Chapter 5
Sliding Interaction of Surfaces

ABSTRACT

This chapter reviews the basics of friction interaction of surfaces. The material presents data for friction coefficient for both solid materials and skin. Further, the authors review contact modeling for both solids and soft materials. The emphasis is on the tribological behavior of soft materials across species. These include the behavior and modeling of friction behavior of human skin as well as the adhesion and friction of fibrillar material in biological attachments. It is shown that, in general, the deformation behavior of skin, soft tissue in general, is complex and depends on many factors (gender, ethnicity, mechanical composition, and functional layering of subsurface layers). This complexity reflects in the sophistication of both the mathematical models developed and the proper data to be substituted in these models to accurately predict behavior.

1. INTRODUCTION

Friction takes place between any two contacting surfaces. It can be external or internal. External friction is friction between solid bodies. It is the manifestation of the forces that resist the movement of a solid object upon embarking on motion. Thus, friction may retard or completely halt movement of complying solid bodies. Internal friction, on the other hand, denotes energy losses inside of a body (solid, gas, or a liquid) due to the resistance of motion between the elements making up the material while it undergoes deformation (fluid friction is also used to describe the friction between layers within a fluid that are moving relative to each other).

Conventionally, friction is regarded as an undesirable effect since it is associated with wasted energy. However, in practice, whether friction is to be deemed undesirable or favored depends on the application. For example, in the case of brakes, high friction is desirable to dissipate the kinetic energy of a moving vehicle whence halting its' motion. Meanwhile, friction between pen and paper is not as desirable since high friction causes difficulty in writing.

Although the study of friction is an ancient art, in our modern times, the engineering and technological aspects of it has been coined as a science named "Tribology. The concept of this science may be defined as: "the science and technology of interacting surfaces, in relative motion, and associated practices" *(Fitch, 2006)*. The word tribology was coined by Peter Jost in a British Government Report in March of 1966 *(Jost, 1966)*. The word originated from the Greek word "tribos" which means rubbing. Although of recent origin, the majority of the topics covered by this discipline are ancient and well known *(Dowson,*

DOI: 10.4018/978-1-6684-5638-5.ch005

1998). To that effect it is often said that "tribology was a name selected for a several-thousand-year-old baby", and they include the study of lubricants, lubrication, friction, wear and bearings.

Tribology evolved into three major branches: mechano-tribology, thermo-tribology, and thermo-mechano tribology *(Blok, 1987)*. The first branch, mechano-tribology mainly investigates the mechanical aspects of rubbing and lubrication. This includes the mechanics of contact between solids, stress and strain development in sliding, mechanics of lubrication etc. The second branch thermo-tribology is concerned with the thermal aspects of rubbing solids. Thus, within this branch topics such as: temperature rise in dry or lubricated sliding, heat transfer between rubbing surfaces, and the effect of thermal energy on friction response are of major concern. The coupling between thermal and mechanical influences in rubbing, meanwhile, is a focus of thermo-mechano-tribology. Here topics such as: thermo-elastic stability of contacts and cases where a coupling between the thermal and the mechanical states of the rubbing solids (e.g., in machining and metal forming) affects the frictional response of materials, are a focus.

Mechano-tribology which is the origin of tribology as a science has its roots in the seminal works of Hertz *(Hertz, (1882-a,b)* and of Osborne Reynolds *(Holm, 1908)*. The first founded the theory of the concentrated and isothermal contact on counter formal surfaces. The second, meanwhile, established the classical theory of isothermal hydrodynamic lubrication of conformal rubbing surfaces. The theoretical aspects of investigating the mechanical aspects of tribology were further consolidated in the early twenties of the twentieth century. That is when Ragner Holm published his findings about the disperse nature of the contact between conformal surfaces *(Holm; 1946,Bowden, & Tabor, 2001)*. The findings of Holm were, later on, considerably extended by *Bowden* and his team in Cambridge *(Bowden, & Tabor, 2001)*. Although the analysis of thermal phenomena associated with frictional events is of recent origin, thermo-tribology is, by far, the oldest of the branches of tribology. It dates back to the moment in history when primitive man learned to "make fire" through rubbing two sticks.

The technological leap witnessed starting the last few decades of the twentieth century resulted in advanced imaging devices that facilitated probing of surfaces and monitoring their interaction within unprecedented resolution. Application of modern technology gave rise to elaborate contact models backed by accurate experimental data and in-depth probing of the physical mechanisms involved. However, the universality of the laws and their ability to predict friction behavior in all possible scenarios is being scrutinized. Contemporary opinions affirm that the classical laws of friction apply to cases where roughness features are deemed "normal" (i.e, no hierarchical features are encountered). Once hierarchy is encountered, then the topographical arrangement of the roughness features plays a major role in determining the evolution of contact between surfaces and development of the friction force within the contact. Thus, in contrast to regimes considered by Amonotons, the true pressure within the area of contact becomes a vital parameter especially if the true area of contact is to be controlled (e.g., in case of ultra-precise modern surfaces).

2. SLIDING OF COMPLYING SOLIDS

Friction takes place between any two contacting surfaces in relative motion. It manifests as a force that resists contacting solids upon embarking on motion. Thus, friction may retard or completely halt movement of complying solid bodies. Friction forces act at the interface between any complying solids in sliding relative to each other, figure 1. A "friction" force is different from a conventional applied force. Newtonian mechanics defines a force as an independent influence that acts on a body from the

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