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WEAR AND FRICTION PROPERTIES OF SHOT PEENED SURFACES OF 36CRNIMO4 AND 36NICRMO16 ALLOYED STEELS UNDER DRY AND LUBRICATED CONTACT CONDITIONS

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Abstract: *Method of Shot peening is often used to increase static and dynamic strength of the work piece. This method can change the characteristics of the surface layer, and thus the tribological properties of such treated surfaces. The quality of the contact surfaces in tribological terms, refers to the roughness parameters and surface microgeometry. Conclusions, presented in this paper, are the result of numerous investigations of tribological behavior of shot peening surfaces in dry and lubricated contact conditions. As materials for tribological tests 36CrNiMo4 and 36NiCrMo16 alloy steels were used. The paper presents a comparative view of tribological behavior of materials under conditions with and without lubrication, as well as in terms of different values of normal load and sliding velocity. Tribological investigations showed that total effects of final machining by shot peening have positive influence on tribological behaviour of machined parts and that they can contribute to the improvement of tribological level of tribomechanical elements.*

Key Words: *shot peening, wear, friction, lubrication*

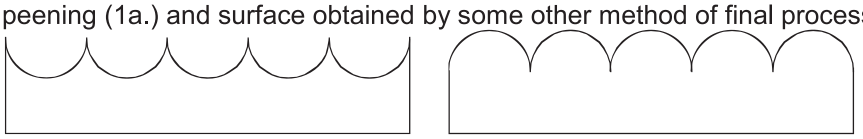
1. INTRODUCTION

Dynamic loads, present in the exploitation process of almost all technical systems, considerably affects reliability of contact elements which form a basic structure of technical systems. Resistance to fatigue of vital elements of technical systems mostly depends on contact layers characteristics. From that aspect, still in the projecting phase, we should pay certain attention to these layers. This is more significant if we know that failure can be gradual (mostly as the consequence of tribological processes development) or unexpected (fracture of elements).

Different methods are used to increase the resistance to fatigue that can occur also due to the wear. Improvement of characteristics is achieved, primarily, by thermal processing (induction and flame hardening), chemical-thermal processing (cementation and nitrating) and processing by surface plastic deforming (surface deforming by rollers, discs and balls, as well as by shot peening). Shot peening is the method of reinforcing contact surfaces, which is widespread in industry due to the very low price and easy integration in any production process. Mechanical characteristics of surface layers are improved by the shot peening.

Micro geometry of contact surfaces is a very important parameter for most of the tribological processes [1-6]. Topography of contact surfaces considerably changes by applying shot peening method, in the sense of worsening surface roughness parameters [7, 8]. The parameters of shot peening process affect, primarily, the schedule of residual stresses, i.e. on mechanical characteristics of material surface layer. Negative effects of surface defects could be eliminated or mitigated by proper choice of parameters of shot peening methods, primarily of ball size, its hardness and speed. The surface obtained after the process is anisotropic surface [9].

It is known that lower wear of surfaces corresponds to a higher fatigue hardness of material. It is not proper to compare surfaces obtained by different mechanical processing (grinding, scraping...), however by these procedures it is possible to achieve completely different distribution of material in surface layer, while the parameters of roughness are almost equal. Figure 1 shows the surface obtained by shot peening (1a.) and surface obtained by some other method of final processing (1b.).



a) Roughness A (Ra=1, Rz=1)   b) Roughness B (Ra=1, Rz=1)

Fig. 1. Schematic view of the surface obtained by shot peening (A) and other methods of final process of surfaces (B) [9].

Topography of surfaces obtained by shot peening has characteristic peaks and valleys, shown in Fig 1a. This profile of surface roughness has positive influence on fatigue toughness in comparison to surfaces obtained by other final processing methods (Fig. 1b). Concentration of stress in bottom of the valley with roughness B is much higher than in the case of roughness A, which due to the presence of tangential force can lead to cracking and later, by its mutual joining, to separation of material from surface layers. The valleys obtained by shot peening, when in contact with lubrication, act like oil reservoirs (oil pockets). The presence of lubrication on these places contributes to generating of hydrodynamic pressure and therefore separation of contact elements [10].

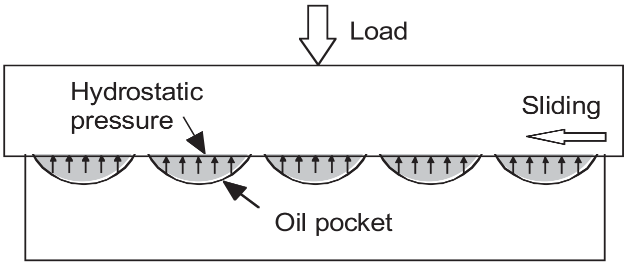


Fig. 2. Influence of contact surface topography obtained by shot peening on lubrication

With relative moving of two surfaces in contact, in the beginning the peaks of surface roughness are elastically deformed without sliding in contact points. The most important result of shot peening are residual stresses in surface layer of material [11, 12]. The increase of surface layer hardness is direct consequence of residual stresses presence. In accordance with that there is also increased elasticity of surface roughness. The risk of separating particles is decreasing with increased limit of elasticity [13].

The lack of shot peening method is that micro-cracks could be conceived due to highly concentrated loads, as well as ball impact of broken balls in the surface, and micro-cracks can spread and make large cracks. If the surface is exposed to variable loads over the period of time, large pitting damage can be produced. These negative consequences could be avoided by thermal process of material before shot peening process or by subsequent chemical process [14].

In recent years, a large number of numerical models and FE simulation with aim to optimize the process parameters of shot peening have been presented and also prediction of influence of certain parameters change on mechanical characteristics and fatigue material resistance [15-20].

With this paper, the authors wanted to show the test results of shot peening influence on tribological characteristics of alloyed steels 36CrNiMo4 and 36NiCrMo16 in conditions with and without lubrication at different values of sliding speed and normal load.

2. MATERIAL

Two alloyed steel, thermally processed (improved), 36CrNiMo4 and 36NiCrMo16 steels, are used for testing of the tribological characteristics of surfaces prepared by shot peening. The chemical composition of the observed materials is given in Table 1, while their mechanical characteristics are given in Table 2.

Tab. 1.
Chemical composition of tested materials

Steel	C%	Si%	Mn%	Cr%	Ni%	Mo%
36CrNiMo4	0.36	0.25	0.65	1.05	1.05	0.20
36NiCrMo16	0.36	0.30	0.60	1.80	3.85	0.33

Tab. 2.
Mechanical characteristics of tested materials

Steel	R_p, MPa	R_m, MPa	A_5, %	Z, %	$KU_{300/3}$, J
36CrNiMo4	900	1150	10	45	35
36NiCrMo16	1050	1340	9	40	30

Samples for tribological testing were made by cutting them from samples aimed for fatigue test. Cutting was realised by machine saw with intensive cooling in order to avoid changes of surface layers, due to high temperature.

Shot peening of samples by steel balls was realised at shot peening machine of ES-1580-1 model, PANGBORN.

Wanted effects of shot peening are obtained if selection of shot peening parameters is realised correctly, such as: ball diameter, Almen intensity, subjected area size coverage and shot duration of shot peening. Shot peening was realised using balls of d=0.8 mm (S330) diameter and 48 - 55 HRC hardness.

Based on literature recommendations, for 15mm thickness of the sample, Almen intensity of 16A was chosen. The largest effects of shot peening occur when the whole area is covered. Hence, coverage of $P=1\times98\%$ was chosen. Duration of shot peening, necessary to achieve wanted Almen intensity (16A) was determined by Almen test strip, by creating saturation curve. Pressure of 4 bar and shot peening time of 5 min correspond to wanted shot peening intensity (16A).

Surface coverage on shot peened sample was observed by the magnifying glass with 10x magnification. It was determined that coverage was 98 % (complete coverage) with shot peening time of 5 min. Appearance of the surface before and after the shot peening for both tested materials are shown in Figure 3 and Figure 4.

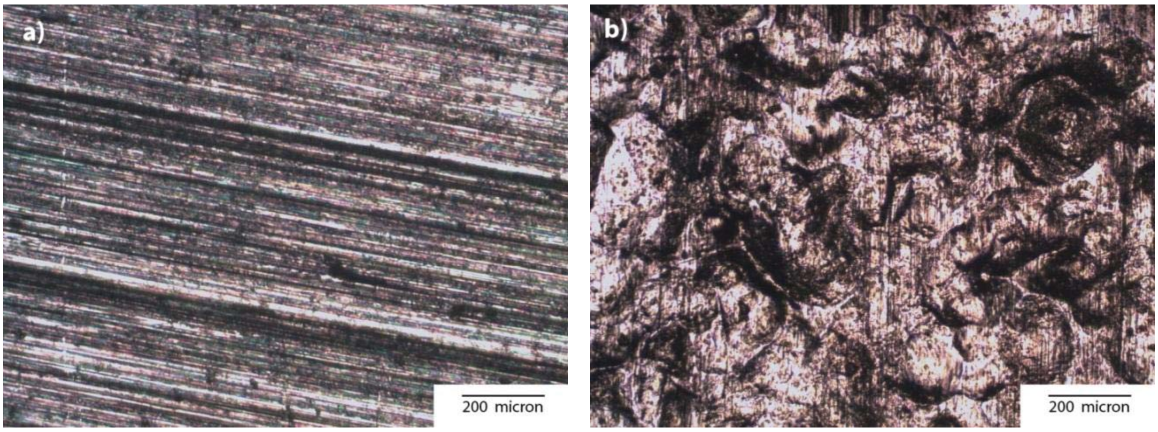


Fig 3. Appearance of the surface before (a) and after (b) shot peening for 36CrNiMo4 steel

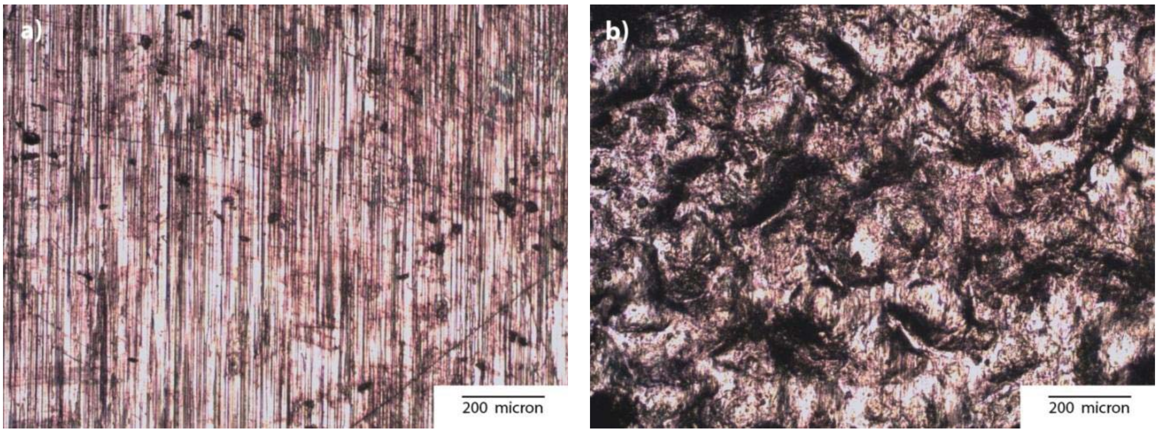


Fig 4. Appearance of the surface before (a) and after (b) shot peening for 36NiCrMo16 steel

3. EXPERIMENT

3.1. Surface topography (Surface roughness)

As a result of shot peening is completely changed topography in sense of height, shape, and statistics, by which shot peening process results and it is illustrated by 3D profile-gram in Figures 5 and 6 where comparative 3D display of ground surface and shot peened surface is shown for both tested materials.

It is obvious that shot peening produced distinguished increase of all altitudinal roughness parameters (R_a, R_q, R_p, R_v, R_y, R_{tm}, R_{pm}), in comparison to initial state obtained by grinding. Worsening of altitudinal roughness parameters is more distinguished with 36CrNiMo4 steel.

Besides the increase of parameters representing height of micro surface roughness, the shot peening process affects high increase of surface roughness parameters, as it is visible on corresponding profile.

Average value of arithmetic mean deviation (Ra) for 36CrNiMo4 steel in ground state is Ra = 0.28 μm and in peened state Ra = 1.81μm, while in case of 36NiCrMo16 steel Ra = 0.62μm is in ground state and Ra = 1.11μm in peened state.

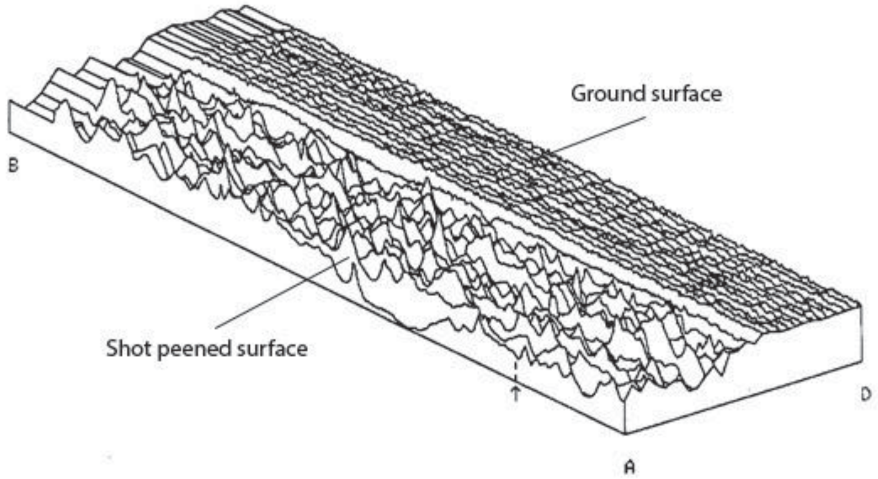


Fig. 5. Comparative 3D view of ground and shot peened surface for 36CrNiMo4

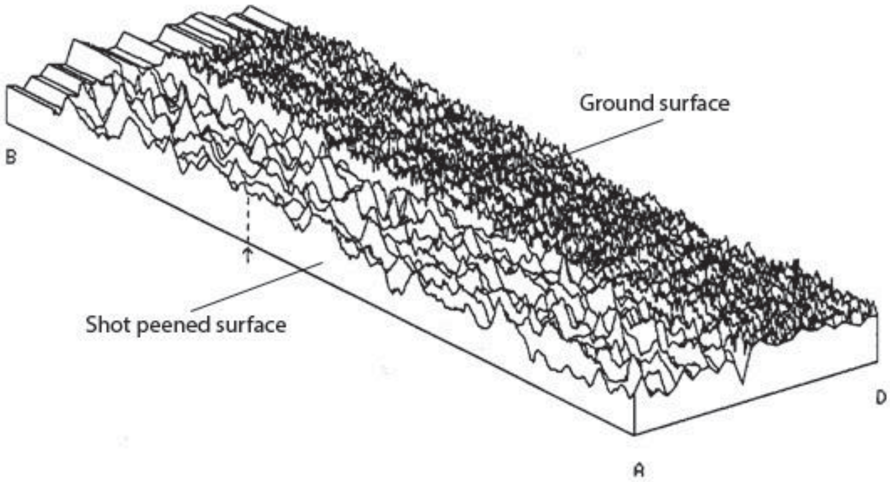


Fig. 6. Comparative 3D view of ground and shot peened surface for 36NiCrMo16

3.2. Micro-hardness

The values of measured hardness, as a function of the distance from the surface, are shown in Figure 7 (36CrNiMo4 steel) and Figure 8 (36NiCrMo16 steel).

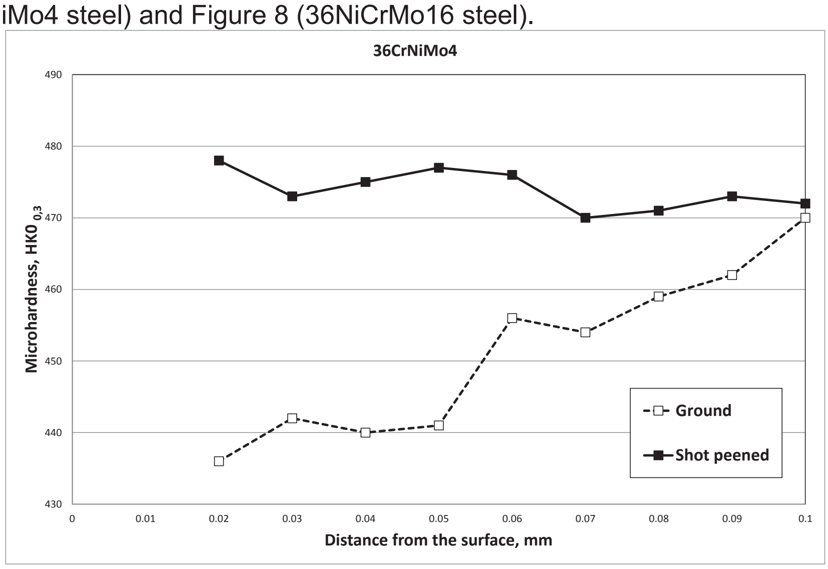


Fig. 7. Micro-hardness of alloyed steel 36CrNiMo4

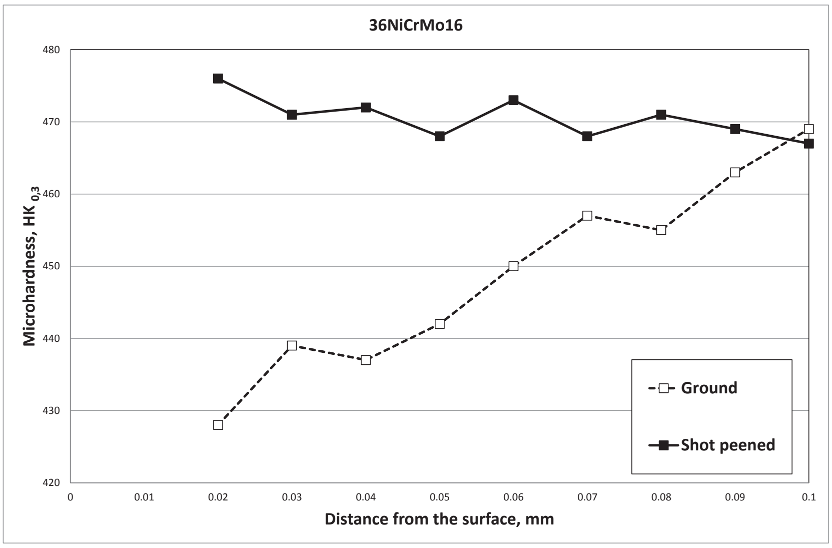


Fig. 8. Micro-hardness of alloyed steel 36NiCrMo16

Decrease of hardness in surface layer occurred in case of both steel samples. However, it is noticeable that peening increased hardness in surface layer up to depth of 0.1 mm. At that depth the hardness is even lower than in the core. For samples made from 36CrNiMo4 steel, the increase of hardness due to peening was 9.63 %, and for 36NiCrMo16 steel the increase is 11.22 %.

3.3 Tribological tests

Tribological tests were carried out in a computer aided block-on-disk sliding testing machine with the contact pair geometry in accordance with ASTM G 77–05. A schematic configuration of the test machine is shown in Figure 9. More detailed description of the tribometer is available elsewhere [21,22].

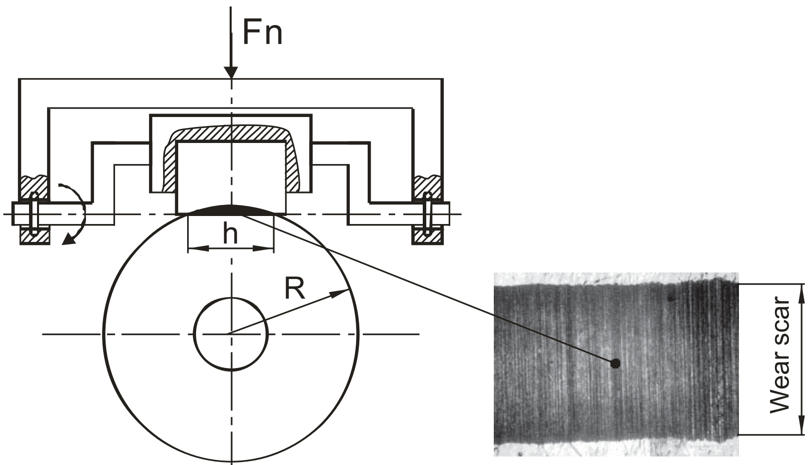


Fig. 9.The scheme of contact pair geometry

The test blocks (6.35x15.75x10.16 mm) were prepared from 36CrNiMo4 and 36NiCrMo16 steel with grounded and shot peened surfaces. The counter face (disc of 35 mm diameter and 6.35 mm thickness) was made of EN: HS 18-1-1-5 tool steel of 62HRC hardness. The roughness of the ground contact surfaces was R_a=0.45 μm. The tests were performed under dry and lubricated sliding conditions at different sliding speeds (0.25 m/s, 0.5 m/s, 1 m/s) and applied loads (10 N, 30 N, 50 N). The duration of sliding was 10 min for dry sliding and 30 min for lubricated sliding conditions. Each experiment was repeated five times.

The tests were performed at room temperature. The lubricant used was ISO grade VG 46 hydraulic oil, a multipurpose lubricant recommended for industrial use at plain and antifriction bearings, electric motor bearings, machine tools, chains, and gear boxes, as well as in high-pressure hydraulic systems. During the tests the discs were continuously immersed up to 3 mm of depth in 30 ml of lubricant.

The wear behaviour of the block was monitored in terms of the wear scar width (Figure 9). Using the wear scar width and geometry of the contact pair, the wear volume (expressed in mm^3) was calculated.

4. RESULTS and DISCUSSION

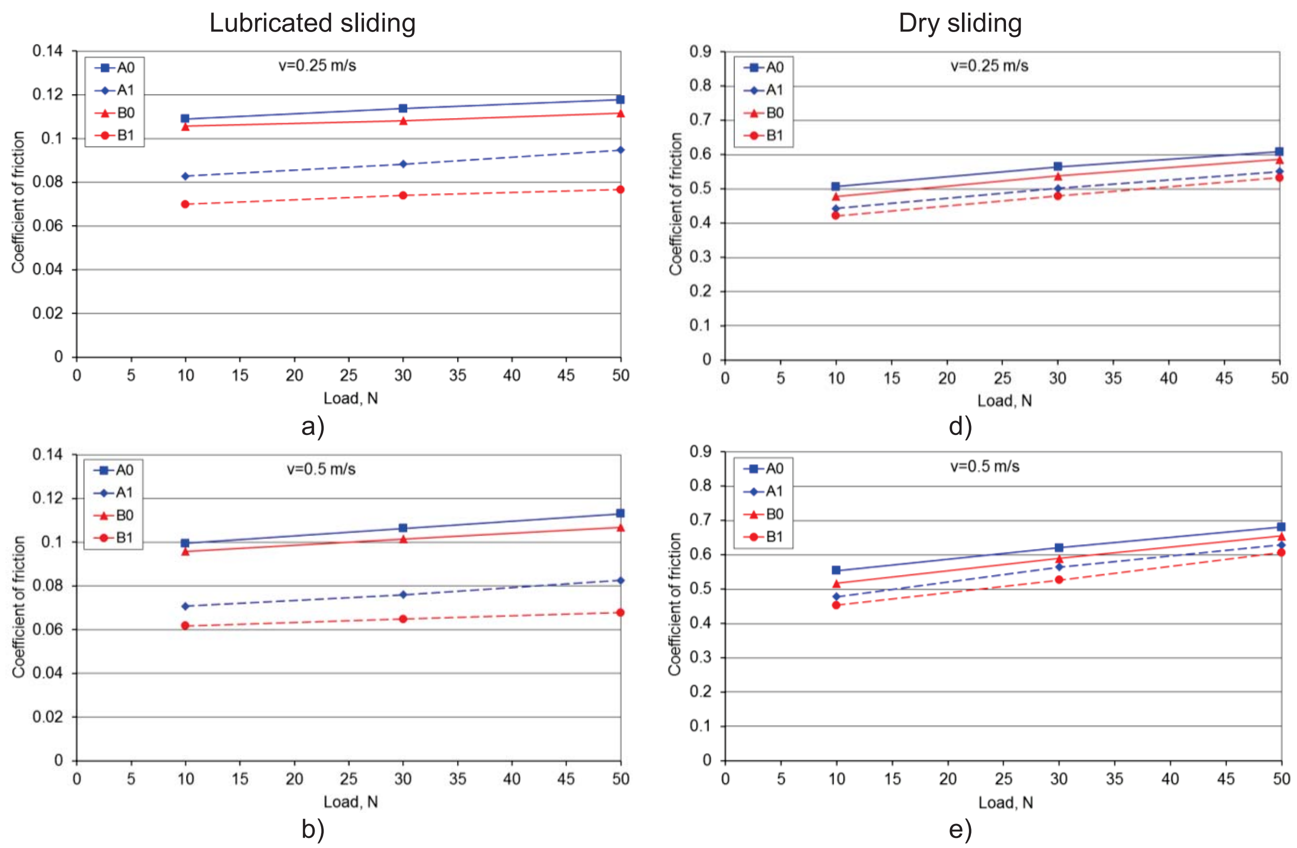
Further in the paper the material 36CrNiMo4 is marked as A, while the material 36NiCrMo16 is marked as B. Also, ground surfaces are marked as “0”, and surfaces made by shot peening as 1.

A0 – 36CrNiMo4, ground
A1 – 36CrNiMo4, shot peening
B0 – 36NiCrMo16, ground
B1 – 36NiCrMo16, shot peening

4.1 Friction

Friction force is very important tribological parameter which depends on numerous parameters, primarily materials of contact elements, contact geometry, quality of contact surfaces, conditions and parameters (sliding speed and normal load) under which contact is achieved.

Friction coefficient of tested samples depending on contact parameters, with and without lubrication, is shown in Figure 10. With increase of normal load, the value of friction coefficient increases and in same contact conditions the increase trend is almost identical for all tested samples. Increase trend of friction coefficient is more distinguished in condition without lubrication. Also, from the diagram it can be clearly seen that 36NiCrMo16 steel has better frictional characteristics in all contact conditions and for all values of contact parameters, in comparison to 36CrNiMo4 steel, as well as surfaces made by shot peening in comparison to ground surfaces. We should notice that the difference in friction coefficient between differently obtained surfaces of the same material is larger in conditions with lubrication, which is also the consequence of contact surfaces topography made by shot peening.



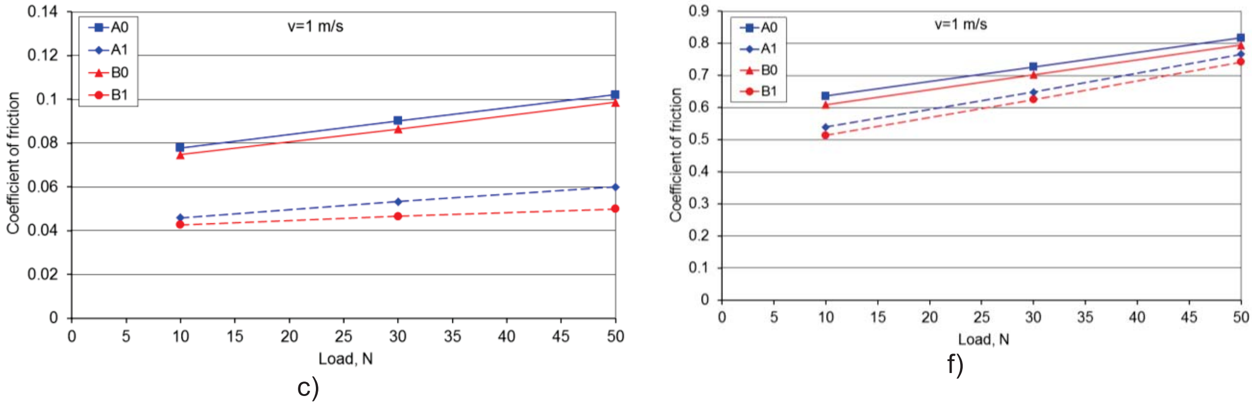
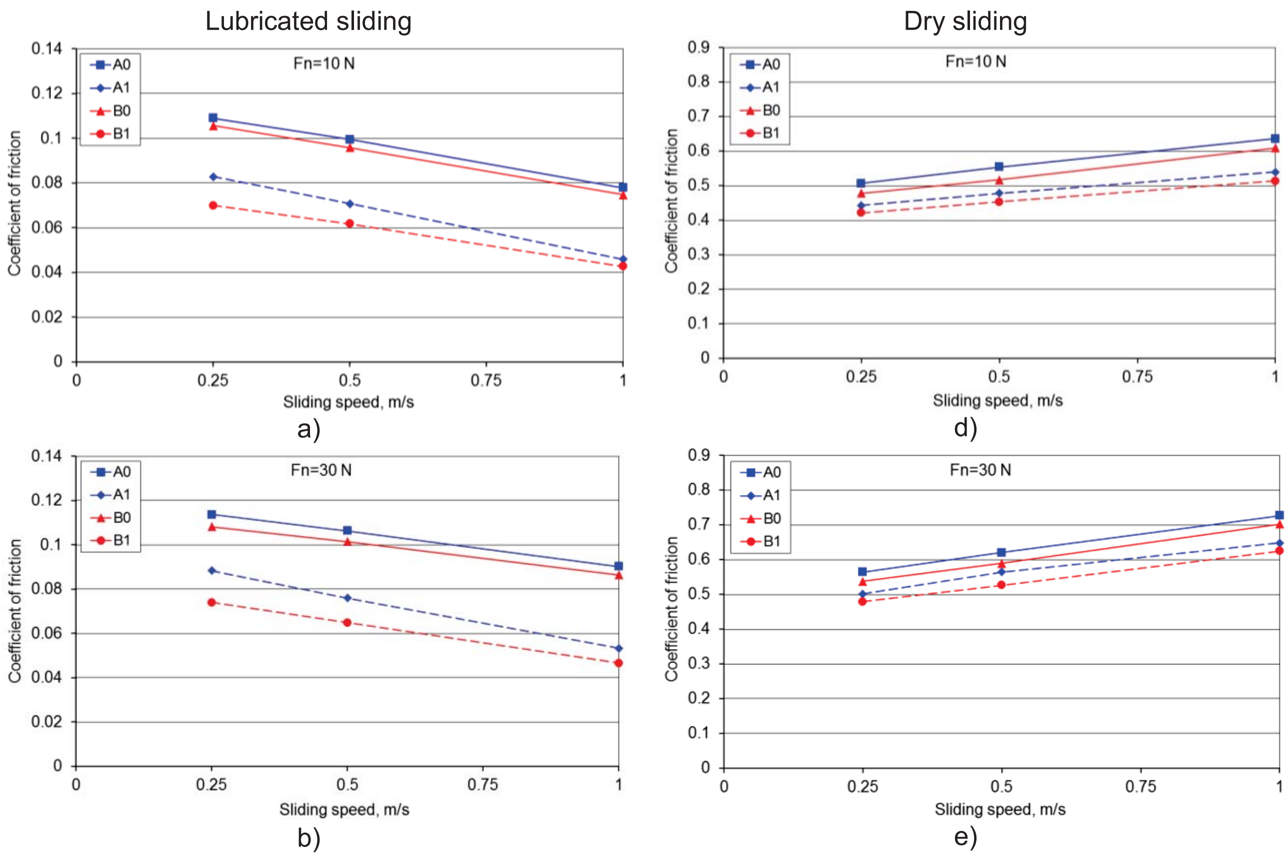
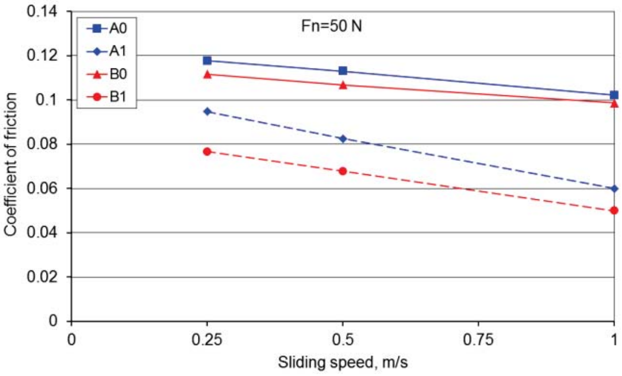


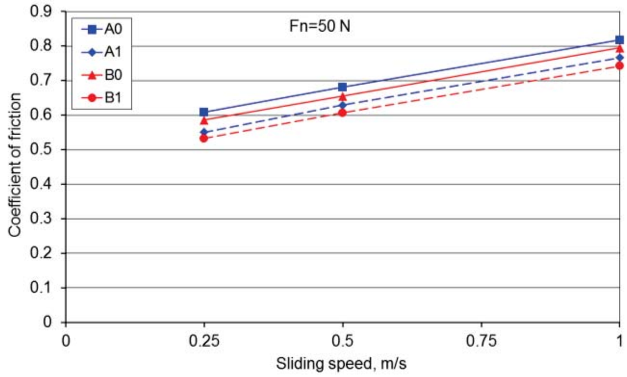
Fig. 10. Friction coefficient dependence of normal load and at constant values of sliding speeds (0,25, 0,5 and 1m/s), in conditions with and without lubrication

Friction coefficient dependence of sliding speed in conditions with and without lubrication is shown in Figure 11, where it can be clearly seen that friction coefficient in conditions without lubrication increases with increase of sliding speed, while in condition with lubrication the friction coefficient decreases with increase of sliding speed. Increase trend of friction coefficient in conditions without lubrication is almost identical for all tested samples, while the decrease is more distinguished for surfaces obtained by shot peening in conditions with lubrication.





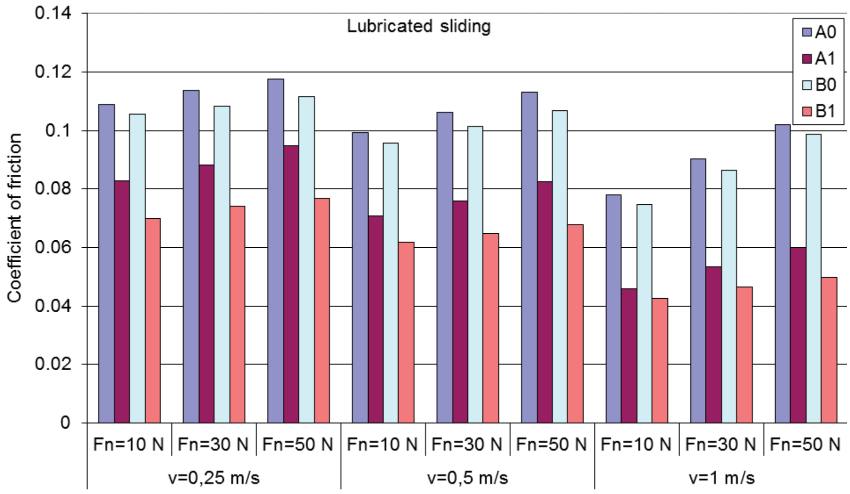
c)



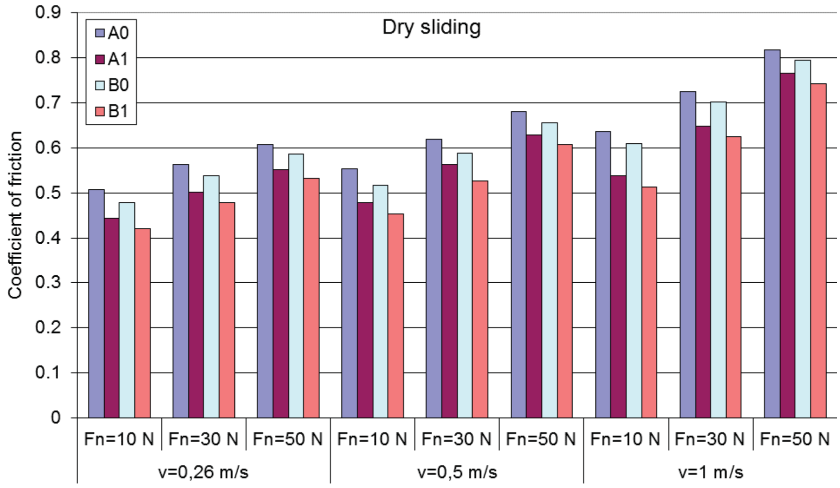
f)

Fig. 11. Friction coefficient dependence of sliding speed at constant values of normal load (10, 30 and 50N), in conditions with and without lubrication

Figure 12 shows histogram display of measured values of friction coefficient for all tested samples, in conditions with and without lubrication. In conditions without lubrication the value of friction coefficient of surfaces obtained by shot peening is for about 10% lower in comparison to ground surfaces of the same material, while the difference in condition with lubrication is within the limit of 20-40%. Bigger difference of friction coefficient values in conditions with lubrication at higher sliding speed has been noticed, which is the consequence of larger quantity of lubricant in the contact zone and specific topography of contact surfaces made as a consequence of shot peening. In those conditions the influence of hydrodynamic pressure is high and it is generated in valleys and considerably contributes to decrease of tribological phenomenon.



a)



b)

Fig. 12. Histogram display of friction coefficient dependence of contact parameters in conditions a) with lubrication and b) without lubrication

4.2 Wear

Wear is continuous unavoidable process that occurs as a consequence of direct contact of tribo-mechanical system elements. Figure 13 represents wear volume changes with change of contact parameters, in conditions with and without lubrications. From the diagram it can be clearly seen that wear volume increases with increase of load for all values of sliding speeds. Also, we notice that increase of wear volume with increase of load is almost identical for all tested samples, especially in conditions with lubrication. Significant increase of wear values with increase of normal load is noticed on ground surfaces in conditions without lubrication and at sliding speeds 0,5 and 1 m/s (Fig. 13e and 13f). The difference occurring at that occasion in comparison to shot peened surface is the result of considerably higher hardness of surface layer of these surfaces in comparison to ground surfaces. The surfaces prepared by shot peening have twice as less wear values in all contact conditions. From the diagrams shown in Figure 13 it can be noticed that 36NiCrMo16 steel has better wear resistance in comparison to steel 36CrNiMo4. This advantage is noticeable at all combinations of sliding speeds and normal load, in conditions with and without lubrication. Better wear resistance is the consequence of better mechanical characteristics of the material itself 36NiCrMo16.

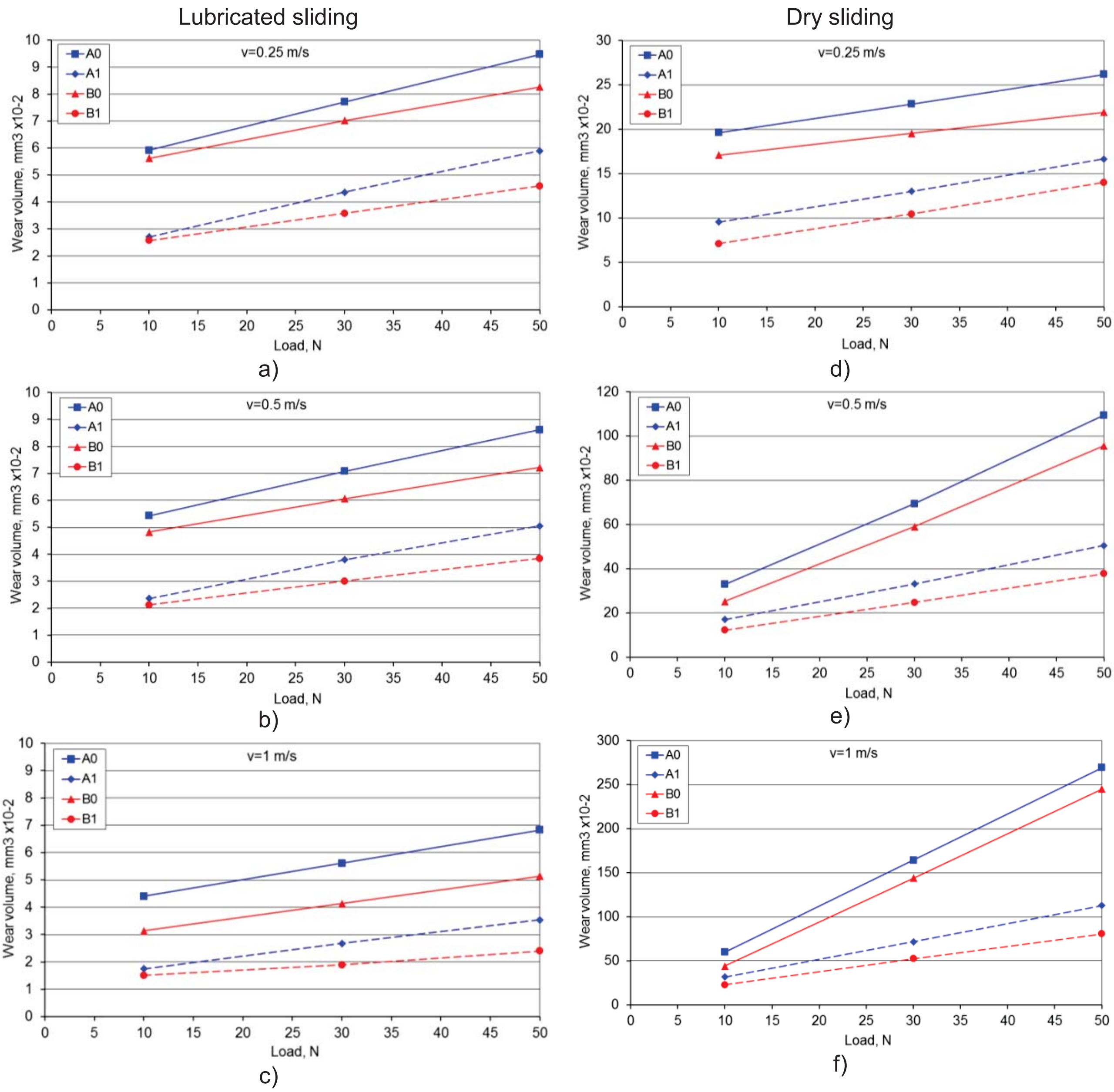


Fig. 13. Wear volume dependence of normal load at constant values of sliding speeds (0,25, 0,5 and 1m/s), in conditions with and without lubrication

Figure 14 represents change of wear volume with change of sliding speed in conditions with and without lubrication. In conditions without lubrication the wear volume increases with increase of sliding speed, while in conditions with lubrication the wear volume decreases with increase of speed, what is in direct dependence with lubricant quantity in contact zone. Namely, because of construction of tribometer itself, where disc at the bottom side is immersed in lubricant bath, we could say that with increase of speed the quantity of lubricant increases and that could be found between contact elements. This effect, to a large degree, depends on oil viscosity used at testing.

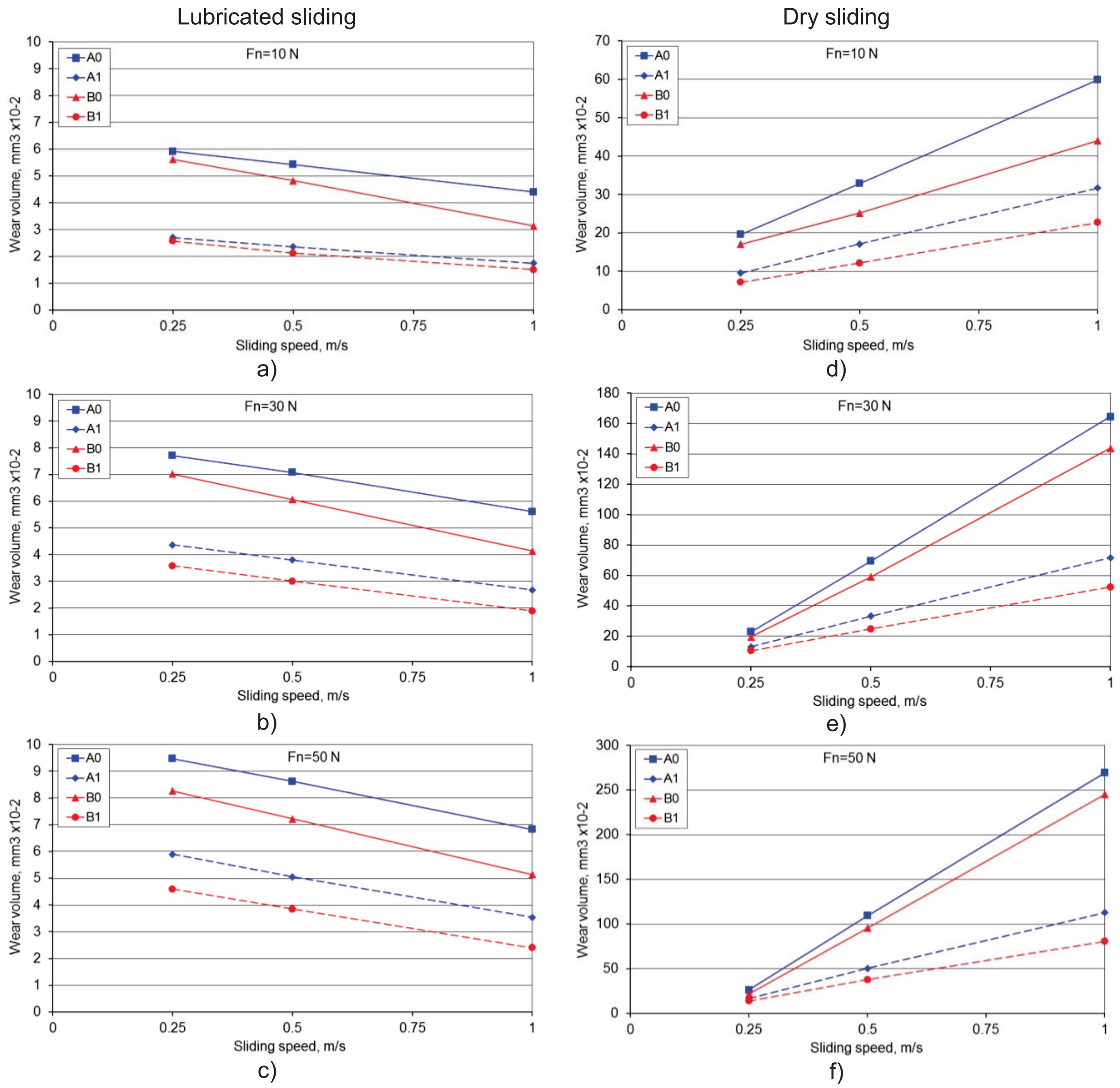
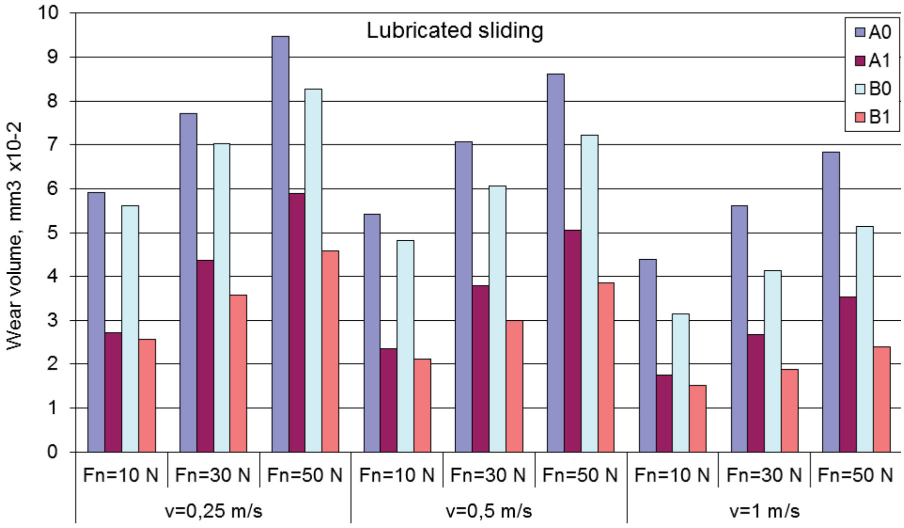
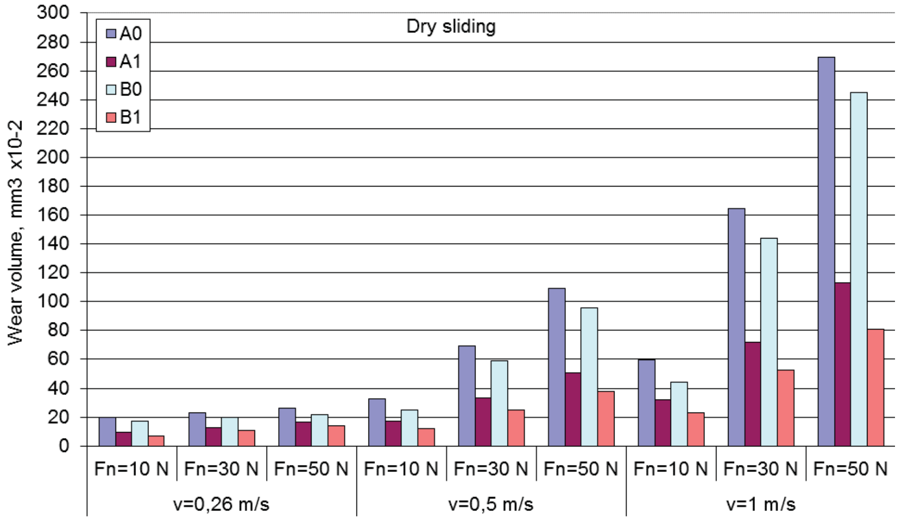


Fig. 14. Wear volume dependence of sliding speed at constant values of normal load (10, 30, and 50 N) in conditions with and without lubrication

Considerably lower wear values of surfaces obtained by shot peening, in conditions with lubrication, are consequence of contact surface topography. In conditions without lubrication the wear volume increases with increase of sliding speed, while in conditions with lubrication the wear volume decreases with increase of speed, what is in direct dependence with lubricant quantity in contact zone. Namely, because of construction of tribometer itself, where disc at the bottom side is immersed in lubricant bath, we could say that with increase of speed the quantity of lubricant increases and that could be found between contact elements. This effect, to a large degree, depends on oil viscosity used at testing.



a)



b)

Fig. 15. Histogram display of wear volume dependence of contact parameters (load, Fn [N]; sliding speed, v [m/s]): a) with lubrication and b) without lubrication

Comparative histograms of the wear volume dependence of load and sliding speed are given in Fig. 15. It is clearly noticed that wear resistance of surfaces obtained by shot peening in all combinations of contact parameters is 50% better in comparison to ground surfaces. This is the consequence of increased hardness and specific topography of surface layers in their valleys, besides lubricants, wear products are retained, and thus they are taken away from contact zone. Also, 36NiCrMo16 alloyed steel has 10-20% better wear properties in comparison to 36CrNiMo4alloyed steel, due to better mechanical characteristics.

Display of wear tracks of tested samples in conditions without lubrication is shown in Figure 16. By analysing wear tracks we could say that, for all tested samples, dominant wear mechanism is abrasive wear, what is verified by parallel scratches and abrasive grooves in direction of sliding and visible in wear tracks.

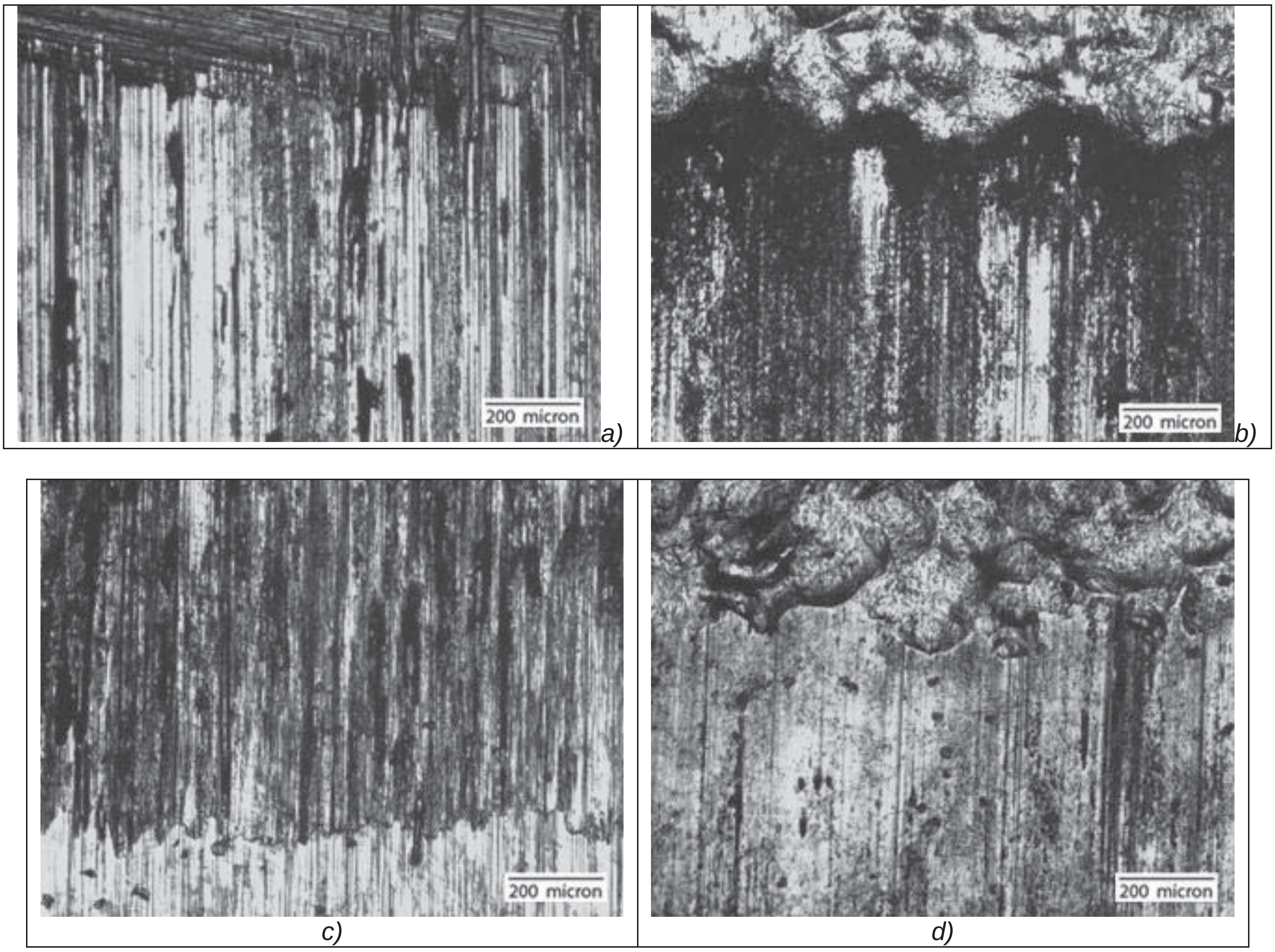


Fig. 16. Optical microscopy of wear tracks for dry contact (36CrNiMo4 steel): a) ground surface, b) shot peened surface and for 36NiCrMo16 steel: c) ground surface, d) shot peened surface

Figure 17 shows wear tracks after the sliding with lubrication. From figures 17b and 17d we can clearly see unworn parts of contact surfaces made by shot peening. Those places served as oil reservoirs and as places where wear products are to be collected during the contact. Based on the appearance of the wear track itself, we could also say that the dominant wear mechanism is abrasive wear. However, based on block-on-disc of contact geometry (contact per line, Herz's pressures) we could say that in initial moments of sliding the dominant wear mechanism is adhesive wear. This assumption especially makes sense at surfaces made by shot peening, primarily because of topography of surfaces, and because of increased elasticity of peeks of surface roughness.

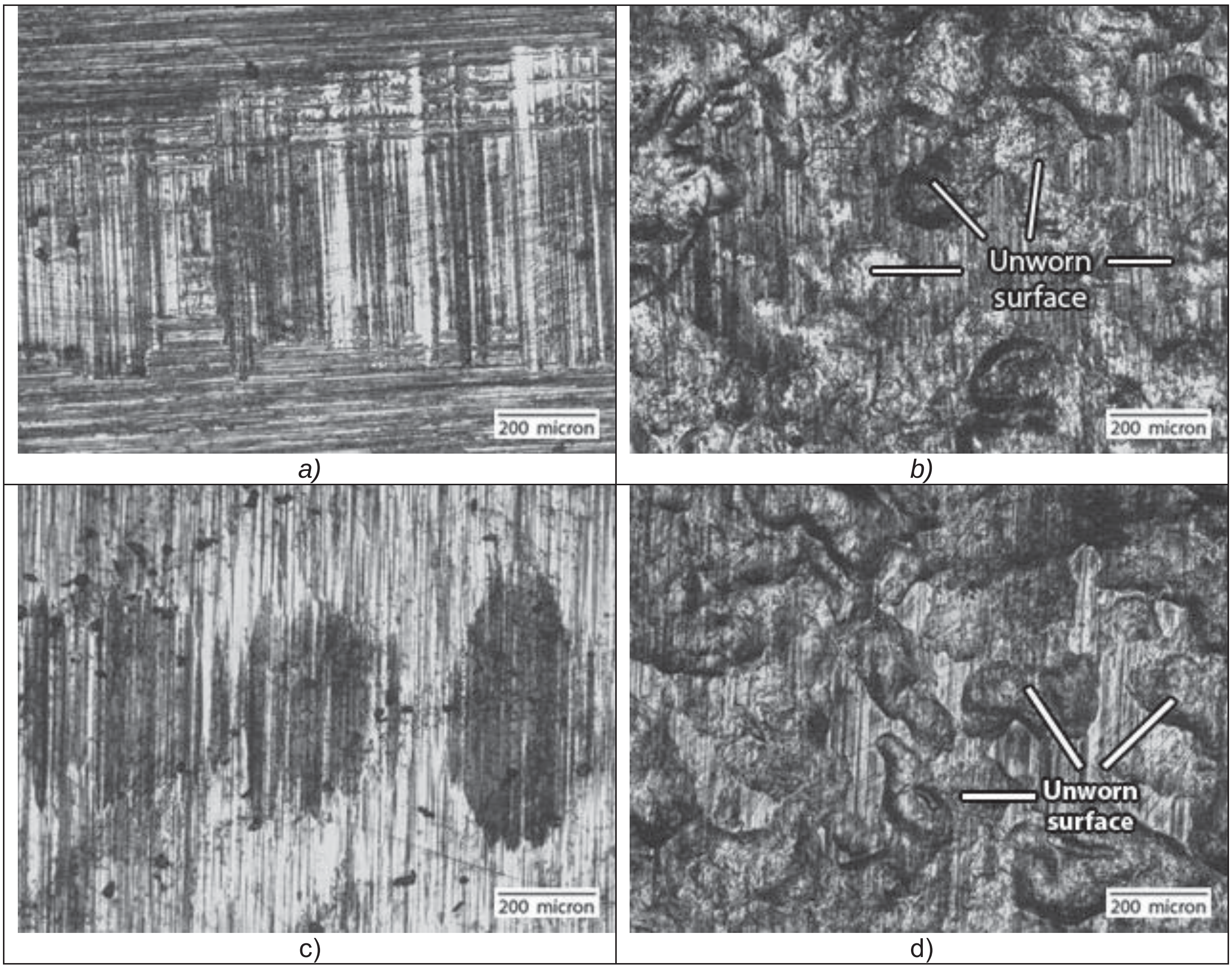


Fig. 17. Display of wear tracks under lubricated sliding conditions for steel 36CrNiMo4 a) ground surface, b) shot peened surface and for steel 36NiCrMo16 c) ground surface, d) shot peened surface

5. CONCLUSION

The results of tribological tests of surfaces made by shot peening, two alloyed steels 36CrNiMo4 and 36NiCrMo16 of very similar chemical compositions and mechanical characteristics, in conditions with and without lubrication, in variation of contact parameters (sliding speed and normal load) indicate following:

Primarily on good repeatability of represented method of testing, referring on small differences in values of friction and wear of these two steels, what is consequence of better mechanical characteristics of steel 36NiCrMo16 in comparison to steel 36CrNiMo4.

Surfaces made by shot peening show better wear resistance in comparison to ground surfaces of the same material. The difference in all contact conditions and at all values of contact parameters goes up to 50% , in favour of surfaces made by shot peening , what is the consequence of positive influence of shot peening process on mechanical characteristics and topography of contact surfaces. The value of friction coefficient in conditions without lubrication is about 10% lower at shot peened surfaces in comparison to ground surfaces, while that difference in conditions with lubrication is within the limit of 20-40%. At higher sliding speeds of contacts in conditions with lubrication, the difference in friction coefficient value is bigger, due to greater quantity of lubricants in the contact zone and possibility of making hydraulic pressure in valleys of surfaces obtained by shot peening.

The dominant wear mechanism was abrasive wear, both in conditions with and without lubrication. In conditions with lubrication, unworn parts of surfaces made by shot peening are clearly seen in wear tracks.

General conclusion is that the shot peening process has positive influence on tribological characteristics of materials in all conditions of making sliding contact.

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