9  A Review on Friction

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9.1  Introduction

Tribology is in general the study of adhesion, friction, lubrication and wear of surfaces in relative motion. It seems that the more we learn about tribology the more complex it appears (Urbakh et al. 2004). Recent advances in friction reveal that it plays a major role in diverse systems and phenomena which although at first glance seemed to be unrelated are found to exhibit common features that are shared by all tribological processes in the fields of physics, chemistry, biology, geology and engineering.

In the explanation of the classical laws of friction, e.g., the static friction, force is proportional to the load, and even since the early attempts (Coulomb 1785) the role played by interactions between asperities at the surfaces of solids was emphasized. Furthermore, the idea was put forward (Bowden and Tabor 1950, 1964) that the real contact area is very small and involves such large stresses that a significant plastification occurs. In simple words, one may view a material surface as being rough, consisting of asperities of different sizes which will deform under pressure. Thus, for static friction, in the frame of the so-called adhesion model, the friction results from the intermolecular adhesion between two surfaces at the points of contact (e.g., see Bowden and Tabor 1950, 1964). The basic assumption of this model is that when placing one surface on top of another, the deformation will cease when the total yield pressure of the asperities becomes equal to the load of the upper surface divided by the total contact area $A_c$. This area is usually several orders of magnitude smaller than the apparent area $A$, e.g., $A_c/A \approx 10^{-6}$ (Johansen et al. 1993); thus, even though the apparent area $A$ may be macroscopic, the actual contact area $A_c$ can be small to such an extent that microscopic randomness may not simply average out. This is the stochastic element that can result in strong fluctuations
of the static friction. Hence, the aforementioned classical friction law, stating that the static friction force is proportional to the load, holds only in an average sense. In the case of dynamic friction, as the velocity increases, there will be more momentum transfer into the normal direction, producing an upward force on the upper surface. This results in an increase in the separation between the two surfaces, thus leading to a decrease in the contact area. In the frame of the adhesion model, the decrease of the contact area reflects a reduced adhesion, which qualitatively explains the experimental results. An alternative model, which uses the collisions between the asperities as the dissipation mechanism, was also suggested. However, in spite of their partial success, these two models cannot fully account for the observed (non-linear hysteretic) phenomena (e.g., see Section 9.2). Both models lead to the following picture: If the fluctuations in the static friction are indeed determined by surface area and contact area, then the dynamic friction should fluctuate for the same reasons. This shows that the deterministic friction velocity relations suggested (e.g., see Section 9.3) hold only in an average sense.

Furthermore, there are puzzles even for fully understanding very simple cases. For example, take a coin and launch it across your desk, recording the distance travelled. Now spin the coin about the axis perpendicular to its surface as you launch it; the coin will travel farther, even if we launch it with the same initial velocity. The coin will stop moving and stop spinning at exactly the same instant (Farkas et al. 2003). The explanation of such experiments (e.g., see Halsey 2003 and references therein) may be achieved on the basis of the suggestion that the coupled equations, describing how the spinning motion of the coin and its velocity both decrease with time, are highly non-linear (cf. The nonlinear nature of friction in general has been reviewed by Urbakh et al. 2004). It is recently shown (Farkas et al. 2003) that even when considering a coin, the sliding on a table is not a simple system. The frictional mechanics of the coin is governed by material phenomena at scales much smaller than the size of the coin. The well-known laws of friction (i.e., the so-called Amonton’s laws) ignore the existence of these complex phenomena at smaller length scales entirely, at the cost of introducing a highly non-linear description of the macroscopic scale of the coin (Halsey 2003).

Finally, we shortly refer to comment on the reason why several attempts have been made to model earthquakes by spring-block systems (with many degrees of freedom). Assume that a block resting on a surface is attached to a spring, the other end of which is pulled at a constant velocity. It has been observed that, at sufficiently slow velocities, the sliding process is not a continuous one, but the motion proceeds by jerks; the contact surfaces “stick” together until (as a result of the gradually increasing pull) there is a