The Effect of Interaction between Neighboring Asperity Contacts on Wear Mode Transition in Sliding Contact of Rough Surfaces

Tomohisa TANAKA *1, Chikara YAMANAKA*2, Keiji KYOGOKU*1, Tsunamitsu NAKAHARA*1

*1Department of Engineering, *2Department of Mechanical and Aerospace Engineering, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo, 152-8552, JAPAN

ABSTRACT
Concerning the final aim, that is to make clear the mechanism of the wear mode transition from mild to severe belong to the increase of contact pressure in adhesive wear, estimation of the yielding condition in subsurface under contact boundary between rough surfaces was attempted in this study. Especially the effects of interaction between neighboring contacts as well as relative sliding on the yielding area were focused. The contacts between asperities were modeled by the contact between two neighboring hard wedges with the parallel axes and soft plane to be simplified. These models were calculated by commercial FEM solver in 2-dimension. Additionally, the effect of the difference between the heights of two wedges on the yielding region was evaluated by comparing the result with that obtained from the simple model of two wedges with the same height in non-sliding contact. The results showed that the effect of the interaction between adjacent contacts and existence of relative slip motion give significant factors to the yielding state, on the other hand, the height difference between neighboring asperities affects little the determination of the yielding region.

INTRODUCTION
It is important to estimate contact condition and wear rate to prevent troubles in machinery. Generally, the wear condition can be divided roughly into two modes, mild wear and severe wear. Burwell and Strang [1] suggested that the transition of wear mode from mild to severe with increase in contact pressure in adhesive wear was caused by the condition when plastically deformed area wraps the whole nominal contact area. In recent years, the authors have tried to estimate the critical pressure at which the plastic region extends to whole the apparent contact area, theoretically and experimentally [2,3]. Each asperity contact was modeled by the contact between sphere and plane for single indentation condition, and by the solution of slip line field theory for sliding condition. Then the sum of plastic region of each contact was calculated with use of such stochastic contact theory.

While, to analyze the plastic region in contact subsurface, FEM analyses were tried on the contact model between a deformable spherical body and a rigid plane by some researchers. In those reports, however, the interaction between contacts of asperity was neglected. Therefore the estimation of critical pressure base on those outcomes can be thought to give inaccurate values even in only normal loading condition. Hence, this paper tries to take this interaction into consideration. To research the effect of interaction between neighboring contact spots, the geometrical models are constructed from a plane and a body which has some asperities with equal or different height although FEM are employed like the reports written above. On the other hand, the relative slip motion of two contact bodies were not consider in the Johnson’s cavity model and FEM analysis performed by other researchers. However effect of the slip is considered to be very important, thus this influence was also checked.

DETAIL OF THE FEM ANALYSES
In conventional study about the rough surface contact, summit of asperity was generally modeled by a sphere in 3-dimensional model or a cylinder in 2-dimensional model. While, two harder wedges are employed as the model of asperities in FEM analyses in this study. In this connection,
Johnson [4] reported validity to consider that the contact between wedge and plane is equivalent to that between cylinder and plane at least in elastic-plastic indentation problem by hard blunt wedge. Schematic illustration of the model of the hard upper body is presented in the figure 1. Two wedges on that body have parallel axes and wedge angles of those are the same, while those heights are not necessarily the same. Contact load is given on the upside of the harder body as distributed load. The solver used here is MSC MARC in combination with 2-dimensional plane strain condition and quadrangle isoparametric mesh model. Each body is assumed to be elastic-pure plastic materials. Material properties of the bodies are listed in Table 1 with other FEM parameters. At the beginning of the calculations, number of mesh is about 2000, while as the calculation progress, if plastic strain in some portion of the body becomes higher than some specific criterion meshes in the portion are divided and that step is recalculated. Therefore finally, the number become over 3000 in the almost all of the conditions although it depend on the calculation condition. The main parameter of the analyses is the ratio of the difference of height of two wedges $\Delta z/l$ and distance between two wedges $l$, and this parameter is controlled by changing $l$. The upper body which has the wedges is modeled by steel in the material property, while the plane is modeled by pure aluminum. In the slip condition, contact load is given in the same way to simple indent analysis, and after the load reached at specific value, then holding the normal load, load to tangential direction is applied for prescribed time.

RESULTS AND DISCUSSION

Some typical results are given as the samples. The figure 2 shows the yielding state for the wedge angle of 165 degrees and different height condition under normal loading. The yielding areas made by each wedge contact are just touching each other. Hatched area in the figure denotes the yielding area (in which the von Mises yield criterion is satisfied). From the figure, it can be remarked that each yielding area is spread a little to center than to outer. Thus it is expected that the yielding area grows if the adjacent contact exists nearby. To assure this idea, calculations for different $l$ have been performed. In the concrete, defining the distance between two wedges in the figure 2 as unity, 7 conditions from 0.5 to 1.5 were calculated for the same load with the figure 1. The figure 3 shows the results from these conditions, and additionally, the result obtained from the single wedge model is also shown as horizontal dashed line. The horizontal axis indicates the sum of length of the yielding area on surface in non-dimensional form dividing by twice of that obtained from single wedge calculation. While, the vertical axis is the non-dimensional distance (divide $l$ by that in the figure 2). Generally, it can be seen that the interaction of the contact makes the yielding area wider, and the area must approach unity for long $l$. On the contrary, if non-dimensional distance becomes shorter than unity, the yielding area properly decrease and must approach 0.5 (result for single wedge). The figure 4 shows the yielding area under slip condition. Contact load is the same with that in the figure 2. Comparing these two figures, it is given that the slip makes the yielding area larger and consequently makes the critical pressure lower.

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REFERENCES


Table 1 Material properties and parameters in analyses

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<tr>
<td>Young's modulus of the soft material (GPa)</td>
<td>70</td>
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<tr>
<td>Young's modulus of the hard material (GPa)</td>
<td>210</td>
</tr>
<tr>
<td>Yielding stress in tension of the soft material (MPa)</td>
<td>30</td>
</tr>
<tr>
<td>Yielding stress in tension of the hard material (MPa)</td>
<td>200</td>
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<tr>
<td>Wedge angle (degree)</td>
<td>165</td>
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<td>Friction coefficient on the contact boundary</td>
<td>0.2</td>
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<tr>
<td>Height difference ratio of two wedges $\Delta z/l$</td>
<td>1, 1/500 ~ 1/2000</td>
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Fig. 2 Yielding area in the softer plane for different wedge height under simple indentation

Fig. 3 Effect of the distance between wedges on the length of the yielding area

Fig. 4 Yielding area in the softer plane for the same condition to the figure 1 except that this is under slip condition