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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.

AIMS AND BACKGROUND

Character and intensity of tribological process and consequently exploitation characteristics 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

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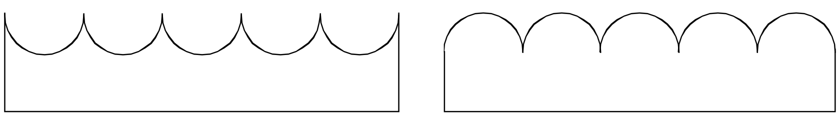
micro-geometry parameters deviate from optimum values, then optimal or equilibrium level to which minimum potential energy corresponds, is realised during a running-in period. Running-in of contact surfaces represents period of initial wear. Intensive plastic forming occurs and also asperities destruction 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 R_a 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 Fig. 1. Surfaces A and B have the same R_a (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 of surface B, because the stress concentration at the bottom of the B valley is much higher than in case of A.



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

Fig. 1. Roughness comparison for surfaces A and B (Ref. 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 that is very important. When there is relative motion between 2 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 (carburising) 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 optimisation of previous parameters, thus contributing to tribological improvement of processed surfaces[9,10].

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.

Microstructure of the tested steel consists of inter-phase structure – trust-it 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 No 8, which belongs to a group of small

Table 1. Chemical composition of 36NiCrMo16 steel

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

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

R_p (MPa)	R_m (MPa)	A5 (%)	Z (%)	$KU_{300/3}$ (J)
1050	1420	9	40	30

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 the 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).

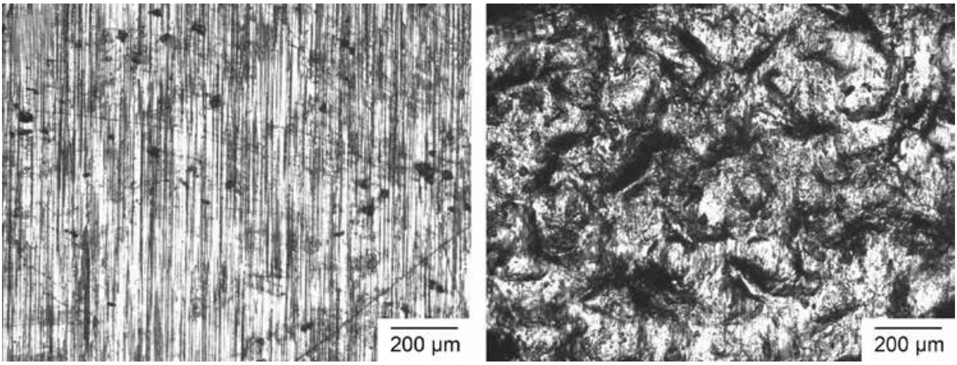
Samples for tribological testing were made by cutting them from samples aimed for fatigue test. Cutting was realised by machine saw with intensive cooling in order to avoid changes of surface layers, due to high temperature.

Shot peening of samples by steel balls was realised at a 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 are obtained if selection of shot peening parameters is realised correctly, such as: ball diameter, the 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, the 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 the 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 10× 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 Fig. 2.



a *b*

Fig. 2. Appearance of the surface before (*a*) and after (*b*) shot peening

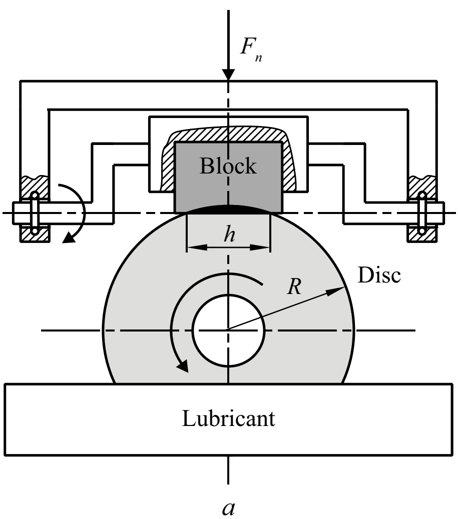
Required assumptions for sample shot peening was made, by determination of shot peening time and conditions for achieving the Almen intensity of 16A. Shot peening was realised under the same conditions that provide the afore-mentioned Almen intensity.

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 Fig. 3*a*. More detailed description of the tribometer is available elsewhere[11,12].

The test blocks (6.35×15.75×10.16 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, 0.5 and 1 m/s) and applied loads (10, 30 and 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 behaviour of the block was monitored in terms of the wear scar width (Fig. 3*b*). Using the wear scar width and geometry of the contact pair, the wear volume and wear rate (expressed in mm³) were calculated.



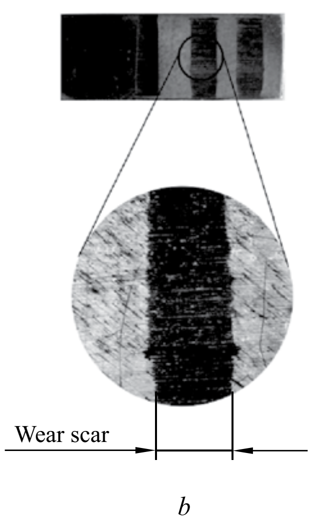


Fig. 3. Scheme of contact pair geometry

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 characterised 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 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 (Figs 4*a* and *b*).

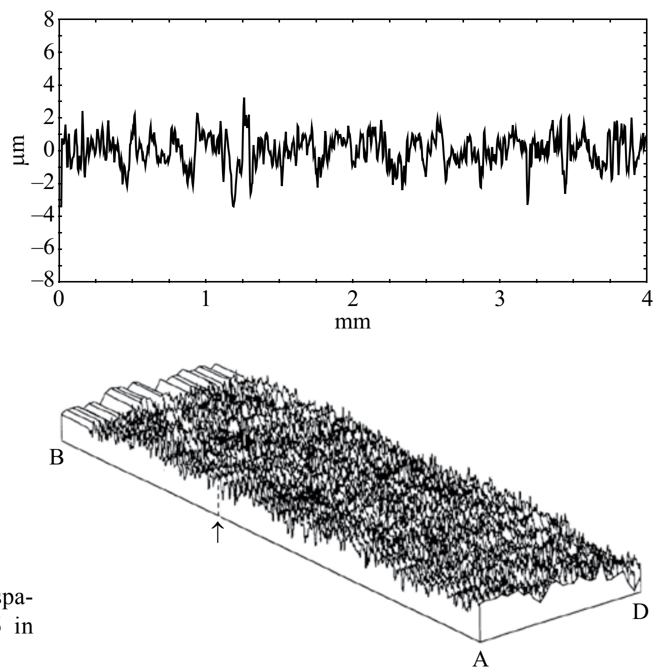


Fig. 4. Surface profile (*a*) and spatial view (*b*) of 36NiCrMo16 in grounded state

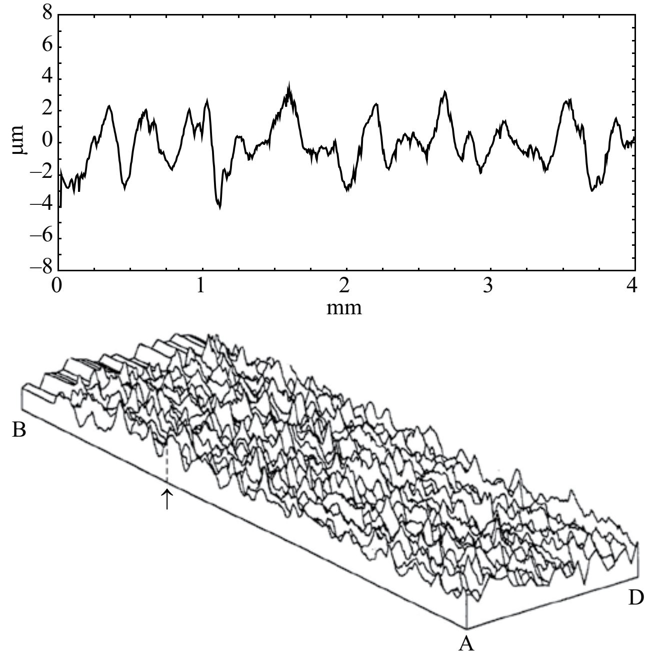


Fig. 5. Surface profile (*a*) and spatial view (*b*) of 36NiCrMo16 in shot peened state

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.

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 $R_a = 0.62$ μm and in shot peened state $R_a = 1.11$ μm.

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 Fig. 6, while wear volume as a function of the sliding speed in the contact zone – in Fig. 7. It can be clearly seen (Fig. 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

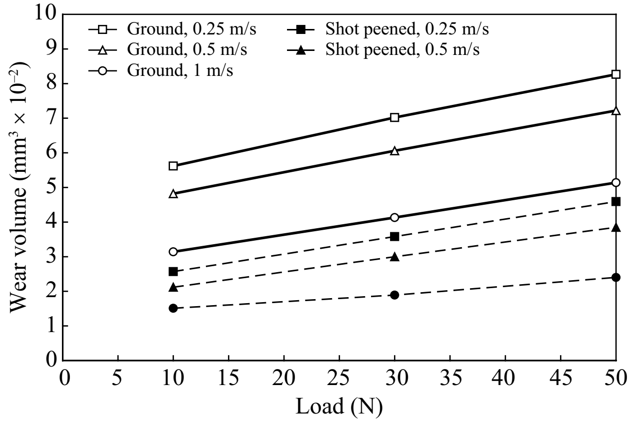


Fig. 6. Change of the wear volume per normal load at different sliding speeds (0.25, 0.5, 1 m/s) under lubricating conditions

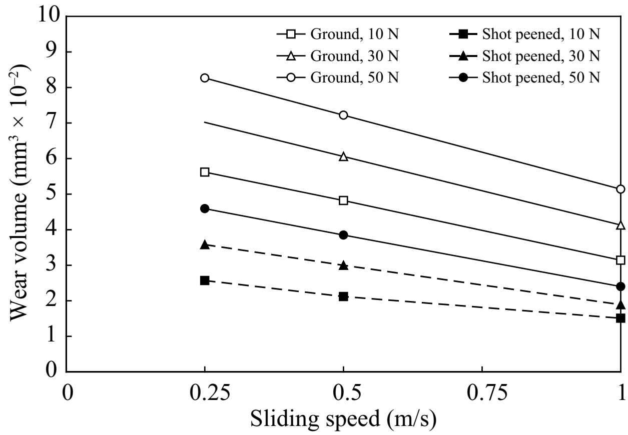


Fig. 7. Change of the wear volume as a function of the sliding speed at different values of normal load (10, 30, 50 N) under lubricating conditions

comparison to grounded surfaces, under the same values of contact parameters (normal load and sliding speed) that is a consequence of the surface topography of shot peened samples, as previously presented in this paper.

It can be clearly noticed that for all tested surfaces, sliding speed increase resulted in wear volume decrease (Fig. 7) that 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, which is also confirmed by wear tracks appearance (Fig. 9).

In order to quantify differences of the wear volume of 2 tested surfaces, histogram representation of this variable for all values of contact parameters is given in Fig. 8. Wear values of shot peened surfaces are almost 50% less than wear

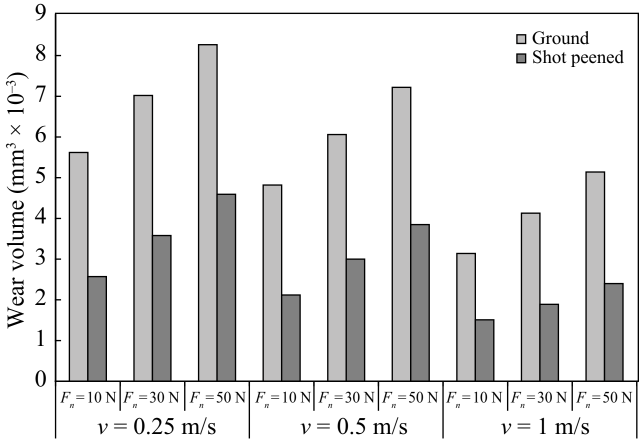


Fig. 8. Histogram representation of the wear volume dependency on sliding speed and normal contact load under lubricating conditions

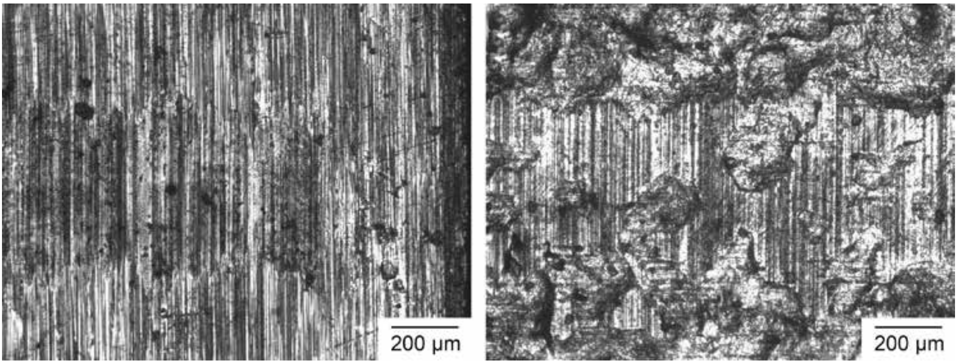


Fig. 9. Wear tracks on 36NiCrMo16 steel samples, under lubricating conditions, in grounded state and shot peened state

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 2 tested surfaces are shown in Fig. 9, whereat 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, the afore-mentioned 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.

CONCLUSIONS

Based on realised investigations, 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 that 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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