Chapter 1

Introduction and motivation

1.1 Introduction

Friction is one of the oldest phenomena in the history of mankind and in particular of natural science. Already, in the stone ages, frictional heat was used to create fire. Experiences with the difficult frictional properties of ice and snow, led to technological inventions, such as skis or sleds. From old Egypt, the first tribologist is known, who poured water in front of a collosus, who was pulled by hundreds of Egyptians. Today, we know that wood on wet sand (friction coefficient $\mu \approx 0.2$) gives lower friction compared to wood on dry sand (friction coefficient $\mu \approx 0.22$-0.5), which made it possible that the collosus could be moved by only 172 persons. Therefore, this early tribologist did a very good job and facilitated the life of his colleagues. We also can learn that the central questions of friction arise in public and goods transportation. In the middle ages, the use of pork fats was quite common for the lubrication of axes of wagons or chariots. Leonardo da Vinci introduced the first modern concepts of friction. He found the dependence of friction on load and the independence of geometrical contact area. Later, Amontons rediscovered and extended da Vincis observations. Thus, they are called da Vinci-Amontons laws. The third friction law is named after Coulomb who found that dry friction is independent of velocity. Already, Coulomb investigated the origins of friction. He suggested that roughness on the micrometer scale is responsible for the occurrence of friction. However, there was experimental evidence against this hypothesis of Coulomb: Highly polished surfaces did not exhibit low, but high friction. An alternative explanation was given by Desaguliers who suggested that molecular adhesion might be the relevant phenomenon. However, molecular adhesion was known to be proportional to contact area, whereas friction was found to be independent of contact area.

It took about 200 years until this controversy was solved. Around 1950, Bowden and Tabor performed systematic, tribological experiments which showed that the contact of a macroscopic body is formed by a number of small asperities. Thus, another contact area, the real area of contact had to

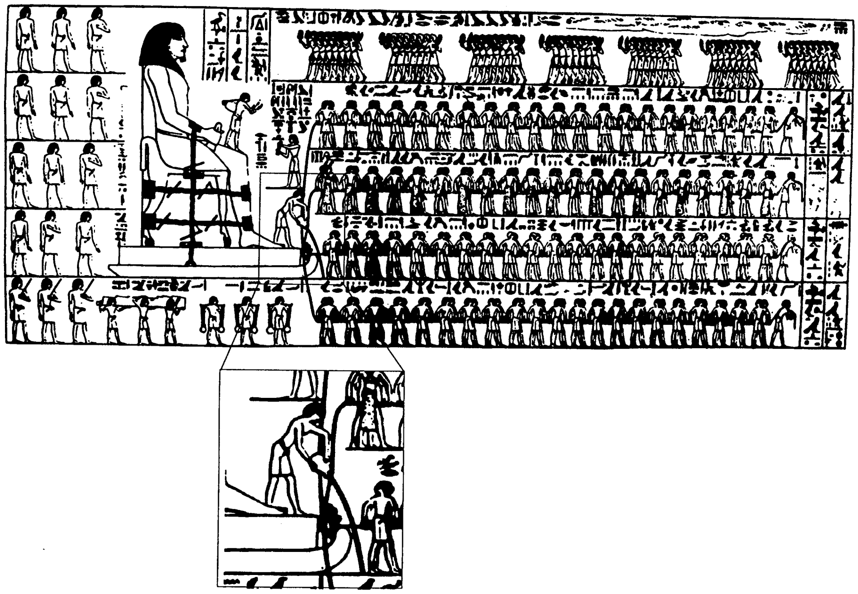

Figure 1.1: 172 Egyptians pull a collosus. One man pours a liquid on the ground in order to reduce friction. (From[1])

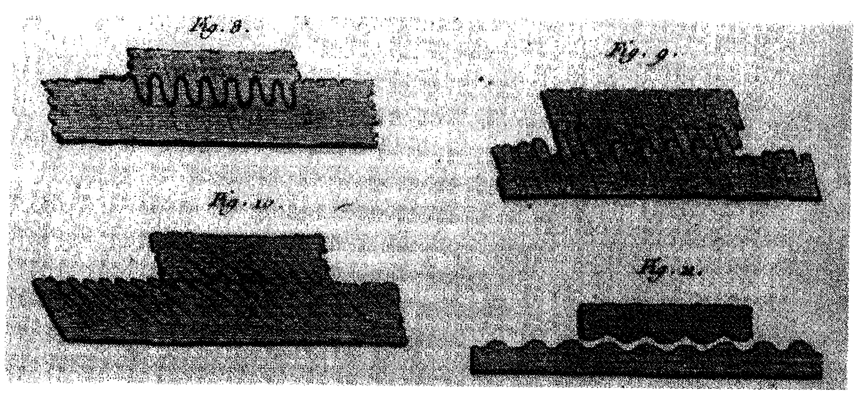

Figure 1.2: Roughness model: Coulomb suggested that roughness is determining friction. (From[1])

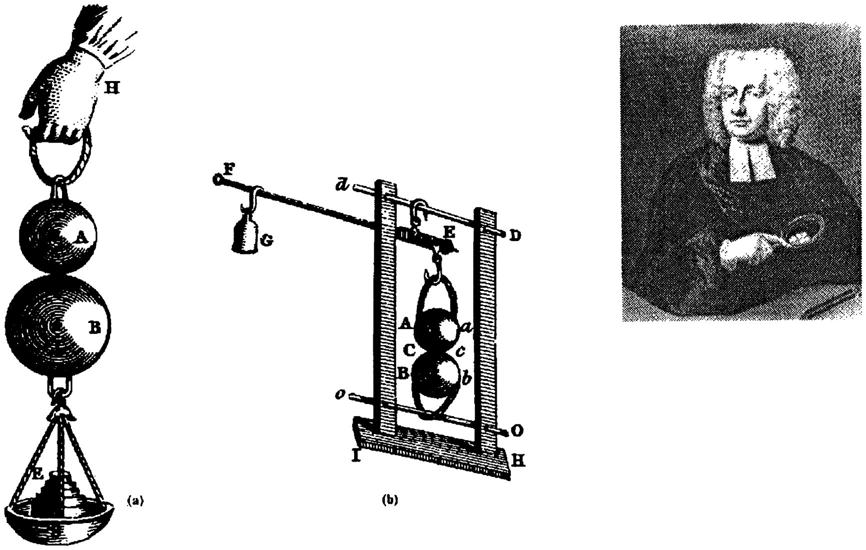

Figure 1.3: In 1725, J.T. Desaguliers demonstrated the cohesion of lead. He also suggested that adhesion might be relevant for friction. (From[1])

be introduced. This new concept was extremely successful and is the basics of most present tribological studies. Essentially, the Bowden-Tabor model states that friction is proportional to the real area of contact

$$F_R = \tau \cdot A_R \tag{1.1}$$

The proportionality constant τ is called shear strength and is related to some intrinsic, more fundamental properties of the interface. From this point of view, Desaguliers was right to assume that adhesion, which is also proportional to the contact area, is more related to friction than roughness. Therefore, the model is also called Bowden-Tabor adhesion model. In first approximation, the real area of contact does not depend on the apparent contact area. By increasing the load, the number of contacting asperities increases with load. The Bowden-Tabor adhesion model explains the da Vinci-Amontons laws of the macroscopic world. However, a basic understanding is still lacking. On which properties does the shear strength τ depend? What are the microscopic mechanisms of friction? How is energy dissipated? How do lubricants affect the shear properties? Can we calculate friction from molecular interaction potentials in a quantitative way? During the last 10 years, the field of tribology on the atomic scale became of interest to a bigger scientific community. Instruments, such as the surface force apparatus, quartz microbalance and the friction force microscope were built for this specific question. Some new phenomena, such as stick-slip on the atomic scale or stick-slip in relation to phase transitions were discovered. Quantitative measurements under well-defined conditions were achieved and compared to theoretical models. Actually, it turned out that the computer simulations, especially the molecular dynamics calculations, were extremely useful for an understanding and visualization of the complex processes. The aim of this book is to provide an overview of tribology. Chapter I gives a brief overview of the history of tribology. Chapter II is an overview of instruments in tribology, where tribometers, surface force apparatus, quartz crystal microbalance and friction force microscopy experiments are described. Then, chapter III and IV will give an overview about the normal and lateral forces which are relevant for tribology. Chapter V will discuss the energy dissipation mechanisms. Chapter VI will give an overview of Nano-Rheology. Chapter VII gives some insights into the close relationship of friction and ultrasonics. The appendix gives some more details on the calibration procedure of friction force microscopy.

1.2 Short outline of the history of tribology

Friction is an every-day experience and almost everybody is aware of its existence. Thus, it is natural that, since a couple of centuries, many researchers tried to get a fundamental understanding. Already, the great pioneers of tribology found, that friction plays a special role in the field of physics and they found phenomenological friction laws, which seemed to be against intuition, e.g., the independence of friction of the contact area. Today, we still learn these three macroscopic laws of friction in school, which were established by Leonardo da Vinci, Guillaume Amontons and Charles Augustin Coulomb:

1. **Independence of the area of contact**
   Friction is independent of the apparent area of contact.

2. **Amonton's Law**
   Friction is proportional to the applied load. The ratio $\mu = F_L/F_N$ is called coefficient of friction. It is larger for static friction than for kinetic friction.

3. **Coulomb's Law**
   Kinetic friction is independent of the velocity.

These three fundamental laws of friction, which are based upon macroscopic experiments, are still not fully understood in terms of more fundamental microscopic processes. In the following, a brief historical review will give a short insight into the work of tribological pioneers. For detailed informations see in the references[1].