Tribology International 38 (2005) 435–441
www.elsevier.com/locate/triboint

Determination of load carrying ability of chemical films developed in sliding point contact

H. So*, C.C. Hu

Department of Mechanical Engineering, National Taiwan University, 106 Taipei, Taiwan, ROC

Received 5 September 2002; received in revised form 16 September 2002; accepted 2 October 2004
Available online 23 November 2004

Abstract

It has already been known for many years that the use of some extreme-pressure (EP), antiwear or friction modifier (FM) additives in mineral oils can produce different kind of boundary or chemical reaction films on sliding contact surfaces of some kinds of steel in boundary lubrication conditions. Using a sliding ball-on-disc configuration lubricated with some kinds of EP or FM, the wear scars on the balls can always reach the same limit size at a specified applied load and sliding velocity. From the fact that the limit sizes of wear scars decrease as sliding speed is increased or applied load is decreased, the load carrying ability of a chemical film can be obtained by extrapolating the data to the condition of zero sliding speed and is so defined that if the contact pressure is greater than this load carrying ability, the contact surfaces will continuously be worn; if the contact pressure is smaller than it, no more wear will occur on the surfaces. Based on this load carrying ability, the hydrodynamic effect of sliding pairs can also be identified. Therefore, the limit size of wear scar at specified sliding speed and applied load can also be predicted in a mixed lubrication condition.

Keywords: Boundary lubrication; Chemical film; Hydrodynamic effect; Mixed lubrication; Wear scar

1. Introduction

Some 20 years ago, the members of the International Research Group on Wear of Engineering Materials published a series of research results. One of the important results was the master curve [1]; they called it IRG transition diagram. In which three regions separated by two transition curves were shown in accordance with the magnitude of the coefficient of friction. They defined the region I to be the partial elastohydodynamics. As the speed was increased under the same load, the condition would change to boundary lubrication (i.e. Region II). If the speed was increased further, the sliding pair would fail in severe wear. They noted that the specimens were probably in an unlubricated condition. This was the region III. Because it was not their main concern, they did not take the shared load carried by hydrodynamic effect into consideration in their paper. However, this neglect raises a question that as the lubrication condition is changed with increasing sliding speed from partial elastohydrodynamic to boundary lubrication, does the hydrodynamic effect disappear? What is the obvious influence of hydrodynamic effect on the wear of sliding pairs?

Some researchers paid attention to the shared load lubrication models [2–5]. They considered that a part of applied load was carried by the lubricant and the rest was carried by direct contact of comparably high asperities in a partial elastohydrodynamic condition. On the other hand, intensive researches into the failure criteria in thin film lubrication [6–10] have been done over many years. Also, the most of such researches did not take the hydrodynamic effect into consideration. The formation of boundary films on the contact surfaces is an important mechanism for preventing scuffing of the surfaces [11,12], when some kinds of extreme pressure or friction modifier additives are added to the base oil. The chemical films formed on the sliding surfaces have their own load carrying ability [13,14]. Within the load carrying ability of a chemical film, the surfaces will not be worn further. Recent study [15] showed

* Corresponding author. Tel.: +886 2 33662685; fax: +886 2 23631755.
E-mail address: honso@ntu.edu.tw (H. So).

0301-679X/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.triboint.2004.10.001

Table 1
Hardness and surface roughness of specimens

	Bearing steel ball	Bearing steel disc
Vickers hardness	850	756
Surface roughness (μm)	0.28	0.043

that when a sliding point contact was subjected to an assigned load and sliding velocity in a boundary lubrication condition, the wear scar on the ball would reach a limit size. Once the wear scar arrived at a limit size, it would stop growing in the subsequent sliding process, unless either the load was increased or the velocity was decreased. The use of different EP or friction modifier in the same mineral oil might result in different limit sizes of wear scars. Therefore, it is sensible to consider that the average pressure acting on the wear scar is equal to the load carrying ability of the chemical film when the scar reaches a limit size. Based on the limit sizes of wear scars, this paper is going to find the load carrying ability of chemical films and identify the part of load carried by hydrodynamic effect in sliding point contact of mixed lubrication.

2. Experiments

A ball-on-disc configuration was used in the present wear test experiments. The sliding velocity of the disc relative to the ball was set at values from 0.157 to 1.88 m/s. The normal load applied in the form of dead weights varied from 19.6 to 98.1 N.

Both the ball specimens of 6.35 mm diameter and the disc specimens of 34.5 mm diameter and 13 mm thick were made from bearing steel (AISI E52100). The hardness numbers and the centre-line average (CLA) surface roughness of the specimens are listed in Table 1.

Three plain paraffin oils were, respectively, employed as the base oils in the tests, namely, HN, MN and LN. Their specific gravities and viscosities are shown in Table 2. Three types of friction modifiers, which also functioned as extreme pressure additives, were added to the base oils in assigned weight percentages to make sample lubricants. The main chemical compositions of the friction modifiers are listed in Table 3.

The goal of the present experiment is to find the limit sizes of wear scars on the ball specimens at various velocities and normal loads. A long sliding distance, i.e. 30, 40, 60…or 120 km was set for each pair of sliding members. Then the sizes of wear scars on the tested balls were measured at the end of those sliding distances. The limit sizes of wear scars at various sliding velocities and normal loads were obtained.

Table 2
Specific gravities and viscosities of plain paraffin oils used in the present study

	Viscosity (Pa s)		Specific gravity		Viscosity index
	40 °C	100 °C	40 °C	100 °C	
LN	0.022	0.0039	0.858	0.810	102.7
MN	0.035	0.0057	0.862	0.814	109.6
HN	0.1102	–	0.875	–	>95

Table 3
Chemical compositions of friction modifiers

Friction modifier	Main compositions (wt%)				
	Ca	N	P	S	Mo
Calcium carboxylate compound	4.6				
Organic molybdenum compound			6.4	12.3	8.1
P/S chemistry		3.1	6.1	6.4	

3. Experimental results

The variation of wear scar size on ball with sliding distance was obtained for sliding pairs lubricated with plain paraffin oils. The results indicated that the wear scars approached a limit size at sufficiently long sliding distances. (Fig. 1) When sliding pairs were lubricated with a base oil added with 5 wt% calcium carboxylate compound in the same test conditions as those tests with plain paraffin oils, the corresponding wear scar sizes were substantially reduced because of the formation of chemical reaction films on the contact surfaces (Fig. 2).

During a test, the coefficient of friction was quite steady when a friction modifier was added to paraffin oil (Fig. 3a). However, when a plain base oil with suitably high viscosity, say, MN or HN was used, the coefficient of friction dropped from a higher value of around 0.13 to a lower value of about 0.04 during a long sliding distance test. Then, the coefficient of friction did not change until the test was ended (Fig. 3b). The sliding pair in such a condition can be considered to be on the border between the mixed and the hydrodynamic lubrication conditions.

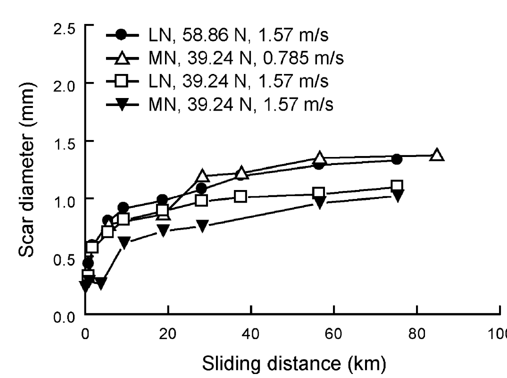

Fig. 1. Variation of wear scar diameter on balls with sliding distance for sliding pairs lubricated with plain paraffin oils.