CALCULUS OF TEMPERATURE FOR SLIDING INDENTATION

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ABSTRACT

The paper presents the influence of speed and normal indentation force on the rise of interface temperature values for sliding indentation into a sliding tribosystem. It is bring into relief, briefly, the negative effects of temperature on thermal and mechanical characteristic of a material on and near the surface. Taking into account this influence low speed values were chosen. The theoretical study is realized for a hard steel ball sliding on a flat piece. Their hardness differs very much so the ball can be considered rigid. It was obtained that for the considered ball speeds and normal forces the Peclet number has a very low value and consequently the rise of the surface temperature is also very low.

KEYWORDS: state temperature, sliding indentation.

1. GENERAL CONSIDERATIONS

In tribosystems with sliding or rolling with sliding, a part of the mechanical work of the sliding forces transforms into heat. This causes a raise of the temperature on the contact surface [2, 8].

The thermal effect is generally disregarded in contact theory. It is considered that between the bodies that came in contact there are no temperature differences, and that the temperature on the contact surface is equal to those of the bodies, no matter the type of the tribosystem (with or without sliding).

In [11] it is considered that the temperature variation inside the triboelements presenting different thermal and elastic constants generates additional thermal tensions, which influence the contact condition by modifying, among other things, of the radius of curvature of the bodies. This leads to the changing of the contact surface and of the tension condition.

On the other hand, the contact pressure determines the distribution and the values of temperatures on the contact surface. This situation allows for the thermal distortion of the profiles and the distribution of the contact pressure to represent correlated aspects.

The thermal regime is one of the main factors that influence the tribological behaviour [14, 12, 15, 16]. Thus, for the lubricated contacts, temperature rising generates lowering of the lubricant viscosity, affecting the thickness of the lubricant layer and the thermal instability of the additives. It is known that surpassing of a certain limit of temperature also influences the physical and chemical properties of the material of the bodies in contact [4, 7, 10]. Firstly the flow limit is diminished [3, 17]. It was found [17] that for partially stabilised zirconium this diminution is of 2.84MPa/°C. The lowering of the elasticity limit results in the diminution of the pressure at which the passing from the elastic to elasto-plastic domain takes place, thus creating the favourable environment for the oxidation wear and thermal wear to appear.

In papers [5, 6] were shown the parameters of the superficial layer and the operating parameters of the tribosystems with sliding that influence the quantity of generated heat and the temperature of the tribosystems which are in contact.

The paper presents a theoretical analysis of the thermal regime for the sliding indentation, i.e. for the situation when an indenter has a sliding motion.

The study has been performed for the tribosystem in the figure 1.

2. DETERMINATION OF THE TEMPERATURE

The amount of generated heat, for a time unit, is

\[ Q = F_t \cdot v \]  

(1)

where: \( F_t \) – friction force; \( v \) - sliding speed.
The corresponding heat flux, considered as having a uniform distribution on the projection of the contact area, is as follows:

\[ q = \frac{4 \cdot F_n \cdot v}{\pi \cdot a^2} = \frac{4 \cdot \mu \cdot F_n \cdot v}{\pi \cdot a^2} \]  

(2)

where: \(a\) – breadth of the plastic trace for indentation with sliding (see fig.1).

The Peclet number, according to which the speed of the heat source is appreciated, is determined by:

\[ P_e = \frac{v a}{4 \alpha} = \frac{v a p C}{4 K} \]  

(3)

where: \(C\) – specific heat; \(\rho\) – specific density; \(K\) – thermal conductivity; \(\alpha\) – thermal diffusion coefficient.

If \(P_e > 5\), it is considered that the thermal source is moving, and if \(P_e < 5\), it is stationary [14].

For mobile heat sources \(q\) with the speed \(v\) on a semifinite solid plan, the medium raise of the regime temperature is determined by using [16, 1]:

\[ T = \frac{1.22 qa}{2 \cdot K \sqrt{\pi (0.6575 + P_e)}} \]  

(4)

and for sources considered being stationary, with:

\[ T = \frac{8q \cdot a}{6 \alpha K} \]  

(5)

It is necessary that fractions \((R)\) and \((I-R)\) of the heat flux that are part of the fix triboelement – noted here FT, and of the mobile one respectively – noted here MT, to be determined.

These have been estimated by using the energy partition method proposed by Blok, in 1937. For equilibrium conditions the temperatures of the two elements are equal. If we equal the temperature raise for the ball and the fix triboelement, we get:

\[ R = \frac{1}{I + \frac{3 \cdot 6.6 \pi}{8} \frac{K_{TM}}{K_{TF}} \frac{1}{\sqrt{\pi (0.6575 + P_e)}}} \]  

(6)

From the above equation, for the fraction of thermal flux \((R)\) that is part of the fix triboelement we further obtain:

\[ R = \frac{1}{I + \frac{3 \cdot 6.6 \pi}{8} \frac{K_{TM}}{K_{TF}} \frac{1}{\sqrt{\pi (0.6575 + P_e)}}} \]  

(7)

The rising of the contact temperature can be determined, according to the equations above, by:

\[ T = \frac{4.88 \cdot \mu \cdot v \cdot F_n}{\pi \cdot a} \]  

(8)

\[ K_{FT} \sqrt{\pi (0.6575 + P_e)} + \frac{3.66 \alpha K_{MT}}{8} \]

The breadth of the plastic trace “\(a\)” depends on indentation normal force \(F_n\) as determined in [13]. For steel with 180HV the relation between them is:

\[ a = 5 \cdot 10^{-12} \cdot F_n^3 - 3 \cdot 10^{-8} \cdot F_n^2 + 0.0004 \cdot F_n + 0.9163 \]  

(9)

The graphics of the Peclet number variations and of the temperature have been drawn (fig. 2 and fig. 3), considering \(\mu = 0.15\); \(\rho = 7840\) Kg/m\(^3\); \(C = 412\) J/Kg/K and \(K = 47\) W/m/K. The maximum value for speed was 0.2 mm/s.

### 3. DISCUSSION

Relation (6) has been determined for the following hypotheses:

- the thermal properties of the bodies are not influenced by temperature;
- the generated heat has a uniform distribution inside the contact area;
- all heat that is produced is taken over by bodies;
- the friction coefficient between bodies has a constant value.

The phenomena and processes that take place on the contact surface do not respect the above
mentioned hypotheses. The thermal conductivity, the density, the specific heat and the elastic module present high variations with the temperature.

The distribution of heat generated along the contact breadth takes after the pressure variation. Part of the generated heat is emitted in the environment, and the friction coefficient shows big enough variations during movement [9].

These phenomena and processes allow for the temperature to display a maximum that is displaced towards the back of the contact area. The movement is more noticeable for bigger values of the Peclet number. In this situation, the generated heat is distributed more on the surface and less in depth.

For smaller values of the Peclet number that were obtained, in the analysis presented in this paper the temperature variation is much flattened. An important part of the generated heat is transmitted inside the body, in depths comparable with the contact breadth.

4. CONCLUSION

For speeds and forces considered, the thermal regime (temperature rising) can be disregarded. Thus, an isothermal regime is fulfilled.

REFERENCES