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Wear 258 (2005) 265–274
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FEM computation of groove ridge and Monte Carlo simulation in two-body abrasive wear

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Received 22 December 2003

Abstract

Abrasion is a stochastic process. It has been realized by some researchers that Monte Carlo simulation is a powerful tool to predict the wear rate of materials. The important issue for the simulation is to collect necessary basic data of worn materials, such as, ductility, plasticity, hardness, etc. The most difficult work, however, is to get parameters related to wear system. A factor, which divides the percentage of debris from total groove volume, is a dominant parameter to predict wear rate of materials. The previous work by the present authors has used the data and results from Azarkhin and Böklen. The curve proposed by Böklen is based on a normal indentation of cone and the data from Azarkhin were obtained from a calculation of upper bound approach. Those results are not adequate for the simulation of groove wear. Therefore, three-dimensional finite element method (FEM) analysis was used in this investigation. Stress and strain of a half infinite plane indented by a sliding sphere tip were calculated with an elastic-linear strengthen plastic deformation model by a commercial software. The curves proposed by Azarkhin and Böklen were modified by the FEM calculation. Monte Carlo simulations of wear rate for AISI1020, AISI1045 and AISI1080 steels were carried out. At the same time, scratch tests were also carried out and profilemeter measurement was done after the scratch test as to propose a groove ridge description expression. The present simulation showed good agreement with the experimental data.

Keywords: Monte Carlo simulation; FEM; Two-body abrasion; Scratch test

1. Introduction

Two-body abrasion is a typical wear mechanism. During this process, hard abrasives usually remove ductile material by micro-cutting and plastic deformation mechanism. It has been reported that the fraction of micro-cutting wear tends to be dominant in two-body abrasion and plastic deformation wear, therefore, can be almost overlooked [1]. Nevertheless, a plastic deformation behavior of worn material still has a strong effect on the wear procedure. Fig. 1 schematically shows across section of a groove with ridges. The volume loss caused by a single grit can be determined by:

$$f_{ab} = \frac{A_g - (A_{r1} + A_{r2})}{A_g} \tag{1}$$

It becomes clear that the quantity estimation for plastic ridges distributed on both sides of groove is quite difficult, therefore, many previous wear models did not include this parameter. This resulted in overrating of the wear volume of worn material.

Kayaba et al. [2], and Hokkirigawa and Kato [3–6] noticed, from in situ SEM observations of scratching surface by hemisphere grit, that wear pattern will change to cutting mode ($f_{ab} \approx 1$) from ploughing mode ($f_{ab} = 0$) and ridge-forming mode ($0 < f_{ab} < 1$) with varying indentation depth. In accordance with the wear mode change, the volume fraction of

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doi:10.1016/j.wear.2004.09.024

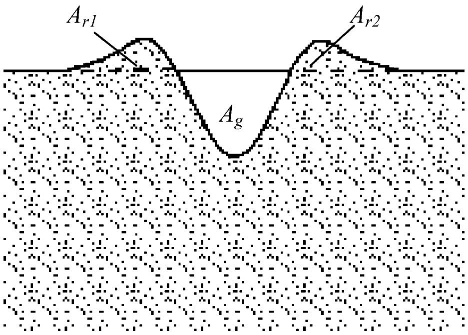

Fig. 1. Schematic representation of groove and ridges.

ridge to groove also varies greatly so as to bring about a large change of wear amount. If f_{ab} is not considered, the estimation of wear amount will be poor too. In the case of pure cutting model, the wear amount will be one order of magnitude larger than real one. Zum Gahr [7–9], therefore, introduced f_{ab} into his models. Because the plastic deformation and strengthening index of materials are not easily obtained from experiments, it makes prediction of wear amount uneasy too.

Monte Carlo method was applied to construct a random simulation model to predict wear amount in two-body abrasion process [10]. The proposed model accurately predicted the wear rate during pin-on-disc tests. However, the data of Azarkhin and Richmond [11], and Böklen [12] were used by the simulation program. From Azarkhin's report upper bound approach was used to build a relationship of ridge geometrical parameters to friction coefficient using a rigid pyramid tip scratching over rigid-plastic material. Böklen carried out a normal indentation test by a hard cone. A curve of ridge height and ductility was obtained. It is evident that test material and contact model both have predominant influences on the ridge geometrical parameter and upper bound approach is also quite weak to simulate real scratch test. Those results are, therefore, not adequate for the purpose of simulation.

Because the exact measurement of ridge geometrical parameters is uneasy and tedious after scratching, the implementation of computer simulation is desirable. With new improvements of computation capability and commercial software of finite elements method (FEM), three-dimensional FE computations with huge number of nodes have become faster with a conventional personal computer. At present, FEM analysis on stress, strain and friction coefficient have been applied by Subhash and Zhang [13]. It is interesting that Bucaille et al. [14] simulated a indenter-scratching process on elastic–plastic plate using Forge3®. A regressive expression was proposed that builds a relation of shape ratio and rheological factor, which is in agreement with the experimental results of Jardret et al. [15]. Although a regressive function of ridge height as indented depth was obtained, Bucaille did not continue research applied to wear rate prediction of material and the description of ridge curve was not given too. Consequently, plastic deformation of carbon steel family was simulated using three-dimensional FEM by the present authors. The forming procedure of plastic ridges on both sides of groove was reproduced and the ridge curves were also got related to the depth and width of the groove. Furthermore, the curves were applied to the previously developed Monte Carlo simulation models used to predict wear rate of carbon steels. Finally, the results predicted by the newly developed model were compared with the results of the previous model.

2. Computer modelling of two-body abrasion

2.1. Assumptions

To construct the Monte Carlo model of two-body abrasion processes, some assumptions should be necessary to simplify the simulation processes.

- Grits surface mated with metal is assumed to be a rigid material and the shapes and relative positions are, then, assumed not to change under loading.
- Two mated surfaces will always remain in parallel during sliding. The relative approach of the two surfaces will, then, vary at any different computing step.
- The material is ductile and undergoes plowing in a frictionless interface in the FE calculations. In our simulations, several friction coefficient values were tried. It has been found that the friction coefficient has a small influence on the simulation results to some extent.
- It has been estimated by the present Monte Carlo simulation program that the contact frequency of conical flank respect to ridge is less than 0.01 for AISI1080 steel under the normal load of 9.80 N and less than 0.23 for AISI1020 steel whose the average ratio of the indented depth to the particle radius is only 1.18 under the normal load of 9.80 N, respectively. Therefore, it will not give rise to great errors if a spherical indenter assumption is introduced in the FEM.
- After the ridge-covered surface is formed the new-formed ridge curve will be treated to be directly overlapped on the previous rough surface as to simplify the simulation process. Although this approximation treatment is rough and tentative, it is indeed quite effective for treating random ridge-covered surface.
- The contact model of K.L. Johnson [16] was used for calculating the approach and penetration of single asperities in this investigation.

During sliding, the grits and their numbers will also vary at a different computing step. The supported load of each grit changes with the number of grits contacted by the specimen surface. However, the total load supported by the metal specimen keeps constant at any time. The volume loss caused by a single grit can be calculated by

$$V_w = n l_{\text{step}} f_{ab} A_g \tag{2}$$

where n is the number of steps and l_{step} the sliding distance per step.