

# 11 First-Principles Atomic-Scale Study of Superlow Friction

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## 11.1 Introduction

Friction is the resistance to the relative motion of two sliding or rolling objects imposed by nonconservative forces [1–3] and, in general, it occurs along with dissipation of mechanical energy and wear. These forces are generated from short- and long-range interactions between the sliding surfaces [4, 5]. The interaction potential can be either attractive or repulsive depending on the distance between surfaces and also on their relative lateral positions. The moving objects are either in direct contact through asperities, or gaseous, liquid or solid lubricants may be introduced between them to reduce the friction.

The dry sliding friction of two surfaces that are in direct contact through their asperities involves many interesting and complex phenomena, such as adhesion, wetting, atom exchange, the breaking and formation of bonds, as well as elastic and plastic deformation. During the relative motion, phonons are generated and electron-hole pairs are created at the expense of damped mechanical energy. Photons may even be emitted. The nonequilibrium phonon distribution generated locally is dissipated by phonon-phonon and electron-phonon coupling. Simulations of dry sliding friction between a metal asperity and an incommensurate metal surface have revealed unusual atomic processes [6]. For example, the lateral force exhibits a quasiperiodic variation with the displacement of an asperity; each period consists of two different stick-slip processes involving structural transitions. It has also been found that the perpendicular elastic deformation of the substrate that is induced by the sliding object is crucial to the energy damping associated with friction [7]. In certain conditions, due to the elastic deformation of the substrate, the corrugation of the surface potential energy can be inverted under high loading forces. This situation gives rise to the occurrence of a second state (*bistability*) in the stick-slip motion and anisotropy in the hysteresis curve [7]. It is also very well-known that the stiffer the sliding surfaces, the smaller the friction coefficient [7].

# Fundamentals Of Friction Wear Of Mater

**K.-H. Zum Gahr**



## **Fundamentals Of Friction Wear Of Mater:**

**Friction and Wear** Giovanni Straffelini, 2015-04-03 This book introduces the basic concepts of contact mechanics friction lubrication and wear mechanisms providing simplified analytical relationships that are useful for quantitative assessments Subsequently an overview on the main wear processes is provided and guidelines on the most suitable design solutions for each specific application are outlined The final part of the text is devoted to a description of the main materials and surface treatments specifically developed for tribological applications and to the presentation of tribological systems of particular engineering relevance The text is up to date with the latest developments in the field of tribology and provides a theoretical framework to explain friction and wear problems together with practical tools for their resolution The text is intended for students on Engineering courses both bachelor and master degrees who must develop a sound understanding of friction wear lubrication and surface engineering and for technicians or professionals who need to solve tribological problems in their work

*Friction and Wear of Polymer Composites* Klaus Friedrich, 2012-12-02 Providing a useful summary of current knowledge on the friction and wear properties of composite materials this book fills the gap between publications on fundamental principles of tribology and those on the friction and wear behavior of metals and polymers Detailed coverage is given of the fundamental aspects of tribology in general and polymer composites in particular the effects of the microstructure of composites on friction and wear behavior under different external loading conditions and the problem of the control of friction and wear behavior in practical situations Although emphasis is on polymer composites associated with bearing type applications part of the book is also devoted to the friction and wear of metal based composites and rubber compounds The data are represented in the form of 277 figures diagrams and photographs and 68 tables The author index covers more than 670 references and the subject index more than 1 000 keywords The book will be of particular interest to those involved in research on some aspects of polymer composites tribology material scientists physical chemists mechanical engineers those wishing to learn more methods for solving practical friction or wear problems designers engineers and technologists in industries dealing with selection reprocessing and application of polymer engineering materials and teachers and students at universities

**Microstructure and Wear of Materials** K.-H. Zum Gahr, 1987-03-01 This new book will be useful not only to practising engineers and scientists but also to advanced students interested in wear It reviews our current understanding of the influence of microstructural elements and physical properties of materials metals polymers ceramics and composites on wear The introductory chapters describe the relation between microstructure and mechanical properties of materials surfaces in contact and the classification of wear processes The following chapters are concerned with wear modes of great practical interest such as grooving wear sliding wear rolling sliding wear and erosive wear Our present understanding of abrasion adhesion surface fatigue and tribochemical reactions as the relevant wear mechanisms is discussed and new wear models are presented In addition to extensive experimental results sketches have been widely used

for clarifying the physical events

**Friction and Wear of Ceramics** Bikramjit Basu, Mitjan Kalin, B. V. Manoj

Kumar, 2020-05-19 This book covers the area of tribology broadly providing important introductory chapters to fundamentals processing and applications of tribology. The book is designed primarily for easy and cohesive understanding for students and practicing scientists pursuing the area of tribology with focus on materials. This book helps students and practicing scientists alike understand that a comprehensive knowledge about the friction and wear properties of advanced materials is essential to further design and development of new materials. The description of the wear micromechanisms of various materials will provide a strong background to the readers as how to design and develop new tribological materials. This book also places importance on the development of new ceramic composites in the context of tribological applications. Some of the key features of the book include: Fundamentals section highlights the salient issues of ceramic processing and mechanical properties of important oxide and non oxide ceramic systems. State of the art research findings on important ceramic composites are included and an understanding on the behavior of silicon carbide SiC based ceramic composites in dry sliding wear conditions is presented as a case study. Erosion wear behavior of ceramics in which case studies on high temperature erosion behavior of SiC based composites and zirconium diboride ZrB<sub>2</sub> based composites is also covered. Wear behavior of ceramic coatings is rarely discussed in any tribology related books therefore a case study explaining the abrasion wear behavior of WC-Co coating is provided. Finally an appendix chapter is included in which a collection of several types of questions including multiple choice, short answer and long answer are provided.

*Friction and Wear: From Elementary Mechanisms to Macroscopic Behavior* Valentin L. Popov, Roman Pohrt, 2019-08-21 Friction and the interaction of surfaces can usually be felt at the scale of the contacting bodies. Indeed phenomena such as the frictional resistance or the occurrence of wear can be observable with plain eye but to characterize them and in order to make a prediction a more detailed understanding at smaller scales is often required. These can include individual roughness peaks or single molecule interactions. In this Research Topic we have gathered a collection of articles representing the state of the art in tribology's endeavor to bridge the gap between nano scale elementary research and the macroscopic behavior of contacting bodies. These articles showcase the breadth of questions related to the interaction of micro and macro scale and give examples of successful transfer of insights from one to the other. We are delighted to present this Research Topic to the reader with the hope that it will further inspire and stimulate research in the field.

**Tribology for Scientists and Engineers** Pradeep L. Menezes, Michael Nosonovsky, Sudeep P. Ingole, Satish V. Kailas, Michael R. Lovell, 2013-12-04 This book describes available tribology technologies and introduces a comprehensive overview of tribology. General up to date knowledge on how tribology is approached in various related areas of research both experimental and computational is provided.

*Modern Tribology Handbook, Two Volume Set* Bharat Bhushan, 2000-12-28 Recent research has led to a deeper understanding of the nature and consequences of interactions between materials on an atomic scale. The results have resonated throughout the field of

tribology For example new applications require detailed understanding of the tribological process on macro and micro scales and new knowledge guides the rational *Principles and Applications of Tribology* Bharat Bhushan, 2013-02-15 This fully updated Second Edition provides the reader with the solid understanding of tribology which is essential to engineers involved in the design of and ensuring the reliability of machine parts and systems It moves from basic theory to practice examining tribology from the integrated viewpoint of mechanical engineering mechanics and materials science It offers detailed coverage of the mechanisms of material wear friction and all of the major lubrication techniques liquids solids and gases and examines a wide range of both traditional and state of the art applications For this edition the author has included updates on friction wear and lubrication as well as completely revised material including the latest breakthroughs in tribology at the nano and micro level and a revised introduction to nanotechnology Also included is a new chapter on the emerging field of green tribology and biomimetics Advances in Friction-Stir Welding and Processing M.-K. Besharati-Givi, P.

Asadi, 2014-12-08 Friction stir welding FSW is a solid state joining process primarily used on aluminum and is also widely used for joining dissimilar metals such as aluminum magnesium copper and ferrous alloys Recently a friction stir processing FSP technique based on FSW has been used for microstructural modifications the homogenized and refined microstructure along with the reduced porosity resulting in improved mechanical properties *Advances in friction stir welding and processing* deals with the processes involved in different metals and polymers including their microstructural and mechanical properties wear and corrosion behavior heat flow and simulation The book is structured into ten chapters covering applications of the technology tool and welding design material and heat flow microstructural evolution mechanical properties corrosion behavior and wear properties Later chapters cover mechanical alloying and FSP as a welding and casting repair technique optimization and simulation of artificial neural networks and FSW and FSP of polymers Provides studies of the microstructural mechanical corrosion and wear properties of friction stir welded and processed materials Considers heat generation heat flow and material flow Covers simulation of FSW FSP and use of artificial neural network in FSW FSP

**Delaware Composites Design Encyclopedia** University of Delaware, 1990-06-26 This book presents a list of six volumes of the Delaware Composite Design Encyclopedia dealing with mechanical behaviour and properties of composite materials microchemical material modeling processing and fabrication technology failure analysis design studies and test methods Volume IV covers the Failure Analysis of Composite Materials Introduction to Tribology Bharat Bhushan, 2013-02-14 A fully updated version of the popular *Introduction to Tribology* the second edition of this leading tribology text introduces the major developments in the understanding and interpretation of friction wear and lubrication Considerations of friction and wear have been fully revised to include recent analysis and data work and friction mechanisms have been reappraised in light of current developments In this edition the breakthroughs in tribology at the nano and micro level as well as recent developments in nanotechnology and magnetic storage technologies are introduced A new chapter on the emerging field of

green tribology and biomimetics is included Introduces the topic of tribology from a mechanical engineering mechanics and materials science points of view Newly updated chapter covers both the underlying theory and the current applications of tribology to industry Updated write up on nanotribology and nanotechnology and introduction of a new chapter on green tribology and biomimetics

**Fundamentals of Friction and Wear** Enrico Gnecco, Ernst Meyer, 2007-05-26 In the past twenty years powerful tools such as atomic force microscopy have made it possible to accurately investigate the phenomena of friction and wear down to the nanometer scale Readers of this book will become familiar with the concepts and techniques of nanotribology explained by an international team of scientists and engineers actively involved and with long experience in this field Edited by two pioneers in the field Fundamentals of Frictions and Wear at the Nanoscale is suitable both as first introduction to this fascinating subject and also as a reference for researchers wishing to improve their knowledge of nanotribology and to keep up with the latest results in this field

*Springer Handbook of Nanotechnology* Bharat Bhushan, 2010-04-23 Since 2004 and with the 2nd edition in 2006 the Springer Handbook of Nanotechnology has established itself as the definitive reference in the nanoscience and nanotechnology area It integrates the knowledge from nanofabrication nanodevices nanomechanics Nanotribology materials science and reliability engineering in just one volume Beside the presentation of nanostructures micro nanofabrication and micro nanodevices special emphasis is on scanning probe microscopy nanotribology and nanomechanics molecularly thick films industrial applications and microdevice reliability and on social aspects In its 3rd edition the book grew from 8 to 9 parts now including a part with chapters on biomimetics More information is added to such fields as bionanotechnology nanorobotics and bio MEMS NEMS bio nanotribology and bio nanomechanics The book is organized by an experienced editor with a universal knowledge and written by an international team of over 150 distinguished experts It addresses mechanical and electrical engineers materials scientists physicists and chemists who work either in the nano area or in a field that is or will be influenced by this new key technology

*Engineering Design for Wear, Revised and Expanded* Raymond G. Bayer, 2019-08-21 A modern presentation of approaches to wear design this significantly revised and expanded second edition offers methods suited for meeting specific wear performance requirements numerous design studies highlighting strategies for use with different tribological elements and mechanical systems proven tactics for resolving wear related problems

**Self-Lubricating Composites** Pradeep L. Menezes, Pradeep K. Rohatgi, Emad Omrani, 2022-01-03 In most tribological applications liquid or grease based lubricants are used to facilitate the relative motion of solid bodies to minimize friction and wear between interacting surfaces The challenges for liquid lubricants arise in extreme environmental conditions such as very high or low temperatures vacuum radiation and extreme contact pressure At these conditions solid lubricants may be the alternative choice which can help to decrease friction and wear without incorporating liquid lubricants Challenges with solid lubricants are to maintain a continuous supply of solid lubricants on the contact surfaces to act as lubricous layer between two sliding surfaces Such a

continuous supply is more easily maintained in the case of liquid lubricants when compared to solid lubricants. The most innovative development to ensure a continuous supply of solid lubricant to the contact surface during sliding is to introduce solid lubricant as reinforcement into the matrix of one of the sliding components. Composite materials are engineered or naturally occurring materials which contain two or more distinct constituents with significantly different chemical, physical and mechanical properties. Composites consist of reinforcement and matrix metal, polymer and ceramics. Among various reinforcements, recent emerging material solid lubricant is found to have many favorable attributes such as good lubrication property. Self lubrication is the ability of a material to provide lubrication to the contact surface to decrease friction and wear rate in the absence of an external lubricant by transferring embedded solid lubricants in the composite to the interface. Self lubricating composites (SLCs) are an important category of engineering materials that are increasingly replacing a number of conventional materials in the automotive, aerospace and marine industries due to superior tribological properties. In SLCs, solid lubricant materials including carbonous materials, molybdenum disulfide (MoS<sub>2</sub>) and hexagonal boron nitride (h-BN) are embedded into the matrices as reinforcements to manufacture a novel material with attractive self lubricating properties. Several studies have been investigated the tribological properties of self lubricating materials. This book fills that gap to have a reference book about self lubricating materials and their properties to help scientists, engineers and industries. This book discusses mechanisms of self lubricating materials, self lubricating properties and the applications for industries. The chapters will be written by authoritative expertise in the field. Additionally, this book will demonstrate fundamental study and most advanced innovations in self lubricating materials as regards to friction and wear. The chapters also include tribological properties of composites and coatings and some practical applications of self lubricating materials.

Wear Particles: From the Cradle to the Grave D. Dowson, G. Dalmaz, P.R.N. Childs, C.M. Taylor, M. Godet, 1992-08-04. The Leeds-Lyon symposia have well established themselves in the tribological calendar. Industrial progress requires a better understanding of interfacial phenomena than now exists and it is exciting to see that the topics addressed in these proceedings volumes are at the forefront of progress in tribological research. These proceedings contain 61 papers written by authors from all over the world covering the entire spectrum of wear particles. Of particular interest is the detailed consideration of a wide range of particle formations and detachments as well as a close look at the physics and chemistry of the wear of mechanisms together with other in depth state of the art analytical contributions.

*Tribology of Polymer and Polymer Composites for Industry 4.0* Hemalata Jena, Jitendra Kumar Katiyar, Amar Patnaik, 2021-08-23. This book first introduces polymers and polymer composites which are widely used in different industrial and engineering applications where the proper selection of fiber filler and polymer can be tailored for particular application. The primary objective of this book is to broaden the knowledge of tribology of polymer composites in a new dimension for Industry 4.0. For instance, the book covers polymer composites used as self lubricating material used in the automotive industry and other manufacturing equipment to reduce the effect of energy loss.

due to friction and wear This book is of interest to researchers and industrial practitioners who work in the field of tribology of polymer composites manufacturing equipment and production engineering Friction Science and Technology Peter J. Blau, 2008-10-20 Should have broad appeal in many kinds of industry ranging from automotive to computers basically any organization concerned with products having moving parts David A Rigney Materials Science and Engineering Department Ohio State University Columbus USA In Depth Coverage of Frictional Concepts Friction affects so many aspects of daily l

Surgery of the Hip E-Book Daniel J. Berry, Jay Lieberman, 2012-12-07 Surgery of the Hip is your definitive comprehensive reference for hip surgery offering coverage of state of the art procedures for both adults and children Modelled after Insall Scott Surgery of the Knee it presents detailed guidance on the latest approaches and techniques so you can offer your patients both young and old the best possible outcomes Consult this title on your favorite e reader conduct rapid searches and adjust font sizes for optimal readability Compatible with Kindle nook and other popular devices Master the latest methods such as the use of fixation devices for proximal femoral fractures hip preservation surgery and problems with metal on metal bearing implants Make optimal use of the latest imaging techniques surgical procedures equipment and implants available Navigate your toughest clinical challenges with vital information on total hip arthroplasty pediatric hip surgery trauma and hip tumor surgery Browse the complete contents online view videos of select procedures and download all the images at [www.expertconsult.com](http://www.expertconsult.com) *Delaware Composites Design Encyclopedia: Failure analysis of composite materials*, 1989



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