ELASTO-PLASTIC ASPERITY CONTACTS OF LAYERED MEDIA

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INTRODUCTION

Contact between rough surfaces plays an important role in friction, wear, and lubrication in tribological systems. An impressive number of works on the contact of rough surfaces have been done (see Ref. [1]). Deterministic asperity contact models, either for elastic-perfectly-plastic or elasto-plastic contact, have been examined in order to investigate the contact performance of surface asperities and the stress distribution of subsurface [2-3]. The deposition of layers is an effective way to improve the tribological performance of rough surfaces with layered materials, and the effects of different layer thickness and different coating-substrate materials on the contact between rough surfaces, especially the pressure distribution and subsurface stress-strain field in the considered the effects of different layered media on contact deformations and stress fields.

However, up to now, few papers were found to have considered the effects of different layered media on contact pressure distribution and subsurface stress-strain field in the elastic-plastic contact between rough surfaces, especially the influence of the yield strength of layered material on the contact performance. By utilizing an elasto-plastic contact model [2], this paper aims at studying the elasto-plastic contact performance of the rough surfaces with layered materials, and investigating the effects of layered material properties and the thickness of coatings on subsurface stress distributions.

ELASTO-PLASTIC CONTACT ALGORITHM

In plain-strain elastic-plastic contact analyses, the von Mises yield criterion is used to predict the plastic zone. The equivalent von Mises stress \( \sigma_{eq} \) is defined as:

\[
\sigma_{eq} = \sqrt{\frac{1}{2} \left[ (\sigma_{xx} - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_{zz})^2 + (\sigma_{zz} - \sigma_{xx})^2 \right]}
\]  
(1)

When \( \sigma_{eq} \) is greater than \( \sigma_y \), the yield strength of material, the material begins to yield. Due to yield, the mechanical behavior of a material will no longer be linear, and the plastic deformation of material will occur. The elasto-plastic FEM and a simplex-type algorithm presented in Ref. [2] are used for the calculation of the contacts between rough surfaces. The strain-hardening stress-strain relationship can be expressed as

\[
H' = \frac{\Delta \sigma}{\Delta \varepsilon_p} = \frac{E_T}{1 - \nu_s / E}
\]  
(2)

where \( H' \) is strain-hardening function related to the elasto-plastic tangential modulus, \( E_T \), and \( E \) the Young’s modulus.

Using the methods mentioned above, the contact between a real rough layered surface and a flat rigid plane is studied. The geometric parameter is the length of the calculation domain, \( L=0.32 \text{nm} \). The contacting model is meshed into 30300 three-node triangular elements with 15415 nodes. In order to express rough surface profile digitized directly from real tribological elements and predict the highly stressed zone of asperity contact, the horizontal and vertical nodal spaces at and directly below the surface are 1.0 \( \mu \text{m} \) and 0.3825 \( \mu \text{m} \). The yield strength, elastic modulus and Poisson’s ratio of the substrate material are equal to 600MPa, 200GPa and 0.3, respectively. The \( rms \) roughness of the surface profile used in the computation is 0.16 \( \mu \text{m} \). Using the ratio of \( E_C / E_S \), where \( E_C \) and \( E_S \) are the Young’s modulus of coating and substrate materials, the hard coating and soft coating are defined. The ratios of \( E_C / E_S = 0.5 \) and 2 mean soft coating and hard coating respectively. Then, different yield strengths of the coating material with different thicknesses of layers are used to observe...
the layered elastic-plastic contact properties. The tangential modulus can be $E_T=0.0$ and $0.1E$.

RESULTS AND DISCUSSION

Deformed surface profile and contact pressure for the layered (the thickness of coating is $100\text{rms}$) and unlayered mediums subjected to the average pressure $p=468\text{MPa}$ when yield strengths of the coating material are $1200\text{MPa}$ and $300\text{MPa}$ are shown in Fig.1. It can be observed from Fig.1(a) that the contact with small coating yield strength contributes a much small pressure peaks but large deformation and brings more asperities into contact. On the other hand, the asperities of the large coating yield strength behave like sharp punches and result in higherasperity contact pressure and smaller pressure-induced deformation. The same conclusions can be drawn up for the hard coating, as shown in Fig.1(b).

Figure 2 compares the relation between contact pressure and non-dimensional average gap for soft coating and hard coating separately with different coating yield strengths and different layer thicknesses. At the same pressure, the average gap increases with the increase of the yield strength. For the soft coating with different yield strengths, the thicker the coating is, the larger the average gap. As to the hard coating, when the coating yield strength is lower than that of substrate, the average gap decreases with the increase of thickness of coating. However, when the yield strength of coating is greater than that of substrate, the change trend is quite contrary.

The relationships of contact pressure and contact area with different coating yield strengths are shown in Fig.3. One can see that the real contact area decreases with the increase of the yield strength of the coating materials, whether the coating is soft or hard. Contours of the von Mises stress for different coating materials under the same load suggest that the majority of the soft coating material yield due to the smaller elastic modulus and yield strength, while the hard coating material has the far smaller plastic zone.

CONCLUSIONS

An elasto-plastic asperity contact model for layered media is employed in this paper to analyze the influence of different layer-substrate materials properties and different coating thicknesses on contact performances. The material is considered to be elastic-perfectly-plastic or elasto-plastic. The results show, at the same contact pressure, the average gap will increase while the real contact area will decrease with the increase of yield strength of the layer material.

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REFERENCES


FIGURES

Figure 1. Asperity contact pressures and deformed profiles for the (a) soft coating and (b) hard coating

Figure 2. Average gap vs. contact pressure with different thickness of the (a) soft coating and (b) hard coating

Figure 3. Contact area vs. contact pressure with the different yield strengths of the hard and soft coating material.