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Finite element analysis and experiments of metal/metal wear in oscillatory contacts

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Abstract

A numerical approach that simulates the progressive accumulation of wear in oscillating metal on metal contacts is proposed. The approach uses a reciprocating pin-on-disk tribometer to measure a wear rate for the material pair of interest. This wear rate is an input to a finite element analysis that simulates a block-on-ring experiment. After the simulation, two block-on-ring experiments were performed with the same materials that were studied in the reciprocating pin-on-disk experiments. The results from the finite element analysis were in close agreement with the block-on-ring experimental results. This approach did not either rely on curve fitting or use the block-on-ring experimental data as model inputs. The finite element analyses were performed by progressively changing nodal coordinates to simulate the removal of material that occurs during surface interaction. The continuous wear propagation was discretized and an extrapolation scheme was used to reduce computational costs of this simulation.

Keywords: Wear modeling; Finite element analysis

1. Introduction

It is desirable to design engineering components for infinite life, unfortunately, in systems where parts are in intimate contact and relative motion wear is inevitable such designs are difficult to realize. Wear predictions are typically made using contact pressures and slip calculated from the first wear cycle and do not account for the changes in the geometry during life. Ignoring the coupled evolution of wear and contact conditions has been shown analytically and experimentally to over-predict [1,2] or under-predict life [3,4]. These analytical techniques are limited to two-dimensional steady contacts, and wear is concentrated on only one component (i.e., one part is assumed to be sacrificial), although, analytically Blanchet [1] did allow for wear to occur on both specimens in the model of the 'scotch-yoke'.

Computer aided engineering software is widely used to calculate stresses, fatigue life, modal analysis, stiffness and compliance of a structure; the fatigue life of a mechanical component; the noise in the passenger compartment; the vibration level; and the safety of a vehicle in a crash. Unfortunately, there does not appear to be a standardized method for including wear within finite element analysis. Finite element analysis has been used in tribology and the study of wear to model the phenomena at two widely different length scales. At the microscopic level, models of differential elements are used to study wear mechanisms [5,6]. Macroscopic modeling uses wear rates or other models of wear as inputs to finite element analysis. These numerical experiments then study wear on geometrically simple components [7–9]. This paper focuses on the macroscopic wear process and predicts the worn

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shape of an oscillating block-on-ring experiment using finite element analysis with all tribological inputs coming from experiments run on a reciprocating pin-on-disk tribometer.

Macroscopic wear modelingwas performed by Podra and Andersson [10] who used an elastic foundation model to calculate the contact pressure distribution and updated the contact surface according to a wear rule. They neglected the shear effect of deformationwhich made it difficult to match both the contact area and maximum contact pressure [11]. They further improved the numerical wear simulation using axisymmetric finite element analysis [7,8]. The contact pressure was calculated from the static finite element analysis and the sliding distance was calculated from the rotational speed. To reduce the total number of simulations, Oqvist [9] applied a variable step size in a two-dimensional wear simulation and compared the results with experimental measurements. The agreement between simulation and experiment was good because the wear coefficient was obtained from the same experiment. Recently, Molinari et al. [5] presented a generalized Archard model by allowing the hardness of the soft material to be a function of temperature. Due to the complexity of the wear model, they only applied to a simple contact problem on the flat surface.

The purpose of the work reported here is to identify critical material wear factors in the oscillating metal-on-metal wear problem, measure these parameters using a simple and inexpensive reciprocating flat geometry wear test and to use these measurements coupled with finite element analysis to predict the wear profile of an experiment with a different wear geometry. The present application is challenging due to the oscillatory sliding motion. After obtaining the wear rate from the reciprocating pin-on-disk experiments, a series of finite element analyses are performed by progressively removing material; this is achieved by moving nodes on the interface in the normal direction. The continuous wear process is discretized into a finite number of steps and the wear rules are applied at each discrete step, requiring an integration scheme. An explicit Euler integration method is employed to numerically integrate the continuous wear progress at discrete steps.

The composition of the manuscript is as follows. First wear rates are obtained from the specimen-level wear test described in Section 2. Second, finite element modeling and simulation results are presented in Section 3. Third, validation of the finite element results is performed in Section 4 using data from block-on-ring experiments. Finally, some concluding remarks and discussion on future directions of research in this area are offered.

2. Experimental method and results for determination of a wear rate

Pin-on-disk tests are performed on the tribometer depicted in Fig. 1 in order to measure the wear rates of the steel samples that were 4340 steel with a surface hardness of 42–58 HRc and RMS surface roughness of 63 nm. An electro-pneumatic

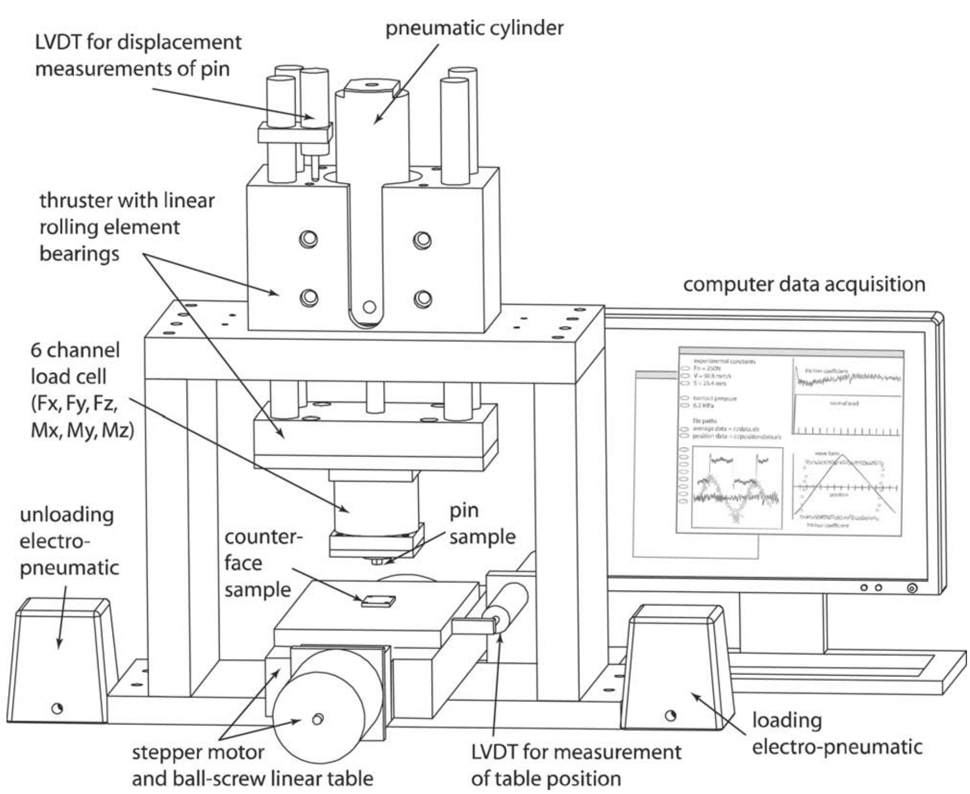

Fig. 1. Schematic of the reciprocating tribometer used to evaluate the wear rate of the self-mated steel contacts. The friction coefficient is continuously monitored and gravimetric analysis of the samples is performed to calculate wear rate.