Wear 330-331 (2015) 79–84

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Study of the effects of damage accumulation on wear

J.C. Miranda [a,b,*], A. Ramalho [a]

[a] CEMUC – Department of Mechanical Engineering, University of Coimbra, Portugal
[b] Research Unit for Inland Development of the Polytechnic Institute of Guarda, Portugal

ARTICLE INFO

Article history:
Received 28 September 2014
Received in revised form
8 December 2014
Accepted 11 December 2014
Available online 20 December 2014

Keywords:
Wear
Friction
Dissipated energy
Wear models

ABSTRACT

Numerous wear equations based on distinct models to predict the wear, are available in the literature. However, most of these models require properties that usually are not easy to obtain, and simple models derived from the Archard equation remain the main base to use in practical situations, by engineers and designers, to predict product life. This equation predicts that wear is a linear function of sliding distance and load, which agrees with several real cases. One important aspect that is neglected in laboratory, in the evaluation of wear rates, is that the tests performed under conditions of uniform contact do not reflect what very often happens with equipments that have operating regimes that can vary from periodic or random and change those contact conditions. Because the additivity is a property of linear functions, this work aims to discuss the application of the additivity property to the Archard equation. A pin-on-disc technique was used to test a hard steel 100Cr6 sphere against a gray cast iron disc. These materials were selected to minimize the adhesion wear component. Different contact conditions, namely normal loads and sliding distances, were investigated to establish a linear basic equation to test as a model to take into account the accumulation of damage resulting from the step loading conditions studied, applying successive different blocks of load. Friction was measured along the experiments and an energetic model was discussed as an alternative way to model the wear. At the end of the tests SEM observations were used to evaluate the wear mechanisms based on the wear scar morphologies.

1. Introduction

Wear and friction of materials are tribologists' main goal of study all over the world. Friction between a pair of materials depends on a lot of factors, that can affect more or less this phenomenon and can produce more or less wear in the contact area. Intuitively, we can say that the factors that affect the friction are among the nature of the material couple, the sliding and loading conditions, and the environment that surrounds the tribological system [1]. However, we could point several more, like lubrication, surface films, surface texture, vibrations and many others [2]. The role to the overall friction value of each one can be very different. On the other hand, some materials exhibit time-dependent tribological behavior with an initial running-in period, marked by changes in friction, temperature and wear rate. This can be observed shortly after the start of sliding contact between fresh, unworn solid surfaces [3]. These temporary variations are sometimes ignored or simply accepted as the normal course of operation, and the tendency is to emphasize the knowledge in the steady state conditions. However, engineers have found the knowledge of such behavior helpful in the running-in period, so that this phase can be conducted in an optimal approach leading to more efficient mechanical systems with longer life and less maintenance interventions. The mechanisms behind this behavior are not completely understood. Three attributes of frictional running-in period behavior have been described in detail in an early publication [4,5]. It is (a) the duration of certain characteristic transients within the running-in period, including the time to reach steady-state, (b) the general trend (shape) of the friction force, versus time of operation, and (c) the instantaneous level of friction fluctuations superimposed upon the general trend.

These aspects mentioned above have been studied extensively, trying to get to know a bit more about the interactions of tribological systems and to develop accurate relationships between all variables and parameters in a system, in mathematical form [6]. The classical approach of Archard's law [7], simplified by Czichos, has been widely used because of its simplicity and inputs needed, like normal load and sliding distance, see Eq. (1). This equation predicts that the wear volume is proportional to the normal applied load and the distance of the sliding of one surface against the antagonist [8–10]. A remaining problem, which makes the application of Archard's equation to real mechanical systems difficult occurs because, in most of the cases, the

* Corresponding author.
E-mail addresses: jcerejo@ipg.pt (J.C. Miranda), amilcar.ramalho@dem.uc.pt (A. Ramalho).

http://dx.doi.org/10.1016/j.wear.2014.12.023
0043-1648/

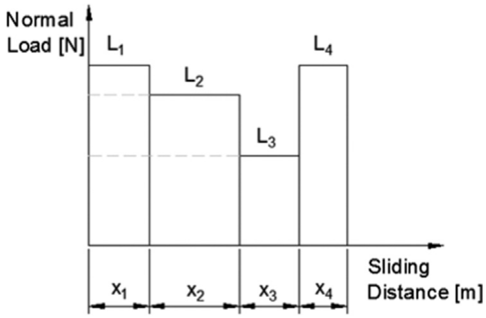

Fig. 1. Loading blocks in an operation cycle.

Table 1
Test conditions (single load).

Distance [m]	Load [N]		
	3	5	7
2000		×	×
5000		×	×
6000	×		
10,000		×	×
14,000	×		
15,000		×	×
20,000		×	×
21,000	×		
30,000	×		
40,000	×		

normal load in the components is not constant during a complete operation cycle. One of the possibilities to analyze these cases is assuming that the load can be considered as a set of blocks with a specific duration of each one, Fig. 1.

Archard's equation being a linear type equation, the properties of linear functions should be verified. Therefore, the superposition of the loading blocks in Fig. 1 should be analyzed considering the singular effect of each loading stage, calculating the wear volume generated, and finally the total volume is achieved by the addition of the several elemental volumes. This scenario assumes a wear damage accumulation effect. So, to verify this, this work aims to discuss the application of the additivity property to the Archard equation.

Alternatively to the Archard equation, the relation between wear and the energy dissipated in the contact will be considered. The energetic approach is a complete method to the study of tribological contacts. This subject has been widely discussed in other places [11–17].

2. Experimental details

2.1. Test materials

The materials tested were a commercial gray cast iron EN-GJL-200, which was tested against a steel DIN 100Cr6 sphere with a diameter of 10 mm. Cylindrical specimens used from the gray cast iron were machined with 10 cm diameter. Then, the surface was finished to a sand paper of 320 mesh. The hardness was measured using a microhardness tester with 2 kg indentation load for 15 s. The medium value obtained was 206 HV for the cast iron disc and 855 HV for the steel ball.

2.2. Test methods

Friction and wear were studied using a sliding tribometer with pin on disc contact. The equipment included a rotating specimen with disc shape of gray cast iron and a stationary sphere of 100Cr6 steel. Normal load was in the range from 3 to 7 N, and the sliding distance from approximately 2000–40,000 m. The sliding speed was always set to 0.5 m/s.

The first set of tests was made to determine the wear coefficient (k) of the simplified equation (1) proposed by Czichos [18] from Archard's equation as follows:

$$V = kNx \tag{1}$$

where V is the wear volume, N is the normal load, x is the sliding distance and k is the wear coefficient or specific wear rate. These sets of tests, Table 1, intended to fulfill a matrix that could get a large spectrum of Nx values and get a linear function of the Archard equation using the data treatment proposed by Ramalho [19].

After these tests were done, another set of tests, Table 2, was made to verify if the wear damage is cumulative linearly. In fact assuming the Archard equation as a linear function of the independent variable

Table 2
Test conditions (multi-load).

Test	Load [N]	Distance [m]
18	2	3150
	6	3150
19	3	8800
	5	8700
20	3	3300
	4	4000
	5	4000
	6	4000
21	2	5300
	3	5400
	4	5300
	5	5200
	6	5200
22	1	3400
	2	3400
	3	3400
	4	3300
	5	3300
	6	3300
23	6	3150
	2	3150
24	6	5200
	5	5200
	4	5300
	3	5400
	2	5300
25	6	3300
	5	3300
	4	3300
	3	3400
	2	3400
	1	3400

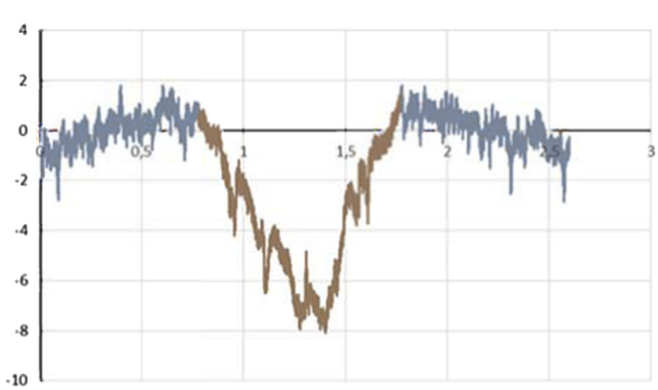

Fig. 2. Example of roughness track.