FRICTION AND WEAR OF MATERIALS

Second Edition

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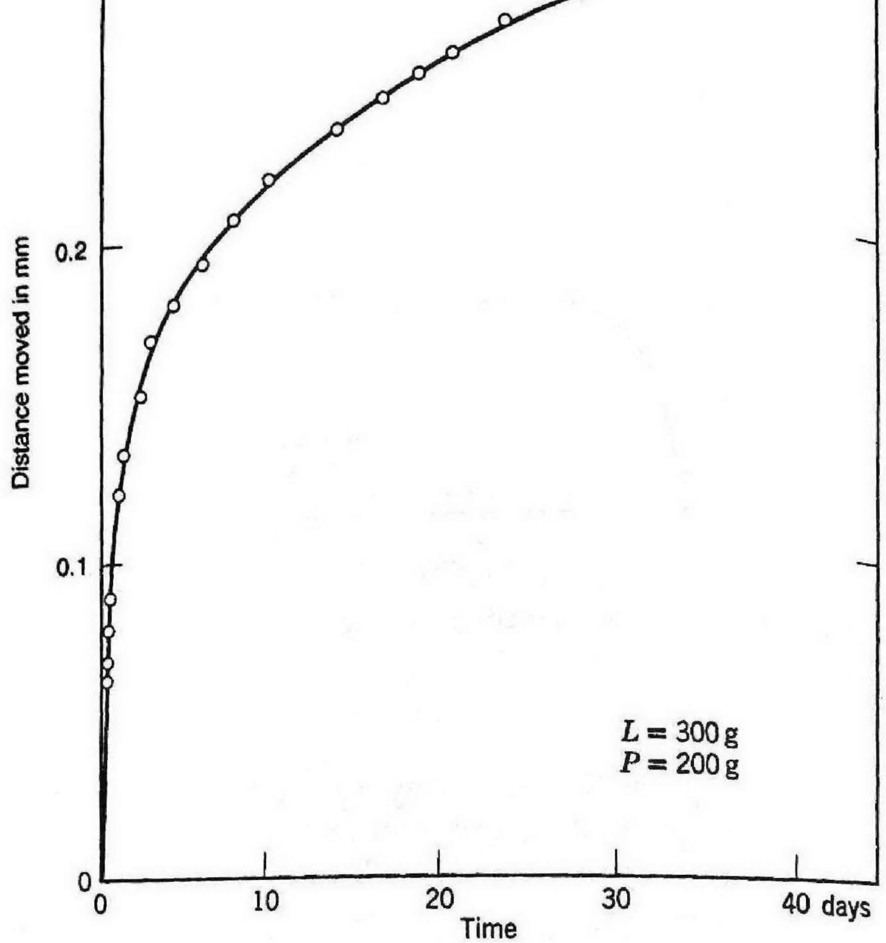

Fig. 4.3 Displacement-time curve for steel on indium, unlubricated.

variables: the applied load, the size of the region of contact, and the sliding velocity. The three quantitative relations are as follows:

1. The friction force F is proportional to the normal force L:

$$F = fL. \tag{4.1}$$

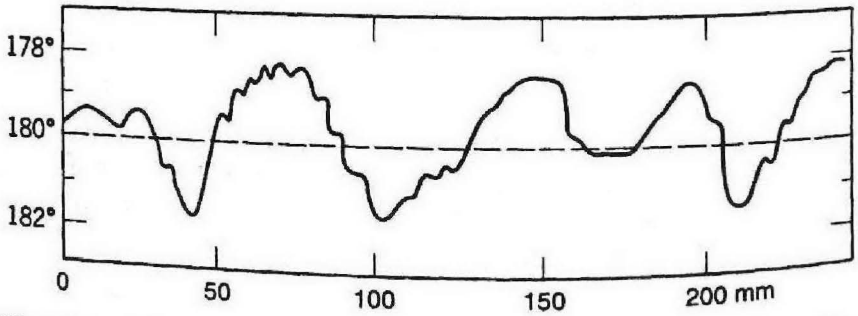

Fig. 4.4 Direction of the friction force as measured from the sliding direction. Steel on steel, lubricated by a machine oil. Load 1000 g velocity 50 mm/sec.

coefficient of friction f (or μ). Alternatively, it is often convenient to express this law in terms of a constant angle of repose, or frictional angle θ defined by

$$\tan \theta = f. \tag{4.2}$$

It may readily be shown that θ is the angle of an inclined plane such that any object, whatever its weight, placed on the plane will remain stationary, but that if the angle is increased by any amount whatever, the object will slide down (Fig. 4.5).

2. The friction force is independent of the apparent area of contact A_a. Thus large and small objects have the same coefficients of friction.
3. The friction force is independent of the sliding velocity v. This implies that the force required to initiate sliding will be the same as the force to maintain sliding at any specified velocity.

Taken together, these three laws provide the quantitative framework within which friction is generally considered by engineers. It is therefore important to discover how closely these laws apply in actual practice.

The first two quantitative laws are generally well obeyed, to within a few percent in most cases (Figs. 4.6, 4.7). Exceptions to the first of them occur mostly with very hard materials like diamond or very soft materials like Teflon (Fig. 4.8) or at loads down to the milligram range (Rabinowicz 1992). In many cases sliding combinations involving materials such as these obey a law of the kind

$$F = c \cdot L^x, \tag{4.3}$$

where c is a constant and x a fraction varying somewhere in the range from $\frac{2}{3}$ to 1. Naturally, in cases where the first law is obeyed, x is exactly 1.

Another case where the friction force is not proportional to the load involves a surface with a thin hard surface layer and a softer substrate. At low loads the hard thin surface layer remains unbroken, and its friction properties predomi-

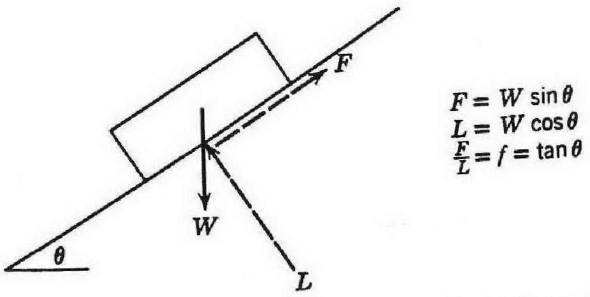

Fig. 4.5 Equilibrium diagram for an object on an inclined plane. Slippage down the plane is imminent.

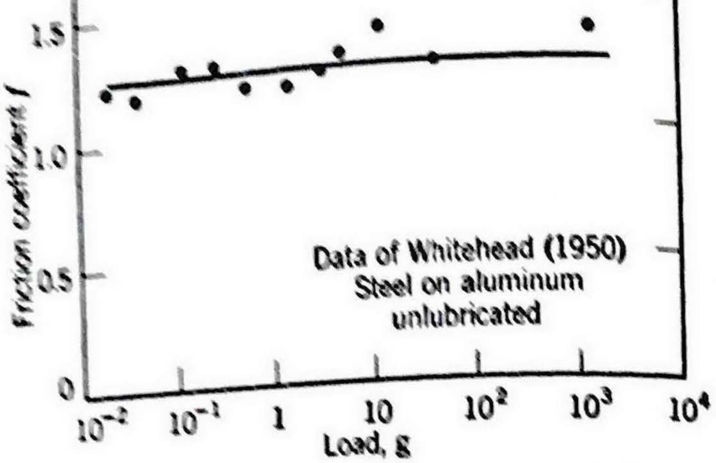

Fig. 4.6 For steel on aluminum, the friction is independent of load over a wide range of loads.

nate. At high loads the surface layer is broken through, and the properties of the substrate become the more important (Fig. 4.9).

Deviations from the second quantitative law, which states that friction is independent of the apparent area of contact, are sometimes noted in very smooth and very clean surfaces. Under these conditions very strong interaction between the surfaces takes place, and the friction force becomes independent of the load but proportional merely to the apparent area of contact (which has become the real area of contact). Such cases are discussed later.

It should be emphasized that the first and second quantitative laws are generally well obeyed and that pronounced exceptions to them are rarities.

Rather typical are situations where, if we change the load or the area by a factor of ten, the friction coefficient changes by a factor of 10% or less. Rather different is the position of the third law which states that friction is independent

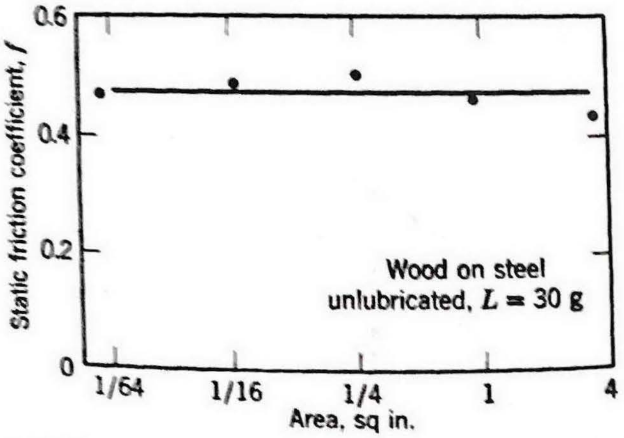

Fig. 4.7 The effect of changes in contact area on the friction of wood on steel. No significant variation is found.