Guide to Friction, Wear, and Erosion Testing

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NOTE: This manual does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this manual to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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Foreword

This book is the product of a career devoted to selecting materials for a multitude of sliding/rolling/eroded mechanical components. Some components were commercial products that had to compete in the world market, and others were parts in production machinery that had to produce those marketed products. The author's responsibility was to achieve useful levels of friction and component life, all at competitive prices.

Kenneth Budinski began with degrees in Metallurgy, with virtually no knowledge of the problem of sliding/rolling surfaces. He progressed through his career with no research funding, no graduate students, and no authorization to conduct academic style research. Nonetheless, he attained a uniquely broad experience in measuring friction and wear of a very wide range of metals, ceramics, and polymers, and with very many surface processes and coatings. Budinski has been a member of Committee G02 of the ASTM (on Wear and Erosion) since 1970, sometime chair of the Committee and of its various subcommittees, and recipient of the highest G02 awards. Hardly a meeting has gone by without Budinski's presentation of yet another careful study of a wear test, together with his rigorous analysis of data from his tests. It is this combination of practical experience and scholarly discussion that has prepared Budinski to write this book. It is part definitions of terms, part identification of tribological (friction, wear, lubrication) mechanisms, part description of standard test machines, and part discussion of the philosophy of testing and material evaluation. This book is one of many of Budinski's writings, including several books, chapters in handbooks, journal papers, and other presentations.

As for test devices, there are hundreds. An account is given in this book on why most of the tests were developed and what fundamental mechanisms of wear or friction are likely functioning in each test. Indeed, in the usual case, several mechanisms may function simultaneously, changing over time of sliding, or changing during start-stop cycles of test, and changing as the use of the intended product changes. Budinski missed none of these points.

This book is a very early progress report on the art of designing a given life into mechanical components. There is not, as too many designers suppose, a direct pathway to selecting that "right" material for every product. Selecting a material to hold a tensile load is simple in that tensile properties of most materials are published and mature equations are in hand to work out the safe dimensions of such parts. Wear properties are not that simple.

There are several mechanisms whereby little bits of material are made to depart from or be rearranged upon a tribological surface. Tribological wisdom begins by identifying the major applicable mechanism and the likely one or two attending mechanisms. Even then, there are no reliable lists of materials showing resistance to specific mechanisms. Neither are there any wear tests that can be linked directly to real products. Budinski sorts out all of these issues in his several chapters. Other authors would likely divide up the overall array differently but probably not better.

The final word is that good tribological design requires a broad knowledge of tribological mechanisms, a feel for what materials may fit the case, a careful resort to wear/friction/erosion testing to narrow the range of choices, and then an assessment of the chosen material in products or production machinery. Getting it right in products puts your very company at stake: getting it right in production machinery only involves more maintenance. Budinski offers several case studies to illustrate these points.

Budinski steps into another world, though, when discussing wear/friction/erosion models. He offers a very few equations without much conviction of their utility. He mentions that if models or equations were further developed there would be no need for tests of the type he describes in this book—a very distant hope. But the many available tests may instruct us on the necessary complexity of useful wear models. Based on the number of mechanisms inherent in the many developed tests, I suggest that useful wear equations may need 30 or more variables. What hope is there, then, in equations for wear that contain 2 or 3 condition variables and only one material variable? Clearly, Budinski's book will not be replaced by useful equations for many decades.

Ken Ludema
Professor Emeritus
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July 1, 2007

Preface

Friction, wear, and erosion are terms that most people use in their daily lives. Most people accept the cost of sport shoes wearing out after 4 months of use; people accept wear of roadways and flooring; people accept 30,000 miles as the limiting use of an automobile before fan belts, brakes, and other components start to wear out.

On a larger scale, most industrialized countries accept about 7% of their gross domestic product as their annual cost of wear, erosion, and unwanted friction. As one example of this annual cost: 450 million auto tires were manufactured in 2006 [1]. Probably 100 million of these tires were required for new vehicles. The remaining 350 million were most likely used to replace worn tires. Assuming that one tire cost $100, this amounts to a cost of wear of 35 billion dollars. This is just one commodity. Another staggering cost is the energy (gasoline) consumed in overcoming friction losses in an automobile. Some estimates for these losses are that as much as 30% of a vehicle's engine horsepower is used in overcoming friction in the sliding components between the gasoline explosion in the cylinders and the traction force transmitted to the roadway.

The point is that friction, wear, and erosion (tribology) concerns cost each and every person, as well as the environment, dearly. However, the world does not have to regard these costs and environmental consequences as inevitable costs of technology. They can be addressed and almost always reduced by appropriate engineering action. People older than 50 years of age will probably remember when the average life of an automobile tire was only about 15,000 miles. Today tire life is typically about 40,000 miles. What happened?

Engineers and scientists worked on this tribology problem. Tires were redesigned to be stiffer, which reduced roadway slip and thus wear. Tire materials were also improved. Undoubtedly, many of these tire improvements came to happen through screening tests conducted in laboratories, bench tests, as they are called. Tire engineers certainly could never make full size tires and run them to death to assess every change that may work. Concepts were screened by bench tests and that is what this guide is about.

This guide reviews current friction, wear, erosion, and lubrication fundamentals and describes the bench tests that are most often used to study and solve tribology problems. Tests are compared and critiqued. Information is presented to help the reader select a test that he or she might use to address a tribology concern that they are responsible for solving. The overall objective of the guide is to lower the annual cost of wear, erosion, and unwanted friction through appropriate tribotesting.

The scope includes tests that are used to study engineering materials (metals, plastics, ceramics, composites, lubricants, coatings, treatments), tests used to solve tribology problems and limited product tribotesting (abrasivity of magnetic media, printer ribbons, web friction etc.). Tire tests are not included—sorry! The tests described in this guide are predominately standard tests developed by consensus through ASTM International. Many countries have standard tests in these same areas, but the tests described in this guide are probably included in country-specific test standards. For example, every country that has tribotesting standards probably has a standard on a pin-on-disk test, a reciprocating pin-on-flat test, a sled friction test, etc. These are the same tests described in this guide. This guide is applicable worldwide.

The intended readership of this guide comprises mostly people who do not normally work in the field: students, designers, maintenance personnel, researchers, and academicians. It will help these people research a particular form of wear or friction, what tests are available, the cautions with each test, and information on how the different tests compare in severity. Also, it discusses how well they simulate real life applications. Veteran tribologists will find this guide a useful reference for ASTM test numbers and test details.

In summary, this guide is about tests (mostly standards) available to address friction, wear, erosion, and lubrication problems. It will serve as a mentor for newcomers to tribology and a useful reference for practicing tribologists. There are 13 chapters. The first presents needed terms and definitions. It is followed by a chapter on the alternates to bench testing: expert systems, modeling, and simulations; then follows a chapter on testing methodology. There are several chapters on specific forms of wear: abrasion testing, adhesive wear testing, plastic/elastomer testing, lubricated wear testing, fretting testing, rolling wear testing, and erosion testing. The guide ends with chapters on friction testing; micro-, nano-, and biotribotests; and correlation of these tests with service.

This book is essentially a project of the ASTM Committee G02 on Wear and Erosion. They are acknowledged for their sponsorship and participation in the review process. This guide is the product of more than 40 years of tribotesting in industry on the part of the author and probably another hundred years of experience in government, industry and academia on the part of the six tribology professionals who reviewed this guide for correctness and completeness. I sincerely thank them for their contributions.

K. G. Budinski

Reference

[1] J. A. Melsom, "50 Years of Keeping the Rubber Industry in the Black," *ASTM Standardization News*, December 2006, p. 41.

KEN BUDINSKI is the technical director of Bud Labs, a ten-year old company that designs and builds friction and wear testers and conducts tribological (friction, wear, erosion, and lubrication) studies for clients. He is Chairman of the ASTM Subcommittee G02.50 on Friction and he previously served as Chair of the G02 Committee on Wear and Erosion. He is a member of the ASTM Committee B08 on Metallic and Inorganic Coatings and a member of the steering committee for the Biannual International Wear of Materials Conference. His duties at Bud labs include test and machine design, and analysis/interpretation of client test results.

Mr. Budinski has a BS in Mechanical Engineering from General Motors Institute (1961) and an MS in Metallurgical Engineering from Michigan Technological University (1963). He worked at Rochester Products Division of GM from 1957 to 1962, starting as a cooperative engineering student and ending as a manufacturing development engineer specializing in die casting. Upon completing graduate studies at Michigan Tech he joined the Materials Engineering Laboratory of the Kodak Park Division of Eastman Kodak Company as a metallurgist. Wear problems at this plant started his interest in wear testing and wear research. This plant made photographic films and the sensitive nature of the products meant that production machines had to run at high speed with no lubricants that could contaminate the film. The films sliding on themselves and other surfaces also required many tribological advances to control friction and prevent scratching. The net result of Kodak's unusual wear and friction requirements led Mr. Budinski to learn as much as possible about tribology and he established one of the most comprehensive tribology labs in the US. His tribology studies were key to many products and to many manufacturing operations. He retired from Kodak in 2002 as Technical Associate and immediately joined Bud Labs as Technical Director.

He became a member of ASTM (G02) in 1972 and participated in most of the interlaboratory studies for developing the G02 Wear and Friction test methods. He has lectured on wear and friction in countless courses. He taught Engineering Materials at Rochester Institute of Technology and Monroe Community College. He participated in a National Science Foundation technology transfer mission to China in 1983 and another to Belarus and Poland in 1996. He shared his materials engineering experience by authoring and coauthoring eight editions of a textbook titled *Engineering Materials: Properties and Selection* (Prentice Hall). He authored the very first book on Surface Engineering (*Surface Engineering for Wear Resistance,* Prentice Hall); he also authored teaching texts on technical writing (*Engineer's Guide to Technical Writing,* ASM) and technical presentations (*Guide to Preparing and Delivering Technical Presentations,* ASTM International). He has presented more than 100 papers at technical conferences and has authored more than 50 papers in refereed journals.

Mr. Budinski is a Fellow in ASTM International, ASM International, and the Rochester Engineering Society. He has won many awards for his technical achievements including "Rochester Engineer of the Year" (2000). His most significant contribution to engineering and science has been sharing his research and learning in tribology and engineering materials. This book is a continuation of this sharing.

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