TRIBOLOGICAL EFFECTS OF SHOT PEENING SURFACE TREATMENT

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ABSTRACT
Results of laboratory investigations that are presented and analyzed in this paper are directly related to the tribological effects of application of the shot peening process, as the finishing machining operation.
Considering the total tribological effects, one can conclude that the final machining of the contact surface by shot peening, can contribute to improvement tribological level of the tribomechanical systems elements.

KEYWORDS**:** Shot peening, Surface, Tribological characteristics

1. INTRODUCTION

Quality of the contact surface, in the tribological sense, represents the complex of micro geometrical characteristics, among which the special importance belongs to the parameters of micro structure and shapes of micro geometry, as well as the series of indicators of the physical - mechanical status of material in the thin surface layer.

The contact surface characteristics, understood in the mentioned way, as the characteristics of the contact layer, represent the technological state that is the result of the machining process. Namely, in the interaction of tool and the machined piece, in the machining operations, besides the micro geometry of the machined surface, also is created the thin limiting layer with its physical, mechanical, as well as chemical characteristics, often completely different with respect to base material, as the consequence of effect of high specific mechanical and thermal actions on material. Though in obtaining the final results, its share exhibits each technological operation, with the appearance of the so called technological inheritance, the special importance belongs to choice of the procedures and conditions of the final machining.

For the proper choice of finishing machining operations, it is necessary to know the laws of expression of certain effects of individual types of machining, as well as parameters of the machining regime and conditions of their realization, on relevant parameters of the surface topography (height, shape and structure of micro geometry), physical - mechanical status of surfaces and the residual stresses in the surface layers.

Exactly these criteria are the ones that contribute the most on the behalf of giving the greater importance to finishing machining processes based on the surface plastic deformation. Namely, the finishing machining processes by surface plastic deformation (based on principles of sliding and rolling friction, or impact) are characterized by, before all, the phenomenon of hardening of the metal layer of the machining piece, in the surface layer subjected to plastic deformation. As a result of this hardening, there happens an increase of all the characteristics of the deformation resistance, and decrease of plastics' characteristics, and the micro hardness increases.

In the paper are presented results of laboratory investigations related to the effects of the shot peening process on friction and wear behavior of treated surfaces. Tribological properties are analyzed from the aspect of microhardness and roughness of surfaces.

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2. EXPERIMENTAL PROCEDURE

For experimental investigations were chosen two kinds of alloyed steels, the steel for betterment *36CrNiMo4*, of domestic production, and the constructive alloyed steel marked *35NCD16T* of French production.
Chemical composition of tested steels is given in Table 1.

Table 1: Chemical composition of steels 36CrNiMo4 and 35NCD16T.

Steel	Percentage content									
	C	Si	Mn	Cr	Ni	W	Mo	Cu	P	S
36CrNiMo4	0.23	0.29	0.32	1.41	4.12	1.15	-	0.14	0.021	0.02
35NCD16T	0.34	0.28	0.48	1.88	4.12	-	0.58	-	0.013	0.01

The microstructure of both steels consists of the inter - phase structure - trustit with some content of martensite.

The magnitude of the austenite grain was determined, according *to JUS C.A3.004*, by the method of comparison to ethalons of *ASTM*. For both materials was obtained the grain size N^{O} *8*, what belongs to the group of small austenitic grains.

Investigation of the content of the non-metallic inclusions was done by comparison with the scale from *JUS.A3.013*, by method according to Jernkontoret. It was established that steel *36CrNiMo4* has non-metallic inclusions from the field *A2* (medium index *0.56*) and *D2* (medium index *1.03*), and steel *35NCD16T* form the field *A1* (medium index *0.43*) and *D2* (medium index *1.25*).

Mechanical characteristics of thermally treated (bettered) samples of steels *36CrNiMo4* and *35NCD16*T are given in Table 2.

Table 2: Guaranteed values of mechanical characteristics for steels *36CrNiMo4 and 35NCD16T.*

Steel	Direction	R_p	R_m	A	Z	$KU_{300/3}$
		MPa		*%*		*J*
		At least				
36CrNiMo4	-	930	1080	11	5	71*
35NCD16T	Longitudinal	1470	1780	8	35	34
	Lateral	1470	1780	7	20	27

* - $KU_{300/2}$

The shot peening procedure of samples was performed on the peening machine of the type *ES - 1580 - 1* of the *PANGBORN* company, with the cast steel balls of diameter *d = 0.8 mm (S330)* and hardness *48 - 55 HRC* with the *Almen* intensity *16A* and *complete coverage (P = 98 %)*.

Hardness was measured on the micro-hardness meter of the *FRANK* company according to method by *Knoop*.

Roughness of the tested surfaces was measured on the computerized measuring system *TALYSURF 6* of the *RANK TAYLOR HOBSON* company.

Tribometric comparative investigations were conducted on the computer supported tribometer *TPD-93* with the *pin on disk* contact geometry, that provides for the linear nominal contact.

Considering their high tribological risk caused by the chosen contact geometry, as the fixed elements (*pins*) were used samples with contact surfaces that are being tested (shot peened, i.

e. ground). In all the tested combinations the counter body was represented by the unused disk made of steel *25CrMo4*, in cemented state (*60 HRC*), with ground contact surface, $R_a = 0.3\ mm$.

The testing operations were performed under the following conditions:

- Normal contact force: F_N = 10 daN,
- Sliding speed: v = 1.5 m/s,
- Contact duration time: t = 10 min,
- Lubrication: by polar oil, limiting regime,
- Number of repetitions: 5.

Samples for tribological tests are shown in Figure 1.

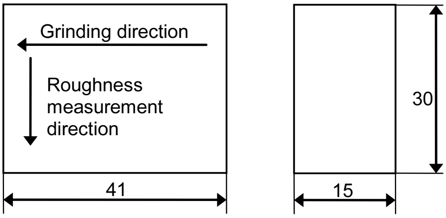

Figure 1: Samples for tribological tests.

3. RESULTS AND DISCUSSION

3.1. Micro hardness and roughness

Hardness measurement method according to Knoop enables measurements at very short distances between the pits and very close to the surface, what is not possible to realize by the *Vickers* method. Hardness measurement was performed on the metallographic grooves made for determination of the metallographic structure, on which the etching was not done.

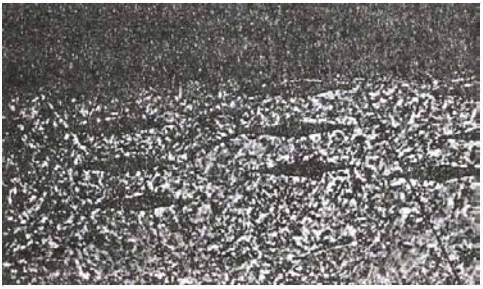

Figure 2: Pits obtained by the micro hardness measurements.

Minimum distance from the surface, at which the hardness still could be measured without having the deformed pit (due to unavoidable taking off the edge layer during grinding), was *0.02 mm*. Hardness was measured at distances from *0.01* to *0.1 mm* in three rows, with lateral displacement (Figure 2). In this way the plastically deformed zone in the vicinity of the previous pit was avoided. The chosen loading of *3 N (≈ 300 p)* enabled obtaining of the pits of the large enough dimensions for measurements of the larger diagonal, with satisfactory accuracy.

Based on the measured values the diagrams were drawn that illustrate the variation of hardness in the surface layer (Figure 3).

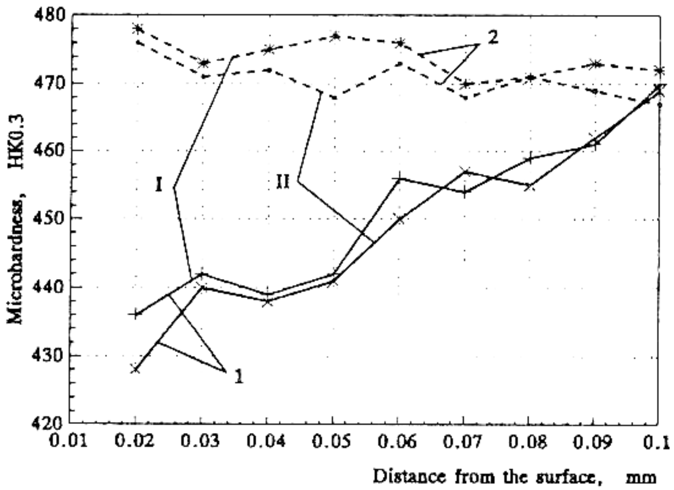

Figure 3: Diagram of micro hardness variation in the surface layer:
I - samples of steel 36CrNiMo4, II - samples of steel 35NCD16T;
1 - ground state (P = 0 %), 2 - Shot peened state (P = 98 %).

During shot peening the hardness was increased in the surface layer all the way to the depth of about *0.1 mm*. For samples made of steel *36CrNiMo4* the hardness increase due to shot peening was *9.63 %*, and for steel *35NCD16T* it was *11.2 %*, (Figure 4).

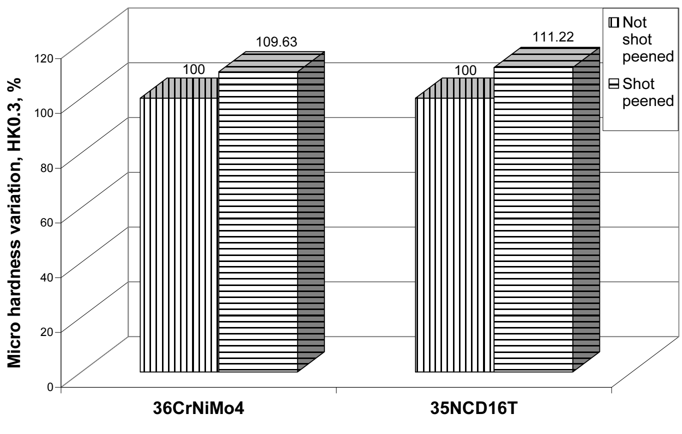

Figure 4: Percentage change of micro hardness in the surface layer.

Due to the shot peening process the very prominent increase occurred of all the height parameters of roughness (R_a, R_q, R_p, R_v, R_y, R_{tm}, R_{pm}), for both tested materials, with respect to the initial state obtained by grinding. In that, to the higher degree of coverage there corresponds the higher degree of roughness increase. Worsening of the height roughness parameters, that is more expressed for steel *36CrNiMo4*, is illustrated on the example of the profile mean arithmetic deviation R_a in Figure 5.

Besides on the increase of parameters that represent the height of micro roughness, the machining by shot peening also has influence on great increase of the parameters of the roughness step.

The mentioned changes in the resultant form are shown through worsening of the structural parameters of micro geometry in the sense of decreasing the bearing area along the profile depth. This is expressed by the change of the profile asymmetry coefficient R_{sk} from negative to positive value, by decrease of the steepness measure of the amplitude distribution curve, and, the most obviously, by change of the shape of the profile bearing curves. The differences in those curves, that correspond to the states of surfaces prior to and after the shot peening, are the most obviously expressed by the comparative presentation for both materials, given in Figure 6.

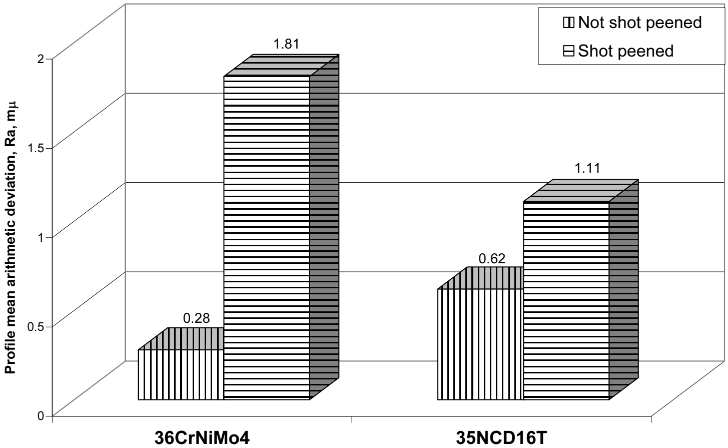

Figure 5: Variation of the profile mean arithmetic deviation (R_a) for the shot peened and not shot peened surface of samples.

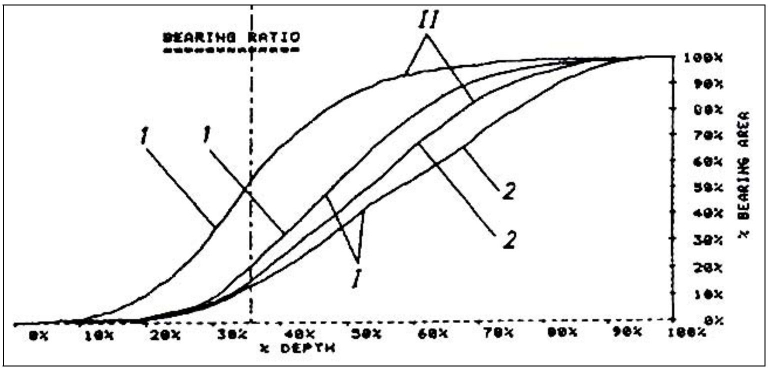

Figure 6: Profile bearing curves:
I - samples of steel 36CrNiMo4, II - samples of steel 35NCD16T;
1 - ground state (P = 0 %), 2 - Shot peened state (P = 98 %).

The completely changed topography of the sample made of steel *35NCD16T*, considering height, shape, step and statistics, that is the result of the machining by shot peening, is illustrated by the *3D* profilogram shown in Figure 7.

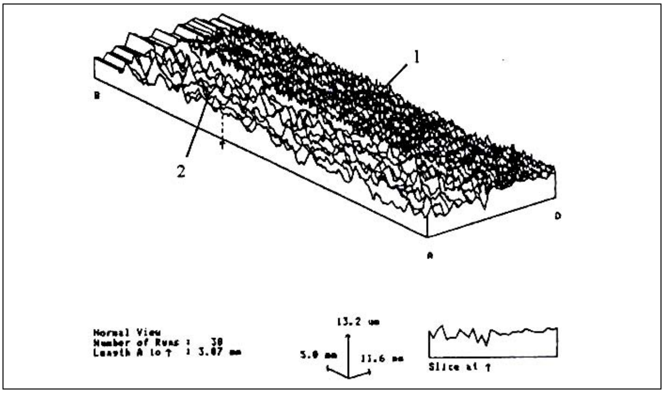

Figure 7: 3D Profilogram of the sample made of steel 35NCD16T:
1 - ground surface, 2 - Shot peened surface.

Based on the obtained results, it is evident that, due to shot peening, the roughness parameters worsening occurred. The reason for this is the low initial roughness that the specimens had prior to shot peening, and the large diameter of the balls that the peening was done with.

3.3. Tribological properties

During the tribological investigations the mild increase of the friction coefficient was noticed. This was the consequence of the change in contact conditions, that comes up as a result of the increase in nominal and real contact surface, due to the progressive development of the wear process on the *pin's* contact surface.

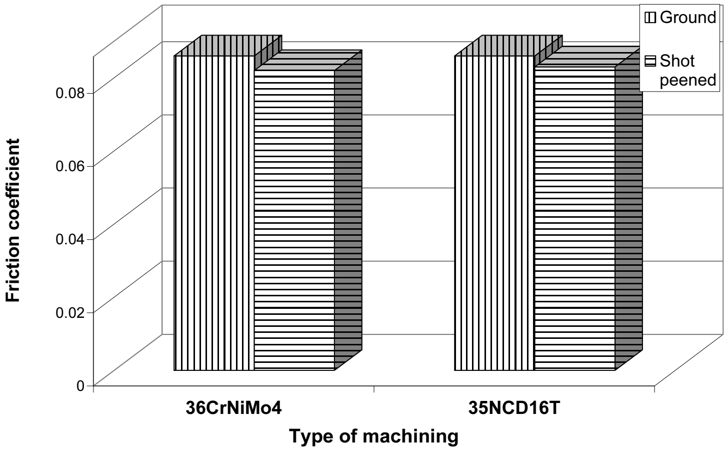

Figure 8: Variation of the medium values of the friction coefficient.

The medium values of the friction coefficient are shown in Figure 8. Though we are dealing with small differences, it can be seen that for the two investigated materials, somewhat lower level of the medium friction coefficient corresponds to the shot peened surface, as compared to the ground surfaces. Such a difference can seem not in accordance with the characteristics of micro geometry, since it was shown earlier that the shot peened surfaces have worse height and structural characteristics of roughness. However, in evaluation of these frictional results, one should keep in mind, that due to the linear contact, high real contact loading, high sliding speed, and significantly lower hardness of the material of *pins* as compared to material of disks, the process of initial wear of the tested surfaces is being unfolding very intensively, thus in friction only take part completely new surfaces, formed during the wear process. In such conditions, the friction process is positively affected by the increased micro hardness of the surface layers obtained by the surface plastic deformation.

Results of measurements of the wear belt width on contact surfaces of *pins*, show that the contact surfaces hardening by the shot peening expresses more prominent effect on wear resistance. This is shown in Figure 9, through the corresponding wear ratio (k), which represents the ratio of the wear parameter value (*wear belt width h*) and product of normal loading (F_N) and friction path (l):

$$k = \frac{h}{F_n \cdot l} \cdot 100,\ \% \qquad (1)$$

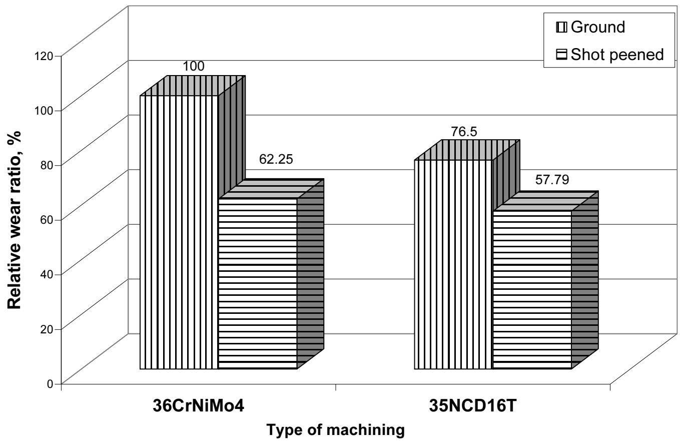

Figure 9: Variation of the relative wear ratio.

It can be seen that the increase of micro hardness of the surface layer, as well as of the generated tribologically desirable residual compressive stresses, due to shot peening, provides for the significant increase of the wear resistance in both materials (*even over 35 %*).

4. CONCLUSION

Shot peening under the given parameters, is manifested by the worsening of both height and structural roughness parameters, with respect to the initial state obtained by grinding. This is the consequence of the low initial wear and somewhat larger diameter of the balls used in machining by shot peening. Simultaneously, the increase was achieved of the hardness in the surface layer all the way to the depth of 0.1 mm. This increase is relatively small, but it is expected for the steels with small initial hardness between 40 and 50 HRC.

Though we are dealing with small differences of the friction coefficient, it can be seen that the lower level of the friction coefficient corresponds to the shot peened surfaces. Such relations are the consequence of long term investigations in which the dominant influence on frictional behavior is not expressed by the parameters of initial micro geometry, considering that the process of running in ends during the initial period of the friction process.

Decrease of the relative wear ratio points to the large improvement of the contact surfaces resistance (over 30 %) which is brought up by the machining by shot peening. This is the consequence, both of the increase of the material micro hardness, and of the significantly more convenient residual compressive stresses in the surface layer.

Thus, based on the total tribological effects, one can conclude that the finishing machining of the contact surfaces by the shot peening process, can contribute to improvement of the tribological level of the tribo mechanical systems elements.

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