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TRIBOLOGICAL PROPERTIES OF SHOT PEENED SURFACES OF 36NiCrMo16 ALLOYED STEELS IN DRY SLIDING CONDITION

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Abstract: *For right choice of final operation procession, in tribological sense, it is necessary to know the legality of manifesting influences of certain types of processing, as well as regime parameters and conditions of their performance on relevant surface topography parameters (height, cloud, and micro-geometry structure), physical-mechanical state and residual voltages of surface layer. Shot peening method is used to increase both statics, and dynamics hardness of work piece. The result of this method is not only surface layer characteristic change of certain piece but also tribological characteristics change of such processed piece.*

The results of laboratory tests, which correspond and analyse together in work, refer to effects of shot peening use, as final processing by surface plastic deforming, in the example of alloyed steel 36NiCrMo16,with their tribological valorisation of friction and wear tests. Tribological studies show that overall effects of final shot peening processing have positive effect on tribological behaviour of processed elements and may contribute to improvement of tribological element level of tribomechanical systems.

Keywords: *Shot Peening, Friction coefficient, Wear, Alloyed Steels*

1. INTRODUCTION

Methods of reinforcement using balls beam is very widespread and generaly accepted in all industries. The static hardness of work piece as well as dynamic is increased by this method. The advantage of this method, of all the other surface reinforcement methods, is that the appliance expenses of this method are relatively small and that it could be very easily integrated into any production process.

Influence of shot peening on properties of work piece surface layers could be valued only from the aspect of their behaviour in exploitation conditions. Considering that, the key position belongs to tribological characteristics in conditions of sliding friction. Namely, acceptance overview of surface deforming by shot peening, by steel balls beam, as final operation of contact surfaces unavoidably must contain also friction and wear issues.

Micro geometry of contact surfaces represents very important aspect which is often neglected during specification of shot peening parameters [1,2]. Tiresome characteristics are influenced by surface topography which originates from production process. Depending on sensitivity of material, this influence is more or less important [3].

Shot peening can eliminate or mitigate negative effect of surface defects, if the size of balls is properly adjusted to surface topography. If the balls are too big, they cannot remove the traces of tools and the influence of shot peening is weak. The surface appearing after shot peening is anisotropic surface [4].

Besides micro geometry change, resulting from shot peening, in the same time it usually also comes to material reinforcement of surface layer, that is to say hardness increase. Therefore, it also comes to elasticity increase of peak or contact points, through which the surface is “carried”, which plays an important role. When relative motion exists between two surfaces, the peaks shall be, in the beginning, elastically deformed without sliding into contact points. The risk of particles separation is reducing with increased limit of elasticity [5,6].

Due to highly concentrated load in the roughness peak, and due to broken balls hitting the surface, the micro-cracks could be conceived, and they can expand, therefore creating large cracks, that may develop into pits. If the surface is exposed to varying loads over times (fretting) it may come to the creation of larger pitting.

Although the residual compressive voltages are the most important consequence of shot peening in order to reduce fretting, the typical roughness (bumps and pitting), created after shot peening, also has important positive effect [7].

Geometrical characteristics, regardless of their importance, can not completely characterize the contact surface quality of tribomechanical elements and their exploitation properties. Physical-mechanical state of contact layers has the crucial influence. Namely, the physical-mechanical state indicators of contact layer, such as the structure, micro-hardness, and residual surface voltages, directly influence the intensity of development wear process [8,9].

2. EXPERIMENTAL TESTING

EN 10083-3: 36NiCrMo16 alloyed steel was selected for testing. Chemical composition of 36NiCrMo16 steel is given in Table 1.

Table 1. Chemical composition of 36NiCrMo16 steel

	Percentage content							
	C	Si	Mn	Cr	Ni	Mo	P max	S max
36NiCrMo16	0.34	0.28	0.48	1.88	4.21	0.58	0.013	0.010

Mechanical characteristics of thermally treated (improved) samples of 36NiCrMo16 steel are given in Table 2.

Table 2. Guaranteed values of mechanical characteristics of 36NiCrMo16 steel

R_p, MPa	R_m, MPa	A_5, %	Z, %	$KU_{300/3}$, J
1050	1420	9	40	30

Microstructure of the tested steel consists of inter-phase structure – trustit with martensite participation. Austenite grain size, determined according to SRPS C.A3.004 (ISO 643, EURONORM 103 and ASTM E-112), using method of comparison with ASTM etalons, is N°8, which belongs to a group of small austenite grains. Investigation of non-metallic inclusions content was realised by comparison with SRPS C.A3.013 (ASTM - E45, DIN 50602) scale, using method according to Jernkontoret chart. It was determined that 36NiCrMo16 steel has non-metallic inclusions from area A1 (mean index of 0.43) and D2 (mean index of 1.25).

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. Machine is designed for controlled surface strengthening by shot peening for parts of different configurations and dimensions.

Wanted effects of shot peening is 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. Manufacturer of balls is Wheelabrator Corporation (USA).

Based on literature recommendations, for 15 mm 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=1×98% 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 is shown in Figure 1.

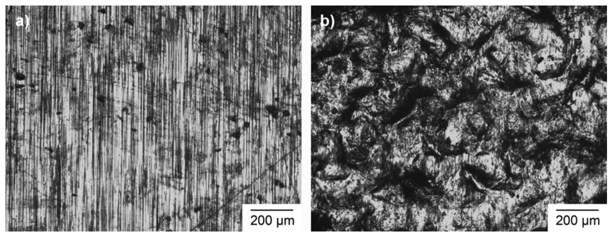


Figure 1. Appearance of the surface before (a) and after (b) shot peening

Required assumptions for sample shot peening was made, by determination of shot peening time and conditions for achieving Almen intensity of 16A. Shot peening was realised under the same conditions that provide aforementioned Almen intensity.

Wear test were carried out in a computer aided block-on-disk sliding wear 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 2a. More detailed description of the tribometer is available elsewhere [10,11].

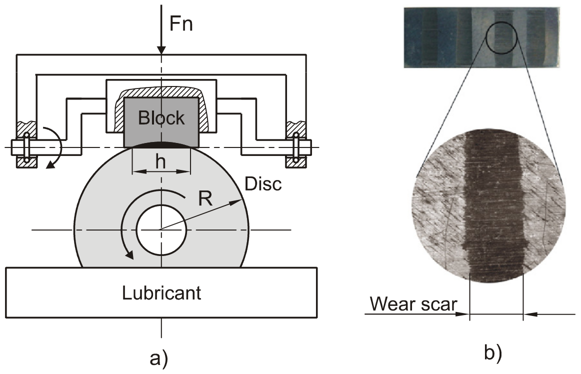


Figure 2. The scheme of contact pair geometry

The test blocks (6.35x15.75x10.16 mm) were prepared from EN 10083-1: 36NiCrMo16 steel with polished 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 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 60 min. Each experiment was repeated five times.

The tests were performed at room temperature. The wear behavior of the block was monitored in terms of the wear scar width (Figure 2b). Using the wear scar width and geometry of the contact pair the wear volume and wear rate (expressed in mm^3) were calculated.

3. TEST RESULTS

The objective assessment of geometrical parameters of mechanical parts surface should include the characteristics of macro-geometry, micro-geometry, and sub micro-geometry, considering the nature and mechanism of geometric imperfections education. Standard parameters of surface roughness, R_a (middle arithmetic roughness aberration) and R_z (middle roughness height), are insufficient as the characteristic, of not only exploitation but also geometric properties of the surface, because they do not give any information about shape and distribution of the roughness. For the dynamic hardness, for example, it is very important the absence of deep grooves and micro-cracks on the surface, because they act as voltage concentrators and become the focus of the fracture. Therefore, micro-geometry, with that point of view, is not only characterized as middle parameters (such as R_a and R_z), but also as local parameters of micro-geometry, for example: depth and radius of bottom profile surface roundness, step of roughness and others. Local parameters of geometry, which describe the height and shape of unit roughness, depth and shape of pitting between them, and distribution of material by height, are very important in friction and wearing.

Roughness measurement was carried on one ground and one shot peened tube, in the direction perpendicular to the direction of grinding.

Besides numerical values of roughness parameters, obtained results are graphically illustrated by appropriate profilometer examples (figure 3a and b).

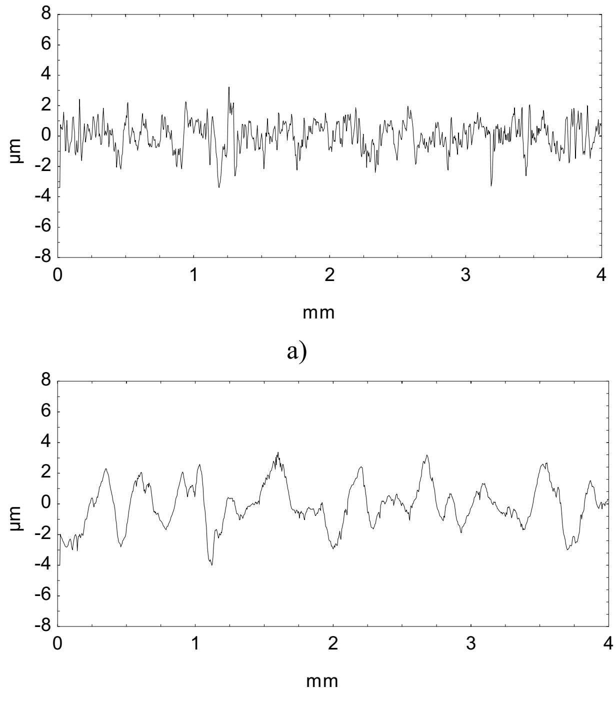


Figure 3. Surface profile sample figure made of steel 36NiCrMo16 in abraded (a) shot peened (b) state

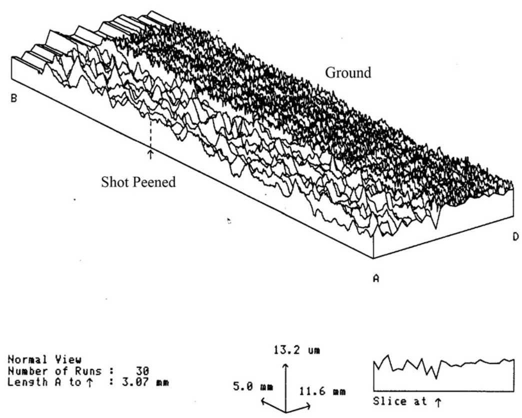


Figure 4. Comparative 3D surface sample figure made of steel 36NiCrMo16 in ground (a) shot peened (b) state

Comparative 3D surface sample figure made of steel 36NiCrMo16 in ground (1) shot peened (2) state is shown in Figure 4.

Profile figure of ground surface is shown in Figure 4a, and completely changed topography regarding height, shape, step and statistics, by which the shot peened processing is resulting, is illustrated by profilometer in figure 4b.

It is obvious that during the shot peening there was very expressed increase of all roughness height parameters (R_a, R_q, R_p, R_v, R_y, R_{tm}, R_{pm}n), in comparison to the initial state obtained by grinding. A higher degree of coverage corresponds to a higher degree of roughness increase.

Besides the parameter increase which represents the height of micro-roughness, shot peened processing by beam of steel balls also influences great parameter increase of step roughness, as it is also visible in appropriate profile records.

Surface roughness (R_a) for steel 36NiCrMo16 in ground state is R_a=0.62μm and in shot peened state is R_a=1.11μm.

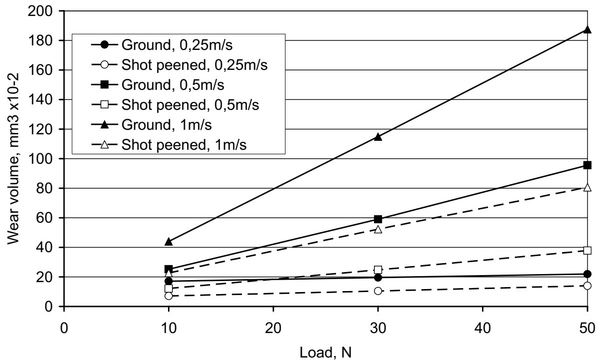


Figure 5. Wear volume change with normal load change for different sliding speeds (0.25, 0.5, 1 m/s) in conditions without lubrication

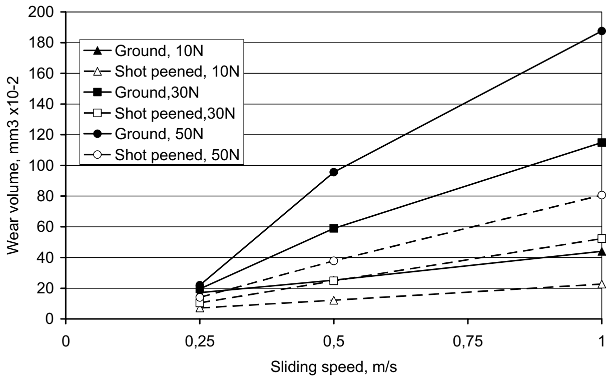


Figure 6. Wear volume change with sliding speed change for different values of normal load (10, 30, 50 N) in conditions without lubrication

Figures 5 and 6 graphically represent the wear volume dependence on normal load value change (fig. 5) and sliding speed value (fig. 6). In Figure 5 it is clear that increase of normal load value leads to, almost linear, increase of wear volume. Also, increase of sliding speed value leads to increase of wear volume value. It should be pointed out, that in all tested conditions, smaller wear volume values are measured for shot peened surfaces in comparison to ground surfaces, which is the consequence of hardness increase in surface layer of shot peened surfaces.

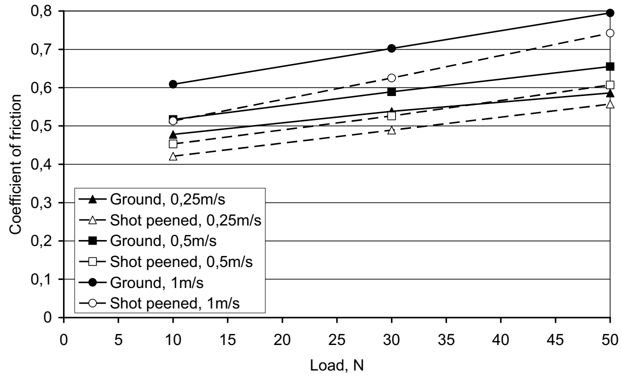


Figure 7. Coefficient friction change with normal load change for different sliding speeds (0.25, 0.5, 1 m/s) in conditions without lubrication

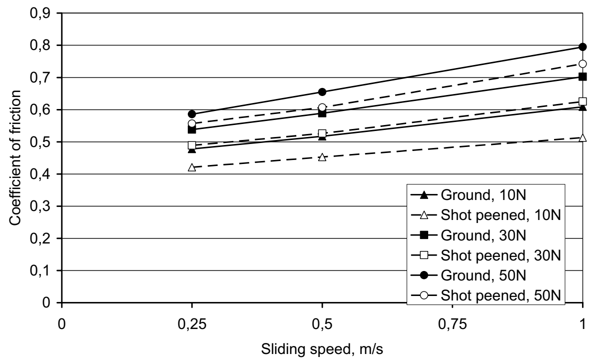


Figure 8. Coefficient friction change with sliding speed change for different values of normal load (10, 30, 50 N) in conditions without lubrication

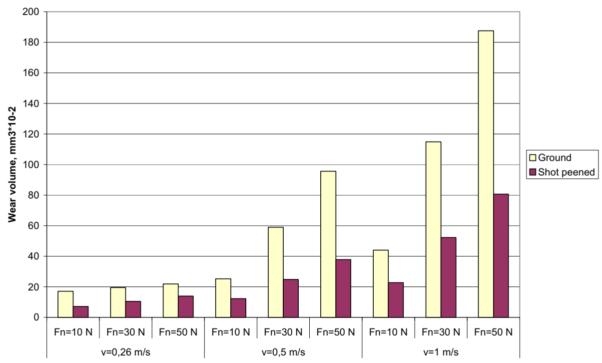


Figure 9. Histogram display of wear volume dependence on speed sliding and normal contact load in conditions without lubrication

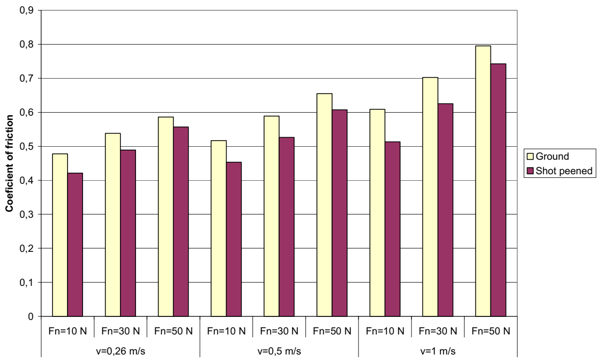
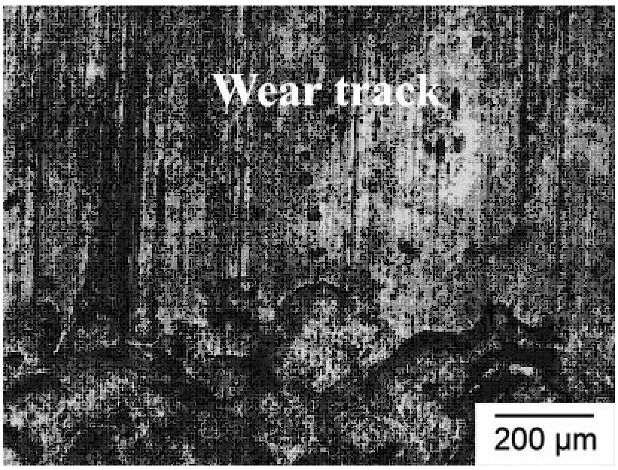


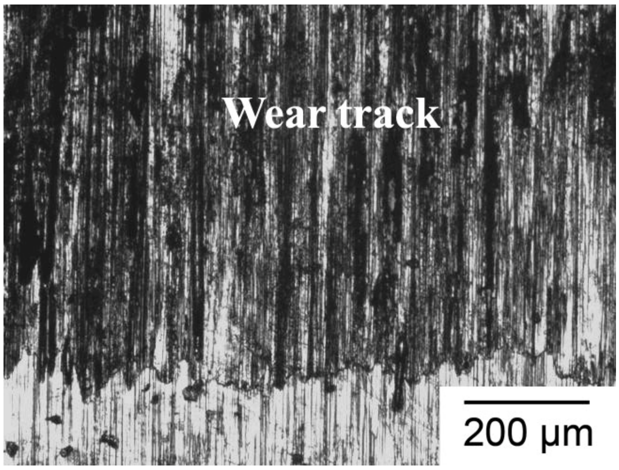
Figure 10. Histogram display of coefficient friction dependence on speed sliding and normal contact load in conditions without lubrication

Figures 7 and 8 graphically represent the coefficient friction dependence on normal load value (fig. 7) and sliding speed value (fig. 8). Increase of normal load value and sliding speed leads to linear increase of coefficient friction value, where it should be pointed out that, in all contact conditions, smaller coefficient friction values are measured for shot peened surfaces in comparison to ground surfaces. The reason for these results could be found in greater hardness of surface layer shot peened surfaces, and partially in the way of making contacts.

Figure 9 on quantitative way represents measured wear volume values, where it is clear that wear of shot peened surfaces in all contact conditions is significantly smaller in comparison to ground surfaces, and the difference itself becomes more apparent with speed increase. Figure 10 represents histogram display of measured coefficient friction values, where shot peened surfaced have 8-10% less coefficient values in comparison to ground surfaces.



a)



b)

Figure 11. Wear traces display on contact without lubrication for steel 36CrNiMo16 in ground (a) and shot peened state (b)

Figure 11 represents wear traces display of tested samples. Figures shows that dominant wear mechanism in contact conditions without lubrication with both tested surfaces is identical, that is to say abrasive wear is dominant.

4. CONCLUSION

Based on performed tests we may conclude following:

- Shot peening eliminates tool traces and surface defects, by modifying surface roughness, and the surface that occurs after shot peening is anisotropic.
- With mentioned parameters performance of shot peening causes deterioration both in height and structural roughness parameters in comparison to initial state acquired by grinding. That is the consequence of small initial roughness and slightly bigger balls diameter which are used in shot peening processing.
- During shot peening surface tests, the smaller values of wear volumes and coefficient friction of shot peened surfaces are measured in the conditions without lubrication of shot peened surfaces in comparison to ground surfaces. However, it should be noted that improvements are more pointed out in terms of resistance to wear, than in terms of coefficient friction value. In addition, histogram displays refer about that, where it is shown that at higher sliding speed values (0.5 and 1m/s) the wear volume values are less than 50% in comparison to ground surfaces.
- Dominant wear mechanism in these tested conditions (dry sliding, block-on –disc) is abrasive wear which can be seen in wear traces display.
- Numerous comparative tribological studies

show that overall effects of final shot peening processing have positive effects on tribological behavior of certain elements and may contribute to improvement of tribological element level of tribo-mechanical systems.

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