Available online at www.sciencedirect.com
ScienceDirect
Wear 261 (2006) 578–591
WEAR
www.elsevier.com/locate/wear

Influence of surface texture on coefficient of friction and transfer layer formation during sliding of pure magnesium pin on 080 M40 (EN8) steel plate

Pradeep L. Menezes [a], Kishore [a], Satish V. Kailas [b,*]

[a] *Department of Metallurgy, Indian Institute of Science, Bangalore 560 012, India*
[b] *Department of Mechanical Engineering, Indian Institute of Science, Bangalore 560 012, India*

Received 1 June 2005; received in revised form 1 December 2005; accepted 12 January 2006
Available online 28 February 2006

Abstract

Surface texture of a harder mating surface has a great influence on frictional behavior during sliding against softer materials. In the present investigation, experiments were conducted using a Pin-on-Plate inclined sliding tester to study the effect of the surface texture of hard surfaces on the coefficient of friction and transfer layer formation. 080 M40 (EN8) steel plates were ground to attain surfaces of different texture with different roughness. Pure magnesium pins were then slid at a sliding speed of 2 mm/s against the prepared steel plates. Scanning electron micrographs of the contact surfaces of pins and plates were used to reveal the morphology of transfer layer. It was observed that the coefficient of friction, formation of transfer layer, and the presence of stick–slip motion depend primarily on the surface texture of hard surfaces, but independent of surface roughness of hard surfaces. The effect of surface texture on coefficient of friction was attributed to the variation of plowing component of friction for different surfaces.

Keywords: Friction; Surface texture; Transfer layer; Pin-on-Plate sliding tester

1. Introduction

Friction plays an important role during sliding and it depends on local contact conditions, such as surface roughness, contact stress, lubrication, and relative speed of the contacting surfaces [1,2]. Considerable work has been done to study the effect of physical properties, lubrication, sliding speed, surface roughness, temperature, contact pressure, crystal structure, and hardness on coefficient of friction using different experimental methods [3–10]. Hiratsuka et al. [11] studied the factors influencing friction and wear between metals and oxides from wear tests on different kinds of pure metals (silver, platinum, copper, magnesium, iron, titanium, aluminium). They concluded that the friction and wear depends on the oxidation activity of the metals, atmospheric oxygen, and relative shear strength of the metal–oxide interface. Määttä et al. [12] studied the friction and adhesion of stainless steel strip against different tool steels. They concluded that the composition of the tool steel does not have a marked effect on the friction between the tool and the work piece. However, the surface topography of the tool has a marked effect, for example, polishing of the tool surface to reduce the surface roughness reduces the friction between the tool and the work piece. The relation between friction and surface topography using various lubricants was studied by Hu and Dean [13]. They found that a random smoother surface could retain more lubricant and reduce friction. Xie and Williams [14] proposed a model to predict the value of overall coefficient of friction and wear rate, when a surface slides against rough harder surface. This model indicates that both friction and wear depends essentially on the roughness characteristics of the harder surface, the mechanical properties of the surfaces, nominal contact pressure or load, and the state of lubrication. Nieminen et al. [15] performed experiments using a scratch tester to measure friction of different material combinations. They concluded that scratch tester could be useful for friction measurements simulating low speed sliding. Lovell et al. [16] studied the variation of sliding friction as a function of normal load by sliding a hard pin on a soft surface. They found that the coefficient of friction increases with

* Corresponding author. Fax: +91 80 23600648.
E-mail address: satvk@mecheng.iisc.ernet.in (S.V. Kailas).

0043-1648/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.wear.2006.01.001

apparent contact pressure due to increased plowing effects. The initial rise in friction was found to be rapid, due to change from elastic to plastic contact, and then levels off once all the contacting asperities deform plastically. Rasp and Wichern [17] studied the effect of surface topography on frictional resistance using different kinds of surfaces. In their experiment the plate surfaces varied from as-received, mirror polished, chemically etched to abrasively scratched parallel and perpendicular to the simulated rolling direction. They found that the arithmetic roughness value (R_a) and lubrication regime have greater influence on frictional resistance than the directionality. Lakshmipathy and Sagar [18] studied the influence of die grinding marks orientation on friction in open die forging under lubricated conditions. They used commercial pure aluminium as the work piece material and H11 steel as the die material. Two sets of dies, one with unidirectional grinding marks and other with criss-cross grinding marks were used. It was found that, for the same percentage of deformation, the dies with the criss-cross ground pattern required lesser forging loads when compared with the die having unidirectionally ground pattern. The friction factor was also lower during the forging process when the die with the criss-cross surface pattern was used. The authors [18] concluded that the lubrication breakdown tendency is more when pressing is done with unidirectionally ground die than with criss-cross ground die. Liu et al. [19] carried out experimental and analytical study of plowing and friction for commercially available metals using a nano-indenter, where the indenter is used to make scratches on the surface of metals under different normal loads. They found that the hardness of the scratched surface dominates the plowing friction mechanism and the contribution of the plowing component to the total friction coefficient is predominant. Malayappan and Narayanasamy [20] studied the bulging effect of aluminium solid cylinders by varying the frictional conditions at the flat die surfaces. Different machining processes like grinding, milling, electro-spark machining, and lathe turning with emery finish were produced on the flat dies to vary the frictional conditions. The authors [20] concluded that the barreling depends on friction and thus surface finish. Wakuda et al. [21] studied the frictional properties of silicon nitride ceramic surfaces in which dimple patterns were machined with different size, density, and geometry against hardened steel. They found that surfaces with dimples show reductions in friction coefficient when compared to lapped smooth surfaces. Wakuda et al. [21] concluded that the tribological characteristics depended greatly on the size and density of the micro-dimples rather than shape of the micro-dimples.

Sometimes, a phenomenon called “stick–slip” motion occurs during sliding if the frictional force does not remain constant, i.e. is an oscillatory function of sliding distance or time. During stick phase, the friction force continuously builds up to a certain value, and once a large enough force has been applied to overcome the static friction force, slip occurs at the interface. This stick–slip motion occurs when the coefficient of static friction is greater than the coefficient of kinetic friction. Bowden and Tabor [22] suggested that static friction is larger than kinetic friction due to molecular bonding between the surfaces. Gao et al. [23] studied the stick–slip phenomena using gold plated copper solid and fiber sliders on a gold coated copper substrate as a function of the humidity, sliding speed and applied load. Gao et al. [23] concluded that the stick–slip amplitude increased with increasing relative humidity and contact spot size and decreased with increasing sliding speed. Hwang and Zum Gahr [24] studied the static and kinetic friction for different pairs of bearing steel 100Cr6 and a commercial alumina under un-lubricated and oil lubricated conditions as a function of normal loads and surface finish (ground and polished). Hwang and Zum Gahr [24] observed that both static as well as kinetic coefficient of friction were slightly lower under lubricated conditions than under un-lubricated conditions. The value of static and kinetic coefficient of friction increases with increasing normal load for the ground surfaces. At a given value of normal load, the static coefficient of friction increases with increasing surface roughness. However, no effect of normal load was observed on pairs with polished surfaces, but static coefficient of friction decreased slightly with increasing normal load on pairs with polished plates. Hwang and Zum Gahr [24] concluded that stick–slip phenomena occurred with both un-lubricated and lubricated pairs under high normal loads depending on the surface finish. Bouissou et al. [25] studied the influence of normal load, slip rate and roughness during sliding of self-mated polymethylmethacrylate (PMMA) under dry conditions. They observed a steady-state regime at low normal pressures and a stick–slip regime at high normal pressures for all slip rates and grades of roughness. For intermediate normal pressures, the transition between the two regimes was controlled by roughness and slip rates. Bouissou et al. [25] concluded that normal pressure is the main parameter influencing the transition between stable sliding and stick–slip motion.

Most of the experiments were based on variation in roughness values rather than on the texture of the surfaces, thus most authors are unable to explain topography effects on friction during sliding processes and no single surface roughness parameter relates to the friction. The exact description of the contact surface and the texture of surfaces are important to understand the tribological system. The characterization of technical surfaces with traditional surface roughness parameter is insufficient to describe the tribological behavior. To improve upon this inadequacy, surfaces are to be simulated to correspond to actual conditions. For allowing more application orientated testing, a method called the Pin-on-Plate inclined sliding test was used in the present work to study the effect of surface roughness and texture of surfaces on the coefficient of friction. This inclined test gives, from a single test, the variation of coefficient of friction with normal load up to 110 N, thus avoiding multiple tests with various loads. The investigation was conducted by means of sliding pure magnesium pin on 080 M40 (EN8) steel plate. The surface morphology of the steel plate was varied by rubbing against various abrasive emery papers and/or polishing with abrasive powders/pastes.

2. Experimentation

Experiments were conducted using a Pin-on-Plate inclined sliding tester, the schematic of which is shown in Fig. 1. The stiffness of the Pin-on-Plate sliding tester was found to be 0.16 μm/N. The Pin-on-Plate sliding tester has a vertical slide