WEAR PREDICTION USING GIWM (*GLOBAL INCREMENTAL WEAR MODEL*) METHOD

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Abstract

Wear is very important parameter in an engineering design. A model for predicting the wear behaviour is presented in this paper. The model, which is called global incremental wear model (GIWM), is build upon an iterative procedure. This study considers the pin-on-disc sliding contact system. The model for computing wear on pin is based on the idea of successively computing the contact radius and thus the contact area due to the flattening of the spherical tipped pin. In order to verify the developed model, the results are plotted together with the published results. There are two publisher results, numerically and experimentally. Results show that the developed GIWM model predicts the wear behavior very well.

Key words: *wear, modeling, sliding contact, contact mechanics.*

1. INTRODUCTION

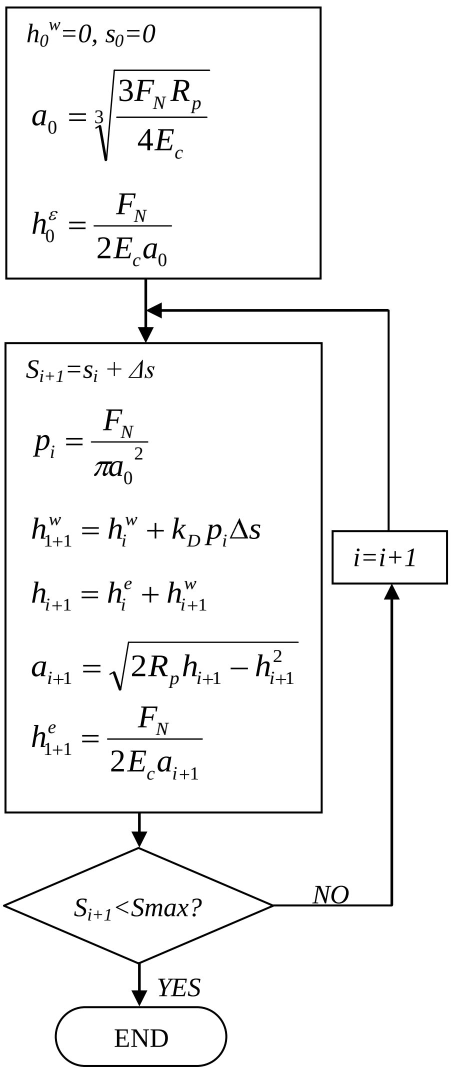
Sliding is a very old problem in engineering. Sliding contact between mechanical components such as gears and cam and followers will result in wear. In many applications wear is avoided. To minimize wear it is crucial to understand why the wear occurs. From such an understanding can emerge predictive models which can help in designing a component and selecting the material for minimizing the loss of material by wear. Wear is a highly complex phenomenon. The character of a surface is determined by the bulk chemical and physical structure as well as environmental condition [1]. The topography is determined by the method of manufacture. The complexity of the phenomenon inhibited any comprehensive modeling for a long time. The mechanical engineers who faced the immediate problem of wear control in machinery had however to respond to the situation by formulating first order models based on purely mechanical concepts. It was recognized in the early nineteen fifties that when metals wear out asperities are involved in this interaction and large strains are incurred at the asperity level or below the asperity root which, in case of metals at least take the material well past the yield point. The first models of adhesive and abrasive wear thus invoked asperity contact and considered the soft asperity or substrate to undergo plastic flow.

Wear has been recognized as meaning the phenomenon of material removal from a surface due to interaction with a mating surface. Almost all machines lose their durability and reliability due to wear, and the possibilities of new advanced machines are reduced because of wear problems. Therefore, wear control has become a strong need for the advanced and reliable technology of the future. Wear is not an intrinsic material property. Wear is a complex function of the system which includes material properties, operating conditions (load, speed), contact geometry, surface roughness, and environment (lubrication, temperature). Therefore, for a given pair of material combination, wear can vary over several orders of magnitude depending on the conditions. This makes evaluation of materials in terms of wear resistance difficult. Common practice is to conduct simulation wear tests to rank materials under the same operating conditions. If the relationship between wear and the operating conditions (load and speed) are linear, relative ranking of materials will hold. Under the influence of chemistry or environment, unfortunately, wear transitions often occur and the relationship between wear and the operating conditions is often not linear. The relative ranking of materials, therefore, will change when the operating conditions are changed. At the same time, material variations abound. Small changes in the alloying elements and processing conditions change the wear characteristics. So even though the material designation is the same, there is no assurance that the chemical composition and microstructure are identical. Because of these factors, literature reports on material wear characteristics have wide ranges.

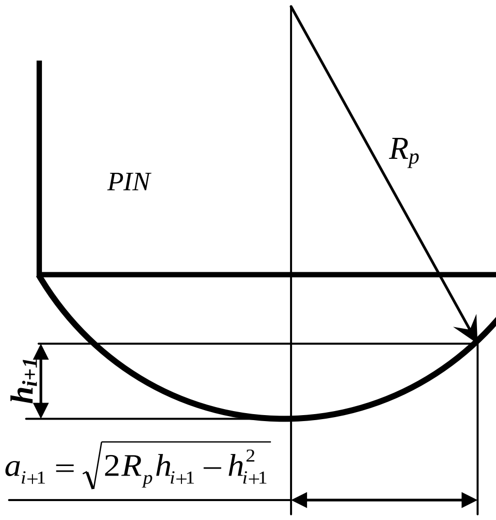
Modeling of wear, in order to derive predictive governing equations, has been a subject of extensive research over the past. The modeling of wear found in the literature can broadly be classified into two main categories, (i) mechanistic models, which are based on material failure mechanism, e.g., ratcheting theory for wear [2] and (ii) phenomenological models, which often involve quantities that have to be computed using principles of contact mechanics, e.g., wear model of Archard [3]. Archard-based wear model have been studied extensively by combining with numerical calculation such as finite element analysis. Podra and Andersson [4] simulated sliding wear of a pin-on-disc with finite element method. Numerical simulation of wear of a cylindrical steel roller oscillating against a steel plate was also performed by Oqvist [5] with a special version of finite element program. The simulation was done in steps and the pressure and the sliding distance was recalculated as the surface geometry changed. Similar to Oqvist, Hegadekatte et al. [6, 7] proposed a modeling scheme for wear in tribometers. The model was claimed to be very efficient. Recently, Mukras et al. [8] introduced a wear prediction model for an oscillatory conforming contact. The model was build upon the same iterative wear prediction procedure. Similar procedure for wear prediction in sliding contact is presented in this paper. The global incremental wear model (GIWM) is adapted from the work of Hegadekatte [7]. The developed pin-on-disc model is then used for predicting the wear from the work of Podra and Andersson [4]. In Podra and Andersson, wear was studied experimentally and finite element analysis-based numerically.

2. MODEL

In the global incremental wear model, GIWM, the term “global” is used to indicate that the wear modeling considers only the global quantities (such as the average contact pressure) and not the location specific quantities (such as local contact pressure).



(a)



(b)

Figure 1. Flowchart of the pin-on-disc global incremental wear model and (b) schematic representation for calculating the contact radius after each increment of sliding distance

The term “incremental” is used because of the average contact pressure is updated at the end of each sliding distance increment due to the resulting increase in the contact area.

The GIWM implemented for the case of a comparatively softer spherical tipped pin sliding over a harder flat disc will be presented in this study. In such a situation it can be assumed that most of the wear occurs on the pin, while negligible wear occurs on the disc. The GIWM for computing wear on pin is based on the idea of successively computing the contact radius and thus the contact area due to the flattening of the spherical tipped pin. Figure 1(a) shows the flow chart of this scheme, where p is the contact pressure, F_N is the applied normal load, a is the contact radius due to elastic displacement and wear, h is the total displacement at the pin tip, R_P is the radius of the pin as sketched in Fig. 1(b), h^e is the elastic displacement, h^w is the current wear depth, k_D is the dimensional wear coefficient, Δs is the interval of the sliding distance, s_{max} is the maximum sliding distance, i is the current wear increment number and E_C is the elastic modulus of the equivalent surface calculated using the following equation [9]:

$$\frac{1}{E^*} = \frac{1-v_P^2}{E_P} + \frac{1-v_D^2}{E_D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

where E_P and E_D are the Young's modulus of the pin and disc materials respectively and the Poisson's ratio of the pin and the disc materials is represented by v_P and v_D respectively.

The global wear modeling scheme begins with the computation of the initial contact radius, a_0 using the Hertz [10] solution for circular contact area:

$$a_0 = \sqrt[3]{\frac{3F_N R_P}{4E^*}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and the elastic deformation normal to the contact using the Oliver & Pharr [11] relation given below:

$$h_{i+1}^e = \frac{F_N}{2E^* a_{i+1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Then the following quantities are calculated for each increment of sliding distance as shown in Figure 1(a) till the maximum sliding distance is reached:

- Based on the applied normal load and the current contact radius using, the average contact pressure is determined as:

$$p_i = \frac{F_N}{\pi a_i^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

- Integral of the linear wear increment

$$\frac{h}{s} = k_D p$$

is computed using the Euler explicit scheme as given below:

$$h_{i+1}^w = k_D p_i \Delta s_i + h_i^w \quad \ldots\ldots\ldots\ldots \quad (5)$$

- As can be seen in Fig.1(b) the current contact radius is calculated based on the sum of the linear wear and the elastic deformation normal to the contact as given below:

$$h_{i+1} = h_{i+1}^w + h_{i+1}^e \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6a)$$

$$a_{i+1} = \sqrt{2R_P h_{i+1} - h_{i+1}^2} \quad \ldots\ldots\ldots\ldots \quad (6b)$$

The average contact pressure, as seen from Equation (4), is used in the computation of wear in Equation (5). Alternatively, the Hertzian maximum pressure can also be used in the wear modeling scheme above. The maximum pressure is then computed as 1.5 times the average pressure as it is the case for the initial Hertzian contact. However, such a computation of the maximum pressure may only be applicable in the initial stage of sliding as long as the contact remains Hertzian. It has been shown in [7] that for large sliding distances the pressure in the contact will approach a flattened distribution. Thus, the global incremental wear model considering the average pressure gives a better approximation for larger amounts of wear in the pin.

3. RESULTS AND DISCUSSIONS

The developed GIWM using averaged contact pressure is used to fit the results of the pin-on-disc experiment of the work of Podra and Andersson [4]. In their experiment the sliding contact between pin and disc was unlubricated. Figure 2 shows the setup of the experiment. A spherical steel pin with a radius of R = 5 mm sliding on a steel disc with normal load F_N = 21 N or F_N = 50 N. The discs and the pins were hardened to HV = 4.6 GPa and HV = 3 GPa, respectively, thus the maximum contact pressures, calculated by Hertz, were assumed to be within the elastic limits. The test rig allowed online measurement of the wear depth and friction torque. The sliding velocity in the tests was v = 25 mm/s.

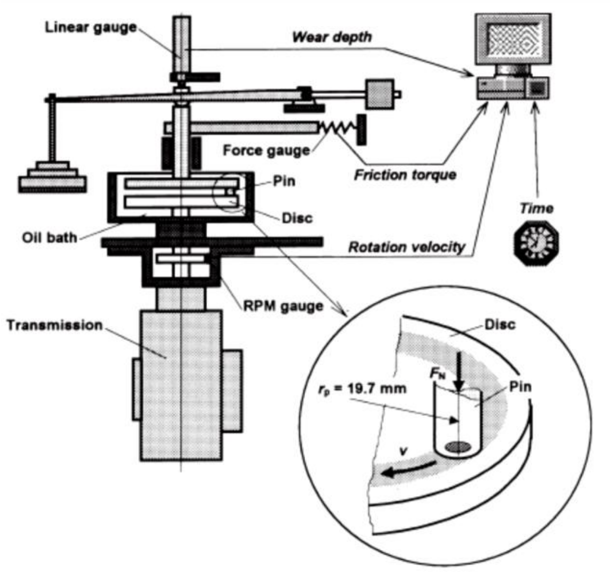


Figure 2. Pin-on-disc tribometer of Podra and Andersson [4]

The constant k_D was identified to be (1.33±0.54 x 10^{-13}) mm^3/Nmm. Figure 3 shows the results of the present GIWM model in predicting the wear depth as a function of the sliding distance for the load of 21 N. It can be seen from the graph that the results from the developed GIWM are in good agreement with the FEM and experiments results of Podra and Andersson [4]. The difference between the GIWM and the FEM results is less than 5%. However, for the difference between the GIWM and the experiments results is relatively higher or about 10%. This deviation is distinctly observed for the sliding distance between 800 and 2200 mm. Similar plot is given in Fig. 4 for the load of 50 N. In this higher load, the GIWM also predicts well the wear behavior of the sliding contact system. However, the GIWM results are closer with the experimental results compare to the FEM results. Start from the beginning of the sliding until the end of the sliding the prediction of the GIWM and the FEM is constantly deviate of about 7%. On the contrary, the GIWM and the experimental results are fit very well until the sliding distance of 800 mm. From 800 mm to 2400 mm the results are start to deviate with the average about 4% and then fit again. Based on the results of two different loads, it is very challenging to explore further the wear prediction model and mechanisms.

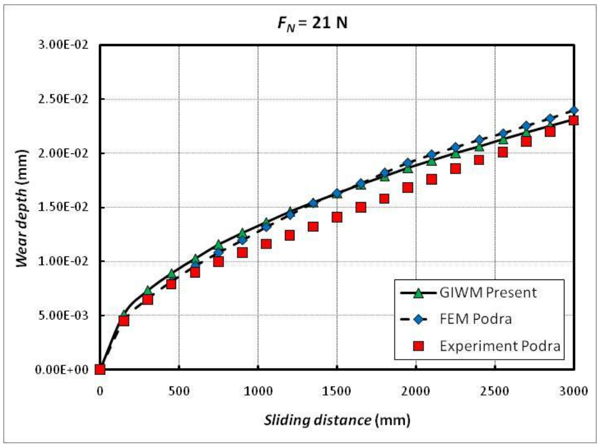


Figure 3. Results from the present GIWM in comparison with the FEM results and the experimental results of pin-on-disc tribometer of [4] for the normal load of 21 N

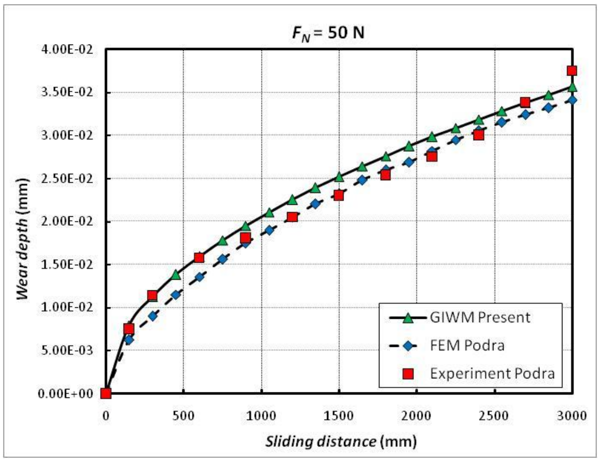


Figure 4. Results from the present GIWM in comparison with the FEM results and the experimental results of pin-on-disc tribometer of [4] for the normal load of 50 N

4. CONCLUSIONS

An iterative model has been presented to predict the wear behaviour of a sliding contact system. A pin-on-disc sliding contact system was chosen for the simulation. Therefore, the model computed wear of the pin. The calculation is based on the idea of successively computing the contact radius and thus the contact area due to the flattening of the spherical tipped pin. The numerical model prediction and the experimental results were compared in order to evaluate the validity of the developed model. The results show that the developed GIWM model predicts the wear behavior very well and perform the simulation faster and cheaper.

REFERENCES

1. S.K. Biswas, New Directions in Tribology, Mechanical Engineering Publication, London, UK (1997).
2. A. Kapoor, K.L. Johnson, Plastic ratcheting as a mechanism of metallic wear, Proc. R. Soc. London A 445 (1994) 367-381.
3. J.F. Archard, Contact and rubbing of flat surfaces, Journal of Applied Physics 24 (1953) 981-988.
4. P. Podra, S. Andersson, Simulating sliding wear with finite element method, Tribology International 32 (1999) 71-81.
5. M. Oqvist, Numerical simulations of mild wear using updated geometry with different step size approaches, Wear 249 (2001) 6-11.
6. V. Hegadekatte, N. Huber, O. Kraft, Finite element based simulation of dry sliding wear, Tribology Letters 24 (2006) 51-60.
7. V. Hegadekatte, S. Kurzenhauser, N. Huber, O. Kraft, A predictive modeling scheme for wear in tribometers, Tribology International, 41 (2008) 1020-1031.
8. S. Mukras, N.H. Kim, W.G. Sawyer, D.B. Jackson, L.W. Bergquist, Numerical integration schemes and parallel computation for wear prediction using finite element method, Wear 266 (2009) 822-831.
9. K.L. Johnson, Contact Mechanics, Cambridge University Press, Cambridge, UK (1985).
10. H. Hertz, Ueber die beruehrung fester elastischer koerper, J. Reine und Angewandte Mathematik 92 (1882) 156-171.
11. W.C. Oliver, G.M. Pharr, An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments, J. Mat. Res 7 (1992) 1564-1583.