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Bharat Bhushan

Biophysics of Skin and Its Treatments

Structural, Nanotribological, and Nanomechanical Studies

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To my grandkids Sahana,
Ashwin, and Joya

Preface

Skin is the outer layer covering human or animal body and is a complex biological structure. Its function is to protect the body from physical and environmental assaults and to provide sensation, heat regulation, water resistance, and so on. Environmental conditions, such as dry and cold weather, can reduce the moisture content of skin and increase the skin roughness and physical discomfort. Skin is damaged as it goes through daily activities. Skin also ages with time. For healthy and beautiful human skin, cleaning and maintenance of skin is a daily process. Various beauty care products involve surface interaction between the product and the skin surface they are applied to. Skin cream is used to improve the skin health and create a smooth, soft, and flexible surface with moist perception by altering the surface roughness, adhesion, friction, elasticity, and surface charge of the skin surface. Rheology of skin cream as a function of cream thickness and strain rate and the binding interaction between skin cream and skin surface and operating environment are some of the important factors affecting the smooth feel and repair of the skin surface. The vibrations generated during the rubbing are a function of friction at the interface and govern the tactile perception of skin texture by the brain.

Atomic force microscopy (AFM) and nanoindentation have recently become important tools for studying micro-/nanoscale properties in beauty care, including human hair, hair conditioner, skin, and skin cream. In this book, we present an overview of the structural, nanotribological, and nanomechanical properties of skin with and without cream treatment as a function of operating environment. Relevant mechanisms are discussed. The result of a triboelectrification study of skin with and without cream treatment is presented. Next, an overview of attempts to develop a synthetic skin for research purposes is presented. Finally, data on tactile response of skin with and without cream treatment are presented.

This is the first book on nanotribological and nanomechanical properties of skin and skin treatment. The book is written for a novice in the field. It should serve as a reference book for researchers, practitioners, and users.

The author would like to thank his former students and senior colleagues who contributed to the research reported in the book. These include Prof. Shirong Ge, Dr. Wei Tang, Dr. Si Chen, and Shuyang Ding. The author would also like to thank Renee L. Ripley for many important contributions during the preparation of the manuscript.

Powel, OH, USA Bharat Bhushan

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About the Author

Dr. Bharat Bhushan received an M.S. in mechanical engineering from the Massachusetts Institute of Technology in 1971; an M.S. in mechanics and a Ph.D. in mechanical engineering from the University of Colorado at Boulder in 1973 and 1976, respectively; an MBA from Rensselaer Polytechnic Institute at Troy, NY in 1980; Doctor Technicae from the University of Trondheim at Trondheim, Norway, in 1990; a Doctor of Technical Sciences from the Warsaw University of Technology at Warsaw, Poland, in 1996; and Doctor Honouris Causa from the National Academy of Sciences at Gomel, Belarus, in 2000 and University of Kragujevac, Serbia, in 2011. He is a registered professional engineer. He is presently an Ohio Eminent Scholar and The Howard D. Winbigler Professor in the College of Engineering, and the Director of the Nanoprobe Laboratory for Bio- & Nanotechnology and Biomimetics (NLB^2) and affiliated faculty in John Glenn College of Public Affairs at the Ohio State University, Columbus, Ohio. In 2013–2014, he served as an ASME/AAAS Science and Technology Policy Fellow, House Committee on Science, Space and Technology, United States Congress, Washington, DC. His research interests include fundamental studies with a focus on scanning probe techniques in the interdisciplinary areas of bio-/nanotribology, bio-/nanomechanics, and bio-/nanomaterials characterization and applications to bio-/nanotechnology, and biomimetics. He is an internationally recognized expert of bio-/nanotribology and bio-/nanomechanics using scanning probe microscopy and is one of the most prolific authors. He is considered by some a pioneer of the tribology and mechanics of magnetic storage devices. He has authored 8 scientific books, 90+ handbook chapters, 800+ scientific papers (Goggle Scholar h-index—105+ with 50k+ citations; Web of Science h-index—80+; ISI Highly Cited Researcher in Materials Science since 2007 and in Biology and Biochemistry, 2013; ISI Top 5% Cited Authors for Journals in Chemistry, 2011), and 60+ technical reports. He has also edited 50+ books and holds 20 US and foreign patents. He is a coeditor of Springer NanoScience and Technology Series and coeditor of Microsystem Technologies, and member of Editorial Board of PNAS. He has given more than 400 invited presentations on six continents and more than 200 keynote/plenary addresses at major international conferences.

Dr. Bhushan is an accomplished organizer. He organized the Ist Symposium on Tribology and Mechanics of Magnetic Storage Systems in 1984 and the Ist Int. Symposium on Advances in Information Storage Systems in 1990, both of which are now held annually. He organized two international NATO institutes in Europe. He is the founder of an ASME Information Storage and Processing Systems Division founded in 1993 and served as the founding chair during 1993–1998. His biography has been listed in over two dozen Who's Who books including Who’s Who in the World. He has received more than two dozen awards for his contributions to science and technology from professional societies, industry, and US government agencies including Life Achievement Tribology Award and Institution of Chemical Engineers (UK) Global Award. His research was listed as the top ten science stories of 2015. He is also the recipient of various international fellowships including the Alexander von Humboldt Research Prize for Senior Scientists, Max Planck Foundation Research Award for Outstanding Foreign Scientists, and Fulbright Senior Scholar Award. He is a foreign member of the International Academy of Engineering (Russia), Byelorussian Academy of Engineering and Technology, and the Academy of Triboengineering of Ukraine; an honorary member of the Society of Tribologists of Belarus and STLE; a fellow of ASME, IEEE, and the New York Academy of Sciences; and a member of ASEE, Sigma Xi, and Tau Beta Pi.

Dr. Bhushan has previously worked for Mechanical Technology Inc., Latham, NY; SKF Industries Inc., King of Prussia, PA; IBM, Tucson, AZ; and IBM Almaden Research Center, San Jose, CA. He has held visiting professorship at University of California at Berkeley; University of Cambridge, UK; Technical University Vienna, Austria; University of Paris, Orsay; ETH Zurich, EPFL Lausanne; University of Southampton, UK; University of Kragujevac, Serbia; Tsinghua University, China; Harbin Institute, China; and KFUPM, Saudi Arabia. https://nlbb.engineering.osu.edu/

Chapter 1
Introduction

Skin is the outer layer covering a human or animal body. It is the largest organ and for humans covers an average surface area of 1.5–2 m^2. Its function is to protect the body from physical and environmental assaults, and to provide sensation, heat regulation, water resistance, and other such functions. Skin ages over time, resulting in changes in skin properties. The skin aging process is the result of two biological processes called intrinsic aging, where changes accumulate over a lifetime, and extrinsic aging, attributed to environmental influences. Aging is a degeneration of tissue (such as degradation of mechanical properties as a result of decreases in collagen) and loss of lipids (responsible for creating a water barrier), and leads to various issues such as sagging skin and wrinkles. In addition to aging, skin also is damaged as it goes through various daily activities. Environmental conditions, such as dry and cold weather, can reduce the moisture content of skin temporarily, and can induce epidermal hyperplasia, mast cell degranulation, cytokine secretion, increased skin roughness, and physical discomfort (Harding et al. 2000; Leyden and Rawlings 2002; Tang and Bhushan 2010; Bhushan 2012; Bhushan et al. 2012).

For healthy and beautiful human skin, cleaning and maintenance of skin is a daily process. The demand for skin care products that prevent or relieve skin damage has created a $2 billion dollar industry in the U.S. alone, as of 2015. As commonly-used skin care products, skin cream and moisturizer increase the moisture content in the outer layer of skin. This hydration creates a smooth, soft, moist, and flexible surface, and alters the tribological properties (surface roughness, adhesion, friction, and wear) and mechanical properties (elastic modulus, hardness, and viscous damping) of the skin surface. Hydration changes the surface feel or tactile perception of cream treated skin when it touches a surface. Beauty care science is interested in the way in which skin cream changes the tribological and mechanical properties, tactile perception, and the effect of the operating environment of skin, as these properties are closely tied to product performance and, ultimately, guide consumers' likes or dislikes of the product (Bhushan et al. 2010,

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