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INFLUENCE OF MECHANO-CHEMICAL SURFACE TREATMENT TCG ON TRIBOLOGICAL PROPERTIES IN BODIES ROLLING CONTACT

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Abstract: *This paper documents the effect of surface conditioning on the lifetime and the efficiency under typical loading conditions. The experimental work to determine the influence of the mechano-chemical surface treatment TCG on the number of cycles until mechanical damage of the contact surface and assessment of the rolling resistance in comparison to an untreated specimen is described in this paper. The surfaces of the specimen are evaluated by both optical and tactile surface measurements. The tests principle consists of the rolling of the cylindrical specimen between three loading discs, while one of them is driven by an electrical motor and at the same time, a loading force is acting upon it. Mechano-chemical surface treatments are a proven way to reduce friction and wear of components in sliding contact, especially under mixed lubrication conditions, but have so far not been considered for the optimization of the rolling resistance of bodies.*

Keywords: Rolling kinematic pair, Rolling resistance, Treatment TCG

1. Introduction

The subject of the paper is the presentation of the experimental work to determine the influence of the mechanochemical surface treatment TCG on the number of cycles to the mechanical damage of the contact surface and the rolling resistance during pure rolling. The mechanochemical surface treatment TCG is one of the products of the Tribonex company (Zhmud, 2019, Tribonex). The tribological properties in the rolling contact of the bodies could be improved by applying an appropriate surface treatment to the contact surface of one of the bodies that co-form the rolling or general kinematic pair. We tried to determine the influence of the mechanochemical surface treatment TCG applied on the specimen contact surface based on the number of cycles to the mechanical damage of the contact surface during rolling. Furthermore, the influence of the treatment TCG was evaluated using the power consumption of the test rig on which the experiments were performed and the rolling resistance coefficient during the pure rolling between the test specimen and the discs. The testing methodology and the experiments themselves were provided by VÚTS, a.s. (VÚTS, a.s.).

2. The test principle

The aim of the experiments is the determination of the number of cycles to the damage of the contact surface and the size of the power consumption of the test rig (VÚTS, a.s.). Both quantities depend on the mechanochemical surface treatment TCG applied to the contact surface of the loaded body 5, magnitude of the loading force F and magnitude of the angular velocities of the rotating bodies. In the case of the test rig, the relation applies between the constant angular velocities Ω_2 and ω of the discs and the specimen respectively:

$$\omega = \frac{D}{d} \cdot \Omega_2, \qquad D = 0.08\,m, \qquad d = 0.02\,m \tag{1}$$

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The kinematic scheme of the conceptual design of the test device for specimens is shown in Fig. 1 in which the parameter $l = 0.227\ m$ indicates the arm length of the two-arm lever.

The tests principle consists of the rolling of the cylindrical specimen 5 among three loading discs 2, 3, 4, while one of the discs is driven by an electrical motor and a loading force F acting on it at the same time. The loaded body is stressed by periodic force F by means of the loading body, the amplitude takes on the size depending on the material of the loaded body and on the method of processing its contact surfaces. In this case, the stress on the contact surface of the specimen has a character of pulses with a period of $2\pi/3$. It is therefore a way of stressing by transient loading. The loading body could represent a cylindrical roller and the loaded body, in analogy with the cam mechanism with a radial cam and roller follower, could correspond to the cam (VÚTS, a.s.). The real implementation of this device is shown in Fig. 1.

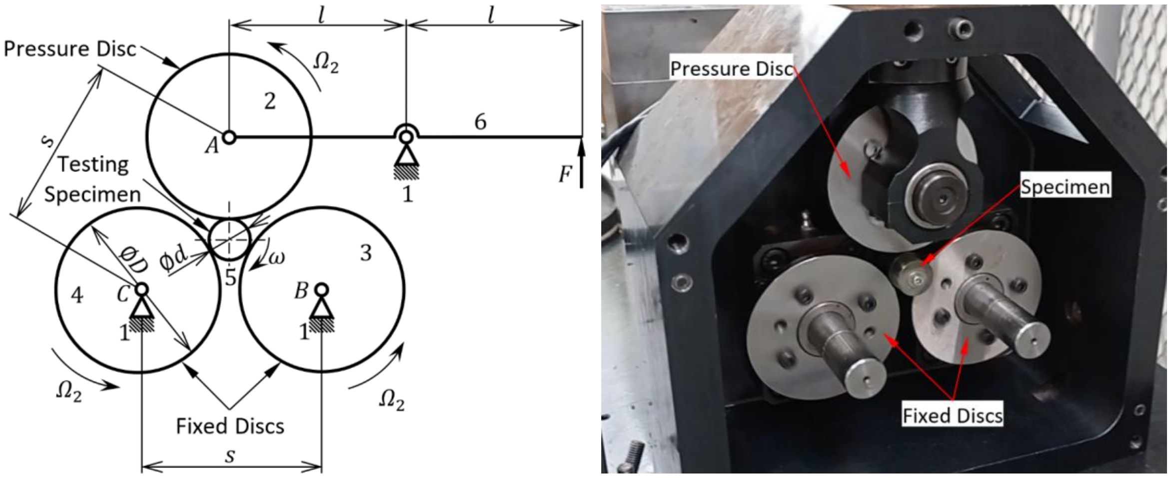

Fig. 1: Kinematic scheme of the testing device and its real implementation.

3. Tests results

The resulting tests of the influence of the mechano-chemical surface treatment TCG on the number of cycles to the mechanical damage of the contact surface and rolling resistance in the general kinematic pair formed by the contact of loading discs 2, 3, 4 with specimen 5 during the pure rolling were carried out at the load level $F = 4000\ N$ and the discs revolutions $n_2 = 800\ rpm$.

Two variants of the specimen design were tested: the specimens without the mechano-chemical contact surface treatment which is indicated as $Specimen\ B$ and the specimens with the mechano-chemical contact surface treatment TCG indicated by term $Specimen\ E2$. The discs with the hardened surface layer $(58 + 2)\ HRc$ are made from the steel indicated as $X153CrMoV12$. Both types of specimens with the hardened surface layer $(58 + 2)\ HRc$ are made from steel indicated as $16MnCr5$.

3.1. Cycles number

The lifetime experiments were always terminated at the specified level of vibrations of the test rigs, which was related to the wear of the contact surface of the specimens. The rig vibrations were assessed using the accelerometer situated on the two-arm lever near to the pressure disc. The tests results are summarized in Tab. 1.

Tab. 1: Summary of the tests results.

Specimen Number	**Specimen Type**	**Hardness HRc before Loading**	**Hardness HRc after Loading**	**Load Cycles Number $W \cdot 10^6\ [cycles]$**
17	B	57.0	62.0	11.3
18	E2	61.0	63.0	25.7
20	B	58.0	61.0	18.4
21	B	58.0	62.0	15.3
22	E2	60.0	63.0	52.6
23	E2	60.0	63.0	36.8

24	E2	60.5	63.0	28.8
25	B	57.0	62.0	15.6
26	B	58.0	62.0	14.5

From Tab. 1, the average number of loading cycles of $Specimen\ B$ at the load level of $4000\ N$ is $\overline{W}_{B(F\,=\,4000\ N)} \doteq 15 \cdot 10^6\ cycles$. While in the case of $Specimen\ E2$ is $\overline{W}_{E2(F\,=\,4000\ N)} \doteq 36 \cdot 10^6\ cycles$. The lifetime ratio is defined as:

$$k_{W(F\,=\,4000\ N)} = \frac{\overline{W}_{E2(F\,=\,4000\ N)}}{\overline{W}_{B(F\,=\,4000\ N)}}, \qquad k_{W(F\,=\,4000\ N)} = \frac{36}{15} = 2.4 \tag{2}$$

Thus, $Specimens\ E2$ with the coating TCG achieve approximately 2.4 times longer service life under given loading conditions than $Specimens\ B$. From the given test results, it is also evident that the cyclic loading of the specimens came about a strengthening of their contact layers.

3.2. Rolling resistance

In order to achieve the most reliable results of the experimental analyses of surface treatment TCG influence on the rolling resistance, the average values of the servomotor power consumption $\bar{P}_i$ for individual specimens i were determined from several multi-hour records, $i = B, E2$. Only pressure disc 2 was driven by the servomotor, fixed discs 3 and 4 were mechanically disconnected from their drives.

Based on the data (i.e. angular velocity Ω_2 and torque M_{Motor}) scanned from the electrical motor (OMRON R88M-1M1K020C-S2) for driving pressure disc 2, its average mechanical power input at the constant angular velocity Ω_2 was determined with the following size: $P_{Motor} = 10.12\ W$. The mechanical power input P_{Motor} of the motor was determined as an average value from the 24 hour recording of the time course of its power consumption.

In the next step we tried to determine the magnitudes of mechanical powers P_A, P_B, P_C in order to exceed the rolling resistances of the bearings in the rotary bearings A, B, C of loading discs 2, 3, 4 at a given constant angular velocity Ω_2 and a given loading force F. SKF bearings were mainly used to the discs mounting. The power dissipation of the bearings was established through the SKF technical support (SKF). The power dissipation P_A in the bearing of pressure disc 2 at a given constant angular velocity Ω_2 and a given loading force F is determined as $P_A \approx 18\ W$. The power dissipations P_B and P_C in the bearings of fixed discs 3 and 4 reach the values $P_B = P_C \approx 12.8\ W$. In the case of fixed discs 3 and 4, the power losses of the bearings are less, because the bearing of the fixed discs does not contain a needle bearing which has higher power losses than ball bearings.

We determine the power dissipation of the rolling resistance of discs 2, 3 and 4 with specimen 5 using the expression:

$$\bar{P}_{\xi i} = \bar{P}_i - P_{Motor} - (P_A + P_B + P_C), \qquad i = B, E2 \tag{3}$$

The average values of the power inputs of the servomotor at a given constant angular velocity Ω_2 and a given loading force F were always determined from several hourly records and reach the values:

$$\bar{P}_B = 73.44\ W, \qquad \bar{P}_{E2} = 71.42\ W$$

Fig. 2 shows an example of a 5-hour record of the time course of the power input of the electric motor to drive the test rig with the inserted Specimen E2. Substituting appropriate values of power inputs into Eq. (3), we calculate the numerical values of power losses $P_{\xi i}$ for the individual specimens:

$$\bar{P}_{\xi B} = (73.44 - 10.12 - 18 - 2 \times 12.8)W = 19.72\ W,$$

$$\bar{P}_{\xi E2} = (71.42 - 10.12 - 18 - 2 \times 12.8)W = 17.70\ W$$

The effect of the mechano-chemical surface treatment TCG on the rolling resistance was expressed as a percentage ratio of the power dissipation $P_{\xi E2}$ in comparison with $Specimen\ B$. This effect is expressed by this equation:

$$e_{P,E2} = \left(1 - \frac{P_{\xi E2}}{P_{\xi B}}\right) \cdot 100\ [\%], \qquad e_{P,E2} = \left(1 - \frac{17.70}{19.72}\right) \cdot 100\ \% = 10.2\ \% \tag{4}$$

If the value of $e_{P,E2}$ is positive, then the effect of the mechano-chemical surface treatment TCG on the rolling resistance is positive, otherwise negative. By comparing the respective values, we can state that the effect of the mechano-chemical surface treatment TCG on the rolling resistance during the rolling at a given constant angular velocity Ω_2 and a given loading force F is positive.

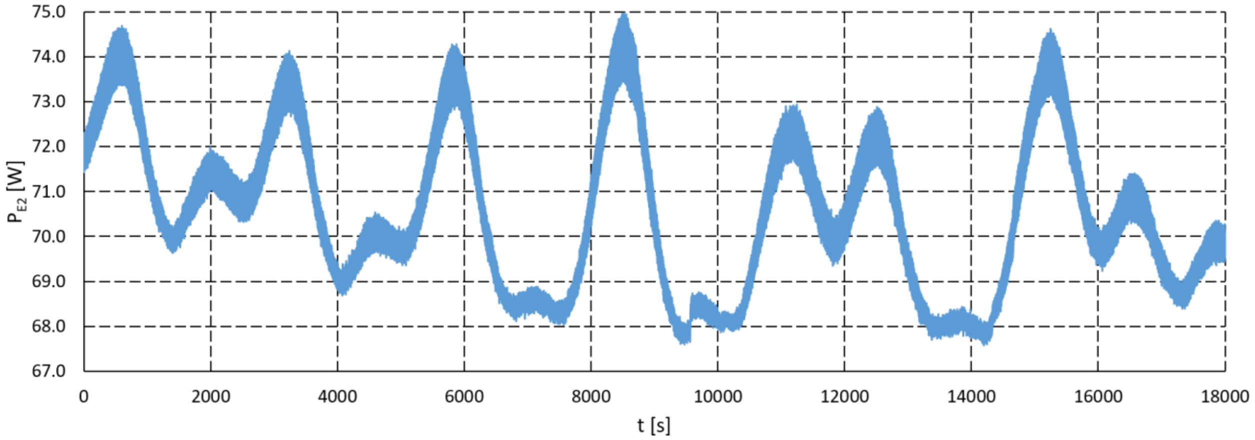

Fig. 2: The time course of the test rig power input to drive of Specimen E2.

4. Conclusions

The aim of the experiments is the determination of the number of cycles to the damage of the contact surface and the size of the power consumption of the test rig. Both quantities depend on the mechano-chemical surface treatment TCG applied to the contact surface of the loaded body, the magnitude of the loading force $F = 4000\,N$ and the magnitude of the angular velocities of the rotating bodies (discs: $n_2 = 800\,rpm$, specimen: $n_5 = 3200\,rpm$).

Based on the analysis of experimental data, it can be concluded:

- $Specimens\ E2$ with the coating TCG achieve approximately 2.4 times longer service life under given loading conditions than $Specimens\ B$. From the given test results, it is also evident that the cyclic loading of the specimens came about a strengthening of their contact layers. The hardness of the contact layers increased on average by a value of 2 HRc.
- During loading, loading force F decreases for the uncoated $Specimens\ B$ by approx. 1 % due to the probable reason of the gradual loss of material in the contact area.
- By comparing the respective values, we can state that the effect of the mechano-chemical surface treatment TCG on the rolling resistence during the pure rolling at a given constant angular velocity Ω_2 and a given loading force F is positive. For TCG coated $Specimens\ E2$, the rolling resistance factor is approx. 10 % better.

Based on the analysis of data from the roughness measuring of the specimens contact surfaces, we can state that the contact surfaces after loading for both specimens B and $E2$ have a similar degree of wear, which is understandable because the test runs were terminated under approximately the same testing conditions. Before loading, specimens $E2$ with a surface provided with a mechano-chemical treatment achieve up to twice as good surface quality in terms of its roughness in comparison to specimens B without surface treatment.

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