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FINITE ELEMENT SIMULATIONS OF THE EFFECT OF FRICTION COEFFICIENT IN FRETTING WEAR

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Abstract: Assuming a constant coefficient of friction (CoF) is a simplification in the finite element (FE) modelling of fretting wear. CoF is an essential factor of energy model for predicting fretting wear. Therefore, taking the variation of CoF into account during fretting wear cycles is necessary. In this research, based on the cylinder/flat fretting wear model, the effects of CoF are studied. At the end of fretting wear cycles, only slightly lower wear depth and wear width for the case of variable CoF model compared to the case of constant CoF model is observed. At the end of the initial running-in stage, the wear depth obtained from the variable CoF model is significantly different from that obtained from the constant CoF model.

Keywords: Fretting wear, FEM, Friction coefficient

1 INTRODUCTION

Finite element method (FEM) is widely used in the simulation of fretting wear. However, to balance efficiency and accuracy, FE model of fretting wear is usually simplified in some aspects, such as assuming constant coefficient of friction (CoF) during the wear process.

CoF is a system-dependent parameter rather than an intrinsic property of a material or combination of materials. It is sensitive to the sliding distance and environment parameters, such as contact pressure and surface quality [1]. Blau [2] grouped the factor impacting the friction behavior as: contact geometry, fluid properties and flow, lubricant chemistry, relative motion, applied forces, third-bodies, temperature and stiffness, and vibrations.

During fretting wear, both applied normal load and displacement have significant influence on CoF. Zhang et al. [3] shows that the CoF of the steady stage decreases with increasing the normal load for a given displacement condition. Similar tendency could also be found in the fretting coupling of high strength alloy steel [4] and steel wire [5]. This tendency may be explained as when the normal load is small, elastic deformation causes asperities of contact surfaces interlock with each other, inducing high CoF. When increasing normal load to activate plastic deformation of asperities, the CoF becomes lower due to less interlocking [3]. In addition, the displacement does affect the CoF under both dry and lubricated contact in a given normal load condition. Besides the continuous changing of contact pressure induced by evolution of contact geometry, debris also plays a significant role. Due to composition of the debris, a critical contact pressure exists at which a transition to a higher CoF occurs [6].

For a given fretting couple, evolution of CoF with number of fretting wear cycles usually could be divided into 3 stages. In the initial running-in stage, CoF is low since the contact surfaces are covered by the oxide and ‘nature pollution’ film weakening the adhesion between contact surfaces. Later on in the second stage, CoF increases gradually because of the removing of this film, and due to the increase of adhesion and abrasion in the substrate interfaces. Then, the balance between generation and ejection of debris are reached. Therefore, CoF keeps stable at this last stage [3].

The motivation of this work is to improve FE modelling of fretting wear in order to increase the accuracy compared to the experimental results. In this study, the effects of variation of CoF during the first few thousands cycles on fretting wear are studied. This paper is divided into 4 parts. After the introduction section, the FE model is described. Then, the effect of CoF are presented. Finally, a conclusion is presented.

2 FE MODEL

2.1 Geometry information

Fig. 1 shows the geometry of the FE model. The dimensions are the same as used in the literature [4], since the simulation results could be validated by the experimental results. The 4-node plane strain element (CPE4) is chosen and the mesh size is refined to 5 µm in the contact surfaces for both pad and sample. The master-slave, surface to surface and finite sliding are defined as the contact interaction. The bottom surface of cylinder is defined as master surface and the slave surface is the top surface of the sample.

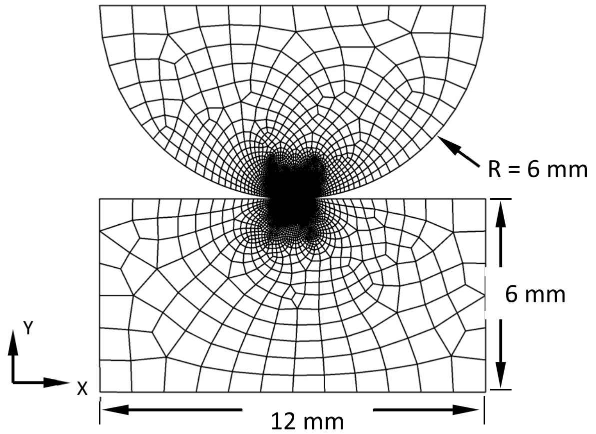


Fig. 1 Geometry and dimensions of basic model

2.2 CoF definition of the first 2500 cycles

In most FE simulations of fretting wear, the CoF is defined as a constant in which case both Archard model and energy model produce the same results. While as **Fig. 2** from reference [4] indicated, at the beginning of fretting wear process, it is in the running-in stage and CoF increases significantly during the first three thousands cycles in both normal load cases, i.e. 185 N and 500 N. Therefore, the influence of variable CoF should be considered in the fretting wear FE model, especially in the study of the running–in stage.

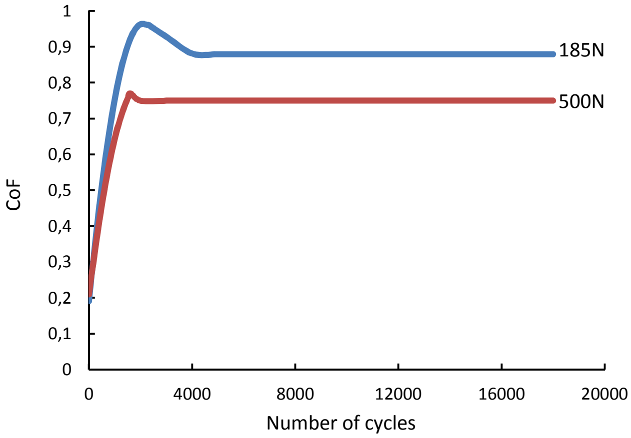


Fig. 2 Evolution of CoF during process of fretting wear for displacement amplitude 25 µm [4]

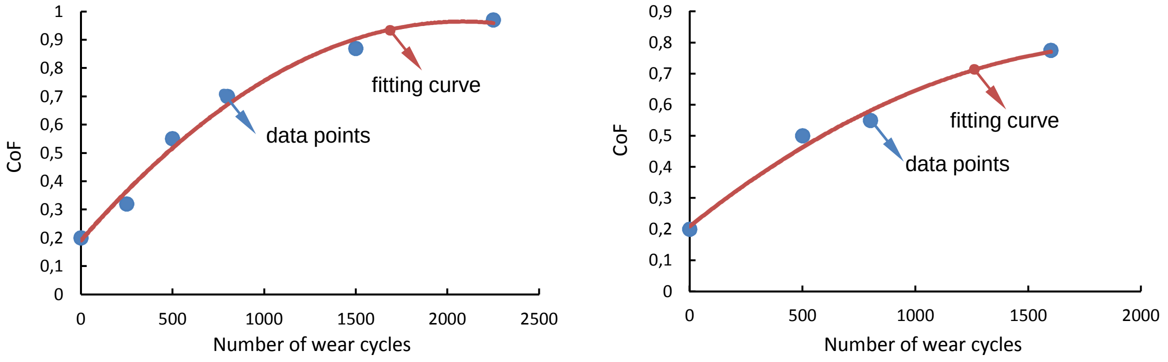
In order to obtain the relation between CoF and number of cycles, the CoF of 185 N and 500 N were extracted and the best fit is made, as illustrated in **Fig. 3** (a) and **Fig. 3** (b), respectively. Since the purpose of best fit is to gain the most accurate formulation describing this relation, the value of R^2 is the only factor considered. Thus, it is polynomial relation in which cases R^2 is closed to 1.

When normal load is 185 *N*, the best fit function which $R^2 = 0.989$ is:

$$CoF = (-1.784) \times 10^{-7} N^2 + 0.000743N + 0.191266 \qquad (1)$$

When normal load is 500 *N*, the best fit function which $R^2 = 0.985$ is:

$$CoF = (-1.428) \times 10^{-7} N^2 + 0.000579N + 0.2094 \qquad (2)$$



(a) (b)

Fig. 3 CoF points and fitting curves, (a) normal load=185 *N*, (b) normal load=500 *N*

2.3 Wear model

Due to explicitly including CoF, the energy wear model is utilized here to simulate the process of fretting wear. This model is proposed by Paulin et al. [7] and also described in our previous research [8]. For completeness and conciseness, the flow chart of wear calculation is presented in **Fig. 4**. The wear depth is calculated at the end of each time increment after achieving convergence of FE results, by the subroutine UMESHMOTION in ABAQUS.

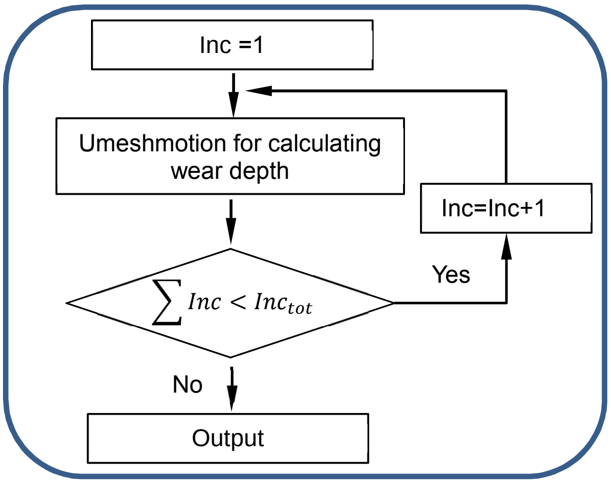


Fig. 4 Flow chart for fretting wear simulation: details of fretting wear module

2.4 Simulation parameters

The material property is the same as that used in reference [4]. Young’s modulus is 200 GPa and Poisson ratio is 0.3. For capturing the influence of CoF variation at the beginning stage, the jump cycle is 100 in both loading conditions until 2500 cycles. The CoF after 2500 cycles of basic model and the coefficient of wear employed in this study are listed in Table 1.

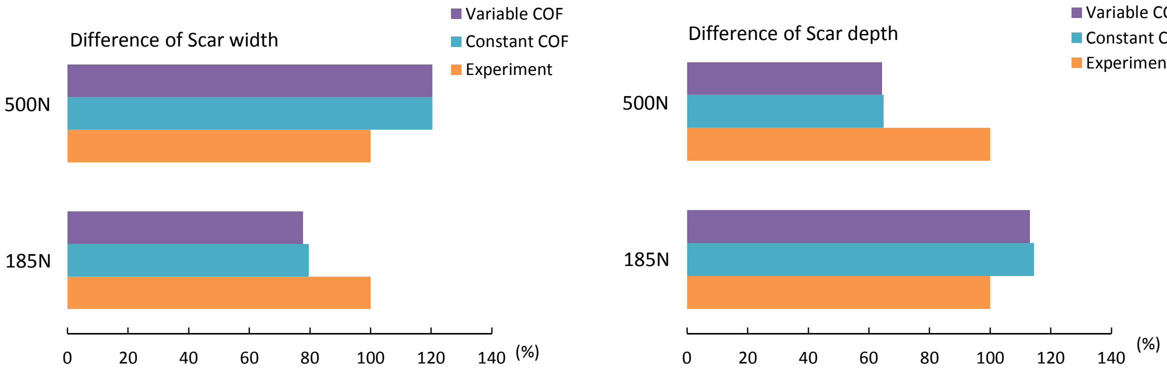
Table 1 Normal load and wear properties used in basic model

Parameters	Normal load(N)	
	185	500
CoF in steady state	0.88	0.75
α_E (MPa^{-1})	3.33×10^{-8}	7.33×10^{-8}
Displacement amplitude (μm), *S*	25	25
Total number of cycles, N_T	18000	18000
Running-in cycles, N_R	2500	2500
Jump cycle in running-in cycles, N_{JC1}	100	100
Jump cycle in transition	500	500
Jump cycle in remaining cycles, N_{JC2}	1000	1000

3 NUMERICAL RESULTS

3.1 Validation

After 18000 cycles, comparison between the results using variable CoF, constant CoF and experiments results of wear depth and wear width is shown in **Fig. 5**. For both normal load cases, the wear width and wear depth of variable CoF model are slightly lower than the basic model with constant CoF. However, considering experimental results, significant differences exist. When the normal load is 185 N, the wear width is underestimated by 20% and the wear depth is larger by 16%. When it increases to 500 N, FE model results are 20% more in wear width and 35% less in wear depth. The reasons for these differences between FE results and experimental ones could be because: a) the wear coefficient used in FE models is global wear coefficient instead of local wear coefficient and b) the influence of debris is not considered in FE models. From this comparison, it is found that variable CoF in full cycles of fretting wear simulation has little impact on the final result of FE fretting wear simulation.

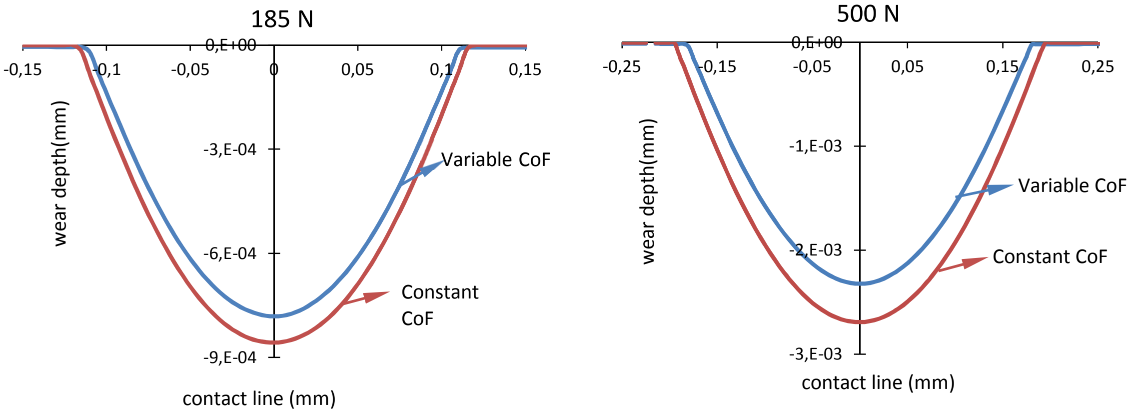


(a) (b)

Fig. 5 Comparison of scar width and depth between cylinder/flat FE model and experiments, N=185 N and 500 N, respectively. R=6 mm, applied displacement 25 mm (a) scar width, (b) scar depth

3.2 Fretting wear in the first 2500 cycles

Fig. 6 shows the wear scar after 2500 cycles in both CoF models. It is reasonable that the prediction of variable CoF model attains smaller wear scar. This is because that, at the running-in stage, the CoF is changing with time, but still less than the constant CoF used. Due to this lower CoF, less dissipated energy from frictional work is used for wear. From this point of view, energy wear model brings more realistic explanation for wear simulation than Archard model.



(a) (b)

Fig. 6 Wear scar comparison between variable CoF and constant CoF cylinder/flat models in first 3000 cycles, (a) normal load=185 N, and (b) normal load=500 N

The specific changes in percentage differences between the two models with number of cycles are shown in **Fig. 7**. For both normal load conditions, differences in wear depth, wear scar and peak contact pressure exhibit similar tendency; i.e. by increasing number of cycles, the differences between variable CoF and constant CoF models decreased. Especially, the differences of wear depth decreased smoothly from approximately 55% after 200 cycles to approximately 10% after 2500 cycles. These changes could be described by a polynomial formula as:

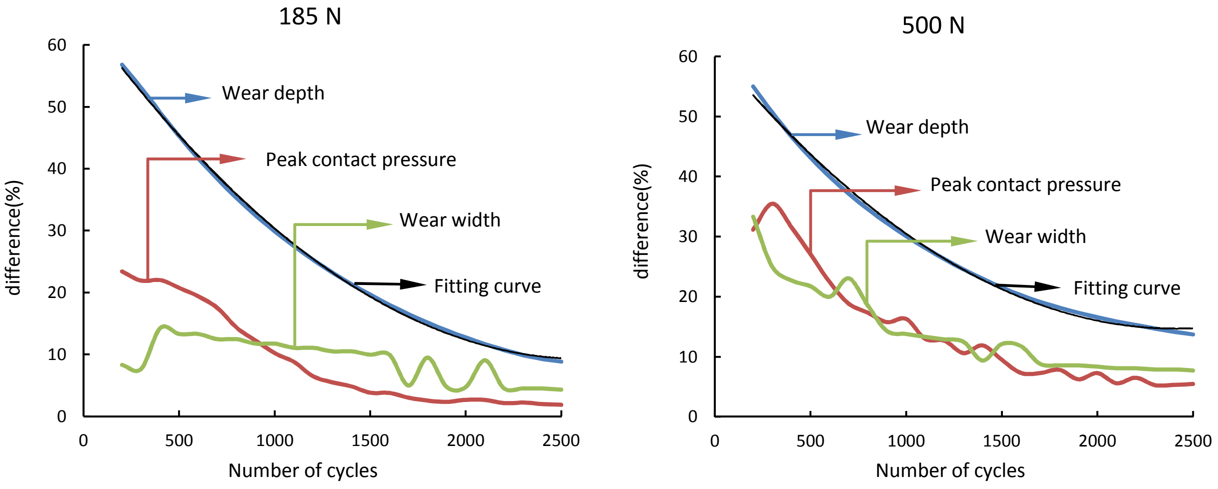
when normal load is 185 N,

$$difference = 8 \times 10^{-6}N^2 - 0.0421N + 64.391, R^2 = 0.9993 \quad (3)$$

When it is 500 N,

$$difference = 8 \times 10^{-6}N^2 - 0.0384N + 60.886, R^2 = 0.9978 \quad (4)$$

Thus, the wear depth after 2500 cycles could be calculated by the best fitting curve instead of fretting wear simulation. However, the other three variables are oscillated with number of cycles. The reasons for this oscillation would be further studied in future work.



(a) (b)

Fig. 7 Influence of variable CoF in wear depth, peak contact pressure and wear width in the first 2500 cycles. (a) normal load=185 N, and (b) normal load=500 N

4 CONCLUSIONS

Two FE models are generated to study the fretting wear process. The effect of variable CoF on fretting wear are analysed based on a basic model having a constant CoF. After 18000 cycles, there are very limited differences in wear width and wear depth between constant CoF and variable CoF fretting wear models. However, after the first 2500 cycles, where CoF increases significantly, the differences in wear width, wear depth and peak contact pressure are clear. All the differences of these variables decreased with time. Particularly, the differences of wear depth reduced smoothly from 55% to 10%.

5 ACKNOWLEDGEMENTS

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