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Thermal analysis of washer-on-disk wear test by micro-genetic algorithm

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ABSTRACT

Maximum contact temperature and temperature distribution are always concerns in the washer-on-disk tribological test because it influences the tribological mechanism occurring in the contact area. However, it is difficult to measure correctly. In the present study, the micro-genetic algorithm method is applied to solve the heat transfer coefficient to the ambient atmosphere and the fraction of heat flux which goes into the disk. Comparisons and verifications are made to check the correctness of the result. It shows that the temperature distribution obtained from the micro-genetic algorithm is both suitable and correct in solving this type of problem.

1. Introduction

In a tribological system, the surface temperature of two mutually sliding worn surfaces is an important index to determine whether the system is under severe wear or not, particularly for metal surfaces. This is because different degrees of oxidational wear behavior will occur at different temperatures. The oxidational wear can be roughly classified into the following two categories: mild oxidational wear and severe oxidational wear [1]. The temperature rise is caused by the heat conduction between two contact surfaces of upper and lower specimens. Quinn [2] proposed an oxidational theory of mild wear based on the fact that a large increase in local temperature at the real area of contact will result in oxidation of the contact surfaces. Rowson and Quinn [3] developed a detailed heat flow analysis for a pin-on-disk configuration and derived the oxidational theory of mild wear.

Chou and Lin [4] utilized the response surface method (RSM) to analyze the oxidational wear in a tribological system. The relationship of friction coefficient, sliding speed, and load with contact temperature has also been analyzed therein. It is therefore obvious from the above that the temperature of the contact surfaces plays a very important role in the degree of oxidational wear.

However, it is difficult to measure the real contact temperature between two mutually sliding surfaces of the wear specimens during tests directly, such as in a pin-on-disk or washer-on-disk wear test. Iliuc [5] introduces some special methods to measure the real surface temperature of two contact surfaces. But the precision of the measurements and their applicability are restricted. Theoretical or numerical solutions for calculating surface temperature distribution have been developed in previous studies. Lin et al. [1] tried to solve the contact problem by assuming the surface temperature distribution at the contact surface of a washer-on-disk test to be a parabolic form in the radial direction. They made the following assumptions in order to simplify the problem to aid calculation:

(1) The temperatures of the top surface outside the wear track of the disk specimen remains at the same constant temperature; the maximum temperature happens at the central circle of the wear track.
(2) No heat convection occurs on the surface areas described above.

Three unknown temperature parameters shown in the temperature expression developed for the parabolic curve were given as boundary conditions, which were then derived and verified through four measured temperatures, three of which were beneath the worn surface and the other one was the temperature of the unworn surface outside the wear track in the disk specimen.

Apart from the analytical method shown in the study of Lin et al. [1] to solve the temperature distribution at the contact surface, the inverse method can also be applied to solve the heat conduction problem. The inverse procedures for the heat conduction problems have been discussed in a book edited by Beck et al. [6]. In addition,

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the techniques for solving the inverse heat transfer problems can also be found in the book by Ozisik and Orlande [7]. The purpose of using the inverse technique is to evaluate one or more unknown characteristics from the knowledge of the measured temperatures at some specific positions of the medium [7]. In the inverse problem, the measured temperature (the effect) is given; the unknown characteristic (cause) is estimated. All the methods given in the books of Beck et al. [6] and Ozisik and Orlande [7] solve the inverse heat conduction problem (IHCP) by a conventional gradient-based optimization model to optimize the unknown parameters or functions.

Another way to solve IHCP is in the use of a genetic algorithm (GA). GA is a computational technique developed for searching the optimum values of unknown parameters based on a process that simulates evolution. Comparisons between the GA method and the gradient-based optimization method have been discussed [8]. For the disk specimen in the washer-on-disk tests, two unknowns (the heat flux that goes into the disk specimen and the heat transfer coefficient of the top surface outside the worn track) need to be optimized. Furthermore, the initial guess values of these two unknowns are hard to determine, and the derivatives of the objective function may be difficult to obtain. Therefore, the GA method is more effective and suitable for our problem than the gradient-based optimization method. The drawback of the GA method is that it consumes more computational time than the gradient-based optimization method due to its slow convergence rate at the later stage of optimization. However, this problem has become less important due to the rapid progress in the computational speed of the personal computer. Liu and Han [8] proposed several further ways in order to improve the computational efficiency. One simple and efficient method termed the micro GA (μGA) method will be utilized in this study, and will be discussed in a later section.

The μGA method is adopted in the present study to solve the temperature distributions of the disk specimen in the washer-on-disk wear test due to the generation of frictional heat flow at the wear track. The two unrealistic assumptions made in the study of Lin et al. [1] for the temperature distribution on the wear track are not necessary in this method. The unworn surface outside the wear track is assumed to have heat convections with an unknown heat convection coefficient of the air. This unknown coefficient is theoretically dependent on several parameters including the geometry of the specimen, temperature gradient, etc. It can be evaluated in this study. Another unknown parameter is the frictional heat flux which is transferred to the disk specimen. In the present study, a constant heat flux distribution over the whole contacting surface with only a fraction of this frictional heat flux transferred to the disk side are assumed. This fraction can also be taken as a constant value in the steady state.

These two unknown thermal parameters can be estimated and optimized via the method of μGA. However, they cannot be solved via direct heat conduction analysis.

2. Experimental details

The experimental data utilized in this paper is that produced by Lin et al. [1]. The upper and lower specimens were all made of AISI 1045 carbon steel and were machined to disks and ring washers for the washer-on-disk wear test machine. The dimensions of the ring-type disks and washers are illustrated in Fig. 1. The thermal conductivity for the AISI 1045 carbon steel is approximated equal to 26.8 W/(m °C). The core and lateral surfaces of the disk were insulated by an asbestos material with thermal conductivity in the range of 0.132–0.264 W/(m °C).

A K-type thermocouple is positioned on disk's top surface by point welding at a distance 14.4 mm from the disk axis to measure the surface temperature Ta. There were three holes drilled at three depths, 5 mm, 8 mm and 11 mm, below the disk's top surface. They were employed to measure temperatures by using three J-type thermocouples. The temperature measured at 11 mm below the top surface, T_L, is considered to be the boundary condition. The temperature at the cross-section of 11 mm below the top surface is considered to be the same as T_L. All the three measured temperatures, T_5, T_8 and Ta, are considered to be the known temperatures that would be compared with the temperatures at the same positions calculated by the micro-genetic algorithm.

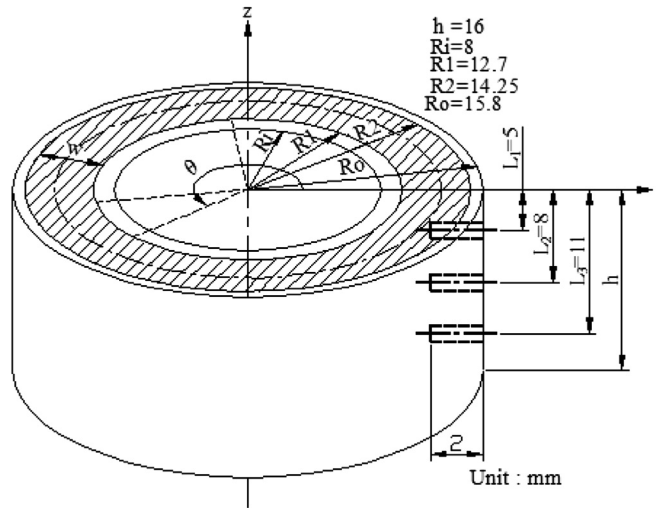

Fig. 1. The dimensions of the ring-type disks and washers.

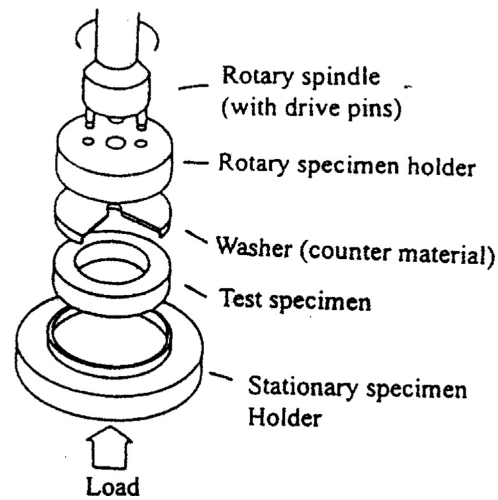

Fig. 2. The schematic diagram of the washer-on-disk wear machine.

Fig. 2 shows the schematic diagram of the washer-on-disk wear machine. The initial disk's bulk temperature during the tests is 25 °C. The ambient temperature is also controlled at 25 °C. The sliding speed of the tests is set to be 2.118 m/s, while the total sliding distance for each test is 4237 m.

3. Heat conduction analysis of the disk

3.1. Problem formulation

Assume that the thermal conductivity for the AISI 1045 carbon steel, k, is constant, the 3-D cylindrical heat conduction