The Effect of Shot Peening on Tribological Behavior of Alloyed Steels

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Abstract

Quality of the contact surface, from tribological aspect, represents complex of microgeometry characteristics, among which parameters of the structure and microgeometry shape have special significance, and range of indicators regarding physical-mechanical state of the material in thin surface layer.

Results of laboratory investigations presented and analysed in the paper are related to effects of using final machining by shot peening as a surface plastic forming, and they are further validated by friction and wear testing.

Based on the overall tribological effects, it can be concluded that final machining of contact surfaces by shot peening can contribute to improvement of tribological level of tribo-mechanical system elements.

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

Introduction

Dynamic loads, important to almost all technical systems during exploitation, significantly influence reliability of the contact elements which represent the main structure of the technical systems. Fatigue resistance of the vital elements of technical systems depends mainly on contact layers characteristics. Therefore, appropriate attention should be devoted to these layers already in the design phase. It is even more important considering that failure can be gradual (mainly as a consequence of tribological processes development) or unexpected (element fracture). In both cases, working time until occurrence of the failure depends mainly on contact layers characteristics.

Microgeometry of contact surfaces represents very important aspect often neglected during specification of shot peening parameters [1,2]. Surface topography generated by production process influences fatigue characteristics. This influence is more or less pronounced, depending on the material tendency towards cracks and defects [3].

Shot peening can eliminate or mitigate negative effect of surface defects, if the balls' size is appropriately adjusted to surface topography. In case when balls are too large, they cannot remove tracks generated by the tool and shot peening influence is weak. Resulting surface after the shot peening is anisotropic.

Cavities created by shot peening have positive effect because they act as reservoirs (oil pockets) for the lubricant and assist lubrication of the contact [4,5]. Sometimes the surface, created by shot peening, is electrochemically or chemically post-treated, to remove (dissolve) peaks of asperities and to preserve valleys and to better adjust the surface to exploitation conditions.

Beside changes of microgeometry created by shot peening, material surface layer is often simultaneously strengthened, i.e. hardness is increased. This is resulting in increase of elasticity of asperities (contact points), which bear the surface, what is very important. In case of relative motion between two surfaces, asperities will be elastically deformed at the beginning, without sliding in contact points. Increased elasticity lower the risk of particles separation [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, thus 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].

Geometry characteristics, no matter how influential, cannot completely characterize the quality of the contact surfaces of tribo-mechanical elements and their exploitation features. Physical-mechanical state of the contact layers has important effect. Namely, indicators of physical-mechanical state of the contact layers, such as structure, microhardness and residual surface stresses directly influence intensity of wear process development [9,10].

Experimental testing

EN 10083-1: 36CrNiMo4 steel has been selected for experimental testing. Chemical composition of 36CrNiMo4 steel is determined by the traditional analytic chemistry method and is given in Table 1.

Table 1. Chemical composition of 36CrNiMo4 steel

	Percent content							
	C	Si	Mn	Cr	Ni	Mo	P, max	S, max
36CrNiMo4	0.36	0.25	0.65	1.05	1.05	0.20	0.035	0.035

Mechanical properties of thermal treated (improved) samples of 36CrNiMo4 steel are: R_p=min 800 MPa, R_m=1000-1200 MPa, A_5=min 11%, Z=min 50% and ISO-V=min 40 J.

The specimens were tested using 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. 1. More detailed description of the tribometer is available elsewhere [11,12].

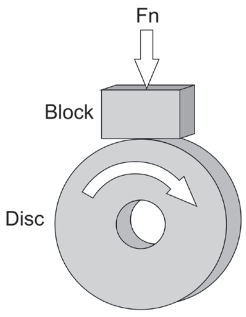


Figure 1. The scheme of contact pair geometry

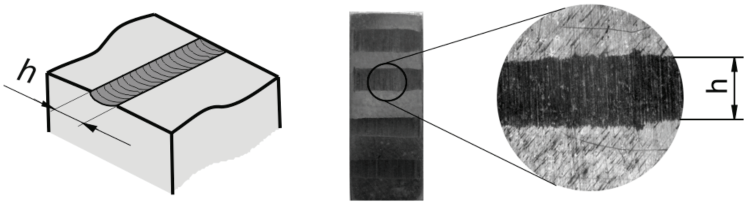


Figure 2. Wear scar

The test blocks (6.35x15.75x10.16 mm) were prepared from *EN 10083-1: 36CrNiMo4* 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 (0.25-1 m/s) and applied loads (10-50 N). Each experiment was repeated five times. The duration of sliding was 60 min.

The tests were performed at room temperature. The lubricant used was ISO grade VG 46 hydraulic oil, a multipurpose lubricant recommended for industrial use in 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 - h (Fig. 2). Using the wear scar width and geometry of the contact pair the wear volume (in accordance with ASTM G77-05) and wear rate (expressed in mm^3) were calculated. The repeatability of the results for replicate tests was found as satisfactory (variation of wear scar width was under 5%).

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

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.

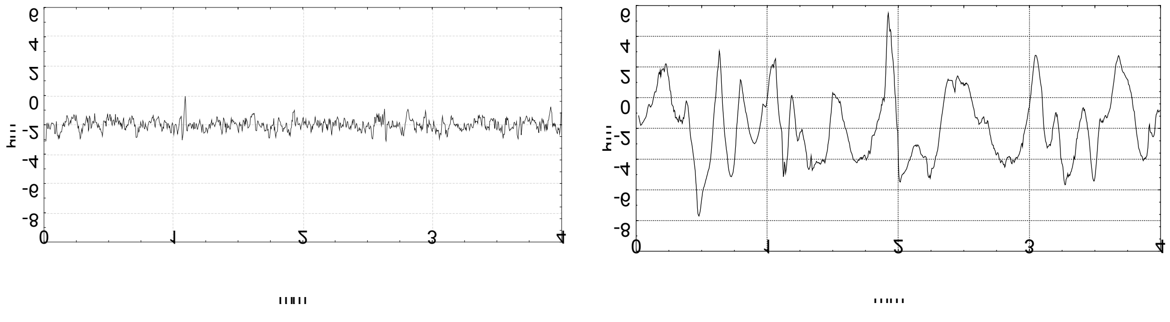
Based on literature recommendations, for 15 mm thickness of the sample, Almen intensity of 16A was chosen. The largest effects of shot peening occur when the whole area is covered. Hence, coverage of $P=1\times98\%$ was chosen. Duration of shot peening, necessary to achieve wanted Almen intensity (16A) 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 10× magnification. It was determined that coverage was 98 % (complete coverage) with shot peening time of 5 min.

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.

Experimental results

Objective evaluation of geometry parameters of surface of machine parts should include macro-geometry, micro-geometry and submicro-geometry, taking into account nature and mechanism of geometry imperfections formation. From this point of view, R_a (arithmetic mean deviation) 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, especially important is avoidance of deep cuts and microcracks on the surface 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 (like R_a and R_z), but also with 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 polished and on shot peened sample, normal to direction of grinding.

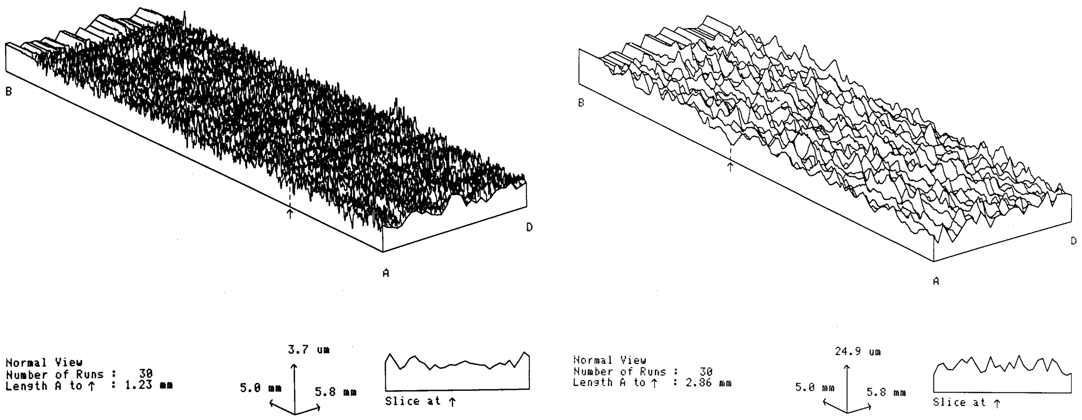


a) b)

Figure 3. Surface profile of 36CrNiMo4 steel sample in ground state (a) and shot peened state (b)

Beside numerical values of roughness parameters, obtained results are graphically illustrated by appropriate examples of profilograms (Figs. 3a and 3b)

Completely changed topography in regards to height, shape, length and statistics resulting from shot peening is illustrated by profilograms in Figs. 4a and 4b, where comparative 3D view of ground and shot peened surface is shown.



a) b)

Figure 4. Spatial view of 36CrNiMo4 steel surface in ground state (a) and shot peened state (b)

It is obvious that due to shot peening, pronounced increase of all roughness height parameters occurred (R_a, R_q, R_p, R_v, R_y, R_{tm}, R_{pm}), compared to initial state obtained by grinding, whereas 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 36CrNiMo4 steel in ground state is R_a=0.28µm and in shot peened state R_a=1.81µm.

Wear volume dependency on changes of contact conditions, normal load and sliding speed is shown in Fig. 5. It can be clearly seen that for all tested surfaces, normal load increase resulted in wear volume increase, while sliding speed increase in the contact zone produced its decrease, what can be a consequence of larger quantities of lubricant in the contact zone. Also, it can be seen that shot peened surfaces for all contact conditions exhibit lower wear level in comparison to ground surfaces, as a consequence of shot peening, as presented earlier in this paper.

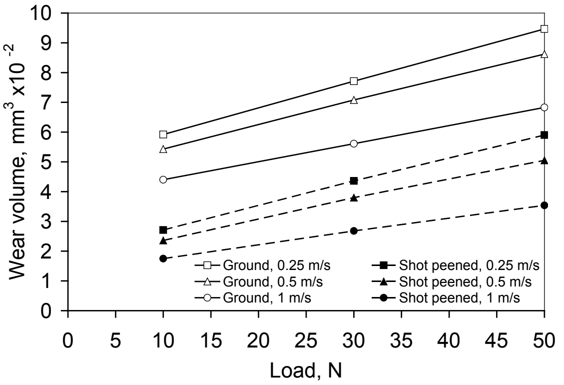


Figure 5. The change of the wear volume per normal load at different sliding speeds (0.25, 0.5, 1 m/s) under lubricating conditions

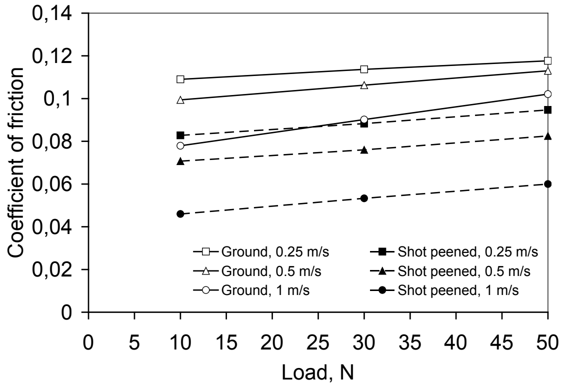


Figure 6. The change of the friction coefficient per normal load at different sliding speeds (0.25, 0.5, 1 m/s) under lubricating conditions

The change of the friction coefficient as a function of normal load is shown in Fig. 6. Since the contact is realised at presence of lubricant, expected low values of friction coefficient were obtained. Normal load increase produced relatively low increase of the friction coefficient, while sliding speed increase produced somewhat higher decrease of the friction coefficient. Shot peened surfaces exhibited lower values of the friction coefficient in comparison to ground surfaces, for all combinations of contact parameters (sliding speed and normal load). In regard to wear level, it can be related to influence of shot peened surfaces topography, in case when contact is realised under lubricating conditions. Friction was in transition regime from boundary to mixed lubrication, at the lowest applied load and the highest sliding speed.

In order to quantify differences of tribological results (the wear volume and the friction coefficient) of two tested surfaces, histogram representation of these variables is given in Fig. 7. Wear values of shot peened surfaces are 40-60% less than wear values of ground surfaces. Lower values of the friction coefficient were recorded at shot peened surfaces, in all contact conditions, irrespective of very pronounced increase of all roughness parameters (R_a, R_q, R_p, R_v, R_y, R_{tm}, R_{pm}), if compared to ground surfaces.

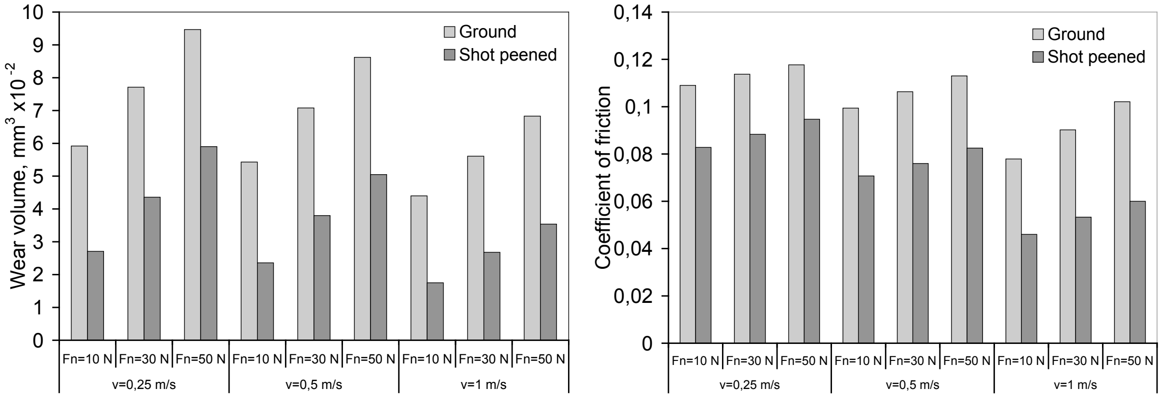


Figure 7. Histogram representation of dependencies of the wear volume and the friction coefficient on sliding speed and normal contact load under lubricating conditions

Wear tracks on two tested surfaces are shown in Fig. 8, whereat in case of ground 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 contact elements (block on disc) was realised only over asperities peaks when these were smoothed. In case of shot peened surface, aforementioned cavities can be clearly observed within the wear track itself, due to which improvement of tribological characteristics occurred, beside positive influence of the increased surface layer hardness due to shot peening.

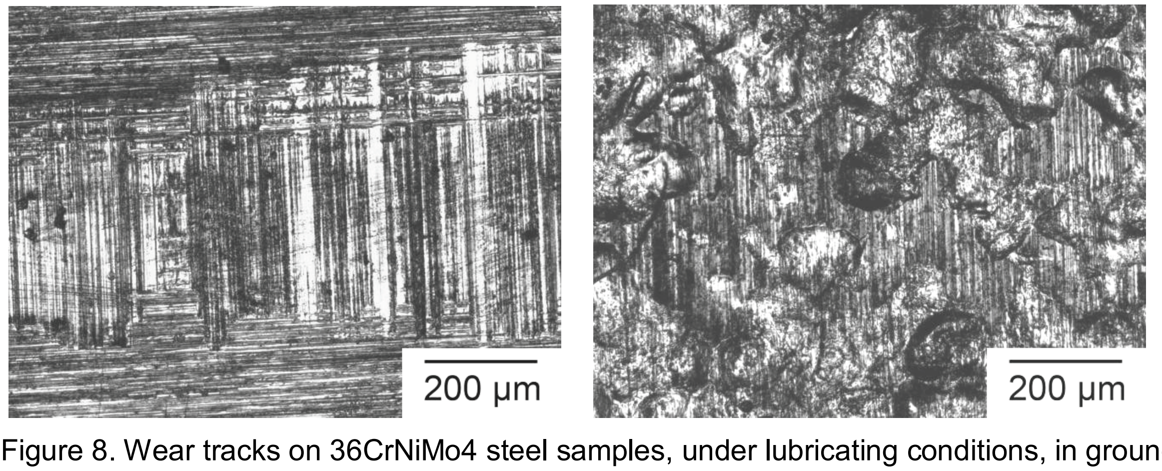


Figure 8. Wear tracks on 36CrNiMo4 steel samples, under lubricating conditions, in ground state (left) and shot peened state (right)

Conclusions

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

- Shot peening eliminates tracks originating from tool processing and surface defects, by modifying surface roughness and hardening of the surface.
- Investigation realised in this paper showed that worsening of surface roughness parameters occur on surfaces obtained by shot peening in comparison with ground surfaces.
- Shot peened surfaces exhibited higher wear resistance (40-60%) and better frictional characteristics (lower friction coefficient from 20 to 30%) if compared to ground surfaces. This is explained by existence of oil pockets that assist lubrication of contact and by increased microhardness of material in surface layers.
- Numerous comparative tribological investigations show that total effects of the shot peening as a final machining have positive influence on tribological behaviour of processed elements and can contribute to improvement of tribological level of tribo-mechanical system elements.

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