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COEFFICIENT OF THE Al/Al STATIC FRICTION AT SMALL VELOCITY AND DISPLACEMENT BOTH

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Abstract. *Static friction can be important influential parameter in many friction connections, especially in sliding bearing. It is necessary to know the basic parameters of the process in order to perform an adequate analysis of this phenomenon. This paper presents the results of experimental estimation of the coefficient of static friction in a sliding bearing loaded with external force and simultaneously exposed to the influence of heat.*

Key words: *static friction, coefficient of static friction, displacement*

1. INTRODUCTION

The static friction occurs at a large number of interrelations of the elements in different structures. In some of them, this way of friction is short-termed so their influence is ignored. On the other hand, at connections such as the pressed joints, the static friction is constantly present; it then has an important role so its influence has to be taken into account [1]. Between these two extreme cases, there are mixed type joints which are temporarily or predominantly working in the static friction regime. The typical example of this kind of joints are the civil engineering structures sliding bearings.

Under the atmospheric and heat changes as well as the external load, the elements of these bearings which are in the friction joint move with extremely low relative velocity. Such cinematic conditions at their contact surfaces induce very prominent static friction effect whose action cannot be ignored [2,3,4]. Because of that, in order to make a correct analyzed of the problem, it is necessary to know its basic parameters. This paper shows one of the procedures for determination of the static friction coefficient at a sliding bearing loaded with a concentrated force and simultaneously exposed to the heat.

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2. THE BASIC DEFINITIONS AND SHORT PRESENTATION OF THE STATIC FRICTION PROCESS

The static friction is defined as a process which occurs when the relative displacement of the friction surfaces is microscopically small. The force of resistance at such displacement is called the static friction force. It acts in tangential plane of the element contact and is always higher than the kinetic friction force which occurs in makroscopic, observable, relative displacement. The result of the static friction force and normal load is the static friction coefficient.

The detailed analysis of the static friction phenomenon shows that when shifting between the absolute state of rest to the sliding, there period of so called pre-displacement occurs. This interval precedes the transition into stable sliding and is characterized by a high increase of the reactive force and a low increase of distance. At the end of this period, the pre-displacement reaches its highest value and it is so called border displacement. That is when the friction joint slides, when the friction value abruptly decreases and the displacement value increases, and constantly does so after that, Fig 1. The border displacement, represents the end of the static and a beginning of the kinetic friction.

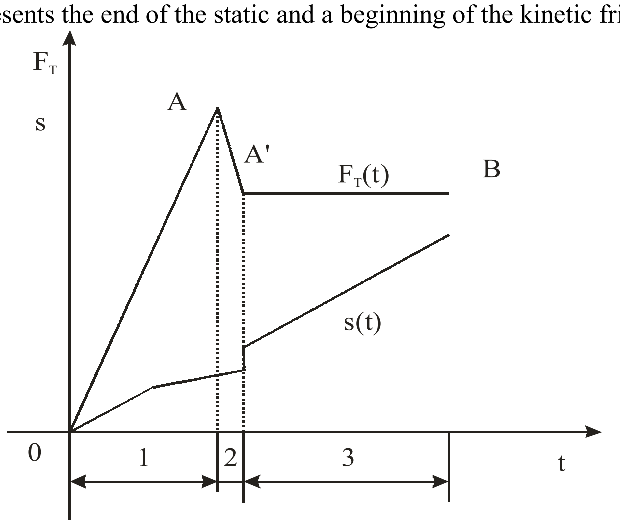

Fig. 1. 1- pre-displacement, 2- sliding, 3- stable sliding

During the pre-displacement, the friction joints have at first mostly elastic and the elasto-plastic character. Depending on which deformations are dominant, (it is on contact conditions, materials etc) the static friction process is more or less reversible.

The pre-displacement duration is variable. It depends mostly on the load and the tangential shearing force: with the increase of load it increases, but with the increase of the tangential force speed it decreases, and vice versa [5,6,7].

The tangential resistance to displacement in the pre-displacement regime is the so-called incomplete friction force. The complete or the static friction force is the tangential resistance at border relative displacement. It is a maximum reactive force which occurs in the moment of the pre-displacement transition in the stable sliding, i. e. in transition of static in the kinetic friction. The value of the static friction force, depends on the same factors as the pre-displacement [5,6,7].

3. BASIC EXPERIMENT DATA

In order to determine the coefficient of the static friction, the experiment is performed on the model of the console beam made from aluminum $AlSiO_5$ module of elasticity $E = 7{,}2 \cdot 10^4$ N/mm^2, square cross section whose fee end lies on the fulcrum of the same material with a circular cross section. The model dimensions in mm and load diagram are shown in Fig. 2. The calculation value of the moving fulcrum reaction is $F_N = 35$ N.

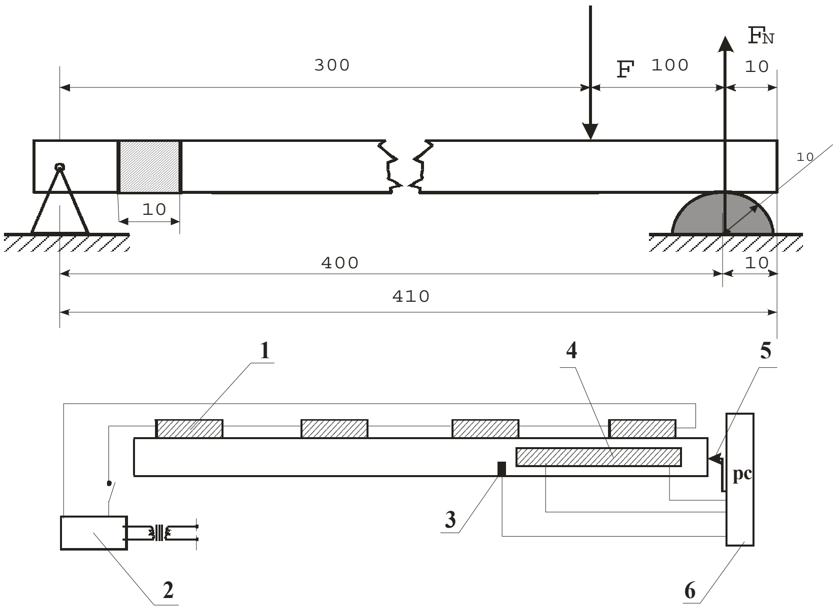

Fig. 2. Scheme of experimental measurement:
1- resistor, 2- rheostat, 3- thermocouple, 4- measuring bend,
5- displacement indicator, 6- personal computer (PC).

Before performing the experiment the surfaces of the bearing beam are cleaned with the acetone in order to remove the grease. In order so that the conditions which are equal to the initial state of rest could be provided, the beam was loaded with the concentrated vertical force F. After some time it was heated along its total length by the conductive method with the resistors connected in series (1), by the average speed of 0.014 °C/s. The Electric power is regulated by the rheostat (2) while the temperature is measured by the thermocouple (3). The measuring bend (4), placed on the surface of the beam opposite to the contact surface has registered the dilatation value of the material. The displacement of the free end of the beam is measured by the displacement indicator (5) placed on the head surface of the beam. All the measurement instruments were connected to the personal computer (6).

4. EXPERIMENT RESULTS AND DISCUSSION

Under the heat influence, in there are thermal stresses in the beam. When it is free and its dilatation is not prevented, the occurrence of the internal force results in the equal elongation of the whole beam. In other words, the elongation of all the material layers and displacement all its cross sections occurs simultaneously. In these conditions the measuring bend (3) and displacement indicator sensor (5) will react to the heat at the same time and the oscillograms of dilatation and displacement will not differ.

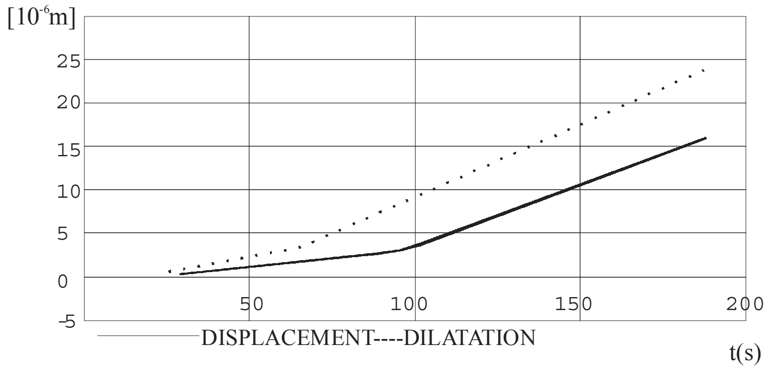

Fig. 3. Diagram of displacement

But in this case the beam is, apart from the internal, simultaneously loaded with the external vertical force. By virtue of that, its lower surface is in classical frictional contact with the fulcrum and the given course of elongation will be different, as it can be seen in the Fig. 3.

Due to the heating and the internal force action, the dilatation of the surface layer is constantly increasing. However, the displacement of the head surface of the beam, i.e. axial beam elongation, does not start simultaneously with the dilatation, on one hand, and on the other – it does not have the same shape.

The cause of such state is the friction force acting at the contact of the beam and the bearing. Namely, when the thermal stress occurs with possibility for relative displacement, the established frictional connections manifest their presence in the form of the reactive force which prevents the contact layer of the material to elongate freely. Its action is relayed to all the layers above the contact one. In such manner this reactive force prevents the simultaneous elongation of all the layers of the material and an adequate displacement of the cross sections of the beam. For that reason the oscillogram of the head surface displacement lags behind the free surface layer dilatation.

Due to the constant action of the friction force, the initial lagging grows bigger, and reaches maximum and then does not change till the end of the process. It means that in that interval a maximum and constant friction force acts on the contact surface of the beam The oscillograms of displacement and dilatation are then parallel because both displacements have the same speed, as seen on the figure 3. In that sense, because of the easy analysis, the oscillograms can be approximately divided on the period before and after the beginning of the parallel course as shown in the diagram 4. The dilatation and displacement of the head surface will have the same speeds in different times.

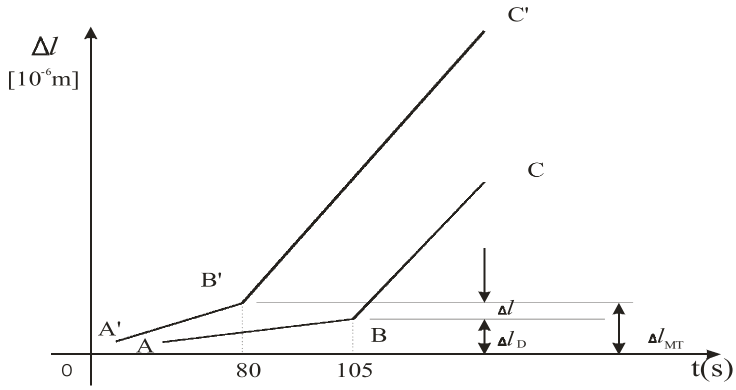

Fig. 4. Oscillogram: ABC – displacement, A'B'C'– dilatation

In this case the average value of the beam head surface speed in the AB period is 0,35μm/s and dilatation speed in the period A'B' is 0,093 μm/s. The common displacement speed (BC and B'C' intervals) is 0,17μm, or $17 \cdot 10^{-8}$ m/s. It is at the same time the relative sliding speed, it is maximum speed of the tangential shearing force.

In respect to the conditions of the experiment, as to the values of the speed parameters and total duration time, one can conclude that the described process corresponds to the static friction in the pre-displacement interval, but also before reaching the limit value.

5. Calculation of the friction coefficient

As the beam cross section dimensions are small in relation to the length, the material dilatation and the occurrences it renders in these directions can be ignored. With this supposition and starting from the exposed consideration, the friction coefficient can be calculated indirectly with the values of the beam head displacement and dilatation in the period of equal speeds.

Displacement indicator measures the resulting displacement which occurs as a difference between the ideal elongation of the free layer and hindered displacement of the head surface in the axial direction. As the displacements correspond to the forces that render them, they will be:

$$F_{MT} - F_T = F_D \tag{1}$$

it is:

$$F_T = F_{MT} - F_D \tag{2}$$

where F_{MT} - is the force which acts in the external free layer of the beam, F_D – the resulting force which effects the displacement of the beam head surface in the axial direction and F_T – friction force, reactive force at the contact of the beam and the fulcrum.

Table 1. Results of measurement

t (s)	Δl_{MT} (μm)	t (s)	Δl_D (μm)	Δl (μm)	Friction Coefficient f
80	5,6	105	3,2	2,4	1,20
85	6,3	110	3,9	2,4	1,20
90	7,0	115	4,6	2,4	1,20
95	7,8	120	5,3	2,5	1,25
100	8,6	125	6,1	2,5	1,25
105	9,4	130	6,9	2,5	1,25
110	10,3	135	7,7	2,6	1,30
115	11,1	140	8,6	2,5	1,25
120	11,9	145	9,5	2,4	1,20
125	12,8	150	10,3	2,5	1,25
130	13,7	155	11,2	2,5	1,25
135	14,7	160	12,2	2,5	1,25
140	15,6	165	13,2	2,4	1,20
145	16,5	170	14,0	2,5	1,25
150	17,5	175	15,0	2,5	1,25

On the basis of Hook's law $\sigma = \varepsilon \cdot E = (\Delta l / l_0)E$, it follows that

$$F_T = (EA/l_0) \cdot (\Delta l_{MT} - \Delta l_D). \quad (3)$$

so the friction coefficient is:

$$f = F_T / F_N = (EA \cdot \Delta l) / (l_0 \cdot F^N); \quad (4)$$

where Δl_{MT}, Δl_D and Δl – in mm, is a dilatation (shown by the measuring bend), displacement (shown by the displacement indicator) and their balance, respectively. Their values in the equal speed interval are given in table 1.

By the substitution of the numerical data for the elasticity model E, N/mm^2, the cross section surface A (mm^2), length of the beam 10 (mm) and the reaction of the fulcrum F_N (N) in the expression (4), the obtained friction coefficient is

$$f = 0{,}50 \cdot 103 \cdot \Delta l \quad (5)$$

As it can be seen from the table 1, its mean value is 1,237 for the observed time interval.

6. Conclusion

The conditions of the presented experiment approximately correspond to the condition in which the real elements of the fulcrums in civil engineering structures are. Because of that, the described experimental approach can serve as a convenient way for determination of the approximate value of the static friction coefficient at loaded sliding bearing. At the same time, this information can be used for general and detailed analysis of the static friction occurrence in many frictional joints.

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KOEFICIJENT STATIČKOG TRENJA Al/Al PRI MALOJ BRZINI I POMERANJU

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Statičko trenje može da bude važan uticajni parametar kod mnogih frikcionih veza, posebno kod kliznih ležišta. U cilju adekvatne analize ove pojave, neophodno je poznavanje osnovnih parametara procesa. U ovom radu su prikazani rezultati eksperimentalnog određivanja koeficijenta statičkog trenja kod kliznog ležišta grede opterećene spoljašnjom silom i istovremeno izložene uticaju toplote.

Ključne reči: *statičko trenje, koeficijent statičkog trenja, pomeranje.*