WEAR PROPERTIES OF SHOT PEENED SURFACES OF 36NiCrMo16 ALLOYED STEELS UNDER LUBRICATED CONDITION

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ABSTRACT

Shot peening processing is used to increase static and dynamic strength of the working part. Not just a change of surface layers characteristics but also a change of tribological characteristics can be obtained by using this method.

Results of laboratory investigations presented and analysed in this paper are related to effects of final machining by shot peening as a surface plastic forming, and they are further tribologically validated by wear tests using 36NiCrMo16 alloyed steel.

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 improvement of tribological level of tribomechanical elements.

KEYWORDS: Shot Peening, Wear, Friction, Alloy Steel

1. INTRODUCTION

Character and intensity of tribological process and consequently exploitation characteristic of tribomechanical elements depend on microgeometry of contact surfaces. Existence of optimum roughness can be discussed from aspects of friction and wear intensity. Roughness variation in both directions if compared to its optimum value is followed by increase of the friction coefficient and wear intensity. Parameters of shape and micro-roughness, such as radius of asperities tips and exponent of the bearing curve of profile, are of special significance for tribological processes development.

Optimum values do not have universal character, but are conditioned by spectra of parameters of working conditions and contact pair structure. In case when micro-geometry parameters deviate from optimum values, then optimal or equilibrium level to which minimum potential energy corresponds, is realised during a running-in period. Running-in of contact surfaces represents period of initial wear. Intensive plastic forming occurs and also asperities destruction followed by surface layer hardening /1/, due to relatively high specific mechanical loads conditioned by small real area of contact at newly machined surfaces.

Microgeometry of contact surfaces represents very important aspect often neglected during parameters specification of shot peening, process qualification and production control /2,3/. Shot peening can eliminate or mitigate negative effects of surface defects, in case when shot bombardment ball is properly adopted to surface topography. Surface that is created after the shot peening is anisotropic.

By knowing Ra roughness parameter, we intuitively know that lower roughness corresponds to higher fatigue time. This is justified if we compare surfaces obtained by the same machining process, but it can be a wrong approach if surfaces created by different processes are compared. It is not correct to compare surfaces created by different processes (grinding, lathe turning, etc.) and that same surface obtained after shot peening.

Schematic representation of surface roughness obtained by shot peening (surface A) and by other processing (surface B) is given in Figure 1. Surfaces A and B have same Ra (mean arithmetic deviation of surface) and thus can be considered to have the same fatigue life Intuitively we know that the fatigue characteristics of surface A are better than surface B, because the stress concentration at the bottom of the B valley is much higher than in case of A.

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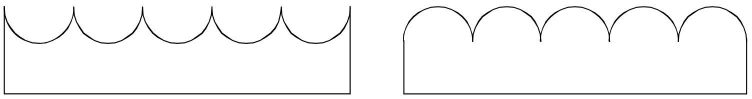

Roughness A (R_a=1, R_z=1) Roughness B (R_a=1, R_z=1)

Figure 1: Roughness comparison for surfaces A and B /4/

On the other hand, valleys have positive effect because they act as reservoirs (oil pockets) for the lubricant and contribute to lubrication of contact /5/. Sometimes, the surface created after shot peening is electrochemically or chemically post-treated in order to remove (dissolve) peaks of asperities and to preserve valleys and to better adjust the surface to exploitation conditions.

Beside changes in microgeometry resulting from shot peening, simultaneous result often obtained is strengthening of the surface layer material, i.e. hardness increase. Due to this, elasticity increase of peaks that “bear” surface occurs, what is very important. When there is relative motion between two surfaces, peaks will be elastically deformed at the beginning, without sliding in contact points. Risk of particles separation decreases, with increased elasticity limit /6/.

Due to high concentrated loads on asperities peaks, as well as a consequence of the impact of broken shot bombards on the surface, microcracks can be initiated and their further growth can create large cracks that can grow into pits. In case when the surface is subjected to variable loads over time (fretting) large pitting can occur.

Pitting occurs on gear flank and at other elements that are engaged in rolling. In this case, asperities peaks have negative influence because loads and stresses accordingly achieve very high values. Combination of shot peening and thermal pre-processing (case hardening) or chemical pre-processing (carburizing) and post-treatment by electropolishing produce excellent results in regards to prevention or postponing the occurrence of pitting /7/.

Even though residual compressive stress is the most important consequence of shot peening, in order to decrease fatigue, typical roughness (peaks and valleys) created by shot peening also has significant positive effect /8/.

Generally speaking, it can be stated that roughness of the surfaces machined by procedures of surface plastic forming is the function of the previous surface state, material characteristics, processing regime elements and tool geometry. Strict demands in relation to roughness class, as well as in relation to structure and shape of microgeometry can be satisfied by optimization of previous parameters, thus contributing to tribological improvement of processed surfaces /9,10/.

2. EXPERIMENTAL TESTING

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

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

	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

Table 1: Chemical composition of 36NiCrMo16 steel

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

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

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 realized 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 realized correctly, such as: ball diameter, Almen intensity, subjected area size coverage and shot duration of shot peening. Shot peening was realized 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 2.

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.

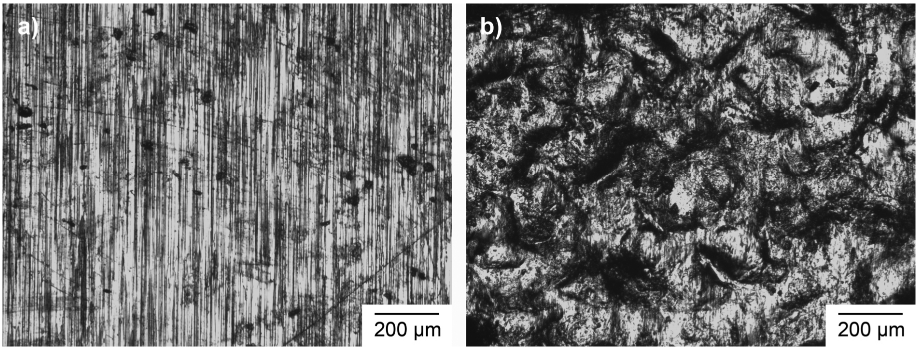

Figure 2: Appearance of the surface before (a) and after (b) shot peening

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Wear tests 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 3a. More detailed description of the tribometer is available elsewhere /11,12/.

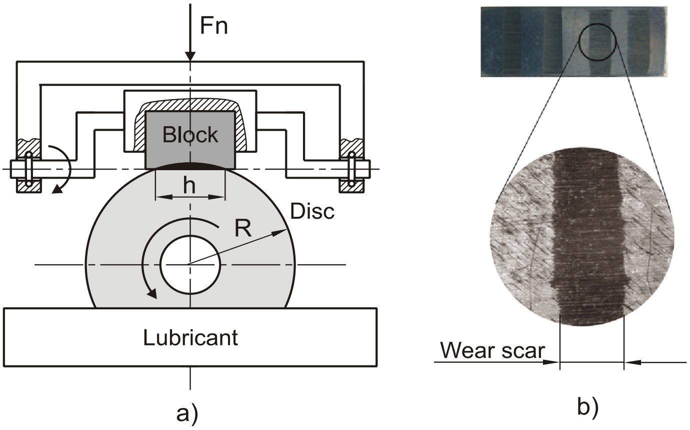

Figure 3: The scheme of contact pair geometry

The test blocks (6.35x15.75x10.16 mm) were prepared from EN 10083-1: 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 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 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 behavior of the block was monitored in terms of the wear scar width (figure 3b). 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

Objective evaluation of surface geometry parameters of machine parts should include characteristics of macro-geometry, micro-geometry and submicro-geometry, taking into account nature and mechanism of geometry imperfections formation. From this point of view, R_a (mean arithmetic deviation of surface) and R_z (mean asperity height) are not sufficient as characteristics, not only in regards to exploitation but also for geometry properties of surface, because they do not provide any information about the shape and distribution of asperities. For instance, in case of dynamic strength parameter, avoidance of deep cuts and microcracks on the surface is especially important, because they act as stress concentration and become source of failure. That is the reason that micro-geometry is not only characterized by mean parameters (such as R_a and R_z), but also by local micro-geometry parameters, such as: depth and radius of rounded bottom of the surface profile, length of asperities etc. Local geometry parameters that describe height and shape of unit asperities, depth and shape of the valleys

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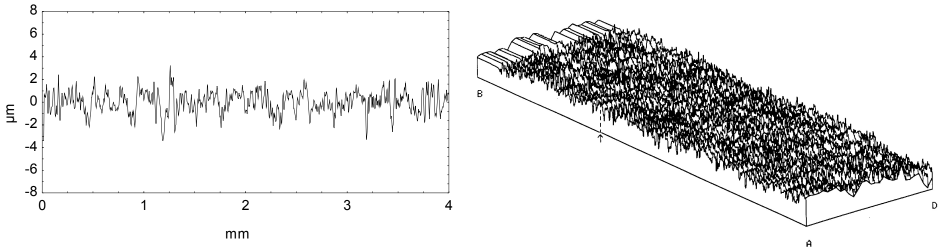
between them and material distribution per asperities height are very important for friction and wear.

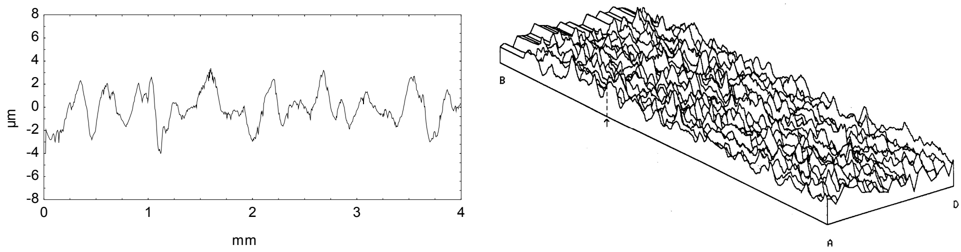
Roughness measurement was realised on one grounded and one shot peened sample, normal to direction of grinding. Beside numerical values of roughness parameters, obtained results are graphically illustrated by appropriate examples of profilograms (Figures. 4a and 4b)



a) b)

Figure 4: Surface profile (a) and spatial view (b) of 36NiCrMo16 in grounded state

Completely changed topography in regards to height, shape, length and statistics resulting from shot peening is illustrated by profilograms in Figure 5a and figure 5b, where comparative 3D view of grounded and shot peened surface is shown.



a) b)

Figure 5: Surface profile (a) and spatial view (b) of 36NiCrMo16 in shot peened state

It is obvious that due to shot peening, of all roughness height parameters (R_a, R_q, R_p, R_v, R_y, R_{tm}, R_{pm}) exhibited pronounced increase, compared to initial state obtained by grinding, whereat larger rate of coverage in shot peening corresponds to larger rate of roughness increase.

Beside increase of parameters that represent height of the micro asperities, shot peening by steel balls influences large increase of roughness length parameters, what is clearly visible in appropriate profile recordings.

Average value of arithmetic mean deviation (R_a) for 36NiCrMo16 steel in grounded state is R_a=0. 62µm and in shot peened state R_a=1.11µm.

Wear volume calculated according to measured values of the worn track width is taken as important tribological indicator of the way the contact is realised. Wear volume dependency on normal load variation is shown in Figure 6, while wear volume as a function of the sliding speed in the contact zone is shown in Figure 7. It can be clearly seen (figure 6) that, normal load increase and consequently contact pressure increase, resulted in wear volume increase. Trend of wear volume increase with normal load increase is rather uniform and linear for all tested contact pairs. Shot peened surfaces resulted in lower values of wear volume in comparison to grounded surfaces, under the same values of contact parameters (normal load and sliding speed), what is a consequence of the surface topography of shot peened samples, as previously presented in this paper.

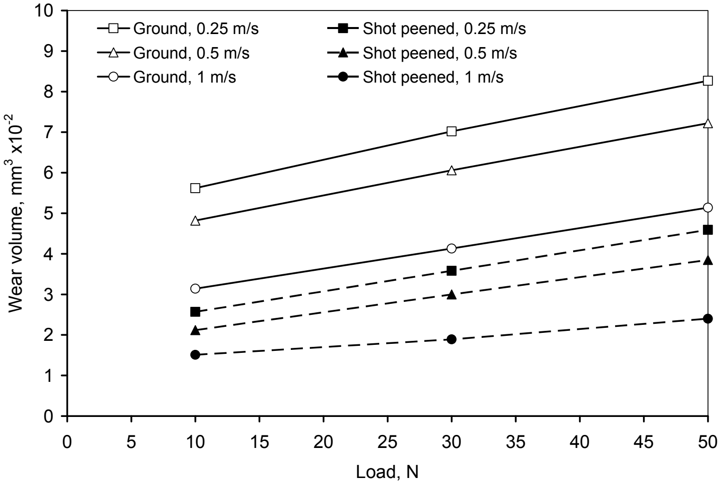


Figure 6: The change of the wear volume per normal load at different sliding speeds (0.25, 0.5, 1 m/s) under lubricating conditions

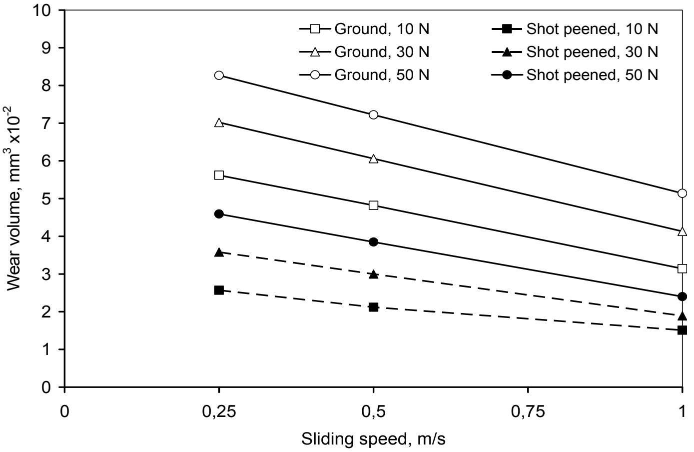


Figure 7: The change of the wear volume as a function of the sliding speed at different values of normal load (10, 30, 50 N) under lubricating conditions

It can be clearly noticed that for all tested surfaces, sliding speed increase resulted in wear volume decrease (Figure 7), what is a consequence of higher level of lubricant in the contact zone. Trend of wear volume decrease with sliding speed increase is also very uniform for all tested contact pairs. Such uniform trend of changes of the wear volume with variation of normal load and sliding speed, points to the fact that the contact is realised at the same way under all combinations of contact parameters, i.e. under the condition of mixed lubrication, what is also confirmed by wear tracks appearance (Figure 9).

In order to quantify differences of the wear volume of two tested surfaces, histogram representation of this variable, for all values of contact parameters, is given in Figure 8. Wear

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values of shot peened surfaces are almost 50% less than wear values of grounded surfaces, under all values of contact parameters. As previously stated, this is a consequence of shot peened surface topography, even though all roughness parameters (R_a, R_q, R_p, R_v, R_y, R_{tm}, R_{pm}) have been significantly increased, if compared to grounded surfaces.

Wear tracks on two tested surfaces are shown in Figure 9, where at in case of grounded surface, abrasive wear can be observed as dominant wear mechanism, based on appearance of the wear track. In case of shot peened surface, it can be concluded that the contact between elements (block on disc) was realised only over asperities peaks when these were smoothed. Based on the wear track appearances on shot peened surfaces, it is clear that the contact was realised under condition of mixed lubrication.

In case of shot peened surface, aforementioned cavities can be clearly observed within the wear track itself and they are the most responsible for improvement of the wear resistance, beside positive influence of the increased hardness of the surface layer due to shot peening.

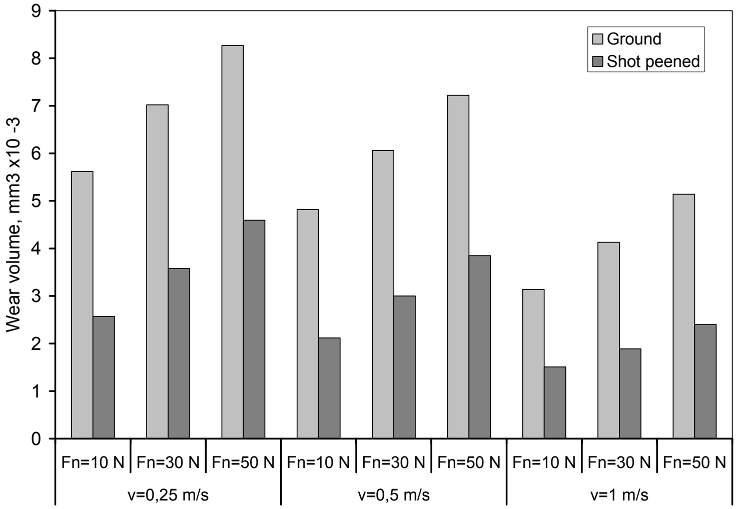

Figure 8: Histogram representation of the wear volume dependency on sliding speed and normal contact load under lubricating conditions

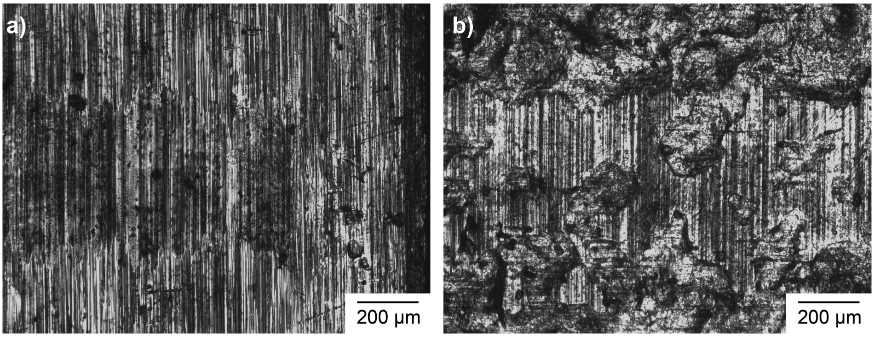

Figure 9: Wear tracks on 36NiCrMo16 steel samples, under lubricating conditions, in grounded state and shot peened state

4. CONCLUSIONS

Based on realised investigation, the following conclusions can be made:

- Shot peening eliminates surface defects and tracks originating from tool processing, by modifying surface roughness. Surface created after shot peening is anisotropic.
- Investigation realised in this paper showed that worsening of surface roughness parameters occurred on surfaces obtained by shot peening in comparison with grounded surfaces.
- All tested surfaces exhibited uniform trend of the wear volume increase with increase of normal load, while increase of sliding speed resulted in decrease of these values, what is a consequence of higher level of lubricant in the contact zone and accordingly better separation of surfaces.
- Shot peened surfaces exhibited higher wear resistance (approximately 50%) if compared to grounded surfaces. This is explained by existence of oil pockets that assist lubrication of surfaces and secondly by increased microhardness of material in surface layers.
- Based on total tribological effects, it can be concluded that the shot peening as a final machining can contribute to the improvement of tribological level of tribo-mechanical system elements.

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