What is Tribology, Anyway?

Fred A. Nichols, Guest Editor

Several years ago, when my boss came to my office and said that he wanted me to manage the tribology program at Argonne National Laboratory, I was mystified. My first response was, "What is tribology?" In the years since, the cards have been somewhat reversed. The initial response of person after person when I mention my position as Tribology Section Manager of the Materials and Components Technology Division is to look blank and pose the same question to me. Having somewhat of a playful nature, I often simply try to drop the term very nonchalantly and continue speaking, taking great delight in the puzzled looks my approach engenders. When somone eventually injects the inevitable inquiry, I give a rather stilted answer, such as:

> "Tribology is the science and art of interacting surfaces in relative motion with respect to one another."

Since this succeeds in erasing only a portion of their curiosity, I eventually have pity on them and say, "It's really the rather mundane areas of friction, lubrication, and wear." I have often pondered and discussed with colleagues whether we did ourselves any favor by coining the word in the first place, but it does serve a useful purpose in at least attempting to obtain a degree of helpful communication between people engaged in the various aspects of this broad area of endeavor.

I suppose that I have continued the common practice of compartmentalizing the field in my selection of papers for this series in the *MRS Bulletin*, for I have chosen to emphasize the "messier" materials aspects in preference to the more classical fluid dynamics and hydrodynamic lubrication. My rationale for this is that we are, after all, writing to a materials audience where there is not a widespread appreciation of the field of tribology. Additionally, I want to emphasize the great practical aspects of the field in many industrial applications, so I have selected authors who are engaged in applied research as well as those in more academic activities.

The first article, by Steve Granick, addresses some of the exciting activities in the area of "molecular" tribology, i.e., studies, both theoretical and experimental, which address the interactions of surfaces from an atomic or molecular viewpoint and use terminology such as interatomic forces and distances, but include not only atomically smooth and "clean" surfaces but also deal with the presence of liquid lubricant between the surfaces at thicknesses so small that significant deviations from macroscopic viscosity concepts are clearly evident. The point is made that this is of real practical importance because the interaction of loaded engineering surfaces occurs through the close proximity of "high spots" or asperities in the respective surfaces, and the locally high pressures give rise to very close approach of the surfaces. On the other hand, the strong increase in viscosity and even glass transitions or "crystallizations" can often maintain small but finite separations of the surfaces.

With the scene set for appreciating the atomic nature of surface interactions, the second paper by D. Landheer and A.T.W. de Gee builds on interatomic interactions to illustrate the more macroscopic aspects of adhesion of surfaces, asperity contacts, interfacial slip, and plastic deformation, introducing the picturesque language of plowing (or, if you learned English rather than "Americaneze," ploughing) and "stick-slip" motion between two sliding surfaces. Illustrative of the complexity of even such elementary interactions is the fact that the relative importance of adhesion and plowing in determining the macroscopically observed friction coefficient remains a topic of dispute in current literature. This article should greatly aid in clarifying, if not settling, that debate.

The third article, by H.S. Kong and M.F. Ashby, explores the even "messier" aspects of localized sliding interactions, i.e., the dissipation of the heat generated from the work of overcoming frictional forces. In the spirit of the now-classic treatments by Ashby and co-workers of deformation maps, sintering maps, and fracture maps, these authors develop friction-heating maps to predict the temperatures generated at the interfaces between sliding bodies of differing mechanical and physical properties. Since actual contacts occur typically over regions small in comparison with the nominal contact areas, correspondingly much higher or "hot-spot" temperatures are obtained in those local regions and a milder but still often considerable general or average "bulk" temperature between the hot spots. The authors have developed a general-purpose computer model that can simulate many different geometries, pressures, and sliding velocities. As a particularly fascinating application of the model, they discuss the well-known fabrication technique of friction-welding, show good concurrence between model and experiment for several systems, and also illustrate why people have found empirically that PTFE (polytetrafluoroethylene) is almost impossible to friction weld. Another application of temperature maps, only hinted at here, is in exploring various domains of mechanisms for friction and wear of sliding couples, thus producing still another "map," namely wear-mechanism maps, now being investigated.

The article by A. Erdemir et al. illustrates the realm of basic friction and wear mechanistic studies, introducing experimental results from the pin-on-disk wear apparatus frequently employed by tribologists and illustrated in the preceding article. These authors apply the friction-heating maps to interpret some interesting aspects of the effect of sliding velocity on both friction and wear and show the extent of localized temperatures, which can exceed the melting point of one or both members of sliding pairs at velocities and pressures of practical interest. Then, in an illustrative application of the mechanistic understanding garnered from this analysis, they proceed to show experimentally, and interpret theoretically, the strong effects of applying a thermally conducting coating to an insulating ceramic. This approach has shown great promise for overcoming the significant drawback to applying ceramic materials at high loads and velocities, namely that their (usually) low thermal conductivity leads to localized melting and strong thermal gradients which generate cracking and lead to high rates of wear. The application of a silver coating, made especially adherent through the process of ion-beam-assisted deposition, is shown to greatly diminish both friction (through easy shear-deformation of the silver) and wear (through reduction of hot-spot temperatures and hence thermal gradients due to greatly enhanced lateral heat transfer).

The final article, by S. Hsu, emphasizes the beneficial effects of a "good" lubricant, which provides relatively low friction and wear even when speeds are too low or loads too high to prevent contact between sliding elements. His interpretation of this phenomenon of "boundary lubrication" entails the chemical reaction between lubricant components and the surfaces involved to form thin films that are relatively easily sheared to give rather low friction and that prevent physical contact, thus lowering wear rates to acceptably low rates. Hsu explains why previously developed lubricants with various additives that performed such functions well for metallic (primarily ferritic) surfaces may not prove at all serviceable for the more modern structural materials such as titanium alloys or the various ceramics being touted for high-temperature applications in such new concepts as the low-heat-rejection engine, which offers the promise of greatly enhanced fuel efficiency for tomorrow's trucks and automobiles. He also discusses the state-of-the-art developments of new lubricants and additive packages scientifically "designed" for these new applications, in contrast to the trial-and-error techniques that have produced basically all of our currently available lubricants.

I hope that the representative collection of papers published here will serve to inform many materials people concerning the basic and applied nature of the strange admixture of classical disciplines collectively known as tribology. It is my further hope that this communication will foster those kinds of interdisciplinary interactions that I think will be so essential to solving the many basic and practical problems remaining in this field which is so intimately linked to the national interests of increased efficiency and reduction of our dependence on imported petroleum.

Acknowledgments

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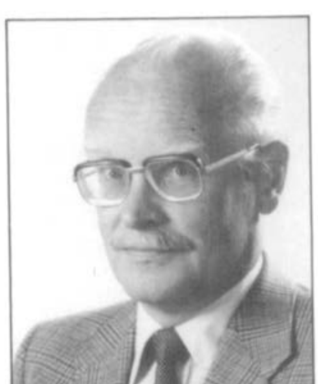

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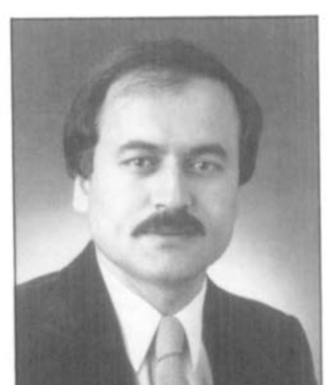

Ali Erdemir

Fred A. Nichols, Guest Editor of this issue of the *MRS Bulletin,* is a senior scientist, Tribology Section manager, and project manager of the U.S. Department of Energy's tribology program at Argonne National Laboratory. He received BS and MS degrees in metallurgical engineering from Carnegie Institute of Technology, and an MBA from the University of Chicago. Nichols is the author of some 70 papers in many areas of materials science, and several in tribology.

Michael F. Ashby is Royal Society Research Professor in the Department of Engineering, Cambridge University, where he received his PhD in 1961. He also studied at the Institute for Metal Physics, University of Göttingen, and was professor of applied physics at Harvard University, with which he is still associated as Honorary Research Fellow. Ashby is a Fellow of the Royal Society and the Royal Swedish Academy of Engineering Sciences, and a member of the Göttingen Academy of Sciences, Materials Research Society of India, and the U.S. National Academy of Engineering. He has authored or co-authored five books, edited five others, and has 150 other publications to his credit. Ashby is also editor of *Acta Metallurgica.*

Antonie Willem Jan de Gee is a professor of mechanical engineering (tribology) at the University of Technology, Delft, the Netherlands, and also at the University of Twente, Enschede. He studied physical chemistry at the University of Technology, Delft and is author or co-author of 150 publications in the field of tribology.

Ali Erdemir is a scientist in the Tribology Section of the Materials and Components Technology Division at Argonne National Laboratory. He received MS and PhD degrees in materials engineering from the Georgia Institute of Technology, and joined Argonne in 1987 as a principal investigator in the Tribology Section. Erdemir's current research interests include solid lubrication and ion-beam modification of materials for corrosion and tribological applications.

George R. Fenske is leader for the Engineered Tribological Interfaces task of the DOE-OTM Tribology Program at Argonne National Laboratory. He joined Argonne National Laboratory in 1979, performing research on the transient behavior of fast-reactor fuel. He helped establish the Tribology Section in the Materials and Components Division at Argonne and was responsible for the development of

George R. Fenske

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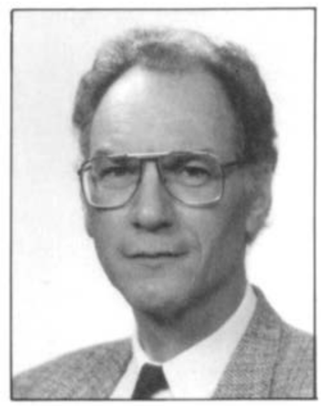

Dick Landheer

facilities to investigate the tribological performance of surface-modified components. Fenske's research focuses on the use of physical vapor techniques to deposit hard and lubricious coating on metallic and ceramic substrates, and on the use of sputter-deposition processes to fabricate optical coatings for x-ray applications. Fenske holds a PhD in nuclear engineering at the University of Illinois at Champaign/ Urbana.

Steve Granick is associate professor in the Department of Materials Science and Engineering and member of the Materials Research Laboratory at the University of Illinois, Champaign/Urbana. He received a BA from Princeton University in 1978 and a Phd in physical chemistry from the University of Wisconsin in 1982, working with J.D. Ferry. Afterward, Granick worked with P-G. de Gennes at the Collge de France and with M.V. Tirrell at the University of Minnesota, joining the University of Illinois in 1985. His research interests emphasize tribology, liquids under confinement, and polymers at surfaces.

Jang-Hsing Hsieh, postdoctoral associate in the Materials and Components Division at Argonne National Laboratory, received a PhD in materials engineering from Georgia Institute of Technology in 1990. His research interests include thin film processing, thin film characterization, and surface engineering.

Stephen M. Hsu is on the staff at the National Institute of Standards and Technology, where he established a tribology group and pioneered novel techniques to study surface interactions. His research interests include surface chemistry, chemical reaction kinetics, wear mechanisms, wear maps, and contact mechanics, and he is actively involved with advanced liquid lubricants for heat engines, ceramic valve wear mechanisms and control, antioxidant mechanisms, and wear resistant ceramics development. Hsu, who holds a PhD from Pennsylvania State University, has published over 80 technical papers and lectured widely on tribology. He was elected chair of the Gordon Research Conference on Tribology in 1988, and has been a director of the Society of Tribologists and Lubrication Engineers since 1987.

Hosung Kong is completing his PhD thesis, "Wear and Friction of Sliding Ceramic Surfaces," at Cambridge University. He received a BS in mechanical engineering at Yonsei University, Seoul, and has been awarded the Hae-Sung Scholarship, the Barclays Cambridge Scholarship, and Overseas Research Studentship. Kong has published six technical papers, co-authored a book, and is co-holder of the patent, "Superfine Oil Filter for Automotives," (Korea, 1989).

Dick Landheer studied mechanical engineering at Delft University, the Netherlands, receiving his MS in 1963. Since then, he has worked in the Mechanical Engineering Department at Eindhoven University, and is involved in research on wear during sliding, and education in tribology and physical metallurgy and materials science engineering. He is currently active in various tribological problems in power transmissions. □