SECTION 1

FUNDAMENTALS

COPYRIGHTED MATERIAL

CHAPTER 1

INTRODUCTION

It is imperative to define and introduce various fundamental concepts of tribology in this very first section. After a brief introduction, this chapter provides some general discussion on tribology with a particular emphasis on interdisciplinary aspects. This chapter is followed by a discussion in Chapter 2 on the typical nature and properties of metals, ceramics, and polymers that are used widely for various tribological applications. The material-intrinsic surface properties, such as hardness, strength, ductility, and work hardening, are very important factors for wear resistance. Since this book largely discusses the case studies of ceramics and composites, the mechanical properties of ceramics are reviewed in Chapter 3. However, other factors, such as load, relative speed, lubrication, temperature, and environment (ambient, inert atmosphere, relative humidity), are equally important. Importantly, the chemical nature and compatibility of mating materials with environment and lubricants as well as their interplay—which defines tribochemical reactions—will have a significant influence on friction and wear of ceramics and composites. Therefore, it is very important to understand the performance of engineering materials and to correlate them with their properties. Such correlation should be made in terms of microstructural, physical, electrical, mechanical, and (tribo)chemical properties under different tribological conditions. In the above perspective, Chapter 4 describes the physical characteristics of typical engineering surfaces, while Chapters 5 and 6 discuss the fundamentals of friction as well as origin/quantitative analysis of frictional heating, respectively. The phenomenological and mechanistic description of various wear mechanisms with a particular focus on fretting wear is provided in Chapter 7. The last chapter of this section briefly discusses the fundamentals of lubrication.

Tribology is now widely accepted as "the science of interacting surfaces in relative motion and practices related there to."[1] Tribology embraces primarily the study of friction, wear, and lubrication and it is strongly an interdisciplinary field.[2] As such, it is much broader in terms of areas that affect it, as well as its having a large effect on many other areas in engineering and sciences. The word "tribology" is derived from the Greek word *tribos*, which means rubbing.[3] It is interesting to observe from a tribologist's perspective that, although tribology seems to be a fresh field, having enormous potential for fundamental research, the history of this important branch of science has its roots in the early ages of humans.[4] Using the friction

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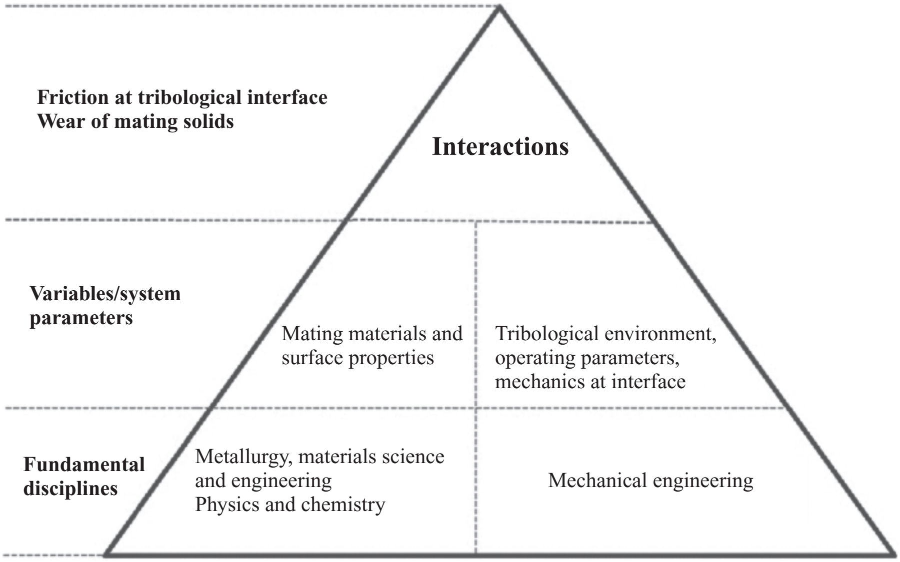

Figure 1.1 Concept triangle illustrating the interaction of basic science and engineering disciplines and multiple parameters, as involved in the science of tribology.

between wood and/or stones in inventing fire is considered as the first utilization of the concept of tribology, and it belongs to Stone Age humans. The other important instances of tribology during early ages seem to be in making drills, bearings, sledges for transporting heavy loads, and so on. In particular, the Egyptian civilization has a record of understanding the significance of friction and wear as well as lubrication during construction of giant pyramids.

As illustrated in Figure 1.1, the science of tribology can be explained based on synergistic interaction among the concepts and ideas drawn from fundamentals of physics and chemistry, as well as metallurgy, materials science, engineering, and mechanical engineering. It may be noted here that conventional metallurgical engineering principles are commonly used to tailor surface properties, for example, case hardening or nitriding of steels to improve wear resistance. On the other hand, various new materials (e.g., ceramics and polymers as well as their composites) have been developed in last few decades using the processing–structure–property correlation, a fundamental concept used in materials engineering. Many of these materials are now considered as potential replacements for traditional metallic materials. In mechanical engineering, multiple research groups actively contributed to the lubrication aspect of tribology. This has major relevance for ball bearings and various lubricated mechanical joints and bearings. A number of textbooks have dealt largely with the lubrication aspect. In this book, a great emphasis has therefore been placed on obtaining understanding based on the materials science aspect. Overall, the response of any tribocouple depends on the surface properties of two mating materials as well as on the tribological interaction with the environment; such interaction also critically depends on the mechanics at the tribological interface. This will result in friction and wear damage of both the mating solids. Therefore, it is important to understand how two mating materials will respond mechanically at a loaded contact experiencing relative motion; equally important is the interaction of the environment and lubrication with the mating couple. These are explained in various chapters throughout this book.

Friction, under nonlubricated conditions, is considered as the resistance to motion that arises from the solid surface interactions at the real area of contact.[5–7] On the other hand, in the presence of lubricants, their viscous flow components and solid–liquid interactions play a major or a key role. Having low friction is important for certain applications such as hinges, rivets, bearings, and human hip joints, but applications such as brakes, clutches, and tires on roads in contrast require much higher or even "high" friction. In any case, the ability to control the optimal friction for a particular application is the goal of every designer; this ability depends on many of the aforementioned parameters and, in great part, on understanding and the performance of materials and their surface properties.

The progressive loss of material due to the tribological interactions at contacting interfaces under relative motion is considered as the definition of the term "wear." Wear may arise from the contact and relative motion of the solid body against a mating solid, but it often also includes a liquid or gaseous counterbody (water jet, air bubble implosions). Thus, the conditions of wear include several forms (sliding, rolling, erosion, impact, cavitation, etc.) in various atmospheric conditions. Wear is detrimental in many engineering applications, leading to failure of the various components and, finally, requiring repair or replacement. If we consider a technical system that drives a great part of modern economies, such as a car or any other vehicle, we find that most expenses for maintenance and replacement are due to tribological issues and wear. For example, wear of tires, brakes, wheel joints, bearings, and windshield wipers, scratches on paint and glass, and replacement of oil and oil filters are major concerns of end users, and consequently of manufacturers as well. On the other hand, sometimes wear is desirable: high wear rates are required for efficient production in some surface finishing processes such as polishing and grinding. However, like friction, not only the amount, but also, primarily, the control and prediction of wear of materials in every application is important for appropriate use and maintenance and is thus the key to success of every tribological application.

It is understood that the extent of friction and wear depends on the system in which the component is utilized.[8] Moreover, friction and wear are not intrinsic material properties, but the tribological features need to be considered as an engineering-system dependent property.[9] Such control over friction and wear can be achieved by proper design, fabrication, and loading of the components. While friction is a direct and momentary response of the tribological components under the contact conditions, wear also includes the loading history of these components. Therefore, understanding and considering materials' nature and responses are critical and very important for tailoring the properties of the materials and achieving the desirable conditions of friction and wear.[10] In this regard, the aim of the material scientist is to control the properties of a specific component by incorporating suitable changes in its composition at the microstructural level during the processing stage, keeping tribological requirements in mind. Such microstructural modification should be correlated with performance at different tribological conditions in order to understand, design, manufacture, and control conventional and novel materials in a specific application, and to use all their capabilities and advantages. This is particularly important for advanced and heavily engineered materials, such as composites, ceramics, and nanomaterials.

In this book, we tend to present the key material properties that are available to a material scientist for designing a material and that have critical influences on the material's tribological behavior. We also discuss the fundamentals of tribology and related key parameters, finally describing and presenting examples of the microstructural control of advanced ceramic and composite materials for optimal tribological performance. We focus on a specific segment of high-tech materials that have a great potential for use in many applications and that, primarily, give much freedom and possibility for future development and innovative solutions. Although the book mainly focuses on the materials perspective, we would like to stress that response and success of every material, no matter how well designed, will finally depend on the tribological system, and this should therefore be considered in the early stages of materials and system development.

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