RESEARCH ON ENERGY DISSIPATED IN A CYCLE OF ELASTIC ADHESION

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ABSTRACT: The present paper argues that adhesion forces and elastic deformation in the contact zone may contribute significantly to the relative displacement during fretting of metals. A simultaneously applied tangential force and normal into contact appears a adhesion force. A tangential force whose magnitude is less equal on greater than the force of limiting friction will not give rise on give rise to a sliding motion.It is determined the energy loss dissipated per fretting cycle.

KEY WORDS: energy, adhesion, slip

1. INTRODUCTION

We assume for simplicity, a contact of the sphere with the flat. The sphere has an elastic(Young's) modulus E_1 and Poisson's ratia ν_1 and the flat has an elastic modulus E_2 and Poisson's ratia ν_2 .It is further assumed that the bodies are ideally elastic material and that the contacting surface are perfectly smooth. A simultaneously applied tangential force F_x will generate a tangential traction $q(\bar{r})$ in the contact surface.

The tangential traction has the same direction everywhere and the points of equal traction are located on a circle with the radius $\bar{r}$.

From Hertizian theory it is known that the compact surface will then be circular, of radius [1], [2], [3].

$$a_H = \left(\frac{3F_z R}{4E^*}\right)^{1/3}$$

where F_Z is the applied normal load, R is the radius of curvature of the sphere, $\frac{1}{E^*} = \frac{(1-\nu_1^2)}{E_1} + \frac{(1-\nu_2^2)}{E_2}$, E^*- the equivalent elastic modulus.

2. ENERGY DISSIPATED IN A CYCLE OF ELASTIC ADHESION

We consider for simplicity the contact between a sphere and a plan. The sphere has the elastic modulus (Young) E_1 and the Poisson coefficient ν_1 and the planar surface E_2 and the Poisson coefficient ν_2

The bodies of ideal elastic materials are considered and the surfaces in contact are perfectly cleaned.

When the angular force increases from zero, micro-slip occurs at the edge of the contact circle penetrating the inside of the radius circle as given by equation (1). [4], [5].

$$c_a(\tau_0,\bar{\beta},k,k_{ad}) = \frac{c}{a} = (1-\frac{\bar{F}}{\beta k_a})^{1/3} = \left(1-\frac{k}{\beta k_{af}(\tau_0,\beta,k_{ad})}\right)^{1/3}. \quad (1)$$

When tangential force $F_x = \mu F_z$ and radius c_a=0 the coarse slip conditions for each point in contact are established. Because the coefficient of friction at slip(μ_k) is less than the static friction coefficient(μ) after the first load with traction load $\bar{F} = \mu$ tangential force decreases at $\bar{F} = \mu_k$. In this case, if the sliding on the surface is continuous, other soldering / sliding movements occur.

During the macro-sliding (total slip) tangential force F_x is provided by the elastic force. For the simple case when μ_k is constant it is possible to determine the dissipated energy per cycle (ΔW) cycle for directional and constant sliding (Fig.1)

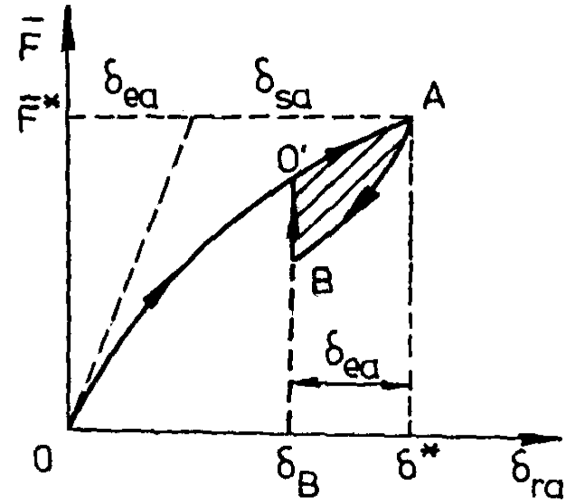

Fig.1 The energy dissipated for one cycle[6]

$$\Delta W = W_{O'A} + W_{AB} + W_{BO'} \qquad (2)$$

where:

$W_{O'A}, W_{AB}, W_{BO'}$ are mechanical energies for curves O'A, AB respectively BO'

Tangential displacement during load (OA) is found using the equation (3)

$$\delta_{rap} = \frac{\pi\beta}{4}\left(1+\frac{E^*}{G^*}\right)\,(1-2\,\bar{p}_0)\left[1-\left(1-\frac{\bar{F}}{\beta k_a}\right)^{2/3}\right] \qquad (3)$$

and using angular traction:

$$\overline{F_{bOA}}\left(\tau_0,\beta,k,k_{ad},p_0',\delta_{r0}\right) = \beta k_{af}\left[1-\left(1-\delta_{r0}/m\right)^{3/2}\right] \qquad (4)$$

with:

$$m\left(\beta,p_0'\right) = \frac{\pi}{4}\beta\left(1-2p_0'\right)\left(1+\frac{E^*}{G^*}\right)$$

the equation for energy determination is:

$$W_{OA}\left(\tau_0,\beta,k,k_{ad,}p_0'\delta_s\right) = \int_0^{\delta^*} F d\delta_{ra} = \beta k_{af}\left\{\delta^* - \left(2/5\right)m\left[1-\left(1-\delta^*/m\right)^{5/2}\right]\right\} \qquad (5)$$

Energy $W_{OA}\left(\tau_0,\beta,k,k_{ad},p_0',\delta_s\right)$ is representated in fig.2 $\left(\delta_s = \delta^*\right)$.

For $\overline{F} = \beta k_a$ (the start of the total slip), $\delta^* = m$ and:

$$W_{OA} = \left(3/5\right)\beta k_a \delta^* \qquad (6)$$

Tangential displacement during discharge (AB) will be:

$$\delta_{ua} = \left(\delta_{ua}/a\right)\left(E^*/p_0\right) = \left(\pi/4\right)\mu_k\left(1+E_*/G^*\right)\left\{2\left[1-\left(\overline{F^*}-\overline{F_{bAB}}\right)/\left(2\mu_k\right)\right]^{2/3}-1\right\} \qquad (7)$$

with:

$$\overline{F}_{bAB}\left(\tau_0,\beta,\delta_s,k,k_{ad},p_0',\mu_k,\delta_{r0}\right) = \overline{F^*} + 2\mu_k\left[\delta_{ra}/(2n)+b\right]^{3/2} \qquad (7')$$

where:

$$n = \left(\pi/4\right)\mu_k\left(1+E^*/G^*\right),$$

and

$$b = \left(1/2\right) + \left(\frac{1}{2}\right)\left(1-\frac{\overline{F^*}}{\mu_k}\right)^{2/3}$$

Force $\overline{F_{bOA}}\left(\tau_0,\beta,k,k_{ad},p_0',\delta_{r0}\right)$ is given in fig.3 and force $\overline{F}_{bAB}\left(\tau_0,\beta,\delta_s,k,k_{ad},p_0',\mu_k,\delta_{r0}\right)$ in fig.4

Because the O'ABA curve is continuous, the following condition results:

$$\left(\beta/\mu_k\right)\left(1-2\overline{p_0'}\right) = 1-\left(1-\beta k_a/\mu_k\right)^{2/3} \qquad (8)$$

to begin total slip with a kinetic coefficient of friction.

During the total slip, the elastic movement component is restored $\left(\delta_{ea}\right)$ and detreminated from the relation (9)

$$\bar{\delta}_{ea} = \frac{\delta_{ea}}{a}\frac{E^*}{p_0} = \frac{\pi}{6}\left(1+\frac{E^*}{G^*}\right)\overline{F}, \qquad (9)$$

Replacing $\overline{F} = F_x/F_z = \beta k_a$

Results:

$$\delta_{ea} = \left(\pi/6\right)\beta k_a\left(1+E^*/G^*\right)$$

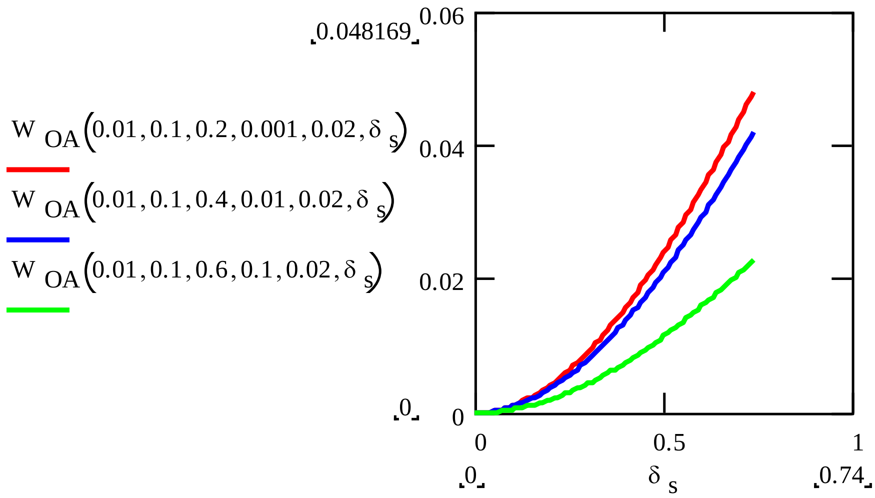

Fig.2 Energy $W_{OA}\left(\tau_0, \beta, k, k_{ad}, p_0^{'}, \delta_s\right)$[7]

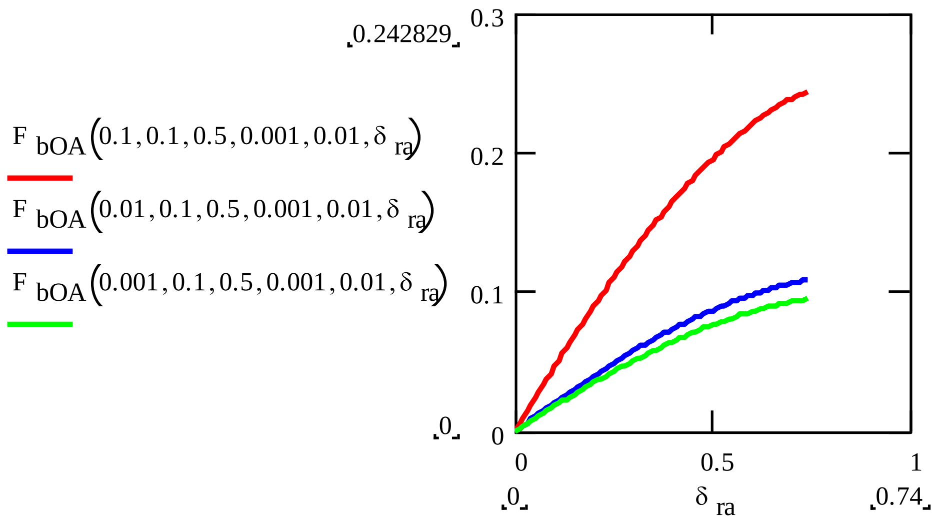

Fig.3 Force $\overline{F_{bOA}}\left(\tau_0, \beta, k, k_{ad}, p_0^{'}, \delta_{r0}\right)$[7]

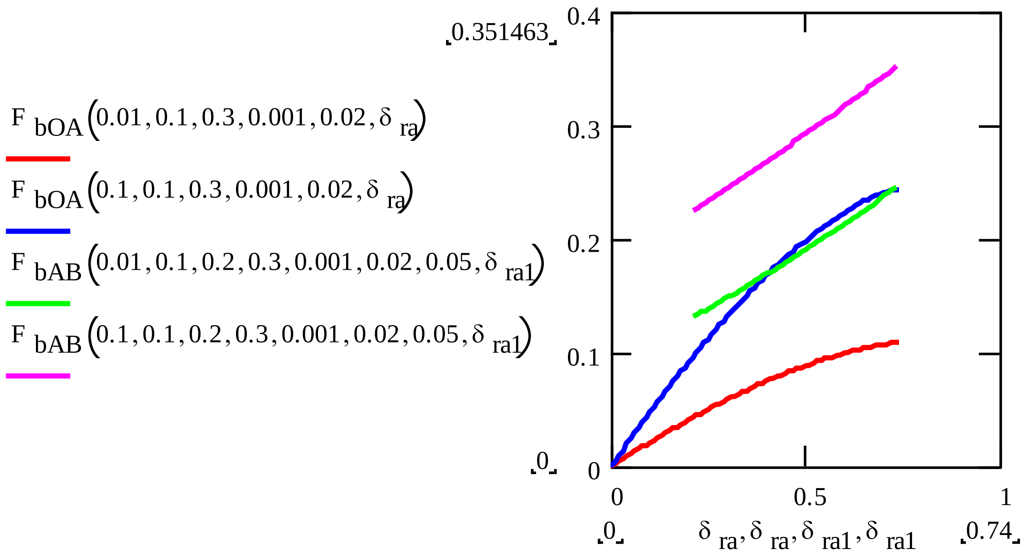

Fig.4 Force $\overline{F}_{bAB}\left(\tau_0, \beta, \delta_s, k, k_{ad}, p_0^{'}, \mu_k, \delta_{r0}\right)$[7]

At the end of the total slip, the coefficient of friction passes from μ_k (kinetic coefficient of friction) at μ (static coefficient of friction), the displacement at point B being:

$$\delta_B = \delta^* - \delta_{ea} = \left(\pi/12\right)\beta\left(1 + E^*/G^*\right)\left(3 - 2k_a - 6\overline{p_0'}\right) \tag{10}$$

The mechanical energy $W_{O'A}$ for the stabilized cycle, will be[8], [9]:

$$W_{O'A} = \int_{\delta_B}^{\delta^*} \overline{F} d\delta_{ra} = \beta k_a \left[\delta_{ea} - \left(2m/5\right)\left(1 - \delta_B/m\right)^{5/2}\right] \tag{11}$$

The mechanical energy, W_{AB} :

$$W_{AB} = \int_{\delta^*}^{\delta_B} \overline{F} d\delta_{ra} = -(\beta k_a - 2\mu_k)\delta_{ea} - \left(4n/5\right)\left\{\left[\delta^*/(2n) + b\right]^{5/2} - \left[\delta_B/(2n) + b\right]^{5/2}\right\} \tag{12}$$

And:

$$W_{BO'} = 0$$

The area inside the curve of Fig.1 represents the energy dissipated during the sliding-sliding motion: $\Delta W = W_{O''A} + W_{AB}$, this energy contributing to the formation of the "third body" for an oscillatory motion with the relative period:

$$\overline{T} = \frac{T}{T_z} = \frac{\delta_{ea} p_0}{2E^*} \tag{13}$$

where: T is the sliding bonding period and T_z is the period of contact slippage ($T_z = a/v$, v - being the continuous sliding speed).

Dissipated cycle energy contributes to material fatigue and wear particles. For the elastic adhesion model, this energy is constant if the friction conditions are the same

3. CONCLUSIONS

Dissipated cycle energy contributes to material fatigue and wear particles. For the elastic adhesion model, this energy is constant if the friction conditions are the same

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