

CONSIDERATIONS REGARDING THE EFFECTS OF TEMPERATURE INCREASE ON THE HARDNESS OF MATERIALS IN FRICTION COUPLINGS WITH SLIDING MOTION

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Abstract: The temperature on the surfaces in sliding motion changes as a result of the operating conditions. The temperature distribution generated during the friction process depends on the forces generated in operation, the speed of sliding, the topography of the surface, the properties of the materials that form the friction coupling.

The purpose of this paper is to analyze the effects of temperature increase on surfaces in sliding motion with implications on the hardness of friction coupling materials.

Keywords: temperature, contact area, hardness

1. INTRODUCTION

As a result of the sliding of two surfaces in contact, there is a release of heat that can lead to changes in the properties and characteristics of the materials in contact. The initiation of such a thermal process is influenced by a surface film that has thermal and mechanical properties different from those of the material layer [1,2,3,4,5].

When the contact pressures have high values, the real contact area is close to or even equal to the contact normal or apparent area and the heat transfer is considered as being one-dimensional.

When the contact pressures have low values, the contact occurs on a finite number of asperities distributed on the nominal or apparent area. In this case, the heat transfer from these asperities to the entire body is three-dimensional.

2. MATHEMATICAL MODELING OF THE HEAT TRANSFER PHENOMENON

In case of the solid isotropic materials of which thermal properties do not change with the temperature, the equation of the energy for the heat conduction has the following form:

$$\frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial z^2} + \frac{W'}{\lambda} = \frac{1}{a} \frac{\partial \theta}{\partial t} \quad (1)$$

where: θ - the temperature;
 x, y, z - cartesian coordinates;

a - the thermal diffusivity $a = \lambda / \rho c$;
 λ - thermal conductivity of the material;
 ρ - density;
 c - specific heat;
 W' - the velocity of generating the heat partition inside of the solid on the unit volume.

For contacts in relative motion, the generated temperature is a moving source. As a result, the temperature at a certain point changes over time. When there are several heat sources (multiple contact points) the temperature at the considered point is influenced by all sources.

In case of a mobile source rectangular type slide-guide ways (having the dimension $B \cdot D$), the average heat flow (q) generated on the contact surface (A_n) when this one moves at the velocity " v " under normal load " F ", is the form:

$$q = \mu \frac{F \cdot v}{A_n} = \mu p v \quad (2)$$

where: μ - the molecular mechanical friction coefficient in the considered point on the surface;
 p - the pressure in the same point;
 v - the relative velocity between surfaces.

A part of this heat flow diffused in the mobile source (the slide) $q_2 = \alpha q$ and the remaining part in the fixed surface (the guide ways) $q_1 = (1 - \alpha)q$. A low fraction of the heat flow in the slide is dissipated through radiation and the rest is dissipated through conductivity and absorbed by the whole mass of the slide.

The assessment of the partition coefficient of the heat is made based on Jaeger hypothesis [4,5,6,7,8], namely the average temperature on the mobile surface (the slide) is equal to the temperature on the fixed surface (of the guide ways). When the heat flow is one-dimensional, the partition coefficient is a simple function depending on the material thermal conductivity.

In order to establish the partition coefficient, it can be considered that the moving speed of the moving element has a decisive influence on the heat dissipation between the sliding coupling elements. In the proposed model, the sliding speed is parameterized. In the specific case of the sliding speed of a rectangular mobile source – the Peclet invariant has the following form:

$$Pe = \frac{vL}{4a_2} \quad (3)$$

where: L – the side of the square, equivalent to heat generation and dissipation $L = \sqrt{BD}$;
 a_2 – the thermal diffusivity of the mobile element material.

Due to the large speed range at which a sliding motion coupling can operate, this invariant can be considered to have values from $0 \leq Pe_1 \leq 0,1$; $0,1 < Pe_2 \leq 5$; $5 < Pe_3 \leq 100$.

Under these conditions, the partition coefficient α on the three ranges of the dimensionless velocity will be:

a) $0 \leq Pe_1 \leq 0,1$

$$\alpha_{01} = \frac{\lambda_1}{\lambda_1 + \lambda_2} \quad (4)$$

b) $5 < Pe_3 \leq 100$

$$\alpha_5 = \frac{1}{1 + 0,795 \frac{\lambda_2}{\lambda_1} \left(\frac{a_1}{a_2} \right)^{1/2} Pe^{1/2}} \quad (4')$$

c) $0,1 < Pe_2 \leq 5$

$$\alpha = (1,02 \cdot \alpha_{01} - 0,02 \cdot \alpha_5) + 0,204(\alpha_5 - \alpha_{01})Pe \quad (4'')$$

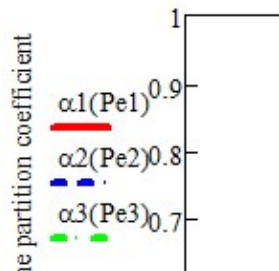


Figure1. The evolution of the partition coefficient of the heat function of the invariant Pe

Figure 1 shows the evolution of the partition coefficient of the heat function of the invariant Pe considered as an indicator of the working parameters.

3. THE HEAT REGIME ESTABLISHED BY MOBILE SOURCE OF HEAT

In the process of force transmission and in the presence of relative motion, in a friction coupling, the phenomena occur at the level of the real contact area. Thus, at the level of the nominal surface, an average temperature of the nominal surface and an instantaneous local temperature of the local micro-zones at the level of the asperities in contact can be defined.

a) The average temperature

By accepting the Jager hypothesis [4,8] according to which the average temperature on the mobile surface is equal to the one on the fixed surface, as soon as the status of thermal balance is achieved, the average temperature of the contact surface will be:

$$T_m = T_o + \alpha \mu p l_m / \lambda_2 \quad (5)$$

where: λ_2 – the thermal conductivity of the mobile surface material;

l_m – the diffusion distance of the heat toward the attachment mechanism of the mobile element;

T_o – the temperature of the attachment system that can be considered 20°C.

Figure 2 shows the evolution of the average temperature of the surfaces being in contact function of pressure, the dimensional elements and the invariant Pe on the 3 ranges of values. The average temperature increase generated by the friction of the surfaces with the load (the pressure generated on the surfaces) and the invariant Pe (on the three intervals) is noted.

A variation of friction coupling material durability with average temperature is accepted [5,6] having the following form:

$$H = H_o (1 + m \cdot \ln(b / T_m)) \quad (6)$$

where: m , b – the constant parameters, experimentally established.

Figure 3 shows how the hardness varies at the average temperature depending on the load (the pressure exerted on the surfaces in contact) and the invariant Pe. For a friction couple with known dimensions, the average temperature increases with loading for the three ranges of the invariant Pe.

The maximum temperature is considered to be the melting temperature of the asperities of the surfaces in contact.

b) Instant warming

The actual contact surface is always smaller than the nominal surface (area), so the amount of heat is significantly higher compared to the nominal one.

It is admitted the hypothesis according to which the real contact area (A_r) increases with the external load as a

result of increasing the number of micro areas (N) and not as a result of increasing the size of the micro area.

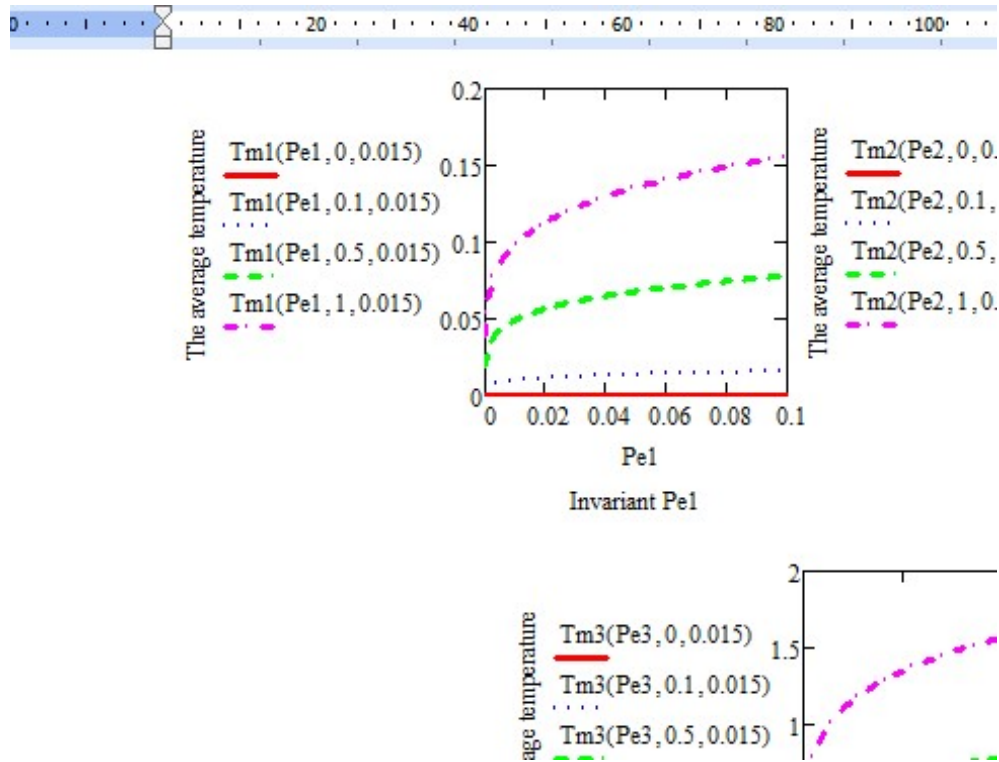


Figure2. The evolution of the average temperature with the load for the 3 intervals of the invariant Pe

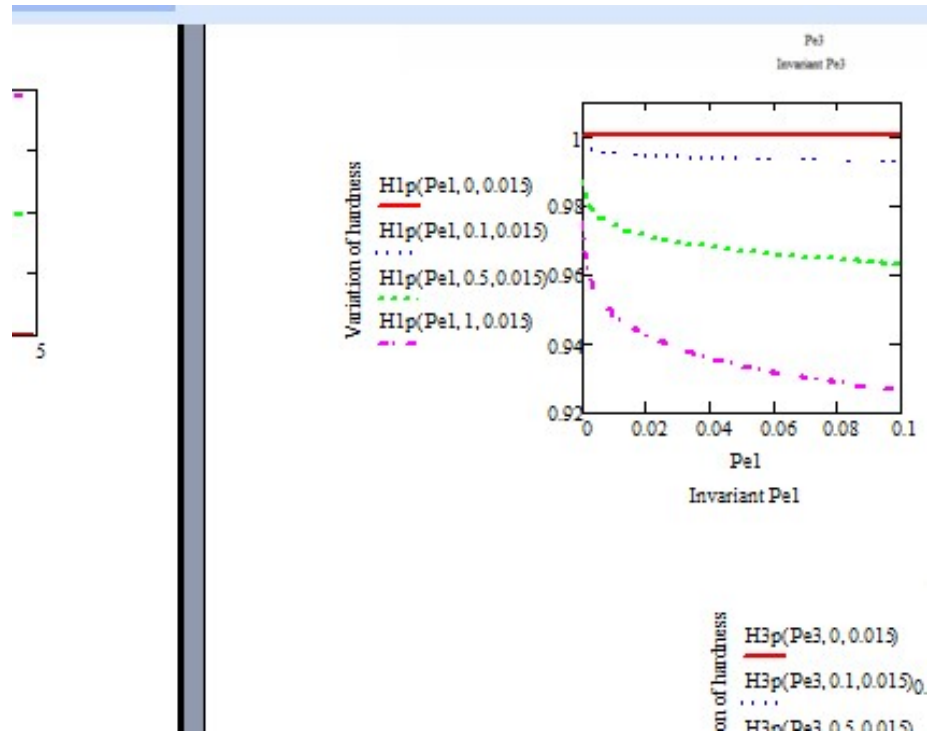


Figure 3. Evolution of hardness at average temperature with loading for the 3 intervals of the invariant Pe

At the same time one can mention that at a very low value of loading ($p \rightarrow 0$) the total number of micro areas $N \rightarrow 1$ and at high values of loading ($p \rightarrow 1$) the micro areas “join themselves” so as $N \rightarrow 1$ and $A_n = A_r$. In order to evaluate the average instant warming on the real contact area for high and low values of Peclet numbers one can accept Tian and Kennedy solutions [3,4] for temperature increase:

$$\Delta T_i = \frac{1,21 r_a \cdot q'}{\lambda_2 \pi^{1/2} (0,6575 + Pe')^{1/2}} \quad (7)$$

where: q' – the average heat flow that is generated through friction at the level of each rugosity;

r_a – the radius of the circular micro contact;

Pe' – the Peclet invariant at the level of the contact micro areas $Pe' = 2 r_a Pe/L$.

For a friction coupler with known dimensional characteristics, figure 4 shows the evolution of the instant warming, the pressure function and the Peclet invariant for the three intervals.

The effects of the average and/or instant warming increase and of the deformation status of the materials is appreciated through decreasing the hardness and of the micro hardness and implicitly through the apparition of the local plastic deformations. Accepting the Lim and Ashby law of variation of temperature as a function of hardness and strain as having the form:

$$\frac{H'}{H_o} = 1 - \frac{\Delta T_i}{20T_i} \cdot \ln \frac{10^6}{\beta \cdot Pe} \quad (8)$$

where: T_i – the melting temperature of the material;
 β – the dimensional characteristic.

Figure 5.a. b shows the variation of the hardness depending on the instant warming with the working parameters (pressure, the invariant Pe) for different dimensional characteristics of the friction coupling.

Figure 5a shows a decrease in hardness with increasing pressure. This decrease is greater at low sliding speeds.

Figure 5b shows the decrease in hardness with increasing speed and at high loads it stabilizes.

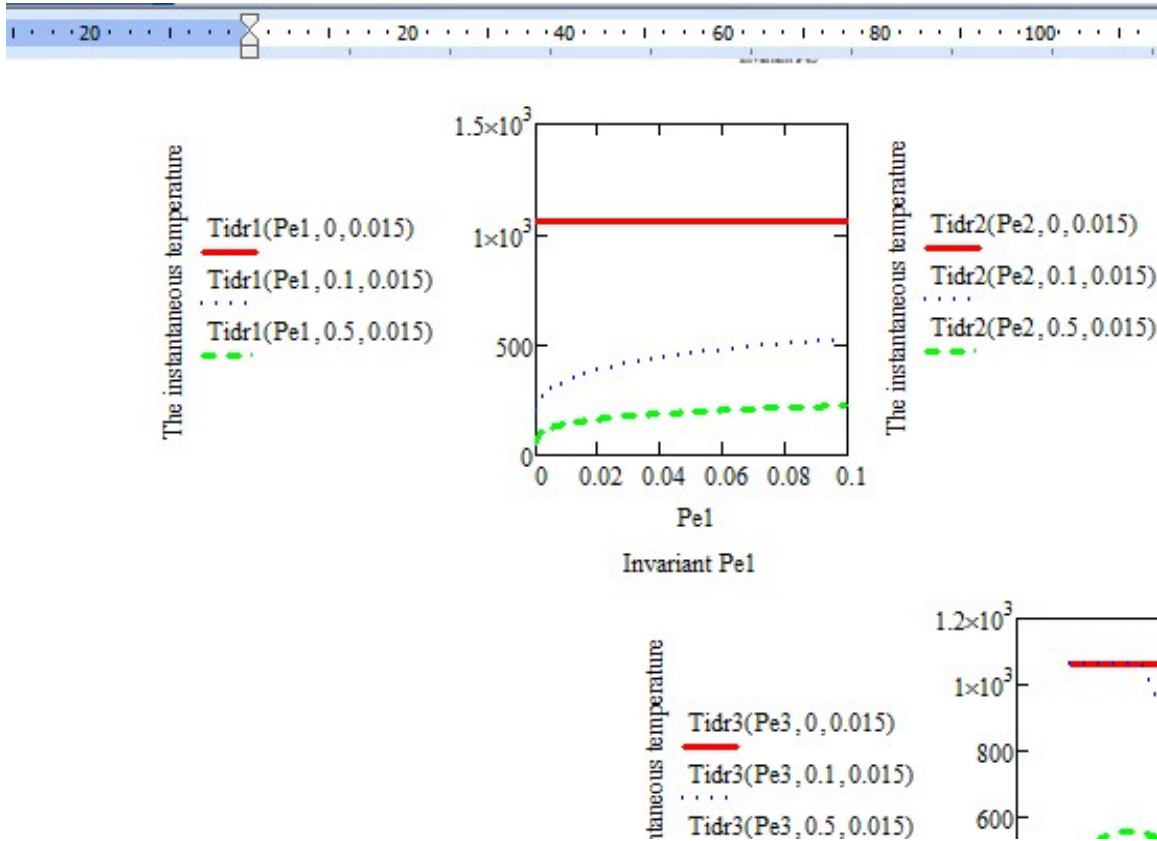


Figure 4. The evolution of the instant warming, the pressure function and the Peclet invariant for the three intervals

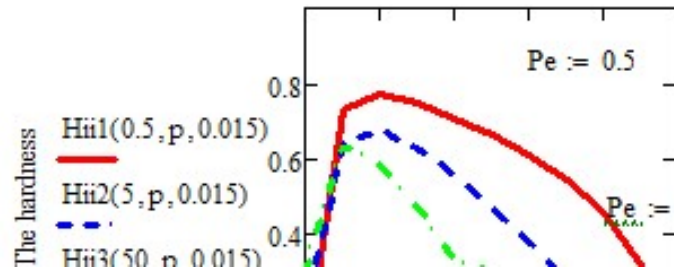


Figure 5.a. The variation of the hardness at the instant warming, function of the pressure

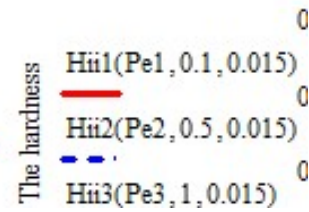


Figure 5.b. The variation of the hardness at the instant warming, function of the invariant Pe

4. CONCLUSIONS

The restriction of the operation of the friction coupling is imposed both by the working conditions and by the physico-chemical characteristics of the components. Correlation of operating conditions with material properties for certain dimensional characteristics of the friction coupling can define a working map.

If the sliding of the surfaces in contact leads to the release of a specific material transformation temperature, the correlation between the load bearing capacity, the speed parameter and the thermal dissipation for different values of the thermal parameter can be defined. For certain limit values of the working temperature, the maximum surface load capacity for a given working speed and loading of the moving element can be defined as a function of the invariant Pe.

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