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INFLUENCE OF OXIDATION LAYER GENERATED ON PREHEATED CONTACT PAIRS ON STATIC COEFFICIENT OF FRICTION

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Abstract: *The subject of the work includes theoretical considerations, conducting experimental tests which are subjected to the analysis of the test results related to the determination of the coefficient of static friction, of contact pairs which were previously heat treated. Contact pairs were, before the procedure to determine the coefficient of friction, heated to temperatures of 50ºC-350ºC and cooled to room temperature. Test results show that, depending on the thermal treatment of contact pairs, there is significant increase in the coefficient of friction. The authors believe that the reasons for the increase of the friction coefficient are related to the creation of oxide and changes in the surface layer of contact pairs.*

Keywords: *coefficient of static friction*, oxidation layer, pre heat treatment, normal load

1. INTRODUCTION

Precisely prediction of static friction is of the essence significance due to its application in many modern tribological systems, such as chucks, clamps, seals, micro-electromechanical systems and so on. Importance of the evaluation of the coefficient of friction is figured long time ago and that area studied some of the first scientists such as Leonardo da Vinci, Guillaume Amontons, Charles Augustin Coulomb, George Rennie and many others [1]. As the force of friction occurs when two bodies are in contacts, based on the relative speed of movement it can be divided into friction at the idle status and the friction in state of motion. Start the movement of any kind is related to the existence of static friction. The static coefficient of friction depends on many parameters, primarily from the surface of contact, normal load, atmosphere and temperature at which contact occurs, surface absorption, quality of surfaces in contact and materials of contact surfaces [2-6]. Many authors have been examining the influence of roughness parameters on the of contact surfaces for the static friction coefficient and came to the conclusion that the static coefficient of friction increases with increasing surface roughness parameters [4, 5]. Some authors have concluded that some of the roughness parameters, such as skewness and kurtosis, have more influence on the static coefficient of friction compared to other parameters [7] [8]. The friction force at idle phase increases with increasing tangential displacements up to the value that is needed to begin movement of the bodies in contact [9]. The main parameters of static friction are the maximum force of static friction, which is realized at the moment of macro displacement, and corresponding value of the micro-movement. The influence of temperature and normal load on the friction characteristics of materials is topic of numerous scientific works [10-13], especially when are concerned materials used in process of hot metal forming. Etsion and Amit [10] experimentally investigated the effect of normal load on the coefficient of static friction for a very smooth metal surface. Normal load is in the range of 10^{-3}N - 0,3N and applied to samples of small diameter made of three different aluminum alloys in contact with nickel-plated finish. The tests were conducted in conditions of controlled humidity and air cleanliness. The dramatic increase of coefficient of static friction was noticed when the normal load reduced to the lowest level. This kind of behavior is attributed to the adhesion forces which have a significant role and which are more prominent at low normal loads and smooth surfaces. To the knowledge of authors the study of static coefficient of friction under conditions of high temperature was not the topic of more extensive theoretical and experimental works [14-17]. Behavior of the static and kinematic friction of materials coupling at different values of temperature and contact pressures investigated Chaikittiratana, Koetniyom and Lakkam [17]. Device which is used for performing of the experiment is specifically constructed for the determination of sliding friction at higher temperatures. It was established that at 100°C there isn't significant change in the coefficient of friction when the contact pressure varies. However, at a temperature of 200°C observed friction coefficient change with the change of the contact pressure. There was an increase in the coefficient of friction when the contact pressure increased from 0.147MPa - 0.252MPa. It is concluded that the increase in temperature significantly increases the coefficient of friction. One of the most important conclusions of this work is that the static coefficient of friction increases with increasing temperature, which is partly a consequence of increase the plasticity of most contact materials at higher temperatures.

The aim of this paper is to determine the influence of previously heat treated contact pairs on the value of the static coefficient of sliding friction, with contact elements made of steel. Experimental measurements were performed on instrumentation developed by the authors, in order to accurately determine the value of the static coefficient of sliding friction at higher temperatures and relatively low values of contact pressures in the variable radius of curvature of contact elements. The results could have a significant aplication in industrial applications.

2. THEORETICAL CONSIDERATIONS

Measurement of the friction coefficient at high temperature in contact pairs is associated with a number of problems of physical and technical nature. Issues related to the reliability of measurements are especially pronounced in the measurement of the friction coefficient under low contact pressure. Problems related to the fact that at high temperatures in the contact pairs must accurately measure very small values of physical quantities (normal and friction force). For measuring small values of the friction force is necessary to exist electronic components in the measuring chain (sensors of force and other electronic components). Since the force sensors, for reasons of measurement reliability, should be outside the zone of high temperatures, it becomes important ,to the signals associated with small displacement and force, that they have to be transmitted mechanically from the high temperature zone (the chamber in which the pair is heated to desired temperature) to the sensor to quantify the value of the friction and normal contact load of contact pair. Mechanical transmission chain of friction force pulls the corresponding measurement errors, especially when it comes to measure very small values of force.

The authors started from the idea that the principle of measuring the static coefficient of friction over the steep plane have to be upgraded and enable measurement in conditions of high temperatures and low values of contact pressure. The principle of measurement of coefficient of friction over the steep plane (Figure 1) is based on gravity. Static coefficient of friction, as it is known is the ratio of the friction force and the force normal to the surface of contact, where condition for equilibrium on a steep plane is given by expression $F_\mu > mg \cdot \sin\alpha$. In the limiting case of sliding friction valid equation is:

$$\mu = \frac{F_\mu}{N} = \frac{mg\sin\alpha}{mg\cos\alpha} = tg\alpha \qquad (1)$$

where are: μ – value of static friction coefficient; F_μ - friction force; m - mass of body; g - acceleration of gravity; α - steep angle of the plane.

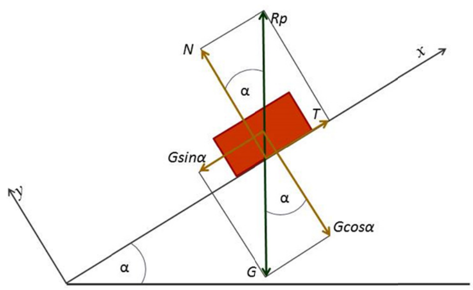

Figure 1. The balance of the body on a steep plane

Measurement error of static coefficient of friction on this principle arising from error of angle measurement in relation to an ideal horizontal position when the body which is located on a steep plane crossed from sleep in a state of motion (Figure 2), respectively:

$$\varepsilon = \frac{tg(\alpha + \Delta\alpha) - tg\alpha}{tg\alpha} \cdot 100, [\%] \qquad (2)$$

where are: $\varepsilon -$relative error of measurement; $\Delta\alpha$ - angular error of measurement α. If one takes into account that the friction coefficient $\mu = tg\alpha$, then the diagram given in Figure 2 can determine the relative measurement error $\varepsilon(\mu)$ which is, among other, function of coefficient of friction.

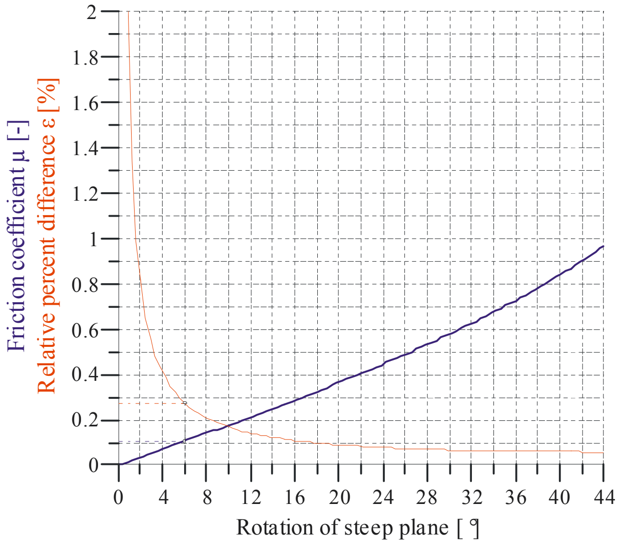

Figure 2. Graphical representation of the relative measurement error of the coefficient of friction over the steep plane

On the basis of eqquation (2) and the diagram (Figure 2) can be noted that values of the coefficient of sliding friction μ> 0.1 with $\Delta\alpha$ = 1' correspond to the measurement error which is less of 0.3%. This means that the principle of measurement can be efficiently used to determine the static friction coefficient at higher temperatures, especially if one takes into account that the sliding coefficient of static friction at elevated temperatures for most materials is greater than the above values.

3. EXPERIMENTAL RESEARCH

Experimental studies were performed on samples made of steel EN X160 CrVMo12 1 which is subjected to heat treatment hardening, with the aim to obtain the high hardness of 64 HRC and wear resistance. Tribological contact pair is realized by setting the rollers of diameters 4 *mm*, 6 *mm*, 8 *mm*, 10 *mm* and 12 *mm*, length 20 *mm*, on prism block (Figure 3). This simulates tribological contact which is, theoreticaly, realized on line. If we take into account that the mass of the rollers is small then we have small values of contact pressure. When rollers are in contact on flat surface block, in the absence of temperature, contact is achieved on tops of some asperities and in that case between most asperities there is no real physical contact. Block and the rollers are made of same material (the aforementioned). Experiments were carried out with increase of temperatures by 50°C, starting from the temperature T_1=50°C up to temperature T_2= 350°C, and after heating samples were left to cool to room temperature. Each measurement was repeated 10 times, so that a total of 350 independent experiments is performed at room temperature after heating the contact pair.

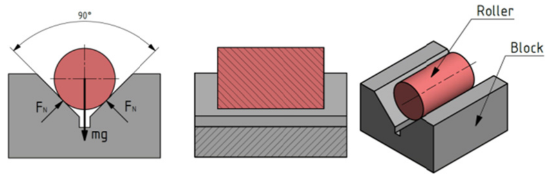

Figure 3. Schematic representation of the contact pair

The coefficient of friction was determined using specially designed devices (Figure 4). Working principle of designed Tribometer is based on rotation of steep plane, which is done on a mechanical principle to the accuracy of the readings of 1'. Namely, rotation steep plane is carried out by manually turning of nonius. Leveling of Tribometer is done using level which provides precision of reading which is less than 0,02/1000 $\mu m/m$.

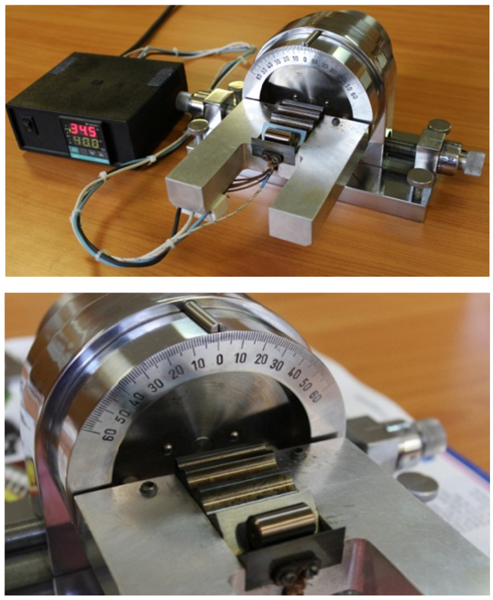

Figure 4. Measuring equipment

Contact pairs were heated to temperatures from 50°C to 350°C with the step of 50°C, after which they are cooled to room temperature. So, determining the size of the static coefficient of friction was performed with contact pairs that were heat treated at temperatures indicated. This means that contact pairs in the process of determining the static coefficient of friction were at room temperature. The results of measurement of the coefficient of friction depending on the weight of rollers, that is, the normal contact load and temperature are shown in Table 1:

d [mm]	F [N]	T [°C]	μ
12	0.174101	20	0.196581
10	0.120903	20	0.185261
8	0.077378	20	0.295619
6	0.043525	20	0.243811
4	0.019345	20	0.229694
12	0.174101	50	0.210229
10	0.120903	50	0.212484
8	0.077378	50	0.218193
6	0.043525	50	0.285514
4	0.019345	50	0.227332
12	0.174101	100	0.190895
10	0.120903	100	0.204541
8	0.077378	100	0.205629
6	0.043525	100	0.243661
4	0.019345	100	0.240049
12	0.174101	150	0.310443
10	0.120903	150	0.284418
8	0.077378	150	0.289048
6	0.043525	150	0.330971
4	0.019345	150	0.351592
12	0.174101	200	0.240052
10	0.120903	200	0.228621
8	0.077378	200	0.23437
6	0.043525	200	0.340861
4	0.019345	200	0.459168
12	0.174101	250	0.270227
10	0.120903	250	0.286718
8	0.077378	250	0.377837
6	0.043525	250	0.322573
4	0.019345	250	0.522993
12	0.174101	300	0.291725
10	0.120903	300	0.366628
8	0.077378	300	0.547985
6	0.043525	300	0.571756
4	0.019345	300	0.389194
12	0.174101	350	0.279639
10	0.120903	350	0.341781
8	0.077378	350	0.354048
6	0.043525	350	0.315233
4	0.019345	350	0.462363

According to the data from Table 1 was formed diagram of static friction coefficient which depending on the normal load and temperatures to which contact pairs are pre-treated.

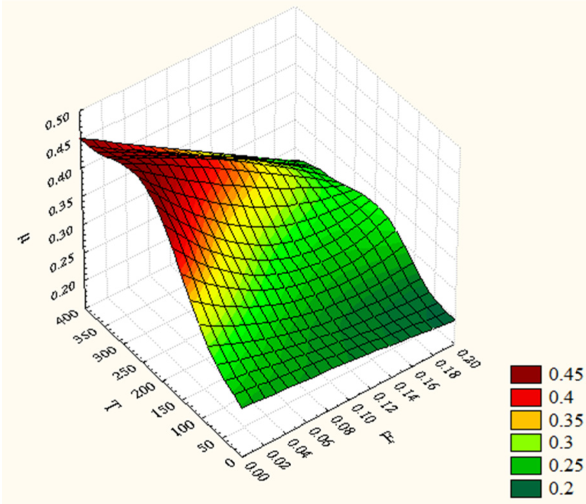

Figure 5. The static coefficient of friction which depending on the normal load and temperature

4. DISCUSSION

Based on theoretical considerations and experimental investigations it can be concluded that the physical principle of measuring the static coefficient of friction over the steep plane can be effectively applied in testing conditions at high values of temperature and low values of contact pressures. It requires a certain precision measurement instrumentation (precision measuring equipment - Tribometer), which is realized with equipment used for conducting this tests. The accuracy of the measurement was the angle of $\Delta\alpha = 1'$. A large number of measurements and a number of repetitions of experiments under identical conditions allow statistical analysis of the results of measurements to minimize random error.

Experimental results of investigation presented in the form of 3D diagram in Figure 5 indicates that for given conditions the temperature treatment of contact pairs have substantial effect on the value of static coefficient of friction. The essential dependence of friction coefficient from temperature, which can be seen from the diagram, expressed that for temperature change from 50^0 C to 300^0 C value of the static friction coefficient increases nearly two times. Based on the foregoing, it is obvious that the changes of static friction coefficient arise from temperature effect on material in contact. It is likely that preheating of contact pairs above the temperature values close to 200^0C leads to physical changes in the surface layers of contact pairs.

With diagram shown in Figure 5 is possible to analyze the effect of normal load on the static coefficient of friction. Normal load in the range of 0.019 to 0, 17 N is used during experiment. From the diagram it can be seen that the minimum values of the normal load in the entire temperature range, corresponding to the maximum value of the coefficient of friction, and reverse. This proves that the static coefficient of friction under conditions of low values of contact pressures and preheat treated contact pairs, just depends on the level of contact pressure, which is in line with tests performed in different conditions [10]. The increase in the contact pressure can lead to lower friction coefficient and reverse.

When analyzing the results, the authors of this work started from the next. Because of preheating of contact pairs it comes to decrease of hardness, which can be the reason for the increase of the friction coefficient. It is possible, and more likely, that oxidation layer is created at the surface of contact pairs with different tribological characteristics comparing to base material, steel EN X160 CrVMo12 1. Theoretically, changes in the structure changes the mechanical properties of hardened steel. With temperature increase hardness and strength decrease, while ductility and toughness increase. During the heating of the samples was three modes layoffs and low firing up to 200^0 C, the transformation of retained austenite 200^0 C - 300^0 C and removing internal stresses of 300^0 C - 400^0 C. This, with increasing tempering temperatures the hardness and strength decrease, while ductility and toughness increase. Oxidation occurs as a chemical reaction between metal and oxygen from the atmosphere. The occurrence of oxidation is possible at room temperature, however, the metals that are exposed to elevated temperatures above 200^0 C are able to create more intense oxidation layer.

The authors were not able to carry out structure analysis of surface layer with electronic microscope, so the question of large increase in the friction coefficient has two options listed. It is unlikely that changes in hardness of steel EN X160 CrVMo12 due to release 1 (Figure 6) from the value of 64 HRC to value of 60 HRC can lead to an increase in the coefficient of friction of approximately 70%. For this reason the authors believe that significant increase in the coefficient of friction is very probably due to the creation of oxides at the surface of contact pairs.

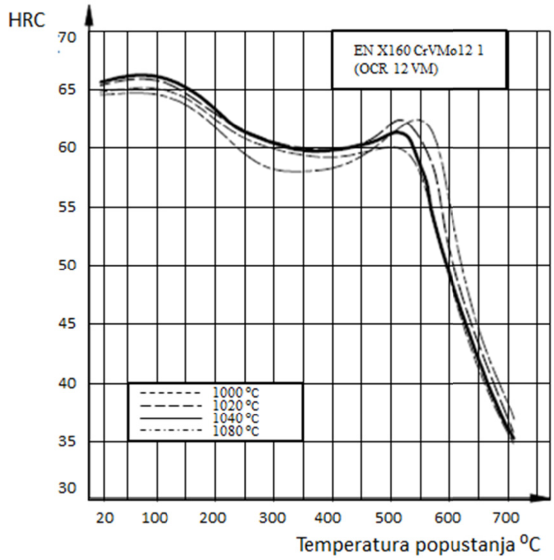

Figure 6. Releasing diagram of material

5. CONCLUSIONS

Based on these tests and analyzing the results, conclusions were made, preheated contact pairs made of steel EN X160 CrVMo12 1, at relatively low temperatures resulting leads to significant change in the value of static coefficient of friction. Results of measuring the static coefficient of sliding friction of the test material, under conditions of high temperature and small values of load contact, indicating a very significant effect of temperature and contact pressure on value. The impact of the minimum values of normal load in the entire temperature range, corresponding to the maximum value of the coefficient of friction, and vice versa. It is very unlikely that the changes of hardness of steel EN X160 CrVMo12 1 due to the release from the value 64 HRC to the value 60 HRC may lead to an increase in the coefficient of friction of approximately 70%. From this reason the authors believe that a significant increase of coefficient of friction is probably a consequence of creation of oxides at the surface of contact pairs.

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