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Review

Latest progress on tribological properties of industrial materials

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ABSTRACT

Wear is closely related to friction and lubrication; the study of these three subjects is known as tribology. In science and technology it is concerned with interacting surfaces in relative motion. Soft or hard film coating, alloying and composite structuring have all been developed to control wear and friction. This is achieved by improving materials and surfaces with some characteristics that improve resistance to friction and wear. In recent years, several new solid lubricant and modern lubrication concepts have been developed to achieve better lubricity and longer wear life in demanding tribological applications. Most of the traditional solid lubricants were prepared in the form of metal, ceramic and polymer–matrix composites. They have been used successfully in various engineering applications. Recent progress in thin-film deposition technologies has led to the synthesis of new generations of self-lubricating coatings with composite or multilayered architectures, by using multiplex surface treatments. In this study, typical wear behaviors of representative materials of metallic alloys, ceramics, polymeric materials, and composites are reviewed in relation to their friction behaviors. Additionally, modeling for the wear prediction is outlined.

1. Introduction

Tribology, which concentrates on friction, wear and lubrication of interrelating surfaces in relative conduct, was explained in 1967 by a commission. 'Tribology' derives from the Greek term 'tribos' indicating detritions or gliding. After, the initial period of ambiguity, the expression 'tribology' has been generally adopted. Since the term tribology is rather new, its denotation is even confusing to some community and funny comparisons with tribes tend to persist as soon as the term 'tribology' is used [1].

Friction is the resistance to movement of individual bodies that are in contact. The term comes to us from the Latin verb fricare, which means to rub. The bodies in substance may be a gas and a solid, or a liquid and a solid; or the friction may be due to inner energy indulgence procedures within one body. Conversely, wear is a phenomenon that occurs in the entire equipment that has touching parts. Three conditions that can cause wear are surface-to-surface contact (frictional wear); surface contact with foreign substance (abrasive wear); and erosion by corrosive materials (corrosive wear). Abrasive wear can be congested by originating a filtration tool to remove the offensive debris. Corrosive wear can be controlled by means of additives that can counteract the imprudent variety that affects the surface. Lastly, lubrication is started between two sliding solids by accumulation a gaseous, liquid, or solid lubricant at the sliding interface to reduce friction and wear and to remove heat and debris created through the sliding course. Lubrication processes can acquire numerous diverse forms, dependent on the gross geometry of the contacting bodies, the roughness and texture of the sliding surfaces, the contacting load, the pressure and temperature, the rolling and sliding speeds, the environmental circumstances, the physical and chemical properties of the lubricant, the material composition, and the properties of the near-surface deposit [2].

In the present study, the theories of friction and wear are outlined and besides experimental investigations, numerical studies on tribological properties of industrial materials are overviewed.

2. Theoretical review

Friction, wear, and lubrication (FW&L) technology impacts various features of daily life, from the wear of one's teeth to the design of complex, high-speed bearings for the space shuttle. More or less each person encounters a FW&L problem from time to time. Intermittently the resolution to the problem is simple and obvious-disassembling, cleaning, and re-lubricating a door hinge, for example. However, the problem itself is hard to explain, the contact circumstances in the system hard to differentiate, and the solution indescribable. Suggestions to problem-solving in the multidisciplinary field of tribology present a broad diversity of alternatives and can comprise such varied fields as mechanical design, lubrication, contact mechanics, fluid dynamics, surface chemistry, and materials science. Suitable information is a very important reserve for solving numerous types of FW&L problems, repeatedly changing the

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Nomenclature

b	bearing pocket diameter (mm)	Q	lubricant flow (m^3/s)
c	radial clearance of bearing (μm)	Q^*	average lubricant flow: $Q^* = Q(h_o^3 LP_s/6\mu l)$ (m^3/s)
d	bearing diameter (mm)	r	bearing radius $r = P_r/P_s$ (mm)
$f_{\min}$	minimum friction force (N)	S	stiffness (N/m^2)
h	film thickness across bearing area (nm)	S^*	average stiffness: $S^* = S/[P_sL(b + l)/h_o]$ (N/m^2)
h_o	minimum film thickness: $h_o = c(1 - \varepsilon)$ (nm)	So	Sommerfeld number: $So = (r/c)^2 \mu N/P$ (–)
h^*	average lubricant film thickness $h^* = h/h_o$ (nm)	W	load (N)
L	length of recess (mm)	W^*	average load: $W/[P_sL(b + l)]$ (N)
N	bearing speed (rev/s)	$W_{\max}$	maximum load (N)
P	load per unit projected bearing area (N)	ε	eccentricity ratio: $\varepsilon = [1 - (h_o/c)]$ (–)
P_r	recess pressure (bar)	μ	viscosity (Pa s)
P_s	supply pressure (bar)	l	bearing land thickness (nm)
P^*	average pressure (bar)		

use of specific tribology theory or engineering equations. In this part of the article, the theories of the friction and wear as well as the lubrication will be overviewed.

2.1. Basic theory of solid friction

The expression "friction" is employed to explain the steady loss of kinetic energy in numerous circumstances where substances move comparative to one another. Solid friction can be described as "the resistance to movement of one solid body over another." The movement may be by sliding or by rolling; the expressions utilized are "sliding friction" and "rolling fiction," correspondingly [2].

The requirement to manage friction is the driving force following its study. In several cases low friction is preferred (bearings, gears, materials processing operations), and occasionally high friction is the goal (brakes, clutches, screw threads, road surfaces). In all of these cases, steady, reproducible, and expected friction values are essential for the design of mechanism and machines that will purpose competently and consistently.

The friction force is the lateral force that must be defeated in order for one solid contacting body to slide over another. It acts in the plane of the surfaces and is generally proportional to the force normal to the surfaces, N, or:

$$F = \mu N \tag{1}$$

The proportionality constant is usually nominated μ or f and is termed the friction coefficient.

Overall, a bigger force is desired to set an inactive body in motion than to maintain the motion; in other words, the static coefficient of friction, μ_s, is frequently rather bigger than the dynamic or kinetic coefficient of friction, μ_k.

A body on a flat surface will commence to move owing to gravity if the surface is increased by the friction angle, θ, where:

$$\mu_s = \tan\theta \tag{2}$$

To defeat friction, the lateral force must be affected over the total sliding space; the result of the two is friction work. The consequential energy vanishes as heat to warm in the type of frictional heating and in other common situations raises in the entropy of the structure. Hence, friction is obviously a course of energy dissipation.

2.1.1. Nature of surfaces

Friction is originated by forces between the two contacting bodies, performing in their interface. These forces are caused by two factors as well the load; the properties of the contacting substance and the area of contact. The friction forces are typically not predictable since both of these factors depend on the exacting conditions. For instance, the properties may be considerably diverse than anticipated from bulk values since the surface material is deformed, consists of segregations, is enclosed by an oxide layer, and so on. Also, the actual area of contact is generally much smaller than the noticeable area of the bodies since actual surfaces are not smooth on an atomic scale [2]. Owing to this reliance of friction on the surface topography and on the properties of the surfaces and the near-surface layers, a short discussion of the pertinent characteristics will be offered.

Surfaces are very complex owing to their unevenness and chemical reactivity and because of their composition and microstructure, which may be very dissimilar from those of the bulk solid. Surface properties, composition, and microstructure may be very hard to decide precisely, creating additional complications.

2.1.2. Basic mechanisms of friction

The particular physical, chemical, or materials-related microscopic affairs that induce friction are named as the basic systems of friction. Numerous diverse systems of this character have been anticipated over the precedent of several hundred years amid scientists and engineers. Fascinatingly, the condition has altered quite little; the identical common fundamental systems are still considered to be accountable for friction. On the other hand, the broad compromise appears to be that all the different systems may be involved in the production of friction although the leading system in each case depends on the exacting condition. For the purpose of this discussion, friction is believed a systems possession. It relies on the character of the two surfaces, the materials, the environment, the function circumstances, as well as vibrations and sample fastening of the equipment [2].

The microscopic systems that are concerned, to varying degrees, in creating friction are (1) adhesion, (2) mechanical interactions of surface asperities, (3) plowing of one surface by asperities on the other, (4) deformation and/or fracture of surface layers such as oxides, and (5) intrusion and local plastic deformation originated by third bodies, mainly agglomerated wear particles, trapped amid the moving surfaces (Fig. 1).

2.1.3. Rolling friction

Sliding friction is the friction that occurs as one solid body slides above another. Though, it has been recognized for thousands of years that it is preferable to roll surfaces rather than to slide them. The resistance to rolling is described as rolling friction and may be incredibly low; for rigid materials it may be as low as 0.001 [3]. An awfully short preliminary argument of this subject follows.