Zhang H , Wang L B , Zhou A G , Shen C L , Dai Y H , Liu F F , Chen J F , Li P , Hu Q K . Effects of 2-D transition metal carbide Ti2CTx on properties of epoxy composites. RSC Adv 6(90): 87341–87352 (2016).

Sorrentino A , Altavilla C , Merola M , Senatore A , Ciambelli P , Iannace S. Nanosheets of MoS2-oleylamine as hybrid filler for self-lubricating polymer composites: Thermal, tribological, and mechanical properties. Polym Compos 36(6): 1124–1134 (2015).

Xiao Q , Han W H , Yang R , You Y , Wei R B , Liu X B . Mechanical, dielectric, and thermal properties of polyarylene ether nitrile and boron nitride nanosheets composites. Polym Compos 39(S3): E1598–E1605 (2018).

Dai W , Yu J H , Wang Y , Song Y Z , Bai H , Nishimura K , Liao H W , Jiang N. Enhanced thermal and mechanical properties of polyimide/graphene composites. Macromol Res 22(9): 983–989 (2014).

Papageorgiou D G , Liu M F , Li Z L , Vallés C , Young R J , Kinloch I A . Hybrid poly(ether ether ketone) composites reinforced with a combination of carbon fibers and graphene nanoplatelets. Compos Sci Technol 175: 60–68 (2019).

Yan Z , Shi X L , Huang Y C , Deng X B , Liu X Y , Yang K. Tribological performance of Ni3Al matrix self-lubricating composites containing multilayer graphene prepared by additive manufacturing. J Mater Eng Perform 27(1): 167–175 (2018).

Zhang L G , Qi H M , Li G T , Wang D A , Wang T M , Wang Q H , Zhang G. Significantly enhanced wear resistance of PEEK by simply filling with modified graphitic carbon nitride. Mater Design 129: 192–200 (2017).
Rodenas T , Luz I , Prieto G , Seoane B , Miro H , Corma A , Kapteijn F , X Llabrés I X F , Gascon J. Metal-organic framework nanosheets in polymer composite materials for gas separation. Nat Mater 14(1): 48–55 (2015).
Wu S , He F , Xie G X , Bian Z L , Luo J B , Wen S Z . Black phosphorus: Degradation favors lubrication. Nano Lett 18(9): 5618–5627 (2018).
Zhang Z Z , Yang M M , Yuan J Y , Guo F , Men X H . Friction and wear behaviors of MoS_2-multi-walled-carbonnanotube hybrid reinforced polyurethane composite coating. Friction 7(4): 316–326 (2019).
Zhang G L , Xie G X , Si L N , Wen S Z , Guo D. Ultralow friction self-lubricating nanocomposites with mesoporous metal–organic frameworks as smart nanocontainers for lubricants. ACS Appl Mater Interfaces 9(43): 38146–38152 (2017).
Peng S G , Guo Y , Xie G X , Luo J B . Tribological behavior of polytetrafluoroethylene coating reinforced with black phosphorus nanoparticles. Appl Surf Sci 441: 670–677 (2018).
Bhargava S , Koratkar N , Blanchet T A . Effect of platelet thickness on wear of graphene–polytetrafluoroethylene (PTFE) composites. Tribol Lett 59(1): 17 (2015).
Li S , Duan C J , Li X , Shao M C , Qu C H , Zhang D , Wang Q H , Wang T M , Zhang X R . The effect of different layered materials on the tribological properties of PTFE composites. Friction 8(3): 542–552 (2020).
Lv Y , Wang W , Xie G X , Luo J B . Self-lubricating PTFE-based composites with black phosphorus nanosheets. Tribol Lett 66(2): 61 (2018).
Chen J , Chen B , Li J Y , Tong X , Zhao H C , Wang L P . Enhancement of mechanical and wear resistance performance in hexagonal boron nitride-reinforced epoxy nanocomposites. Polym Int 66(5): 659–664 (2017).
Min Y J , Kang K H , Kim D E . Development of polyimide films reinforced with boron nitride and boron nitride nanosheets for transparent flexible device applications. Nano Res 11(5): 2366–2378 (2018).
Yang M M , Zhang Z Z , Zhu X T , Men X H , Ren G N . In situ reduction and functionalization of graphene oxide to improve the tribological behavior of a phenol formaldehyde composite coating. Friction 3(1): 72–81 (2015).
Qiu S L , Hu Y X , Shi Y Q , Hou Y B , Kan Y C , Chu F K , Sheng H B , Yuen R K K , Xing W Y . In situ growth of polyphosphazene particles on molybdenum disulfide nanosheets for flame retardant and friction application. Compos Part A: Appl Sci Manuf 114: 407–417 (2018).
Chen Z Y , Yan H X , Guo L L , Li L , Yang P F , Liu B. A novel polyamide-type cyclophosphazene functionalized rGO/WS_2 nanosheets for bismaleimide resin with enhanced mechanical and tribological properties. Compos Part A: Appl Sci Manuf 121: 18–27 (2019).
Zhang H , Wang L B , Chen Q , Li P , Zhou A G , Cao X X , Hu Q K . Preparation, mechanical and anti-friction performance of MXene/polymer composites. Mater Design 92: 682–689 (2016).
Kandanur S S , Rafiee M A , Yavari F , Schrameyer M , Yu Z Z , Blanchet T A , Koratkar N. Suppression of wear in graphene polymer composites. Carbon 50(9): 3178–3183 (2012).
Lahiri D , Hec F , Thiesse M , Durygin A , Zhang C , Agarwal A. Nanotribological behavior of graphene nanoplatelet reinforced ultra high molecular weight polyethylene composites. Tribol Int 70: 165–169 (2014).
Zhao J , Chen G Y , He Y Y , Li S X , Duan Z Q , Li Y R , Luo J B . A novel route to the synthesis of an Fe_3O_4/h-BN 2D nanocomposite as a lubricant additive. RSC Adv 9(12): 6583–6588 (2019).
Xiao Y L , Yao P P , Fan K Y , Zhou H B , Deng M W , Jin Z X . Powder metallurgy processed metal-matrix friction materials for space applications. Friction 6(2): 219–229 (2018).
Wang X J , Lu M Y , Qiu L , Huang H , Li D , Wang H T , Cheng Y B . Graphene/titanium carbide composites prepared by sol-gel infiltration and spark plasma sintering. Ceram Int 42(1): 122–131 (2016).

Working of Functional Components in Self-Healing Coatings for Anti-Corrosion Green Tribological Applications

X. Li , D. Zhang , Z. Liu , Z. Li , C. Du , and C. Dong , "Materials science: Share corrosion data," Nature News, vol. 527, no. 7579, p. 441, 2015.

B. Hou et al., "The cost of corrosion in China," NPJ Materials Degradation, vol. 1, no. 1, pp. 1–10, 2017.

B. Aïssa , D. Therriault , E. Haddad , and W. Jamroz , "Self-healing materials systems: Overview of major approaches and recent developed technologies," Advances in Materials Science and Engineering, vol. 2012, pp. 1–17, 2012.

T. Ahmed , H. H. Ya , R. Khan , A. M. Hidayat Syah Lubis , and S. Mahadzir , "Pseudo-ductility, morphology and fractography resulting from the synergistic effect of CaCO3 and bentonite in HDPE polymer nano composite," Materials, vol. 13, no. 15, p. 3333, 2020.

H. U. Khalid , M. C. Ismail , and N. Nosbi , "Permeation damage of polymer liner in oil and gas pipelines: A review," Polymers, vol. 12, no. 10, p. 2307, 2020.

T. Ahmed , H. Ya , S. Mahadzir , R. Khan , and M. A. Alam , "An overview: Mechanical and wear properties of HDPE polymer nanocomposites reinforced with treated/non-treated inorganic nanofillers," Advances in Manufacturing Engineering, pp. 231–241, 2020.

M. A. Alam , H. Ya , P. Hussain , M. Azeem , S. Sapuan , and T. Ahamad , "Experimental Investigations on the Surface Hardness of Synthesized Polystyrene/ZnO Nanocomposites," in Advances in Manufacturing Engineering: Springer, 2020, pp. 345–352.

F. Zhang et al., "Self-healing mechanisms in smart protective coatings: A review," Corrosion Science, vol. 144, pp. 74–88, 2018.

P. Lan , E. E. Nunez , and A. A. Polycarpou , "11466 Advanced Polymeric Coatings and Their Applications: Green Tribology," 2019.

M. Samadzadeh , S. H. Boura , M. Peikari , S. Kasiriha , and A. Ashrafi , "A review on self-healing coatings based on micro/nanocapsules," Progress in Organic Coatings, vol. 68, no. 3, pp. 159–164, 2010.

A. Stankiewicz , I. Szczygieł , and B. Szczygieł , "Self-healing coatings in anti-corrosion applications," Journal of Materials Science, vol. 48, no. 23, pp. 8041–8051, 2013.

S. Dello Iacono , A. Martone , and E. Amendola , "Corrosion-resistant self-healing coatings," in AIP Conference Proceedings, 2018, vol. 1990, no. 1, p. 020010: AIP Publishing LLC.

R. Sanka , B. Krishnakumar , Y. Leterrier , S. Pandey , S. Rana , and V. Michaud , "Soft self-healing nanocomposites," Frontiers in Materials, vol. 6, p. 137, 2019.

D. G. Shchukin , "Container-based multifunctional self-healing polymer coatings," Polymer Chemistry, vol. 4, no. 18, pp. 4871–4877, 2013.

Y. Yang and M. W. Urban , "Self-healing polymeric materials," Chemical Society Reviews, vol. 42, no. 17, pp. 7446–7467, 2013.

M. Zheludkevich and A. Hughes , "Delivery Systems for Self Healing Protective Coatings," in Active Protective Coatings: Springer, 2016, pp. 157–199.

M. Zheludkevich , J. Tedim , and M. Ferreira , ""Smart" coatings for active corrosion protection based on multi-functional micro and nanocontainers," Electrochimica Acta, vol. 82, pp. 314–323, 2012.

A. Kumar , L. Stephenson , and J. N. Murray , "Self-healing coatings for steel," Progress in Organic Coatings, vol. 55, no. 3, pp. 244–253, 2006.

M. W. Keller , S. R. White , and N. R. Sottos , "A self-healing poly (dimethyl siloxane) elastomer," Advanced Functional Materials, vol. 17, no. 14, pp. 2399–2404, 2007.

C. Mangun , A. Mader , N. Sottos , and S. White , "Self-healing of a high temperature cured epoxy using poly (dimethylsiloxane) chemistry," Polymer, vol. 51, no. 18, pp. 4063–4068, 2010.

H. Choi , K. Y. Kim , and J. M. Park , "Encapsulation of aliphatic amines into nanoparticles for self-healing corrosion protection of steel sheets," Progress in Organic Coatings, vol. 76, no. 10, pp. 1316–1324, 2013.

S. García et al., "Self-healing anticorrosive organic coating based on an encapsulated water reactive silyl ester: Synthesis and proof of concept," Progress in Organic Coatings, vol. 70, no. 2–3, pp. 142–149, 2011.

W. Wang , L. Xu , X. Li , Z. Lin , Y. Yang , and E. An , "Self-healing mechanisms of water triggered smart coating in seawater," Journal of Materials Chemistry A, vol. 2, no. 6, pp. 1914–1921, 2014.

D. Sun , H. Zhang , X.-Z. Tang , and J. Yang , “Water resistant reactive microcapsules for self-healing coatings in harsh environments,” Polymer, vol. 91, pp. 33–40, 2016.
M. Mahmoudian , E. Nozad , M. G. Kochameshki , and M. Enayati , “Preparation and investigation of hybrid self-healing coatings containing linseed oil loaded nanocapsules, potassium ethyl xanthate and benzotriazole on copper surface,” Progress in Organic Coatings, vol. 120, pp. 167–178, 2018.
D. Y. Zhu , M. Z. Rong , and M. Q. Zhang , “Self-healing polymeric materials based on microencapsulated healing agents: From design to preparation,” Progress in Polymer Science, vol. 49, pp. 175–220, 2015.
S. D. Mookhoek , “Novel routes to liquid-based self-healing polymer systems,” 2010.
H. Jin , C. L. Mangun , D. S. Stradley , J. S. Moore , N. R. Sottos , and S. R. White , “Self-healing thermoset using encapsulated epoxy-amine healing chemistry,” Polymer, vol. 53, no. 2, pp. 581–587, 2012.
M. M. Caruso et al., “Robust, double-walled microcapsules for self-healing polymeric materials,” ACS Applied Materials & Interfaces, vol. 2, no. 4, pp. 1195–1199, 2010.
M. T. Gokmen , B. G. De Geest , W. E. Hennink , and F. E. Du Prez , ““Giant” hollow multilayer capsules by microfluidic templating,” ACS Applied Materials & Interfaces, vol. 1, no. 6, pp. 1196–1202, 2009.
Y. Yang , Z. Wei , C. Wang , and Z. Tong , “Versatile fabrication of nanocomposite microcapsules with controlled shell thickness and low permeability,” ACS Applied Materials & Interfaces, vol. 5, no. 7, pp. 2495–2502, 2013.
C. D. Dieleman , P. J. Denissen , and S. J. Garcia , “Long-term active corrosion protection of damaged coated-AA2024-T3 by embedded electrospun inhibiting nanonetworks,” Advanced Materials Interfaces, vol. 5, no. 12, p. 1800176, 2018.
A. Yabuki , W. Urushihara , J. Kinugasa , and K. Sugano , “Self-healing properties of TiO2 particle–polymer composite coatings for protection of aluminum alloys against corrosion in seawater,” Materials and Corrosion, vol. 62, no. 10, pp. 907–912, 2011.
A. Hughes , J. Laird , C. Ryan , P. Visser , H. Terryn , and A. Mol , “Particle characterisation and depletion of Li2CO3 inhibitor in a polyurethane coating,” Coatings, vol. 7, no. 7, p. 106, 2017.
S. Kongparakul et al., “Self-healing hybrid nanocomposite anticorrosive coating from epoxy/modified nanosilica/perfluorooctyl triethoxysilane,” Progress in Organic Coatings, vol. 104, pp. 173–179, 2017.
M. Zheludkevich , K. Yasakau , S. Poznyak , and M. Ferreira , “Triazole and thiazole derivatives as corrosion inhibitors for AA2024 aluminium alloy,” Corrosion Science, vol. 47, no. 12, pp. 3368–3383, 2005.
D. Snihirova , M. Taryba , S. V. Lamaka , and M. F. Montemor , “Corrosion inhibition synergies on a model Al-Cu-Mg sample studied by localized scanning electrochemical techniques,” Corrosion Science, vol. 112, pp. 408–417, 2016.
M. Montemor et al., “Evaluation of self-healing ability in protective coatings modified with combinations of layered double hydroxides and cerium molibdate nanocontainers filled with corrosion inhibitors,” Electrochimica Acta, vol. 60, pp. 31–40, 2012.
E. Shchukina , D. Shchukin , and D. Grigoriev , “Effect of inhibitor-loaded halloysites and mesoporous silica nanocontainers on corrosion protection of powder coatings,” Progress in Organic Coatings, vol. 102, pp. 60–65, 2017.
K. Zhang , L. Wang , and G. Liu , “Copper (II) 8-hydroxyquinolinate 3D network film with corrosion inhibitor embedded for self-healing corrosion protection,” Corrosion Science, vol. 75, pp. 38–46, 2013.
Y.-H. Liu , J.-B. Xu , J.-T. Zhang , and J.-M. Hu , “Electrodeposited silica film interlayer for active corrosion protection,” Corrosion Science, vol. 120, pp. 61–74, 2017.
G. L. Li , Z. Zheng , H. Mo¨hwald , and D. G. Shchukin , “Silica/polymer double-walled hybrid nanotubes: synthesis and application as stimuli-responsive nanocontainers in self-healing coatings,” ACS Nano, vol. 7, no. 3, pp. 2470–2478, 2013.
H. Wei et al., “Advanced micro/nanocapsules for self-healing smart anticorrosion coatings,” Journal of Materials Chemistry A, vol. 3, no. 2, pp. 469–480, 2015.
M. Serdechnova , S. Kallip , M. G. Ferreira , and M. L. Zheludkevich , “Active self-healing coating for galvanically coupled multi-material assemblies,” Electrochemistry Communications, vol. 41, pp. 51–54, 2014.

D. Borisova , H. Mo¨hwald , and D. G. Shchukin , “Influence of embedded nanocontainers on the efficiency of active anticorrosive coatings for aluminum alloys. Part II: Influence of nanocontainer position,” ACS Applied Materials & Interfaces, vol. 5, no. 1, pp. 80–87, 2013.
N. P. Tavandashti and S. Sanjabi , “Corrosion study of hybrid sol–gel coatings containing boehmite nanoparticles loaded with cerium nitrate corrosion inhibitor,” Progress in Organic Coatings, vol. 69, no. 4, pp. 384–391, 2010.
W. Trabelsi , E. Triki , L. Dhouibi , M. Ferreira , M. Zheludkevich , and M. Montemor , “The use of pre-treatments based on doped silane solutions for improved corrosion resistance of galvanised steel substrates,” Surface and Coatings Technology, vol. 200, no. 14–15, pp. 4240–4250, 2006.
D. Snihirova , L. Liphardt , G. Grundmeier , and F. Montemor , “Electrochemical study of the corrosion inhibition ability of “smart” coatings applied on AA2024,” Journal of Solid State Electrochemistry, vol. 17, no. 8, pp. 2183–2192, 2013.
S. Neema , M. Selvaraj , J. Raguraman , and S. Ramu , “Investigating the self healing process on coated steel by SVET and EIS techniques,” Journal of Applied Polymer Science, vol. 127, no. 1, pp. 740–747, 2013.
K. Aramaki , “XPS and EPMA studies on self-healing mechanism of a protective film composed of hydrated cerium (III) oxide and sodium phosphate on zinc,” Corrosion Science, vol. 45, no. 1, pp. 199–210, 2003.
A. S. Hamdy and D. Butt , “Novel smart stannate based coatings of self-healing functionality for AZ91D magnesium alloy,” Electrochimica Acta, vol. 97, pp. 296–303, 2013.
T. C. Mauldin and M. Kessler , “Self-healing polymers and composites,” International Materials Reviews, vol. 55, no. 6, pp. 317–346, 2010.
S. Li and J. Fu , “Improvement in corrosion protection properties of TiO2 coatings by chromium doping,” Corrosion Science, vol. 68, pp. 101–110, 2013.
A. Pilbáth , T. Szabó , J. Telegdi , and L. Nyikos , “SECM study of steel corrosion under scratched microencapsulated epoxy resin,” Progress in Organic Coatings, vol. 75, no. 4, pp. 480–485, 2012.

Nano-Indentation and Indentation Size Effect on Different Phases in Lamellar Structure High Entropy Alloy

Cantor, B. , et al., *Microstructural development in equiatomic multicomponent alloys* . Materials Science and Engineering: A, 2004. 375 : pp. 213–218.
Yeh , et al., *Nanostructured high-entropy alloys with multiple principal elements: Novel alloy design concepts and outcomes* . Advanced Engineering Materials, 2004. 6 (5): pp. 299–303.
Zhang, Y. , et al., *Solid-solution phase formation rules for multi-component alloys* . Advanced Engineering Materials, 2008. 10 (6): pp. 534–538.
Gao, M.C. and D.E. Alman , *Searching for next single-phase high-entropy alloy compositions* . Entropy, 2013. 15 (10): pp. 4504–4519.
Zhang, Y. , et al., *Microstructures and properties of high-entropy alloys* . Progress in Materials Science, 2014. 61 : pp. 1–93.
Borkar, T. , et al., *A combinatorial assessment of Al x CrCuFeNi 2 (0< x< 1.5) complex concentrated alloys: Microstructure, microhardness, and magnetic properties* . Acta Materialia, 2016. 116 : pp. 63–76.
He, F. , et al., Stability of lamellar structures in CoCrFeNiNb x eutectic high entropy alloys at elevated temperatures. Materials & Design, 2016. 104 : pp. 259–264.
Lu, Y. , et al., *A promising new class of high-temperature alloys: eutectic high-entropy alloys* . Scientific Reports, 2014. 4 : pp. 1–5.
Ma, S. and Y. Zhang , *Effect of Nb addition on the microstructure and properties of AlCoCrFeNi high-entropy alloy* . Materials Science and Engineering: A, 2012. 532 : pp. 480–486.
Rogal, Ł. , et al., *Microstructure and mechanical properties of the new Nb25Sc25Ti25Zr25 eutectic high entropy alloy* . Materials Science and Engineering: A, 2016. 651 : pp. 590–597.
Liu, W.-J. , et al., *Effect of micro-alloying element boron on the strengthening of high-strength steel Q690D.* Metallography, Microstructure, and Analysis, 2015. 4 (2): pp. 102–108.

Chaki, T. , *Mechanism of boron-induced strengthening of grain boundaries in Ni3Al* . Philosophical Magazine Letters, 1991. 63 (3): pp. 123–126.
Rodríguez-Castro, G. , et al., *Mechanical properties of FeB and Fe2B layers estimated by Berkovich nanoindentation on tool borided steel* . Surface and Coatings Technology, 2013. 215 : pp. 291–299.
Campos-Silva, I. , et al., *A study of indentation for mechanical characterization of the Fe2B layer* . Surface and Coatings Technology, 2013. 232 : pp. 173–181.
Almasri, A.H. and G.Z. Voyiadjis , *Nano-indentation in FCC metals: Experimental study* . Acta Mechanica, 2009. 209 (1): p. 1.
Guo, S. , C. Ng , J. Lu and C.T. Liu , *Effect of valence electron concentration on stability of FCC or BCC phase in high entropy alloys* , Journal of Applied Physics, 2011. 109 (10): pp. 1–5.
Leong, Z.Y. , *A new semi-empirical method based on a distorted tetragonal scheme for the structure prediction and alloy design of multiple-component alloys* , Thesis, University of Sheffield, 2017. http://etheses.whiterose.ac.uk/id/eprint/17022 (accessed February 1, 2018).
Tsai, M.-H. and J.W. Yeh , *High-entropy alloys: A critical review* , Materials Research Letters, 2014. 2 : pp. 107–123.
Qian, L. , M. Li , Z. Zhou , H. Yang , X. Shi , *Comparison of nano-indentation hardness to microhardness* , Surface and Coatings Technology, 2005. 195 : pp. 264–271.
Lentz, J. , A. Röttger , W. Theisen , *Hardness and modulus of Fe2B, Fe3(C,B), and Fe23(C,B)6 borides and carboborides in the Fe-C-B system* , Materials Characterization, 2018. 135 : pp. 192–202.

Improving Tribological Performance of Meso Scale Air Journal Bearing Using Surface Texturing

Bhore, S. P. and Darpe, A. K. 2014. Rotordynamics of micro and mesoscopic turbomachinery – a review. Journal of Vibration Engineering & Technologies 2(1):1–9.
Kim, D. and Bryant, M. D. 2004. Hydrodynamic performance of meso scale gas journal bearings. ASME International Mechanical Engineering Congress and Exposition 47136:1089–1098.
Hwang, T. and Ono, K. 2003. Analysis and design of hydrodynamic journal air bearings for high performance HDD spindle. Microsystem Technologies 9:386–394.
Murthy, A. N. , Etsion, I. , and Talke, F. E. 2007. Analysis of surface textured air bearing sliders with rarefaction effects. Tribology Letters 28:251–261.
Gu, L. , Guenat, E. , and Schiffmann, J. 2020. A review of grooved dynamic gas bearings. Applied Mechanics Reviews 72(1):010802.
Kim, H. J. , Park, I. K. , Seo, Y. H. , Kim, B. H. , and Hong, N. P. 2014. Wire tension method for coefficient of friction measurement of micro bearing. International Journal of Precision Engineering and Manufacturing 15(2):267–273.
Zhang, X. , Chen, Q. , and Liu, J. 2017. Steady characteristics of high-speed micro-gas journal bearings with different gaseous lubricants and extreme temperature difference. Journal of Tribology 139(2):021703.
Zhang, W. M. , Meng, G. , and Peng, Z. K. 2013. Gaseous slip flow in micro-bearings with random rough surface. International Journal of Mechanical Sciences 68:105–113.
Matele, S. and Pandey, K. N. 2018. Effect of surface texturing on the dynamic characteristics of hydrodynamic journal bearing comprising concepts of green tribology. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology 232(11):1365–1376.
Gachot, C. , Rosenkranz, A. , Hsu, S. M. , and Costa, H. L. 2017. A critical assessment of surface texturing for friction and wear improvement. Wear 372:21–41.
Rosenkranz, A. , Grützmacher, P. G. , Gachot, C. , and Costa, H. L. 2019. Surface texturing in machine elements−a critical discussion for rolling and sliding contacts. Advanced Engineering Materials 21(8):1900194.
Gropper, D. , Wang, L. , and Harvey, T. J. 2016. Hydrodynamic lubrication of textured surfaces: a review of modeling techniques and key findings. Tribology International 94:509–529.

Hingawe, N. D. and Bhore, S. P. 2019. Tribological performance of surface textured automotive components: A review. Automotive Tribology 287–306. https://doi.org/10.1007/978-981-15-0434-1_15
Sudeep, U. , Tandon, N. , and Pandey, R. K. 2015. Performance of lubricated rolling/sliding concentrated contacts with surface textures: A review. Journal of Tribology 137(3):031501.
Brizmer, V. and Kligerman, Y. 2012. A laser surface textured journal bearing. Journal of Tribology 134(3):031702.
Kango, S. , Sharma, R. K. , and Pandey, R. K. 2014. Comparative analysis of textured and grooved hydrodynamic journal bearing. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology 228(1):82–95.
Meng, F. M. , Zhang, L. , Liu, Y. , and Li, T. T. 2015. Effect of compound dimple on tribological performances of journal bearing. Tribology International 91:99–110.
Shinde, A. B. and Pawar, P. M. 2017. Multi-objective optimization of surface textured journal bearing by Taguchi based Grey relational analysis. Tribology International 114:349–357.
Zhang, H. , Hafezi, M. , Dong, G. , and Liu, Y. 2018. A design of coverage area for textured surface of sliding journal bearing based on genetic algorithm. Journal of Tribology 140(6):061702.
Tala-Ighil, N. and Fillon, M. 2015. Surface texturing effect comparative analysis in the hydrodynamic journal bearings. Mechanics & Industry 16(3):302.
Tala-Ighil, N. and Fillon, M. 2015. A numerical investigation of both thermal and texturing surface effects on the journal bearings static characteristics. Tribology International 90:228–239.
Hingawe, N. D. and Bhore, S. P. 2019. Effect of partial texture on the hydrodynamic performance of meso scale air bearings for mesoscale turbo-machines. Proceedings of the ASME 2019 Gas Turbine India Conference https://doi.org/10.1115/GTINDIA2019-2517.
Hingawe, N. D. and Bhore, S. P. 2019. Tribological performance of a surface textured meso scale air bearing. Industrial Lubrication and Tribology 72(5):599–609.
Hingawe, N. D. and Bhore, S. P. 2021. Investigation on Hydrodynamic Characteristics of Textured Meso Scale Gas Bearing, in Mechanisms and Machine Science. Springer, *Singapore* , 525–535.
Zhang, Q. , Guo, G. , and Bi, C. 2005. Air bearing spindle motor for hard disk drives. Tribology Transactions 48(4):468–473.
Guenat, E. and Schiffmann, J. 2019. Multi-objective optimization of grooved gas journal bearings for robustness in manufacturing tolerances. Tribology Transactions 62(6):1041–1050.
Chen, C. Y. , Liu, C. S. , Li, Y. C. , and Mou, S. 2015. Geometry optimization for asymmetrical herringbone grooves of miniature hydrodynamic journal bearings by using Taguchi technique. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology 229(2):196–206.
Orr, D. J. 2000. Macro-scale investigation of high speed gas bearings for MEMS devices (*Doctoral dissertation), Massachusetts Institute of Technology*, Cambridge, MA.
Qiu, M. , Delic, A. , and Raeymaekers, B. 2012. The effect of texture shape on the load-carrying capacity of gas-lubricated parallel slider bearings. Tribology Letters 48(3):315–327.
Grützmacher, P. G. , Rosenkranz, A. , Szurdak, A. , Grüber, M. , Gachot, C. , Hirt, G. , and Mücklich, F. 2019. Multi-scale surface patterning–an approach to control friction and lubricant migration in lubricated systems. Industrial Lubrication and Tribology. https://doi.org/10.1108/ILT-07-2018-0273.
Shinde, A. B. and Pawar, P. M. 2017. Effect of partial grooving on the performance of hydrodynamic journal bearing. Industrial Lubrication and Tribology 69(4):574–584.
Qiu, M. , Minson, B. R. , and Raeymaekers, B. 2013. The effect of texture shape on the friction coefficient and stiffness of gas-lubricated parallel slider bearings. Tribology International 67:278–288.
Fowell, M. T. , Medina, S. , Olver, A. V. , Spikes, H. A. , and Pegg, I. G. 2012. Parametric study of texturing in convergent bearings. Tribology International 52:7–16.

Textured Tool Surfaces for Improved Lubrication and Friction in Sheet Metal Forming

Ingarao, G. 2017. “Manufacturing Strategies for Efficiency in Energy and Resources Use: The Role of Metal Shaping Processes.” Journal of Cleaner Production 142 (January): 2872–2886. https://doi.org/10.1016/j.jclepro.2016.10.182.

Shah, R. , M. Woydt , and S. Zhang . 2021. “The Economic and Environmental Significance of Sustainable Lubricants.” Lubricants 9 (2): 21. https://doi.org/10.3390/lubricants9020021.

Sulaiman, M.H. 2017. “Development and Testing of Tailored Tool Surfaces for Sheet Metal Forming.” Technical University of Denmark (DTU), Kongens Lyngby, Denmark.

Singh, Y. , A. Farooq , A. Raza , M.A. Mahmood , and S. Jain . 2017. “Sustainability of a Non-Edible Vegetable Oil Based Bio-Lubricant for Automotive Applications: A Review.” Process Safety and Environmental Protection 111 (October): 701–713. https://doi.org/10.1016/j.psep.2017.08.041.

Syahir, A.Z. , N.W.M. Zulkifli , H.H. Masjuki , M.A. Kalam , A. Alabdulkarem , M. Gulzar , L.S. Khuong , and M.H. Harith . 2017. “A Review on Bio-Based Lubricants and Their Applications.” Journal of Cleaner Production 168 (December): 997–1016. https://doi.org/10.1016/j.jclepro.2017.09.106.

Mannekote, J.K. , S.V. Kailas , K. Venkatesh , and N. Kathyayini . 2018. “Environmentally Friendly Functional Fluids from Renewable and Sustainable Sources – A Review.” Renewable and Sustainable Energy Reviews 81 (June 2016): 1787–1801. https://doi.org/10.1016/j.rser.2017.05.274.

Amiril, S.A.S. , E.A. Rahim , and S. Syahrullail . 2017. “A Review on Ionic Liquids as Sustainable Lubricants in Manufacturing and Engineering: Recent Research, Performance, and Applications.” Journal of Cleaner Production 168: 1571–1589. https://doi.org/10.1016/j.jclepro.2017.03.197.

Zainal, N.A. , N.W.M. Zulkifli , M. Gulzar , and H.H. Masjuki . 2018. “A Review on the Chemistry, Production, and Technological Potential of Bio-Based Lubricants.” Renewable and Sustainable Energy Reviews 82 (February): 80–102. https://doi.org/10.1016/j.rser.2017.09.004.

Kang, Z. , Y. Fu , D. Zhou , Q. Wu , T. Chen , Y. He , and X. Su . 2021. “Reducing Engine Oil and Fuel Consumptions by Multidimensional Laser Surface Texturing on Cylinder Surface.” Journal of Manufacturing Processes 64 (April): 684–693. https://doi.org/10.1016/j.jmapro.2021.01.052.

Yang, L. , Y. Ding , B. Cheng , J. He , G. Wang , and Y. Wang . 2018. “Investigations on Femtosecond Laser Modified Micro-Textured Surface with Anti-Friction Property on Bearing Steel GCr15.” Applied Surface Science 434 (March): 831–842. https://doi.org/10.1016/j.apsusc.2017.10.234.

Shivakoti, I. , G. Kibria , R. Cep , B.B. Pradhan , and A. Sharma . 2021. “Laser Surface Texturing for Biomedical Applications: A Review.” Coatings 11 (2): 124. https://doi.org/10.3390/coatings11020124.

Ranjan, P. and S.S. Hiremath . 2019. “Role of Textured Tool in Improving Machining Performance: A Review.” Journal of Manufacturing Processes 43 (July): 47–73. https://doi.org/10.1016/j.jmapro.2019.04.011.

Bech, J. , N. Bay , and M. Eriksen . 1999. “Entrapment and Escape of Liquid Lubricant in Metal Forming.” Wear 232 (2): 134–139. https://doi.org/10.1016/S0043-1648(99)00136-2.

Dubar, L. , C. Hubert , P. Christiansen , N. Bay , and A. Dubois . 2012. “Analysis of Fluid Lubrication Mechanisms in Metal Forming at Mesoscopic Scale.” CIRP Annals – Manufacturing Technology 61 (1): 271–274. https://doi.org/10.1016/j.cirp.2012.03.126.

Sulaiman, M.H. , P. Christiansen , and N. Bay . 2017. “The Influence of Tool Texture on Friction and Lubrication in Strip Reduction Testing.” Lubricants 5 (1). https://doi.org/10.3390/lubricants5010003.

Popp, U. , and U. Engel . 2006. “Microtexturing of Cold-Forging Tools – Influence on Tool Life.” Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 220 (1): 27–33. https://doi.org/10.1243/095440505X32968.

Krux, R. , W. Homberg , M. Kalveram , M. Trompeter , M. Kleiner , and K. Weinert . 2005. “Die Surface Structures and Hydrostatic Pressure System for the Material Flow Control in High-Pressure Sheet Metal Forming.” Advanced Materials Research 6–8: 385–392. https://doi.org/10.4028/www.scientific.net/AMR.6-8.385.
Pawlus, P. , R. Reizer , M. Wieczorowski , and G. Krolczyk . 2020. “Material Ratio Curve as Information on the State of Surface Topography—A Review.” Precision Engineering 65 (September): 240–258. https://doi.org/10.1016/j.precisioneng.2020.05.008.
Steitz, M. , P. Stein , and P. Groche . 2015. “Influence of Hammer-Peened Surface Textures on Friction Behavior.” Tribology Letters 58 (2): 1–8. https://doi.org/10.1007/s11249-015-0502-9.
Franzen, V. , J. Witulski , A. Brosius , M. Trompeter , and A. E. Tekkaya . 2010. “Textured Surfaces for Deep Drawing Tools by Rolling.” International Journal of Machine Tools and Manufacture 50 (11): 969–976. https://doi.org/10.1016/j.ijmachtools.2010.08.001.
Groche, P. , J. Stahlmann , J. Hartel , and M. Köhler . 2009. “Hydrodynamic Effects of Macroscopic Deterministic Surface Structures in Cold Forging Processes.” Tribology International 42 (8): 1173–1179. https://doi.org/10.1016/j.triboint.2009.03.019.
Bay, N. , D. D. Olsson , and J. L. Andreasen . 2008. “Lubricant Test Methods for Sheet Metal Forming.” Tribology International 41 (9–10): 844–853. https://doi.org/10.1016/j.triboint.2007.11.017.
Olsson, D.D. , N. Bay , and J.L. Andreasen . 2004. “Prediction of Limits of Lubrication in Strip Reduction Testing.” CIRP Annals – Manufacturing Technology 53 (1): 231–234. https://doi.org/10.1016/S0007-8506(07)60686-6.
Trzepiecinski, T. , Hirpa G. Lemu . 2020. “Recent developments and trends in the friction testing for conventional sheet metal forming and incremental sheet forming.” Metals 10 (1): 47.
Bay, N. 2011. “Trends and Vision in Metal Forming Tribology.” Steel Research International 82, Planetary (Special Edition): 15–26.
Nielsen, P. S. , K.S. Friis , and N. Bay . 2011. “Testing and Modelling of New Tribo-Systems for Industrial Sheet Forming of Stainless Steels.” Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology 225 (10): 1036–1047. https://doi.org/10.1177/1350650111415331.
Sulaiman, M.H. , R.N. Farahana , M.J.M. Ridzuan , H. Jaafar , L. Tajul , and J.A. Wahab . 2019. “Manufacturing Strategies and Tribology of Tailored Tool Surface Topographies for Enhanced Lubrication in Metal Forming.” In *Proceedings of 3rd Mytribos Symposium*, 47–51.
Sulaiman, M.H. , P. Christiansen , and N. Bay . 2018. “Development and Testing of Tailored Tool Surfaces for Sheet Metal Forming.” In *8th JSTP International Seminar on Precision Forging (ISPF)*, 69–72.
Wanheim, T. , and T. Abildgaard . 1980. “A Mechanism for Metallic Friction.” In *Proceedings of the 4th International Conference on Production Engineering Tokyo*, 122–27.
Siebel, E. 1923. “Untersuchungen Über Bildsame Formänderung Unter Besonderer Berück-Sichtigung Des Schmiedens.” Maschinenbau/Betrieb 9: 307–312.
Steitz, M. , P. Stein , and P. Groche . 2015. “Influence of Hammer-Peened Surface Textures on Friction Behavior.” Tribology Letters 58 (2): 1–8. https://doi.org/10.1007/s11249-015-0502-9.

Green Machining Techniques

Sivarajan, S. and Padmanabhan, R. (2014). Green machining and forming by the use of surface coated tools. Procedia Engineering, 97, 15–21.https://doi.org/10.1016/j.proeng.2014.12.219
Sultana, N. , Dhar, N. R. , and Zaman, P. B. (2019). A review on different cooling/lubrication techniques in metal cutting. American Journal of Mechanics and Applications, 7, 4, 71–87. https://doi.org/10.11648/j.ajma.20190704.11
Singh, G. , Aggarwal, V. , and Singh, S. (2020). Critical review on ecological, economical and technological aspects of minimum quantity lubrication towards sustainable machining. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2020.122185.
Dixit, U. S. , Sarma, D. K. , and Davim, J. P. (2011). Dry machining. Springer Briefs in Applied Sciences and Technology, 19–28. https://doi.org/10.1007/978-1-4614-2308-9_3
https://www.mmsonline.com/articles/the-new-rules-of-cutting-tools-introduction, accessed on 07.12.2020.

Ranjan, P. and Hiremath, S. S. (2019). Role of textured tool in improving machining performance: A review. Journal of Manufacturing Processes, 43, 47–73.
Thomas, S. J. , and Kalaichelvan, K. (2017). Comparative study of effect of surface texturing on cutting tool in dry cutting. Materials and Manufacturing Processes. https://doi.org/10.1080/10426914.2017.1376070
Sugihara, T. , Singh, P. , and Enomoto, T. (2017). Development of novel cutting tools with dimple textured surfaces for dry machining of aluminum alloys. Procedia Manufacturing, 14, 111–117. https://doi.org/10.1016/j.promfg.2017.11.013
Durairaj, S. , Guo, J. , Aramcharoen, A. , and Castagne, S. (2018). An experimental study into the effect of micro-textures on the performance of cutting tool. The International Journal of Advanced Manufacturing Technology, 98(1–4), 1011–1030. https://doi.org/10.1007/s00170-018-2309-y
Niketh, S. and Samuel, G. L. (2018). Drilling performance of micro textured tools under dry, wet and MQL condition. Journal of Manufacturing Processes, 32, 254–268. https://doi.org/10.1016/j.jmapro.2018.02.012
Arslan, A. , Masjuki, H. H. , Kalam, M. A. , Varman, M. , Mufti, R. A. , Mosarof, M. H. , Khuong, L. S. , and Quazi, M. M. (2016). Surface texture manufacturing techniques and tribological effect of surface texturing on cutting tool performance: A review. Critical Reviews in Solid State and Materials Sciences, 41(6), 447–481. https://doi.org/10.1080/10408436.2016.1186597
Orra, K. and Choudhury, S. K. (2018). Tribological aspects of various geometrically shaped micro-textures on cutting insert to improve tool life in hard turning process. Journal of Manufacturing Processes, 31, 502–513. https://doi.org/10.1016/j.jmapro.2017.12.005
Bobzin, K. (2017). High-performance coatings for cutting tools. CIRP Journal of Manufacturing Science and Technology, 18, 1–9. https://doi.org/10.1016/j.cirpj.2016.11.004
Deng, Y. , Chen, W. , Li, B. , Wang, C. , Kuang, T. , and Li, Y. (2020). Physical vapor deposition technology for coated cutting tools: A review. Ceramics International. https://doi.org/10.1016/j.ceramint.2020.04.168
Capasso, S. , Paiva, J. M. , Junior, E. L. , Settineri, L. , Yamamoto, K. , Amorim, F. L. , Torres, R. D. , Covelli, D. , Fox-Rabinovich, G. , and Veldhuis, S. (2019). A novel method of assessing and predicting coated cutting tool wear during Inconel DA 718 turning. Wear, 202949. https://doi.org/10.1016/j.wear.2019.202949
Chekalova, E. , and Zhuravlev, A. (2019). Increasing the wear resistance of a complex profile cutting tool by applying a diffusion discrete coating. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2019.08.053
Santecchia, E. , Hamouda, A. M. S. , Musharavati, F. , Zalnezhad, E. , Cabibbo, M. , and Spigarelli, S. (2015). Wear resistance investigation of titanium nitride-based coatings. Ceramics International, 41(9), 10349–10379. https://doi.org/10.1016/j.ceramint.2015.04.152
Rizzo, A. , Goel, S. , Grilli, M. L. , Iglesias, R. , Jaworska, L. , Lapkovskis, V. , Novak, P. , Postolnyi, B.O. , and Valerini, D. (2020). The critical raw materials in cutting tools for machining applications: A review. Materials, 13(6), 1377. https://doi.org/10.3390/ma13061377
Liu, B. , Wei, W. , Gan, Y. , Duan, C. , and Cui, H. (2020). Preparation, mechanical properties and microstructure of TiB2 based ceramic cutting tool material toughened by TiC whisker. International Journal of Refractory Metals and Hard Materials, 93, 105372. https://doi.org/10.1016/j.ijrmhm.2020.105372
Traxel, K. D. and Bandyopadhyay, A. (2020). Diamond-reinforced cutting tools using laser-based additive manufacturing. Additive Manufacturing, 101602. https://doi.org/10.1016/j.addma.2020.101602
Tu, L. , Tian, S. , Xu, F. , Wang, X. , Xu, C. , He, B. , Zuo, D. , and Zhang, W. (2020). Cutting performance of cubic boron nitride-coated tools in dry turning of hardened ductile iron. Journal of Manufacturing Processes, 56, 158–168. https://doi.org/10.1016/j.jmapro.2020.04.081
Chetan, Ghosh, S. , and Venkateswara Rao, P. (2015). Application of sustainable techniques in metal cutting for enhanced machinability: A review. Journal of Cleaner Production, 100, 17–34. https://doi.org/10.1016/j.jclepro.2015.03.039
Krolczyk, G. M. , Maruda, R. W. , Krolczyk, J. B. , Wojciechowski, S. , Mia, M. , Nieslony, P. , and Budzik, G. (2019). Ecological trends in machining as a key factor in sustainable production – A review. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2019.02.017
Yildiz, Y. and Nalbant, M. (2008). A review of cryogenic cooling in machining processes. International Journal of Machine Tools and Manufacture, 48(9), 947–964. https://doi.org/10.1016/j.ijmachtools.2008.01.008

Hong, S. Y. and Ding, Y. (2001). Cooling approaches and cutting temperatures in cryogenic machining of Ti-6Al-4V. International Journal of Machine Tools and Manufacture, 41(10), 1417–1437. https://doi.org/10.1016/s0890-6955(01)00026-8

Stampfer, B. , Golda, P. , Schiebl, R. , Maas, U. , and Schulze, V. (2020). Cryogenic orthogonal turning of Ti-6Al-4V. The International Journal of Advanced Manufacturing Technology, 111, 359–369. https://doi.org/10.1007/s00170-020-06105-z

Dhar, N. R. , Islam, S. , Kamruzzaman, M. , and Paul, S. (2006). Wear behavior of uncoated carbide inserts under dry, wet and cryogenic cooling conditions in turning C-60 steel. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 28(2), 146–152. https://doi.org/10.1590/s1678-58782006000200003

Yong, A. Y. L. , Seah, K. H. W. , and Rahman, M. (2006). Performance of cryogenically treated tungsten carbide tools in milling operations. The International Journal of Advanced Manufacturing Technology, 32(7–8), 638–643. https://doi.org/10.1007/s00170-005-0379-0

Vicentin, G. C. , Sanchez, L. E. A. , Scalon, V. L. , and Abreu, G. G. C. (2011). A sustainable alternative for cooling the machining processes using a refrigerant fluid in recirculation inside the toolholder. Clean Technologies and Environmental Policy, 13(6), 831–840. https://doi.org/10.1007/s10098-011-0359-z

Yıldırım, Ç. V. , Kıvak, T. , Sarıkaya, M. , and Şirin, Ş. (2020). Evaluation of tool wear, surface roughness/topography and chip morphology when machining of Ni-based alloy 625 under MQL, cryogenic cooling and CryoMQL. Journal of Materials Research and Technology. https://doi.org/10.1016/j.jmrt.2019.12.069

Rubio, E. M. , Agustina, B. , Marín, M. , and Bericua, A. (2015). Cooling systems based on cold compressed air: A review of the applications in machining processes. Procedia Engineering, 132, 413–418. https://doi.org/10.1016/j.proeng.2015.12.513

Ginting, Y. R. , Boswell, B. , Biswas, W. K. , and Islam, M. N. (2016). Environmental generation of cold air for machining. Procedia CIRP, 40, 648–652. https://doi.org/10.1016/j.procir.2016.01.149

Wu, Z. , Yang, Y. , Su, C. , Cai, X. , and Luo, C. (2016). Development and prospect of cooling technology for dry cutting tools. The International Journal of Advanced Manufacturing Technology, 88(5–8), 1567–1577. https://doi.org/10.1007/s00170-016-8842-7

Kumar, S. and Gandotra, S. (2020). Effect of cooling air on machining performance during hard turning. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2020.06.263

Fan, Y. , Hao, Z. , Lin, J. , and Yu, Z. (2015). New observations on tool wear mechanism in machining Inconel 718 under water vapor + air cooling lubrication cutting conditions. Journal of Cleaner Production, 90, 381–387. https://doi.org/10.1016/j.jclepro.2014.11.049

Li, C. , Xu, J. , Chen, M. , An, Q. , El Mansori, M. , and Ren, F. (2019). Tool wear processes in low frequency vibration assisted drilling of CFRP/Ti6Al4V stacks with forced air-cooling. Wear, 426–427, 1616–1623. https://doi.org/10.1016/j.wear.2019.01.005

Singh, R. , Dureja, J. S. , Dogra, M. , Kumar Gupta, M. , Jamil, M. , and Mia, M. (2020). Evaluating the sustainability pillars of energy and environment considering carbon emissions under machining ofTi-3Al-2.5 V. Sustainable Energy Technologies and Assessments, 42, 100806. https://doi.org/10.1016/j.seta.2020.100806

Jozić, S. , Bajić, D. , and Celent, L. (2015). Application of compressed cold air cooling: achieving multiple performance characteristics in end milling process. Journal of Cleaner Production, 100, 325–332. https://doi.org/10.1016/j.jclepro.2015.03.095

Nadolny, K. , and Kieraś, S. (2020). New approach for cooling and lubrication in dry machining on the example of internal cylindrical grinding of bearing rings. Sustainable Materials and Technologies, 24, e00166. https://doi.org/10.1016/j.susmat.2020.e00166

Peng, R. , Jiang, H. , Tang, X. , Huang, X. , Xu, Y. , and Hu, Y. (2019). Design and performance of an internal-cooling turning tool with micro-channel structures. Journal of Manufacturing Processes, 45, 690–701. https://doi.org/10.1016/j.jmapro.2019.08.011

Bleicher, F. , and Reiter, M. (2018). Wear reduction on cutting inserts by additional internal cooling of the cutting edge. Procedia Manufacturing, 21, 518–524. https://doi.org/10.1016/j.promfg.2018.02.152

Uhlmann, E. , Riemer, H. , Schröter, D. , Sammler, F. , and Richarz, S. (2017). Substitution of coolant by sing a closed internally cooled milling tool. Procedia CIRP, 61, 553–557. https://doi.org/10.1016/j.procir.2016.11.267

Chen, J. , Fu, Y. , Qian, N. , Ching, C. Y. , Ewing, D. , and He, Q. (2020). A study on thermal performance of revolving heat pipe grinding wheel. Applied Thermal Engineering, 116065.

https://doi.org/10.1016/j.applthermaleng.2020.116065
Chen, J. , Fu, Y. , He, Q. , Shen, H. , Ching, C. Y. , and Ewing, D. (2016). Environmentally friendly machining with a revolving heat pipe grinding wheel. Applied Thermal Engineering, 107, 719–727. https://doi.org/10.1016/j.applthermaleng.2016.07.030
Chen, J. , Fu, Y. , Gu, Z. , Shen, H. , and He, Q. (2017). Study on heat transfer of a rotating heat pipe cooling system in dry abrasive-milling. Applied Thermal Engineering, 115, 736–743. https://doi.org/10.1016/j.applthermaleng.2016.12.138
Wu, Z. , Xing, Y. , Liu, L. , Huang, P. , and Zhao, G. (2020). Design, fabrication and performance evaluation of pulsating heat pipe assisted tool holder. Journal of Manufacturing Processes, 50, 224–233. https://doi.org/10.1016/j.jmapro.2019.12.054
Wu, Z. , Deng, J. , Su, C. , Luo, C. , and Xia, D. (2014). Performance of the micro-texture self-lubricating and pulsating heat pipe self-cooling tools in dry cutting process. International Journal of Refractory Metals and Hard Materials, 45, 238–248. https://doi.org/10.1016/j.ijrmhm.2014.02.004
Rozzi, J. C. , Sanders, J. K. , and Chen, W. (2011). The experimental and theoretical evaluation of an indirect cooling system for machining. Journal of Heat Transfer, 133(3), 031006. https://doi.org/10.1115/1.4002446
Shu, S. , Cheng, K. , Ding, H. , and Chen, S. (2013). An innovative method to measure the cutting temperature in process by using an internally cooled smart cutting tool. Journal of Manufacturing Science and Engineering, 135(6), 061018. https://doi.org/10.1115/1.4025742
Banerjee, N. and Sharma, A. (2018). A comprehensive assessment of minimum quantity lubrication machining from quality, production, and sustainability perspectives. Sustainable Materials and Technologies, 17, e00070. https://doi.org/10.1016/j.susmat.2018.e00070
Hamran, N. N. N. , Ghani, J. A. , Ramli, R. , and Haron, C. H. C. (2020). A review on recent development of minimum quantity lubrication for sustainable machining. Journal of Cleaner Production, 122165. https://doi.org/10.1016/j.jclepro.2020.122165
Singh, J. and Chatha, S. S. (2020). Tribological behaviour of nanofluids under minimum quantity lubrication in turning of AISI 1055 steel. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2020.09.156
Khunt, C. P. , Makhesana, M. A. , Patel, K. M. , and Mawandiya, B. K. (2021). Performance assessment of vegetable oil-based minimum quantity lubrication (MQL) in drilling. Materials Today: Proceedings, 44(Part 1), 341−345. https://doi.org/10.1016/j.matpr.2020.09.741
Virdi, R. L. , Chatha, S. S. , and Singh, H. (2020). Experimental investigations on the tribological and lubrication behaviour of minimum quantity lubrication technique in grinding of Inconel 718 alloy. Tribology International, 106581. https://doi.org/10.1016/j.triboint.2020.106581
Virdi, R. L. , Chatha, S. S. , and Singh, H. (2020). Machining performance of Inconel-718 alloy under the influence of nanoparticles based minimum quantity lubrication grinding. Journal of Manufacturing Processes, 59, 355–365. https://doi.org/10.1016/j.jmapro.2020.09.056

Future Outlooks in Green Tribology

R. Shah , M. Woydt , N. Huq and A. Rosenkranz . Tribology meets sustainability, Industrial Lubrication and Tribology, 2020, https://doi.org/10.1108/ILT-09-2020-0356.
A. Anand , M. Irfan Ul Haq , K. Vohra , A. Raina and M.F. Wani . Role of green tribology in sustainability of mechanical systems: A state of the art survey, Materials Today: Proceedings, 4, 2, Part A, 2017, 3659–3665.
K. Holmberg and A. Erdemir . The impact of tribology on energy use and CO2 emission globally and in combustion engine and electric cars, Tribology International, 135, 2019, 389–396.
S. Betancourt-Parra . Leonardo da Vinci's tribological intuitions, Tribology International, 153, 2021, 106664.
I. Tzanakis , M. Hadfield , B. Thomas , S. M. Noya , I. Henshaw , and S. Austen . Future perspectives on sustainable tribology, Renewable and Sustainable Energy Reviews, 16, 6, 2012, 4126–4140.