Tribology International 81 (2015) 53–60

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Thermomechanical modeling and transient analysis of sliding contacts between an elastic–plastic asperity and a rigid isothermal flat

Xi Shi [a,*], Aizhong Wu [b], Chuan Jin [a], Shaoxing Qu [c]

[a] *School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China*
[b] *Currently with Shanghai Institute of Special Equipment Inspection and Technical Research, Shanghai 200333, PR China*
[c] *Department of Engineering Mechanics, Zhejiang University, Hangzhou 310027, PR China*

A R T I C L E   I N F O

Article history:
Received 29 May 2014
Received in revised form
24 July 2014
Accepted 7 August 2014
Available online 17 August 2014

Keywords:
Thermomechanical contact
Frictional heat
Slip weakening

A B S T R A C T

To investigate thermomechanical contacts between an elastic–plastic sphere and a rigid flat, simulations with slip rates ranging from 0.1 m/s to 10 m/s were performed. As interfaces with strong interfacial bonding but weak substrate were specifically targeted, slip initiation was treated as shear failure of the softer material in numerical simulations. The simulations show that both sliding friction coefficient and friction stress are significantly dependent on slip rate while the maximum static friction coefficient is independent of that. Moreover, the energy release during the transition from full stick to full slip is comparable to the shear fracture energy of the material.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Frictional sliding is a typical thermomechanical problem. Most frictional work caused by mechanical contact of sliding surfaces transforms into heat, which leads to an increase of contact temperature and ultimately changes the material properties and friction behavior. At low slip rates, friction power, defined as the friction multiplied by the sliding speed, is small and the heat generated at asperity contact can diffuse away over the contact duration. Therefore, low-speed sliding contact results in small temperature increase and negligible effect on friction. At high slip rates, however, there is insufficient time for frictional heat to diffuse away, thus causing increase of contact temperature and decrease of friction [1]. Consequently, high-speed sliding can induce intense transient heating or even melting of contact junctions, such that leads to lower shear strength and friction [2–4].

The disk brake in a vehicle is one of the typical examples of thermomechanical contacts. In a disk brake device, the increase of contact temperature resulted from frictional heating can degrade the braking performance and foment the excessive wear of the friction pad. In addition, the local high temperature (hot spots) leads to non-uniform thermal expansion of the disk [5], such non-uniformity tends to cause a low frequency vibration known in automotive disk brake community as hot judder [6].

Undesirable impact between a slider and a rotating disk in magnetic storage system is another example of thermomechanical contacts. Erasure of information can occur during slider-disk impacts [7] as loss of data is mainly determined by the change of stress and temperature reached inside the magnetic recording film on top of the disk [8]. Interestingly in geophysics, thermomechanical behaviors of faults during earthquake slip have also been extensively investigated, and it is argued [1,9,10] that the flash temperature during earthquake slip can weaken the frictional resistance of the faults interface, and subsequently affect the seismic propagation.

Fully coupled thermal-stress analysis of frictional contact is a complex issue. In addition, it is computationally expensive to deterministically describe surface morphology, and hence simplifications are usually applied to the analysis. As assumed in the Greenwood and Williamson (GW) model [11], for instance, a real surface, randomly distributed with a large number of asperities, was simplified as a statistical surface covered with simple identical spherical asperities, the contact behaviors of real rough surfaces were then investigated by integration based on the simplified asperity contact model. It has been widely accepted that a meticulous study of a single asperity contact is a very fundamental step in investigating rough surfaces contact. On the other hand, contact behaviors of two bodies are significantly impacted by the mechanical properties of materials, which, often change with contact temperatures. Therefore, temperature-dependent material properties (e.g. Young's modulus, yield strength, etc.) should be appropriately weighted in understanding and predicting thermomechanical contact behavior. More importantly, knowing why and

---

[*] Corresponding author. Tel.: +86 21 34207061; fax: +86 21 34207062.
E-mail address: xishi@sjtu.edu.cn (X. Shi).

http://dx.doi.org/10.1016/j.triboint.2014.08.004
0301-679X/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

a	contact radius
a_0	contact radius before applying tangential load
A	contact area
E	Young's modulus
E^*	combined Young's modulus, $E^*=((1-\upsilon_1^2)/E_1+(1-\upsilon_2^2)/E_2)^{-1}$
ε_{pl}	plastic strain
ε_u	ultimate strain
ε_Y	engineering strain at yielding point
G	energy release due to friction transition from stick to slip
G_C	fracture energy
G_{IIC}	shear fracture energy
p	normal stress
P	normal load
P_0	normal load before applying tangential load
Q	friction force
r	radial co-ordinate measured from the center of the contact
R	radius of the sphere
t	loading time
T	temperature
T_0	unit simulation time
τ	shear stress
τ_c	critical shear stress
u_x	tangential displacement
V_x	tangential sliding velocity
x,y,z	Cartesian co-ordinates
μ	friction coefficient
μ_s	static friction coefficient
υ	Poisson's ratio
σ_c	critical stress for crack growth
σ_{true}	true stress
σ_u	ultimate strength
σ_Y	yield stress of material under uniaxial tension
ω_0	normal displacement before applying tangential load
ω_c	critical contact interference

how the variations of material properties influence the interfacial friction is a critical part in developing the simulation model.

In the literature, a large number of numerical investigations about thermomechanical contacts have been reported in the past few years. For example, in order to simulate the impact of slider and magnetic disk, finite element models have been developed [12–14], in which the slider and disk were modeled as a rigid sphere and an elastic–plastic body respectively. By performing a coupled thermal-stress analysis, the plastic deformation, contact temperature and contact stress evolution of layered or patterned media were determined. Similarly, the finite element method (FEM) was extensively adopted to investigate temperature rise [15,16] and friction-excited thermo-elastic instability (TEI) [17,18] during braking of vehicle. In addition to FEM, other numerical methods such as the conjugate gradient technique and the fast Fourier transform method were also utilized to investigate transient thermomechanical contact [19–21].

These existing studies are distinctive and valuable, however, in these works the phenomenological Coulomb friction law was employed while the temperature-dependent variations of friction coefficient were critically neglected. Different from the phenomenological friction law, a physics-based friction model has been proposed in our previous work [22]. For elastic–plastic contacts in that model a shear stress criterion was used to determine the local slip initiation, with which the friction transition from full stick (via partial slip) to gross sliding can be self-consistently simulated. In Ref. [22], however, the frictional heating had been ignored since the focus was primarily on the quasi-static contact. In this work, in order to investigate the transient sliding contact between a deformable spherical asperity and a rigid flat at different slip rates, the previously developed contact model was extended by taking frictional heating into consideration.

2. Thermomechanical contact model

2.1. Shear strength criterion for slip initiation

In a case that two bodies are pressed into contact by a normal load and then followed by a ramping tangential load, the applied tangential load will not give rise to gross sliding when it is less than the maximum static friction. However, a limited tangential loading will lead to a 'slip' of partial interface [23], while the remainder of the interface sustaining in a 'stick' contact. In pace with the increasing tangential loading, the stick zone keeps shrinking until the tangential force reaches a critical value at some point, which indicates impending gross sliding. In order to determine the local slip initiation, it was assumed that no slip occurs anywhere within the contact area at first [23], slip then is likely to occur in those regions where the shear traction τ exceeds a specified value τ_c. To address this issue, the local Coulomb friction law was typically adopted. According to Mindlin [24], for example, local slip occurs once the shear traction τ reaches to μp (μ, p are the coefficients of friction and contact pressure, respectively). A disadvantage of Coulomb friction model is that one has to know the friction coefficient before the solution, which is more or less arbitrary. For this reason, the local slip was treated as the interfacial failure, and the shear strength of the weaker material was set as the critical frictional shear stress τ_c in Ref [22]. Whenever the frictional shear stress in the contact area reaches the shear strength, local slip occurs at that point; and if all the points in the contact area slip, then the sphere is said to be in (gross) sliding contact with the flat. In the implementation, the contact pair was assumed to be in full stick condition before tangential loading; once tangential load is applied, the shear stress criterion was used to judge the sliding initiation. In FEM simulations the shear strength was set as $\sigma_Y/\sqrt{3}$, where σ_Y is the yield stress under uniaxial tension according to the von Mises criterion. As the local slip was assumed to associate with the failure of contact junction, the proposed incipient sliding criterion can straightforwardly manifest the dependence of friction on the mechanical properties of the material.

2.2. Temperature dependent yield strength

It has been known that the load carrying capacities of engineering materials are weakened as increasing temperature [25]; besides, the experiments confirmed that the contact temperature rise tends to weaken the frictional resistance of surfaces [1,2]. With these, it can plausibly be inferred that the influences of temperature on dry frictional contact are rooted primarily in the temperature dependence of material properties. Based on such an idea, in this work, the shear strength of the contact material is not constant any more but depends on temperature at each location inside the contact area. The critical shear stress was still set as $\sigma_Y/\sqrt{3}$, while σ_Y was considered as a function of contact

Download English Version:

https://daneshyari.com/en/article/7003095

Download Persian Version:

https://daneshyari.com/article/7003095

Daneshyari.com