ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 9, No. 1. 2003

# Investigation of Non-abrasive Antifrictional Surface Finishing

**K. Tiškevičius[1], J. Padgurskas[1*], I. Prosyčevas[2]**

[1]Faculty of Engineering, Lithuanian University of Agriculture, Studentų 15, Akademija, LT-3031 Kaunas, Lithuania
[2]Institute of Physical Electronics, Kaunas University of Technology, Savanorių 271, LT-3009 Kaunas, Lithuania

Received 09 September 2002; accepted 10 October 2002

Non-abrasive antifrictional surface finishing is one of the most perspective technique of surface treatments. The technique is very simple, easily and economically applied. The papers outlines the description of this method, there are discussed some effects and a scheme of a device designed for realizing this technique is given. There is also given the operation principles of surface activating materials glycerin and ammonium bichromate in forming coatings, chemical reactions and their products.

The tribotechnical experiments were carried out with pair "steel – aluminium alloy" in the case of adaptation period and extreme loads conditions. The obtained experimental results are shown by images of load variation, friction moment dependences graphs, treated by NASF and working surfaces.

To form a brass coating on steel 45 surface, there may be used both organic (glycerin) and inorganic (ammonium bichromate) substances. The obtained surfaces by NASF technique may hold out much greater loads, their wear is almost 5 times less than of those ones which were not treated. Rollers with PAM ammonium bichromate more easily were adapting themselves to load change.

*Keywords*: friction, coating, surface activating materials, non-abrasive antifriction surface finishing.

## 1. INTRODUCTION

Surface friction of components causes about 80…90 % of machines damages and is used about one fourth of produced energy [1]. These facts force to constantly seek ways to lessen the effects of these phenomena effects – to develop new more effective technologies of surface treatment, and at the same time applying various phenomena and their combinations. Besides, there is also an important economical factor - the price of the treatment.

Non-abrasive antifriction friction surface finishing is based upon frictional metal transfer [1]. The essence of NASF is that treated surface, using metal transfer in friction process, is coated with thin layer (2 – 4 μm) brass or other plastic metal. This thin layer during surface pair work is modified into a film protecting the friction surfaces from direct interaction and being able to restore itself after its damage. Then it is realized non-wearing effect.

Prior to coating the surface should be cleaned, and moistened with activating liquid. During the treatment oxide film is being destroyed, the rod surface is plastisized and makes conditions for adhesion with steel surface. After NASF in a formed layer there is made >10 % of vacancies, due to which the surface smearing with oil achieves up to 100 %, decreases time for the surfaces running-in, wear losses, signally increases wear pair resistance to wear [1, 4, 5].

A significant advantage of NASF in comparison with other finishing treatment operations is that this technique is rather simple and does not require complicated arrangements.

When treating NASF the steel or cast iron components, their surface not only is coated with 2 – 4 μm thick layer but may also be hardened up to 70 μm [2, 3].

The most significant factors effecting coating quality and finished surface properties are: material and its state; surface macrogeometry and heat removal; roughness of the treated surface, material of rubbing-in rod, pressing force, sliding rate and longitudinal shift; surface activating material; the number of passing [1, 6].

The aim of the present work is to investigate the steel surfaces, treated with NAFSF, tribotechnical features when working in pair with aluminium alloy, and also the possibility to activate surface before treatment with ammonium bichromate.

## 2. SURFACE ACTIVATING

Non-wearing effect is lightly realized in the pair "steel–aluminium alloy" when slushed with glycerin. In the first there occurs brass dicomposition on the friction surface. Glycerin acts as if it were weak acid. The brass alloying elements (Zn, Sn, Fe, Al, etc) go over into oil, and as a result the number of copper atoms on the brass surface increases. As the surfaces rub themselves, there occurs new alloying elements diffusive indraught onto the surface, which also go over into oil. Then the surface brass layer becomes cupric and more vacancies are formed in it, some of them combine forming pores which are filled with molecules. As glycerin is a decomoposer of cupric oxides than on the friction surface such oxides are not formed. Cupric film is very active and is capable to cohere with steel surface, therefore steel surface is covered with a thin cupric film. As the cupric layer becomes thinner the brass alloying elements begin to dissolve. This process takes place until on the brass and steel surface layers are formed 1 – 2 μm thick cupric film.

As the servovite film is formed in glycerin there occur some changes for which U. S. Simakov and A. A. Poliakov have determined the following chemical reactions [7, 8]:

*Corresponding author. Tel.: + 370-37-397553; fax.: + 370-37-397724.
E-mail address: *juozas_padgurskas@hotmail.com* (J. Padgurskas)

a) chemical transformations related to molecular mass decreasing:

$$H_6C_3(OH) \rightarrow H_2CO + H_4C_3(OH)_2O + H_3C_3(OH)_3O \; ; \qquad (1)$$

b) reciprocity between transformation products; there takes place restoration of corrosion products and solution of active metals and their compounds:

$$H_2CO + CuO \rightarrow HCOOH + Cu \; ;$$

$$H_4C_3O + CuO \rightarrow H_3C_3(OH)_3O + Cu \; ;$$

$$Fe + 2\,H_3C_3(OH)_3O \rightarrow$$
$$\rightarrow H_3C_3(OH)_3O - Fe - H_3C_3(OH)_3O \; ;$$

$$Fe_2O_3 + 6HCOOH \rightarrow$$
$$\rightarrow 2HCOO - FeHCOO - OOCH + 3H_2O;$$

$$Fe + CuO \rightarrow FeO + Cu \, . \qquad (2)$$

Such processes run when treating NAFSF and activating surfaces with glycerin.

Glycerin is an organic substance, while ammonium bichromate is inorganic one. When carrying out searching investigation there has been determined that the substance mentioned above may also help in forming brass coating on the steel surface. As in the literature the use of this substance for coatings was not found, then as a possible process course, from chemical point of view, might be as follows. Ammonium bichromate is an oxidiser. When dissolving in water, it is formed chromic acid.

$$(NH_4)_2Cr_2O_7 + H_2O \rightarrow$$
$$\rightarrow (NH_4)OH + Cr_2O_3 + H_2Cr_2O_4 \qquad (3)$$

The formed volatile components as ammonium hydroxide evaporate (drying or rubbing surfaces when rises their temperature). Chromic acid during friction mode dissolves metals of both rubbing surfaces (surface layer). When the acid is reducing, there occurs oxidation, therefore there is being formed a microabrasive $Cr_2O_3$.

$$(NH_4)OH + H_2Cr_2O_4 + Cu + Zn \rightarrow$$
$$\rightarrow CuO + Cu(OH)_2 + ZnO + Zn(OH)_2 + Cr_2O_3 \qquad (4)$$

Working further, CuO begins to contact with Fe and reduces, thus growing a Cu layer on the steel surface.

$$CuO + Fe \rightarrow Cu + Fe_2O_3 \qquad (5)$$

Zinc oxide ZnO under these conditions do not reduce, therefore a great part of it is taken away as admixtures and are removed from the contact zone. As the process of coating formation is not only chemical but also a mechanical one therefore part of the ZnO and $Cr_2O_3$ remains in coating.

Such are the processes during finishing when activating with ammonium bichromate. These reactions are partly based upon the data of carried out by us investigation when there was determined that the amount of copper ions on the coating surface is greater than on the brass surface; there was found a small amount of chrome.

The difference between the activation variants of both surfaces is that when the surface is forming there occur different chemical reactions and are formed other compounds. At the end the coating can be evaluated only after having carried out its investigation in detail.

Activating with ammonium dichromate coating colour is obtained a bit other; this shows partly different coatings composition. One of the basic common features of these coatings is formation of atomic cuprum on the surface. We can predict that when activating with ammonium bichromate, the distribution of materials on the coating is more even.

## 3. EXPERIMENTAL

### 3.1. Equipment

The samples were rubbed in with a self-constructed device (Fig. 1). As a vibrator there was applied a standard perforator. The latter transfers low frequency vibrations onto the rubbing in rod through a shaft-core and affect its end surface from the side of the driving gear. An electric motor and core drive cause the rubbing-in tool to rotate. An elastic element – spring ensures the rod a corresponding pressure force.

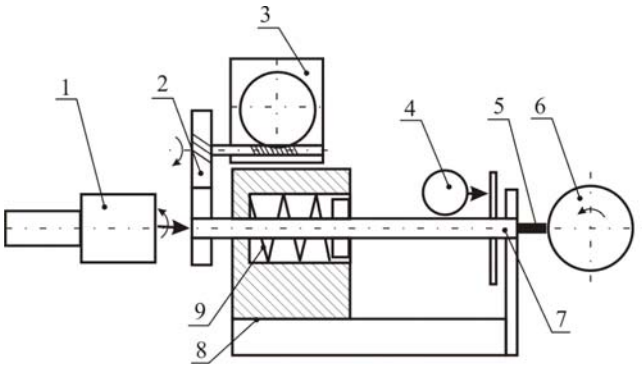



**Fig. 1.** Schematic diagram of the device: 1 – vibrator, 2 – drive of rubbing-in rod, 3 – motor of rubbing-in rod drive, 4 – indicator, 5 – rubbing-in rod, 6 – treated component, 7 – core, 8 – frame, 9 – short element

Wearing tests were carried out with a machine СМЦ-2, the schematic diagram of which is shown in Fig. 2. The load applied to the surface by a load screw during testing and later was not corrected, therefore the load, as the surfaces were wearing, was decreasing.

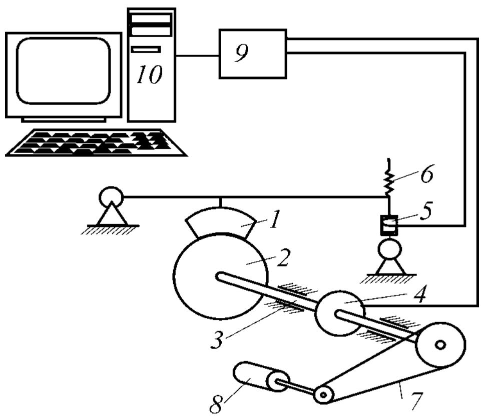



**Fig. 2.** Schematic diagram of the modernized machine СМЦ-2: 1 – shoe, 2 – roller, 3 – shaft of rubbing machine, 4 – sensor of torque moment, 5 – load sensor ZF-500, 6 – load screw, 7 – belt drive, 8 – electric motor, 9 – registration plate ADC-200/20, 10 – computer

NASF was carried out by altering surface activating material, pressure force of the rubbing in rod, other parameters (passings number, sliding rate) keeping constant.

Samples treatment time, by set mode, was different. Thus it was attempted to explain how much time it is necessary for the formation of coating. The shortest time of treatment until the full formation of the coating was for those samples, which were activated with ammonium bichromate ($(NH_4)_2Cr_2O_7$), pressure force being 48 MPa.

With NASF there were treated steel rolls (steel 45, hardened, tempered (the average surfaces hardness 48.6 HRC (standard deflection $\sigma$ = 1.143) chemical composition: C – 0.45 %, Si – 0.27 %, Mn – 0.65 %, $\sigma_B$ = 598 MPa). The rolls were tested in the pair with shoes, made of aluminium alloy AMO 7-3 (Al – 90.07 %, Si – 0.30 %, Mg – 0.10 %, Cu – 8.69 %, Zn – 0.33 %, Fe – 0.38 %, Mn – 0.13 %).

The rolls surface roughness was measured with a Roughness-meter HOMMEL TESTER T500.

### 3.2. Data analysis

As may be seen from the data given in Table 1 lesser surface roughness is obtained having rubbed-in samples by using glycerin. This may be explained by the fact that ammonium bichromate more activates brass rubbing-in rod and thus making conditions to carry on adhesion processers and to transfer rod material in the larger parts. This also reflects in the surface roughness parameters, according to which one can affirm that when using glycerin for rubbing in, the coating becomes more even. Having measured coating thickness preliminarily indirectly (etching the coat and measuring the depth of notch), there was determined that coating thickness is 2…4 μm thicker in the samples whose were treated using ammonium bichromate. This may be seen and in images of rubbed-in surfaces in Fig. 3.

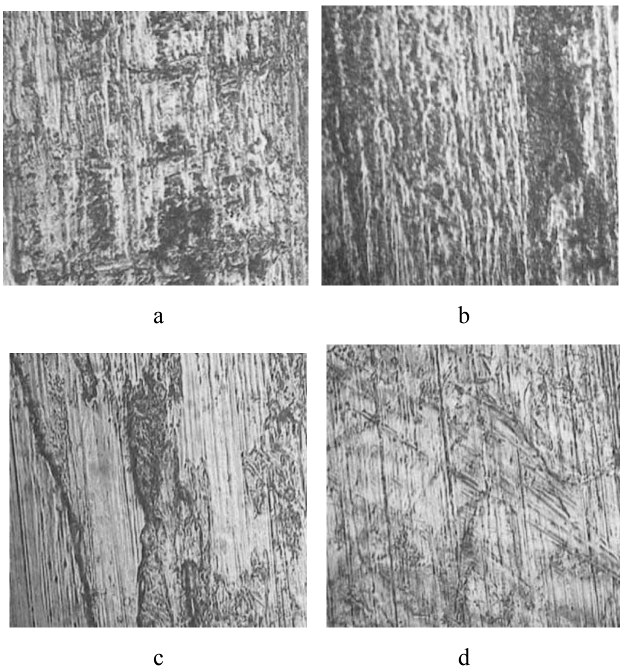



**Fig. 3.** Images of rubbed-in surfaces (increased 600 times): a – with ammonium bichromate, b – with glycerin, pressing 32 MPa, c – with ammonium bichromate, d – with glycerin, pressing 48 MPa

**Table 1.** Roughness of surfaces

| Rubbed in with: | Average roughness | |
|---|---|---|
| | $R_a$, μm | $R_z$, μm |
| Non-treated | 0.349 | 2.654 |
| Glycerin | 0.403 | 3.273 |
| Ammonium bichromate | 1.620 | 8.660 |

Surface roughness and visual evaluation are not the only and basic coating parameters. Much significant coating parameter is its chemical composition, which was determined with shortwave analytical X-ray spectrometer Spark-1. In Table 2 is given chemical composition of the samples surfaces treated by different modes.

**Table 2.** Coat composition after treatment samples with NAFSF

| Sample rubbed in with: | Coat composition, % | | |
|---|---|---|---|
| | Cu | Zn | Cr |
| Rubbing in rod | 61.60 | 38.18 | – |
| Ammonium bichromate ($p$ = 32 MPa) | 65.09 | 29.95 | 0.012 |
| Ammonium bichromate ($p$ = 48 MPa) | 65.12 | 34.78 | 0.03 |
| Glycerin ($p$ = 32 MPa) | 70.33 | 26.73 | – |
| Glycerin ($p$ = 48 MPa) | 81.78 | 18.00 | – |

According to this data it should be first of all noted that when treating the surfaces by greater rod pressure force, in the latter remain less various admixture. There has been determined that on the coating, formed by activating with ammonium bichromate, there has been found Cr element. The increasing of cupric atoms, in comparison with the rubbing-in rod, is being found in all samples, the greatest - in the sample when treated using glycerin and 48 MPa pressure force. Secondly, the treatment time of this sample was the greatest, this might influence the beginning of the servovite film formation (the number of Zn atoms on the surface decreases).

Tribotechnical experiments were provided with the goal to value used tribo pair in running-in period, and also in extreme mode.

At first there was performed the operation in of unloaded surface (≈ 20 min), then they were gradually loaded till the set limit.

It is very difficult to state actual load applied to roll surface because when the surfaces work in, actual contact area constantly changes. It is said that when the surfaces are fully worked in, actual contact area achieves 80…90 % of nominal area [9]. At first this area is very small and may attain approximately 10 %. There was designed to change actual outlined shoe pressure to roll surface due to dependence, shown in Fig. 4. The load diagram for samples according to mentioned law above assuming that at the initial moment the contact area of the surfaces is 1 % and when the samples are fully loaded, the area reaches 6 % of nominal shoe area (shoe area $S$ = 68.7 sq.mm), is shown in Fig. 5.

The change of friction moment in running-in period is shown in diagrams in Fig. 6.

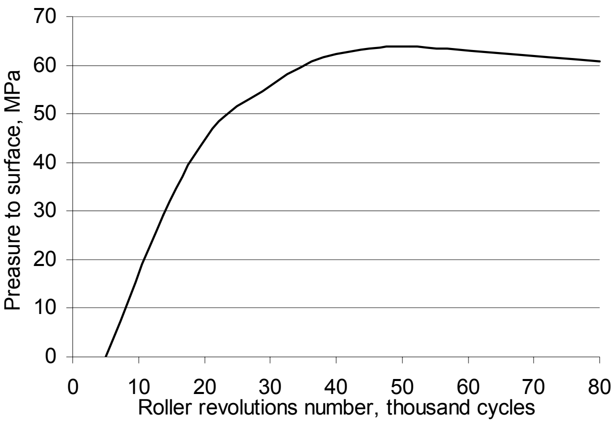



**Fig. 4.** Dependence of pressure force onto the samples surfaces

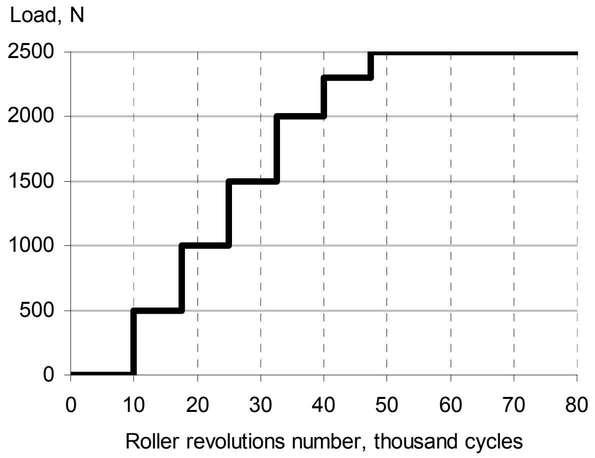
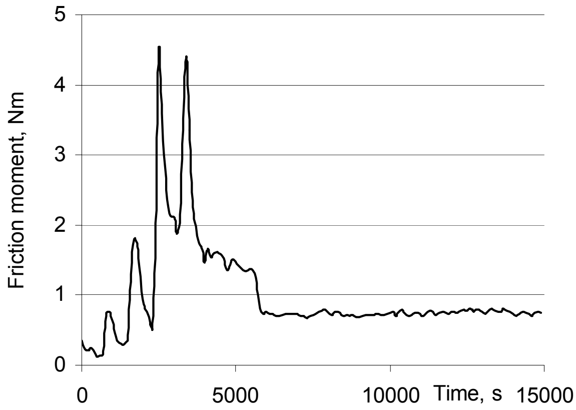



**Fig. 5.** Load diagram in samples rubbing machine

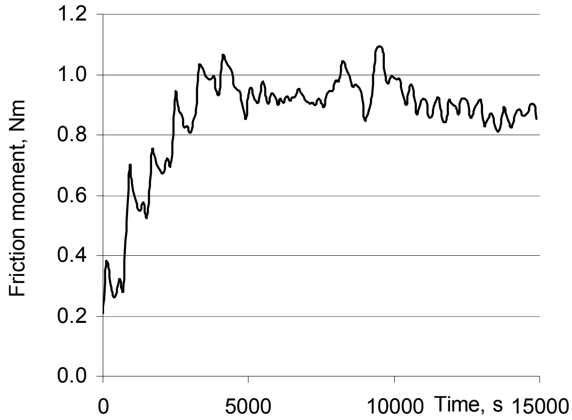
During the working in of the surfaces, i.e. loading the surfaces, there was observed a little another image. If the friction moment rises evenly in the tribo pairs with brass coatings and only slightly increases having increased load, then on the surfaces without coating the process takes place in completely another way. According to this one can affirm that the surfaces treated by NASF, being extreme loads and during working in adjust themselves much better and quickly than the surfaces without coatings (Fig. 6).

The peaks of friction moment show the actively taking place adhesion processes which quicken the wear of surfaces. Here we see again that in friction pairs, where the samples are with coating, the processes take place on much smaller surface area or not so intensively as in the pairs with samples without coating. This might indirectly show also the formation of servovite film, but it is only a presumption.

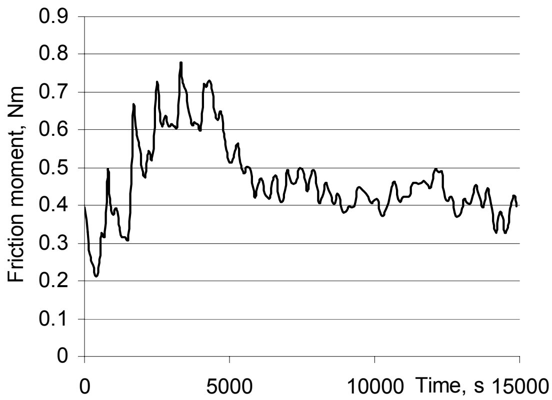
Further work of the surfaces and their wear may be represented as follows. Surfaces without coating, after a corresponding amount of work done, begin to stick (there take place surfaces adherence processes), this causes the increasing surfaces wear resulting in further decreasing of load to the surface. According to the tests data it is possible to affirm that there settle such loads which in reality may hold out given surfaces when other modes (sliding rate, temperature, lubrication) do not change. This once more shows the capability of surfaces with coatings of holding out greater loads.




a




b




c

**Fig. 6.** Friction moments in working-in mode: a – control variant (non-treated by NASF); b – samples treated when activating with glycerin; c – samples treated when activating with ammonium bichromate

If in tribo pairs after NASF, having increased load, friction moment only slightly increases and comparatively rapidly becomes stable, then without the NASF this process takes place in quite another way. The friction moment peaks shows that the cohesive surface processes occur rather actively accelerating surface wear. Therefore it can be affirmed that the surfaces treated with NASF show better working-in.

After run-in there were carried out wear testings, the duration of which was $t$ = 800.000 cycles or 90.000 cycles. During these testings on the surfaces not treated with

NASF, manifested itself sticking. In the surfaces treated with NASF the sticking phenomena were not noticed. This allows to affirm that during the settled mode for the friction pairs whose rollers were treated with NAFSF critical loads may be significantly greater than in a control variant (not treated with NASF).

Having carried out the tests, the rollers and shoes were once more weighed (scales SCALTEC SBC 31). Weighting samples were determined the summary wear size of the samples in run-in and in steady wear modes. Average test results are illustrated in Fig. 7. Using ammonium bichromate for rubbing in, these values are approximately twice as large as in other cases, but this can be explained as being due to the fact that the coating of the latter rollers is rather uneven and thick, therefore it is obvious that during the working-in process this wears most quickly until there is formed the necessary microrelief.

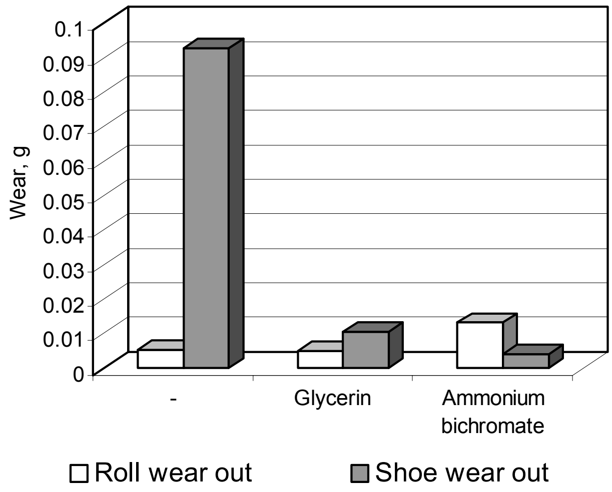
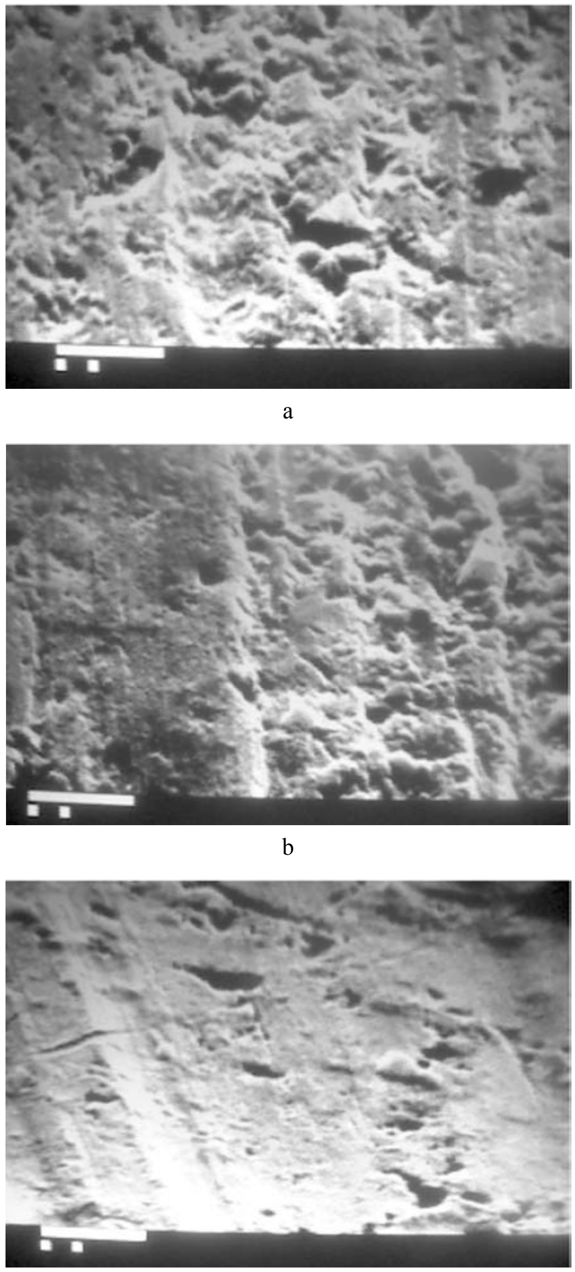



**Fig. 7.** Wear results of samples

There is completely different picture examining the amounts of shoes wear. Here we can distinctly see friction pair operation differences. The smallest wear of the shoes has been obtained using ammonium bichromate. Generally comparing the rollers with coating and without it, it is safe to assume that in such a pair with rolls treated with NAFSF the wear of shoes might be at least 5 – 10 times less after a corresponding amount of work done.

Given above data we will illustrate by surface images. Fig. 8 shows surface photographs obtained by electronic scanning microscope (JOEL 35). Light dash below shows a 10 μm length segment.

Among the shoes, working in pair with rubbed in roller, no essential differences, being such a magnification, were observed. According to the overall surface image it can be affirmed that cohesive processes took place in all pairs. Visually more even shoe from a pair with non rubbed in sample surface image may be explained by the fact that in this case the latter processes took place rather more intensively, therefore after the friction mode has been settled, there was formed a certain surfaces microrelief and the process turned to much lesser surface areas. On the surfaces of samples with coatings adhesive processes took place slower, wear was significantly less.



a

b

c

**Fig. 8.** Images of aluminium shoes surfaces after 25 h amount of work done (in pair with roller): a – rubbed in with ammonium bochromate; b – rubbed in with glycerin; c – not rubbed in

Besides, the coating, whose main constituent part is copper, is comparatively soft, its hardness is close to shoe hardness, therefore part of the torn off particles might settle down on the other places of the surfaces. AS the images are not coloured it is difficult to say whether the rises, seen on the surfaces, or not coating remains.

On the surfaces it is also possible to observe some signs of abrasive wear. And although the shoe surface from the pair with untreated roller visually appears more even, there cannot be affirmed that the latter worked under easier conditions. From these images one can affirm that the rollers treated with NASF work under other friction and wear conditions than the untreated rollers. To say more exactly about the formed during the friction processes microrelief and present in them materials one could after having investigated the surfaces with atomic force microscope. The latter investigation might allow determine the presence of servovite film, which is when realizing non-wear effect in friction pairs, on the friction surfaces [6].

During the tests samples wear in working-in and settled modes were not determined separately, therefore it is difficult to say which components of the value belong to working-in and to settled mode. Nevertheless, the obtained results in working-in and extreme loads areas, to our opinion, allow to affirm that the treatment of steel surfaces with NASF, working in pair with aluminium alloy, improves their working-in, increases critical loads, reduces friction losses and wear. The investigation result also allow expect that ammonium bichromate may be used in activating surfaces to be treated. Final conclusion concerning ammonium bichromate may be drawn after having carried out investigation under the conditions of permissible operational loads.

## 4. CONCLUSIONS

1. Treating steel friction surface with NASF brass rod, activating the surface both by glycerin and ammonium bichromate, on the surface is being formed 2…4 μm thick coating, on the surface of which, due to selective transfer, increases copper concentration (comparing with rod material).
2. The treatment of steel friction surface with NASF improves friction pair working-in when treated surface works in pair with aluminium alloy (less friction moment increase, having increased load), and increases critical loads. The best working-in is characteristic for the friction surfaces whose are treated using ammonium bichromate.
3. Friction pairs with rollers treated with NASF under working-in and extreme loads conditions according to total shoe and roller wear, wear in an average 5 – 10 times less than with non-treated rollers. Less of all wear the rollers treated when activating surface with glycerin, while shoes – using ammonium bichromate.

**REFERENCES**

1. **Garkunov, D. N.** Tribotechnika. Moscow: Mashinostrojenie, 1985: 424 p. (in Russian).
2. **Polcer, G., Firkovskij, A., Lange, I., et al.** Finishing Antifriction Nonabrasive Treatment and Selective Transfer *Durability of Rubbing Machine Components.* Moscow, Mashinostrojenie, 1992: pp. 86 – 122 (in Russian).
3. **Garkunov, D. N.** Analysis of Wear and Selective Transfer *Nonwear and Tribotechnology Effect* 1 1992: pp. 9 – 11 (in Russian).
4. **Dzidolikas, B., Juzenas, E., Serapinas, V., Padgurskas, J.** Investigation of Nonabrasive Antifriction Finishing Treatment by Increasing Triboeffeciveness *Mechanika* (*Mechanics*) *ISSN 1392 - 1207* 3 1995: pp. 49 – 52 (in Lithuanian).
5. **Padgurskas, J., Rukuiza, R., Votter, M., Wollesen, V.** New Tribotechnical Materials for the Friction Pair Radial Lip Seal / Shaft *Industrial Lubrication and Tribology* 51 (5) 1999 England, MCB University Press, 1999: pp. 233 – 238.
6. **Garkunov, D. N.** Tribotechnika (Wear and Nonwear): Textbook. Moscow, Publishing House MCXA 2001: 616 p. (in Russian).
7. **Poliakov, A. A., Ruzanov, F. I.** Friction on the Basis of Self-organization. Moscow, Nauka, 1992: 135 p. (in Russian).
8. **Simakov, U. S.** Physical – chemical Processes at the Selective Transfer. Selective Transfer in Heavily Loaded Friction Units. Moscow, Mashinostroenije, 1982: pp. 88 – 111 (in Russian).
9. **Karassik, I. I.** Methods of Tribological Tests in Standards of Various Countries. Moscow, Science & Technique Centre, 1993: 328 p. (in Russian).