Journal of KONES Powertrain and Transport, Vol. 16, No. 1 2009

THE PREPARATION OF SURFACE LAYER OF NON-ALLOYED STEEL TO COOPERATION WITH LUBRICATING MEDIUM

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Abstract

This paper discusses the influence of cold working to energy conditions of the surface layer of steel 15; it is evaluated with the use of free surface energy calculated (with polar-dispersive method) on the basis of wetting angle measurements. The samples subjected to such working method were also subjected to scuffing resistance tests performed on the pair of counter-samples made of steel 45.

In the paper procedure of scuffing was described. Moreover, the methods of results evaluation were put. The tests were carried out in lubricating conditions of different mechanisms of interaction with the lubricated surface. They found out that the free surface energy increase influenced the scuffing resistance decrease for the pairs lubricated with surface non-active substances. However, the resistance increased for the pair lubricated with substances reacting chemically with the surface. In the paper example of test results, average valves of free surface energy were presented. The obtained tests results were verified by the comparison with the results of the experiment where the surface layer energy conditions were evaluated with the use of Auger electron spectroscopy. Changes with cold plastic work to the surface layer can prepare it to co-operation with active lubricants and thus increase its adhesive scuffing resistance.

Keywords: *surface layer, energy conditions, free surface energy, adhesive scuffing, wetting angle, auger electron spectroscopy*

1. Introduction

Contemporary formation of the surface layer from the point of view of its resistance to adhesive wear and scuffing is realized according to three most important demands: positive strength gradient on the wall, higher hardness and preparation for co-operation with the lubricant.

The demand concerning the surface layer preparation for the co-operation with the lubricant is, among others, connected with the fact that the condition for maintaining the lubricant layer separating the friction elements is, in substantial degree, the surface layer ability to reconstruction. Macroscopic characteristics of the surface layer makes possible to regard it as a certain kind of a chemical reactor where different physicochemical reaction occur during friction. Our present knowledge concerning the physicochemical domain allows only in a slight degree to cause changes in the metal surface layer; the changes are desirable from the point of view of durability of the lubricant layer being maintained mainly due to the application of suitable improvers [1].

As far as the surface layer is concerned, its ability to maintain the lubricant through formation of the suitable surface micro-geometry is of basic importance as its oil capacity is increased this way. Nowadays, working being the most commonly used to improve the oil capacity includes: plateau honing, oscillating burnishing and electrochemical or chemical etching. Although the mentioned methods differ significantly in realization technology, they allow for achieving a similar effect in the form of a system of micro-valleys on a smooth surface.

The demand of preparation of the surface layer for the co-operation with the lubricant can be realized mainly by the formation of the right roughness.

Roughness formation of the surface of the higher oil capacity and ability to break the friction contact allows for significant increase of the scuffing resistance of sliding pairs operating in conditions of mitigated solid friction. When determining the roughness parameters, the following aspects being important from the point of view of tribology are not taken into account [2]:

- properties of oil applied for lubrication;
- critical dimensions of adhesive tacking which cannot be tress passed, otherwise friction focuses can occur;
- relations between time of moving from one projection of irregularity to another and time necessary for reconstruction of the lubricant layer;
- size of wear products which should partly be able to gather in cavities.

Here, it would be worth coming back to the conclusion stated at the occasion of increasing surface hardness through cold working. They proved experimentally that the application of such working for creation of the surface layer of the element of the friction pair lubricated with the non-active substance is the reason of its cold adhesive scuffing resistance deterioration. This situation is most probably caused by the surface layer energy condition increase enabling to achieve, in friction energy conditions, the threshold being necessary for adhesive tacking occurrence. These are, of course, tacking of I kind and their main activator is just the plastic deformation. However, if they used for the pair lubrication the lubricants containing additives type EP reacting chemically with the surface, its higher energy conditions and consequent higher chemical activity could cause quicker and stronger bonding between antiscuffing additives and surfaces of friction elements. But, in order to achieve such effect, it is necessary to apply a working method allowing controlling the plastic deformation of the surface layer, thus enabling to control its properties. The simplest and cheapest cold working method allowing meeting the mentioned condition is pressure burnishing.

In order to explain this problem, they started the research work aiming at the evaluation – with a direct and indirect method – of changes of carbon steel surface layer energy conditions due to the cold plastic deformation, and then the determination of cold adhesive scuffing of pair with a steel element subjected to burnishing.

2. Samples preparation and tests methods

For tests they used samples made of steel 15 for which degrees of cold work were matched on the basis of the consolidation diagram. The initial material was not subjected to plastic work and the applied degrees of cold work complied, approximately, a half of the section of the consolidation proportional increase (ab. 25 %) and near the cold work “saturation” (ab. 50 %). The samples were subjected to cold work on the high pressure and then – in order to obtain the same roughness, they were hand grinded with the use of abrasive paper of granularity 500.

Free surface energy was determined on the basis of wetting angle parameters on the surface of the samples. For this purpose, they applied the goniometer PG3 of the firm Fibro System AB, where the samples were put after cleaning them with acetone and drying. On the surface of so prepared samples, they put water of special cleanness and diiodomethane drops (and volume 2 μl). The drops were put with the use of so called released drop method, it means that the drop is released from the applicator immediately after the contact with the base. The wetting angle between the sample surface and the plane being tangent to the drop surface was measured after the balance conditions were established. As balance conditions they assumed the conditions where the wetting angle value was stabilizing (i.e. it stopped decreasing in the effect of drop spreading on the surface). The wetting angle measurement procedure was repeated 10 times and then for the obtained mean value the free surface energy was determined (with the use of goniometer software basing on so called polar-dispersive method). For each kind of samples they repeated 12 times the determination of the free surface energy value.

The scuffing tests were performed on the Amsler A135 friction machine and the geometry being characteristic for the friction pair is shown in the Fig.1. The counter-samples were made of steel 45 and subjected to quenching in oil and tempering – in the effect the obtained hardness was 45 ± 2 HRC.

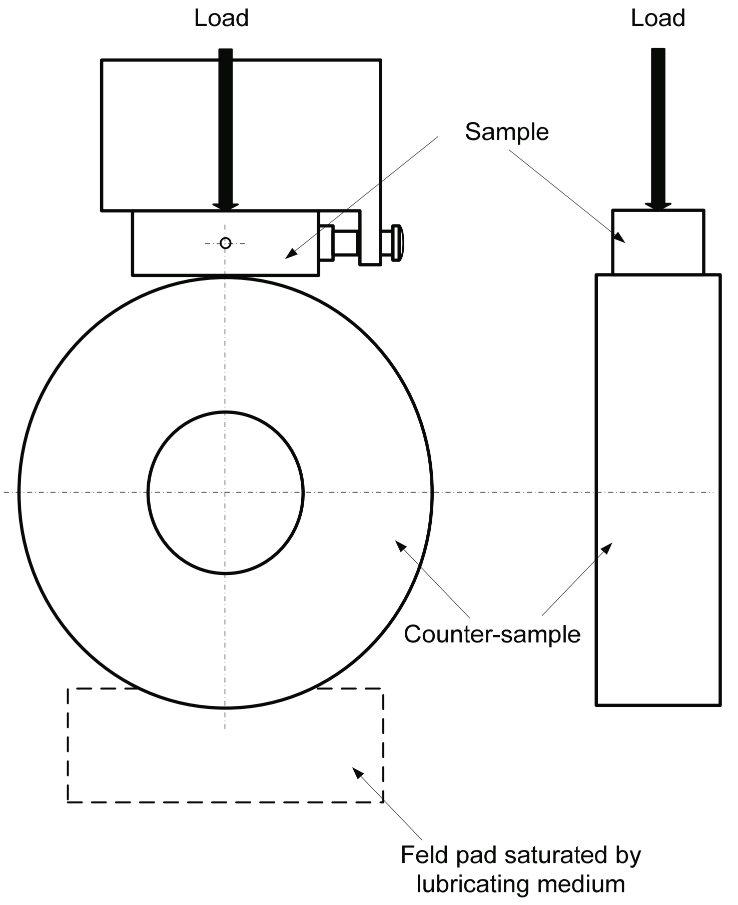

Fig. 1. Geometry of friction pair used in scuffing test performed on the Amsler A135 friction machine

The tests were carried out at sliding speed v = 0.4 m/s, and load applied according to the procedure shown in the Fig. 2 (during the test, force of pressing the sample to counter-sample was increased gradually).

The friction pair was lubricated with the use of a felt pad absorbed with lubricant. They used a new felt pad for each test. Lubricants were chosen depending on the mechanism of their interaction with the metal surface during friction. So, they applied for lubrication:

- paraffin oil, as non-active substance influencing only through its viscosity,
- 0.05 molar solution of n-cetyl alcohol in paraffin oil as substance able to physical adsorption on the lubricated surface,
- 0.05 molar solution of dibenzyl disulfide (substance able to chemisorption and polymer ageing creation) in paraffin oil,
- 0.05 molar solution of elementary sulphur able to chemical reaction, in paraffin oil.

The end of the scuffing test took place when first symptoms of the scuffing process were observed. As a criterion of its occurrence, they assumed a sudden increase and instability of the friction moment, together with the appearance of tacking traces on the sample. If scuffing initiation did not occur before the application of the highest load, i.e. 200 daN, lubrication was stopped and the test was continued to the moment of its occurrence.

They applied two scuffing resistance measures: time measured from the beginning of the test to the moment of scuffing occurrence and specific force respective to the scuffing beginning. In certain cases, the values of these measures were not consistent, i.e. the shortest time to scuffing occurrence was not always respective one to the lowest pressure.

Taking this fact into account, they introduced a generalized scuffing resistance index W_{OZ} being the ratio of time before scuffing occurrence and the respective surface pressure. The W_{OZ} index was used for scuffing resistance evaluation.

For each combination of applied lubricants and degrees of cold work, they carried out three scuffing resistance tests. As a reference point for crushed samples, they applied ground samples being not subjected to cold plastic work.

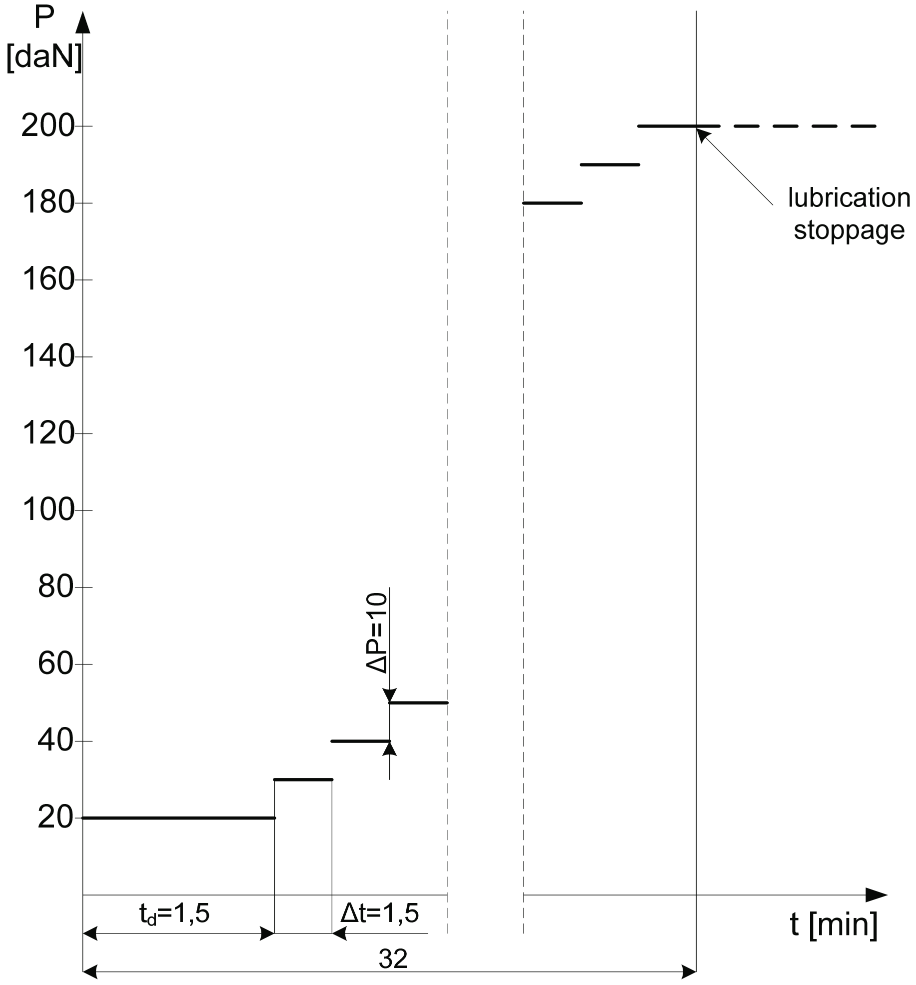

Fig. 2. Procedure of load applying in the scuffing research (energy conditions valuation by free surface energy): P - load, ΔP - load increment, t - time, t_d – running-in time, Δt – work time under a given load

3. Tests results and discussion

The Fig. 3 presents values determined according to the earlier discussed procedure and mean free surface energy values for the individual kinds of samples. For each of them, they calculated mean value confidence intervals for the assumed significance level being 0.1.

The analysis of the diagram presented in the Fig. 3 shows a distinct increase of the free surface energy value for the samples subjected to the maximum used cold work degrees – 50 %. The difference characterizing the mean values for both working methods is close 11 $mJ \cdot m^{-2}$ (for ground samples the mean value of the free surface energy was 42.08 mJ·m^{-2}, and for the samples subjected to 50 % cold work – 52.86 mJ·m^{-2}). One can also observe a slightly increasing tendency between the ground samples (42.08 mJ·m^{-2}) and the samples subjected to 25 % cold work (44.87 mJ·m^{-2}). However, from the point of view of statistics the differences are not important.

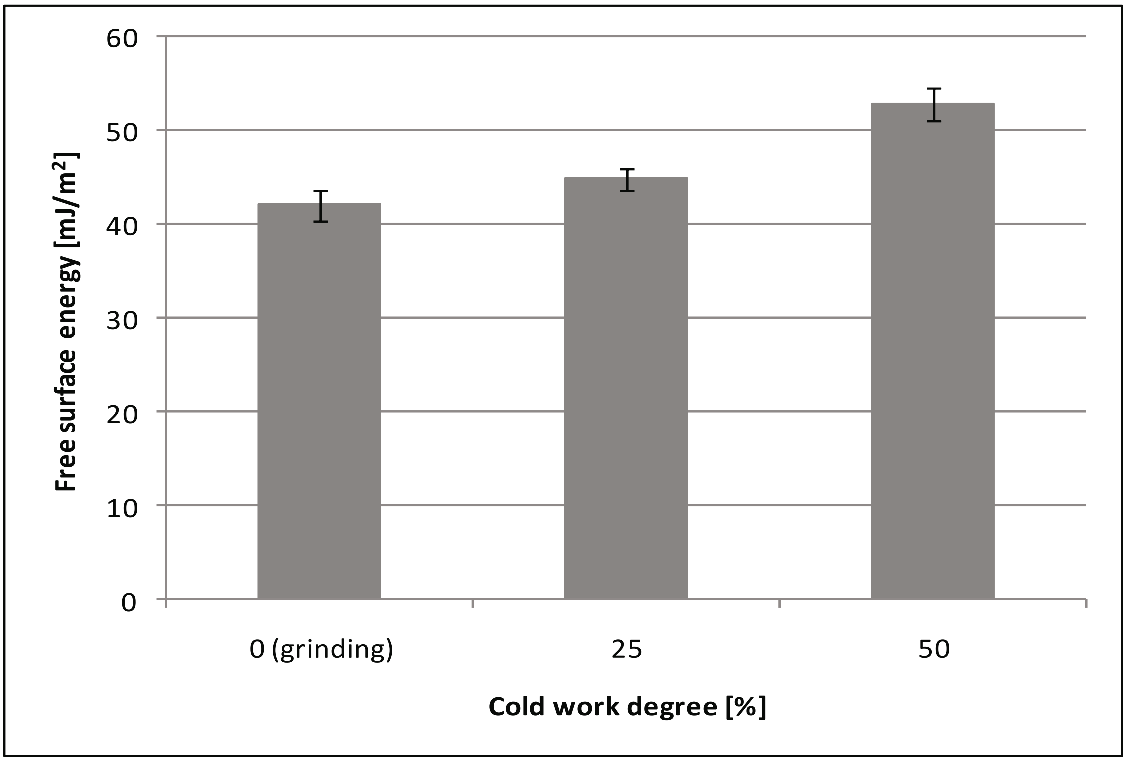

Fig. 3. Average values of free surface energy depending on used treatment method

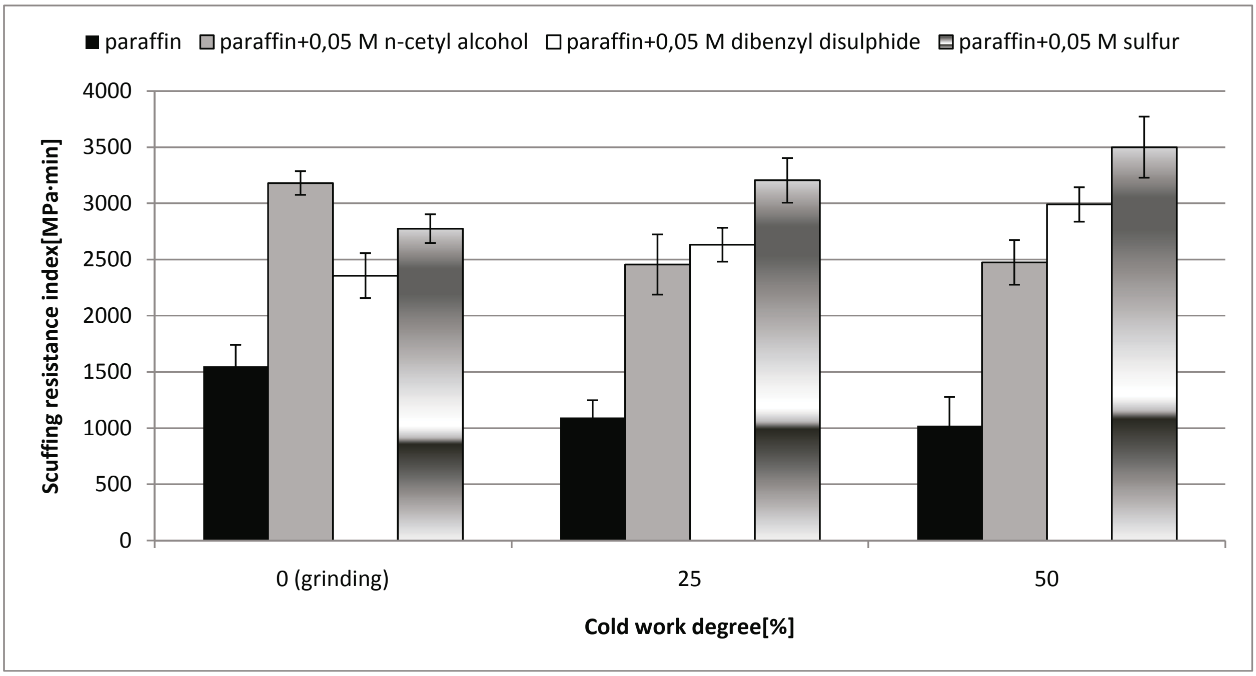

Fig. 4. Average values of free surface energy depending on used treatment method

The Fig. 4 presents the influence of the sample cold work degree and the kind of the applied lubricant on scuffing resistance (defined by the scuffing resistance index).

The scuffing resistance tests results presented in the Fig. 4 allow for the identification of specified tendencies of values changes of the scuffing resistance index depending on the cold work degree and on the kind of the applied lubricating substance.

In case of applying, for the lubrication of the tested pair, lubricating substances not interacting chemically with the surface (paraffin oil and 0.05 molar n-cetyl alcohol solution in paraffin oil), the value of the scuffing resistance index was significantly decreasing. This is probably the effect of higher surface layer energy conditions due to cold work (which is presented graphically in the Fig. 3). Higher energy accumulation in the surface layer allows the tested materials to obtain quicker the energy tacking threshold, in the effect leading to the occurrence of adhesive tacking and scuffing.

The situation is different for scuffing resistance of the pair lubricated with substances interacting chemically with the surface. In case of the pair lubricated with 0.05 molar dibenzyl disulphide solution in paraffin oil one can observe a slight increase of the scuffing resistance for samples subjected to 25 % cold work and it is quite distinct (ab. 630 MPa·min) for samples of 50 % cold work. Such situation can be explained by a probably acceleration of chemical reaction, caused by higher energy conditions, between the lubricated surface and active components of the lubricating substance. This leads to sooner occurrence of boundary layers protecting the surface against the occurrence of adhesive tacking. The application of cold work exceeding 50 % (then the surface layer was not hardened any more) can lead to scuffing resistance deterioration as the so called “cold work saturation” is exceeded. This, in turn, destroys the surface layer which becomes more inclined for different kinds of wear.

A similar tendency was observed for the pairs lubricated with 0.05 molar solution of elementary sulphur in paraffin oil. For the pairs of 25 % cold work the scuffing resistance index value increase of ab. 430 MPa·min was observed, however, for the pairs of 50 % cold work - of ab. 730 MPa·min. In this case, the scuffing resistance increase should be also seen in the surface layer energy accumulation in the effect of cold work. Such situation caused higher reactivity of the surface layer and its tendency to quick bonding with the antiscuffing additive. It is worth pointing out, that for the pairs lubricated with chemically active substances one can observe specific differences in the scuffing resistance. In case of the pairs lubricated with paraffin oil with addition of sulphur the resistance increase value was ab. 100 MPa·min higher than in case of lubrication with paraffin oil with addition of dibenzyl disulphide. So, the conclusion is that in case of carbon steel the addition of elementary sulphur in oil acts more effectively against scuffing than the addition of dibenzyl disulphide.

The obtained test results seem to be very similar to the results of another experiment [3] connecting the surface layer energy condition with scuffing. In this experiment, the evaluation of the surface layer energy condition of steel 45 samples (ground and burnished) was carried out with the application of the indirect method using Auger electron spectroscopy. The research procedure was as follows: the prepared samples were placed in the vacuum chamber and subjected to accelerated argon ion etching. During the whole etching process, the appearing Auger electron spectrum was analyzed height measurement of its individual peaks. Stabilization of this value (no changes in three subsequent measurements) means that the surface is maintained physically clean, all oxides and all kinds of impurities are removed. The evaluation of the surface energy condition was made on the basis of the measurement of time of etching necessary to obtain a clean surface.

The longer is this time the higher is the energy condition characterizing with the appearance of thicker layers of oxides and impurities. To analyze ferrous metals one can best determine spectra of three elements: oxide, carbon and iron. Iron and carbon are main alloy components of these materials, but oxide creates an oxide layer in the near-surface zone of the surface layer.

The tests were carried out on the Auger electron spectroscope of the French firm Riber. The cleaned and dried samples were placed in a special vacuum chamber of pressure range $1 \cdot 10^{-9}$ Tr.

The argon ion beam applied for etching characterized with energy 1500 eV and current emission intensity 50 μA, whereas in case of the primary electron beam necessary to take off the following Auger electron spectra – it was energy 3 eV and current emission intensity 54 μA. For such chosen parameters of argon ions beam the etching time was ab. 0.2 Å/s taking off the next spectra and the height measurement of the analyzed elements peaks took place every 10 min.

The test results obtained with the use of the Auger electron spectroscopy method are presented in the Table 1.

Tab. 1. Time of argon ion etching to physical cleaned surface obtaining

Treatment method	**Time of argon ion etching [min.]**
Grinding	100
Burnishing force 1.6 kN	100
Burnishing force 3.2 kN	130
Burnishing force 4.8 kN	200

The results of the presented experiment also show that cold plastic work can cause the surface layer energy conditions. It is well visible especially in case of maximum applied burnishing force – 4.8 kN. The obtained results of the energy condition evaluation were compared with scuffing resistance tests. When the tested pairs were lubricated paraffin oil, the burnishing force increase caused the scuffing resistance decrease. However, when oil with EP additives (trade oil Tranself EP) was used for lubrication, for sampled being cold worked with force 3.2 kN the distinct scuffing resistance increase was observed. For cold work with force 4.8 kN, this resistance decreased. It was caused by the fact that the application of such force provoked cold work saturation exceeding which was confirmed experimentally.

So, one can state that conclusions of both presented experiment indicate the fact of the surface layer energy accumulation due to cold work and its significant influence on scuffing resistance.

4. Summary

The results of the performed tests show that the surface layer energy accumulation means its scuffing resistance decrease. This statement concerns the pairs which were lubricated with the use of substances not interacting chemically with the surface layer. Higher energy condition of the surface layer in the effect of cold plastic work (in this case – surface cold work) causes the probably increase of activity of its atomic structure elements and thus it becomes an accelerator of different phenomena and processes, including - among others – adhesion. In consequence, the adhesive tacking occurrence process is accelerated directly influencing the surface layer adhesive wear intensity and its especially dangerous form – namely scuffing.

The same mechanism can be used to achieve the scuffing resistance increase, if, for the pair lubrication is applied the substance being chemically active in relation to the co-operating surface. In such case, the surface layer energetic excitation can be used to accelerate formation of boundary layers occurring in the effect of reaction between EP additives of the lubricating substance and the lubricated surface.

Summing up, control over changes introduced by cold plastic work to the surface layer, including above all the energy conditions, can prepare it to co-operation with active lubricants and thus increase its adhesive scuffing resistance – further research works should go in this direction.

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