LOGISTICS OF EXPERIMENTING WITH STRENGTHENING THE SURFACE LAYERS OF MACHINE PARTS

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DOI: 10.17973/MMSJ.2016_10_201699

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The authors within the scientific contribution present the logistics of laboratory experimenting with strengthening the stressed surface layers of machine parts. The project for strengthening the surface layers was conducted without the use of ultrasonic strengthening via the newly developed device with a static pressing force. Emphasis was placed on the stage of identification of samples surface layers, their microstructure, roughness and hardness after lathe turning and shot peening as well as on the wear of the used forming element after shot peening. The process of experiment results in the modelling of technological conditions and parameters of a newly-designed and verified technology with formulating the logistics steps for practical use.

Logistics can be seen, in addition to a structured arrangement of relationships and activities, as a control system process able to efficiently use available resources in terms of time and value within the various activities at the lowest costs incurred.

KEYWORDS

logistics, experimenting, technological process, strengthening of the surface layers, roughness and hardness of the parts, modelling

1 INTRODUCTION

Logistics in general largely influence the processes of production, distribution and consumption, as well as the reliability and durability of machines, equipment and devices.

Defects and damages of machinery parts and parts of other technical devices should be minimized on the following grounds in terms of their normal operation. The causes of machine parts damages are for example corrosion cracking, brittle fracture, material fatigue and so on. These failures are most often found in surface layer of the stressed parts. The reason is the unfavourable condition of the surface layer in these stressed areas. That is why the attention should be paid to the surface layer condition of the manufactured parts to ensure higher quality, reliability and durability of these parts. The foreground is taken by so called residual stresses resulting from the use of previous finishing technologies. The part "inherits" many features or at least some of them partially after the technologies which effected on it during the manufacturing process. The properties of manufactured flats surfaces are of special importance for the part operation. These properties are a consequence of the working methods and conditions. Furthermore, the surface properties are influenced by the used materials types and metallurgy technologies [Sedlacek 1992].

Therefore the theoretical and experimental activities are constantly developed and the great attention is focused on improving the logistics process and in particular on monitoring and improving the quality of the surface layers.

2 THE ANALYSIS OF PARTS SURFACE LAYERS CONDITION

The system objective of our research work was accuracy modelling at strengthening the surface layers of parts with an emphasis on improving the surface layers quality via plastic deformation [Pilc 2014].

Experiments were carried out for strengthening the surface layers (without ultrasonic strengthening) with a newly developed device and the pressing force was exerted statically, not dynamically. Within the experimental part we focused mainly on the surface layers condition, especially on microstructure, hardness and roughness. Within the experimentation the following objectives were set:

1. Analysis and comparison of the surface layers properties of metal parts after working.
2. Analysis of stress in the surface layers and comparison of selected technologies for strengthening the surface layers.
3. The formalization of process results before non-ultrasonic hardening of surfaces basing on the experimentation results.
4. Experiment logistics for static strengthening with characteristics of the device invented for its implementation.
5. The sequence of experiments implementation.
6. The processing of measurement results, discussion and generalization.

The process of plastic deformation in the surface layer was analysed after various methods of strengthening the surface layers of metal materials. At this the particular technical characteristics and parameters of the surface layers plastic deformation process were identified. The process is carried out with dislocation movement of one of the two mechanisms - slip and twinning. The mechanism of plastic deformation depends on the crystallographic structure of metals and the individual terms of plastic deformation. On the basis of analysis results the status and quality parameters of the parts functional surface layers strengthening were evaluated [Kralik 2013], [Sherrit 1999].

3 EXPERIMENTAL WORKS LOGISTICS

The experiment aim was to determine the surface layer condition of the cylindrical part outer surface after the static shot peening in comparison with the surface initial condition after lathe turning. Geometric and physical parameters, parameters of cylindrical test samples lathe turning remained constant throughout the experiment and we only changed values such as the forming tool pressing force F, the diameter of the forming element (the ball) d, movement of the tool at shot peening f and a forming element material. Experimentally the following parameters were determined as follows: the sample surface roughness Ra after each lathe turning operation and shot peening, worked sample hardness by Vickers HV after lathe turning operation, shot peening and forming element wear after shot peening.

3.1 *Methods and Order of the Experiment*

The experiment was conducted in the order as follows:

- lathe turning of the cylindrical test samples,
- strengthening the outer turned surface of the rotary part by the shot peening in different input conditions,
- wear determination of strengthening device forming elements,

- metallographic evaluation of the samples surface layer after lathe turning operation and static shot peening.

With applying the method of experimenting the tests were performed for selected materials of device and the testing samples for verification and expansion of existing knowledge.

This methodology and logistical technological procedures are prepared for further improvement and prospects for use while implementing the research and development and realization projects in research and development and realization cooperation with industry practice. Number the subchapter consecutively, i.e. the subsections of section 2 are numbered 2.1, 2.2, 2.3 etc. We recommend using no more than three levels of headings.

Equipment and materials used within the experiment methods and order of the experiment

Equipment and instruments:

- Universal centre lathe TOS Trencin SN 50 A,
- Dynamometer Kistler Type 9257A,
- Profilometer Taylor Hobson Surtronic 3+,
- Hardness tester WPM Leipzig HP 250 with diatestor Carl Zeiss Jena,
- Optical metallographic microscope Carl Zeiss Jena NEOPHOT 21,

For capturing the microstructure we used a digital camera taking the image through the microscope ground glass:

- The optical table meter OGP QVI Sprint MVP 200,

Devices:

- The device for static shot peening the surface with damping

Shot peening device Fig. 1 is made up of:

- Cage - material 7050 (alloy),
- Linear housing Bosch Rexroth STAR 020 (067-20),
- A strengthening element - balls for bearings - material - steel and silicon nitride Si3N4,
- Damping element - material - polyurethane, hardness 85 +/- 5 Shore A,
- The device round bar 020 - material - precision steel Cf 53,

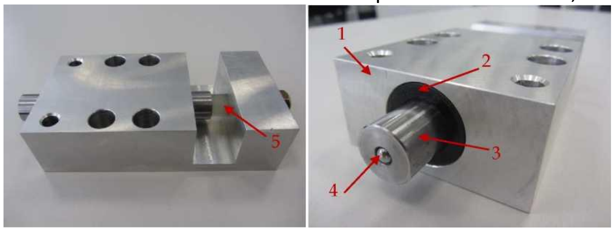

Figure 1. Device for surface static shot peening

1) cage, 2) linear housing, 3) the device round bar, 4) forming element (steel ball), 5) damping element (polyurethane)

The left corner lathe knife with changeable cutting tool SANDVIK Coromant mounted on the holder MITSUBISHI MWL NR 2020K08

Semi-finished work piece:

Round Bar ø 78 mm, material - steel 12060.1 (C56E2). For more features see Tab. 1 and Tab. 2

Chemical composition [%]	C	Mn	Si	P	S	Cr	Ni	Cu
	0.52 up to 0.60	0.50 up to 0.80	0.17 up to 0.37	0.04	0.04	0.25	0.30	0.30

Table 1. Chemical composition of steel 12060.1

Mechanical properties	A [%]	Z [%]	Re [MPa]	Rm [MPa]
	13	30	380	min. 650

Table 2. Mechanical properties of steel12060.1 (C56E2)

4 THE LOGISTIC ORDER OF EXPERIMENTING

We set the number of test samples as 24 pcs, on which the experiments for surface strengthening with static shot peening were conducted. It is possible to work 8 samples in one lathe clamping. The samples were made of round bar in the centre lathe using the corresponding lathe blade without a cutting fluid.

The technological parameters at the samples lathe turning are shown in Tab. 3, the sample after lathe turning can be seen in Fig. 2.

f [mm]	n_s [1/min]	a_p [mm]	v_c [m/min]
0.2	500	0.5	123

Table 3. Technological parameters at the samples lathe turning

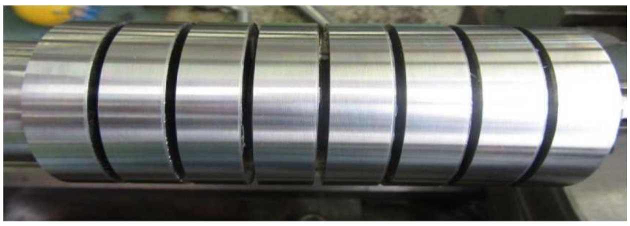

Figure 2. Testing sample after lathe turning

Characteristic values of the surface measured with profilometer after lathe turning are shown in Tab. 4.

Ra1 [μm]	Rq [μm]	Rz DIN [μm]	Ry [μm]
2.2	2.5	11	12.1

Table 4. Surface values after lathe turning

where:

Ra1 - initial roughness of worked sample after lathe turning

Rq - average square deviation of profile, Rz - profile maximum height, Ry - arithmetic average,

In terms of the experiment the initial roughness Ra1 of the worked sample was monitored. So the samples were prepared for static shot peening. We conducted strengthening with the shot peening also on the centre lathe. Shot peening device was mounted on a dynamometer connected to the computer software so that we could monitor and adjust individual forming forces at the static shot peening.

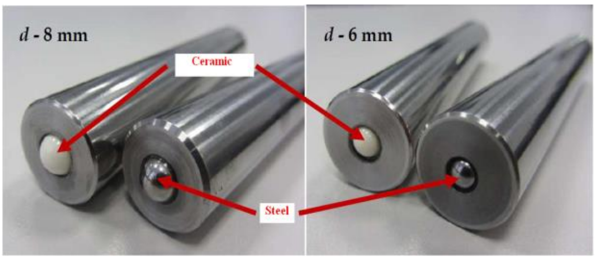

Figure 3. Forming elements of the shot peening device

The roller bearings balls were used as forming elements of the shot peening device Fig. 3. The balls were made of steel and ceramics based on silicon nitride Si_3N_4. We set two diameters 6 and 8 mm for each material of the ball. The edge was created on each ball to fit firmly in the drilled hole of the lathe forming bar - material Cf 53. The ball was fixed in the hole with 2-component adhesive. Each bar had the balls on both sides, thereby saving the material. For each type of strengthening device we selected two movements, for each movement - 3 same forces which we have chosen on the basis of the calculated power of the procedure. The shot peening of samples was carried out under the constant lubrication with quality cutting oil Ekolube CPN 211. This oil is a concentrate of ingredients (chlorinated paraffins) used for the very tough materials cutting [Krajny 2011], [Sherrit 1999].

After the static shot peening we measured the surface roughness Ra2 on all samples using a profilometer. The roughness around the circumference of each sample was measured 10 times to obtain the relevant average roughness value of shot peened samples. On the chosen samples the Vickers hardness was measured using hardness tester HP 250 (Fig. 4). We have chosen the Vickers hardness measurement because by the physical definition it meets best the required accuracy of obtaining the measured values (the most accurate method of hardness measuring). The sample was fixed on the triangular prism. Because of the measurement relevance, the samples were tested at four points of the circumference with a margin of 90 °. We carried out the hardness test with load HV30 where the puncture depth was about 0.1 mm. According to the diagonals d1 and d2 we determined the average value of the diagonal d from which with the help of standard tables we determined hardness. The resulting value was modified with the correction factor for the convex cylindrical surfaces. The resulting hardness was compared with the hardness calculated by the following formula:

$$HV_x = \frac{2 \times X \times \sin\frac{136°}{2}}{d^2} \times k \qquad (1)$$

where:

X - the test load value HV (old units)

d - the average value of the diagonal puncture [mm]

k - correction factor for the convex cylindrical surfaces which is read from tables (standard EN ISO 6507-1: 1997) on the basis of the ratio d/D, where D is the diameter of the test sample.

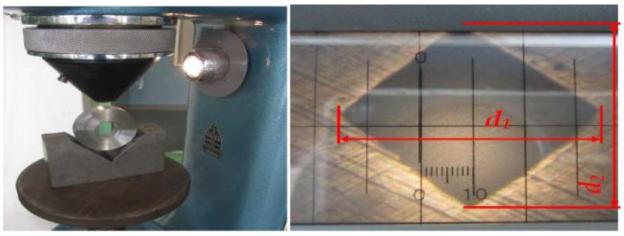

Figure 4. Measuring of Vickers hardness with the hardness tester

The next step of the research was to show the metallographic structure of the sample surface with the lowest roughness and highest hardness after the shot peening. We performed the analysis of samples surface with an optical metallographic microscope.

- Metallographic sample preparation consisted of the following activities:
- Mechanical grinding with sandpaper (600 grit),
- Mechanical polishing with alumina aqueous suspension on the felting disc,
- Visibility of the structure by the etching in NITAL (1.5 up to 3% nitric acid in methyl alcohol),

5 EXPERIMENT RESULTS

Operation conditions of static shot peening and final roughness of some samples after static shot peening are shown in Tab. 5.

No. of sample	D[mm]	d (mat.) [mm]	f [mm]	Fcalc. [N]	Fsel. [N]	Ra2 [μm]	q [MPa]
1.	77	6	0.08	176.96	180	1.62	760
2.	77	6	0.08	176.96	300	1.28	760
3.	77	6	0.08	176.96	700	0.45	760
4.	77	6	0.11	176.96	180	0.86	760
5.	77	6	0.11	176.96	300	0.81	760
6.	77	6	0.11	176.96	700	0.49	760
7.	77	8	0.08	314.60	320	0.88	760
8.	77	8	0.08	314.60	700	0.64	760
9.	77	8	0.08	314.60	1000	0.33	760
10.	77	8	0.11	314.60	320	0.96	760
11.	77	8	0.11	314.60	700	0.74	760
12.	77	8	0.11	314.60	1000	0.49	76
13.	77	6	0.08	176.96	180	0.45	760
14.	77	6	0.08	176.96	300	0.37	760
15.	77	6	0.08	176.96	700	0.37	760
16.	77	6	0.11	176.96	180	0.38	760
17.	77	6	0.11	176.96	300	0.58	760
18.	77	6	0.11	176.96	700	0.49	760
19.	77	8	0.08	314.60	320	0.34	760
20.	77	8	0.08	314.60	700	0.23	760
21.	77	8	0.08	314.60	1000	0.27	760

22.	77	8	0.11	314.60	320	0.34	760
23.	77	8	0.11	314.60	700	0.29	760
24.	77	8	0.11	314.60	1000	0.28	760

Table 5. Operation conditions of static shot peening and final roughness of some samples after static shot peening

Steel
silicon nitride Si_3N_4

D - diameter of the worked sample,
d - diameter of the forming element (balls),
F - forming device movement,
Fcalc. - calculated pressing force of the forming device,
Fsel. - selected pressing force of the forming device,
Ra2 - sample surface roughness after static shot peening,
Q - pressure of the forming element

Measured sharpness of some samples surfaces after the static shot peening are shown in Tab. 6.

No. of sample	Ra [μm]									
1.	1.56	1.62	1.64	1.6	1.64	1.64	1.62	1.64	1.64	1.62
2.	1.3	1.32	1.26	1.28	1.24	1.28	1.32	1.26	1.26	1.28
3.	0.44	0.44	0.48	0.46	0.46	0.46	0.46	0.44	0.44	0.46
4.	0.98	0.86	0.76	0.86	0.84	0.9	0.86	0.8	0.8	0.92
5.	0.76	0.8	0.86	0.8	0.8	0.76	0.84	0.78	0.9	0.82
6.	0.46	0.48	0.52	0.5	0.48	0.46	0.48	0.5	0.56	0.48
7.	0.94	0.96	0.92	0.82	0.78	0.96	0.94	0.86	0.82	0.8
8.	0.6	0.62	0.62	0.66	0.66	0.58	0.62	0.68	0.64	0.68
9.	0.34	0.36	0.3	0.38	0.3	0.34	0.3	0.32	0.3	0.38
10.	0.96	1	0.96	0.98	0.98	0.92	0.94	0.98	0.96	0.96
11.	0.68	0.74	0.8	0.7	0.82	0.7	0.7	0.7	0.82	0.72
12.	0.36	0.46	0.78	0.58	0.46	0.46	0.44	0.48	0.46	0.44
13.	0.38	0.44	0.44	0.52	0.56	0.5	0.44	0.36	0.38	0.44
14.	0.34	0.34	0.4	0.36	0.42	0.34	0.4	0.4	0.34	0.36
15.	0.42	0.4	0.32	0.36	0.36	0.38	0.36	0.36	0.38	0.36
16.	0.34	0.34	0.4	0.38	0.4	0.42	0.36	0.36	0.42	0.36
17.	0.54	0.54	0.52	0.76	0.54	0.5	0.64	0.6	0.58	0.54
18.	0.52	0.5	0.48	0.46	0.46	0.5	0.48	0.52	0.52	0.44
19.	0.38	0.28	0.32	0.42	0.36	0.38	0.26	0.36	0.36	0.3
20.	0.26	0.22	0.24	0.2	0.2	0.24	0.26	0.22	0.26	0.2
21.	0.28	0.24	0.28	0.28	0.3	0.28	0.26	0.26	0.28	0.28
22.	0.28	0.38	0.36	0.36	0.28	0.38	0.3	0.32	0.34	0.38
23.	0.28	0.3	0.2	0.32	0.34	0.28	0.3	0.34	0.26	0.3
24.	0.24	0.26	0.3	0.3	0.28	0.28	0.28	0.28	0.28	0.28

Table 6. Measured sharpness of some samples surfaces after the static shot peening

The results of Tab. 6 are shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8.

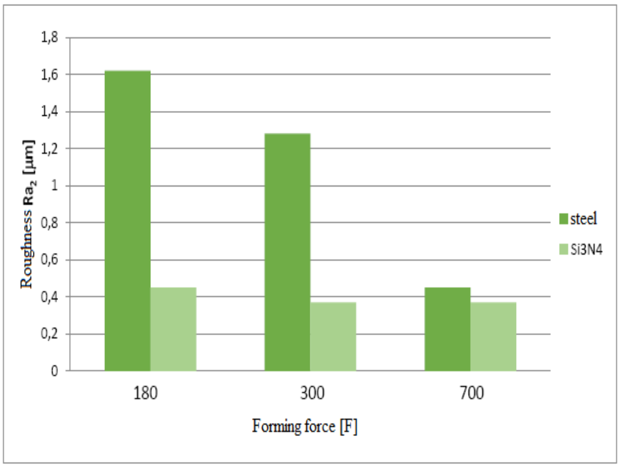

Figure 5. Dependence of surface roughness from the forming force F and the strengthening element material at d=6 mm, f=0.08 mm

Figure 7. Dependence of surface roughness from the forming force F and the strengthening element material at d=8 mm, f=0.08 mm

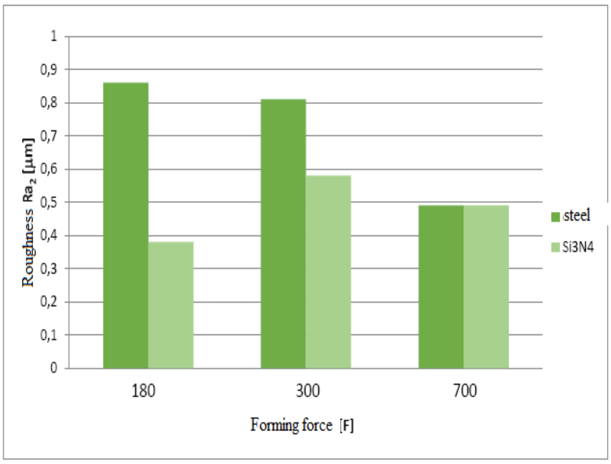

Figure 6. Dependence of surface roughness from the forming force F and the strengthening element material at d=6 mm, f=0.11 mm

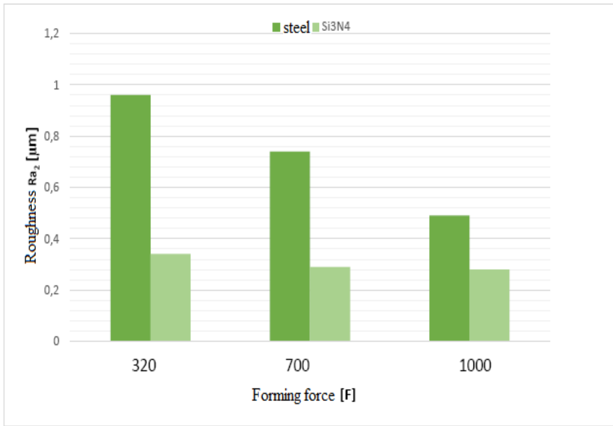

Figure 8. Dependence of surface roughness from the forming force F and the strengthening element material at d=8 mm, f=0.11mm

Results from Vickers hardness test HV30 are shown in Tab. 7-11, wherein:

D - sample diameter
d1 - diagonal length
d2 - diagonal length
d - the average diagonal length
k - correction factor (Standard EN ISO 6507-1: 1997)
HV30tab - table hardness value (calculated on the basis of the value d)
HV30calc - calculated hardness value

No. of puncture	D [mm]	d1 [µm]	d2 [µm]	d [µm]	k	HV30tab	HV30calc
1	77	516	520	518	1.005	207	208
2	77	547	516	532	1.005	197	198
3	77	485	500	493	1.005	229	230
4	77	522	495	509	1.005	215	216
			diameter	518	1.005	208	208

Table 7. Hardness values of the lathe turned sample S

No. of puncture	D [mm]	d1 [µm]	d2 [µm]	d [µm]	k	HV30tab	HV30calc
1	77	516	529	523	1.005	203	205
2	77	525	528	527	1.005	200	202
3	77	515	507	511	1.005	213	214
4	77	507	517	512	1.005	212	213
			diameter	518	1.005	208	208

Table 8. Hardness values of Sample 1

No. of puncture	D [mm]	d1 [μm]	d2 [μm]	d [μm]	k	HV30tab	HV30calc
1	77	500	502	501	1.005	222	223
2	77	510	507	509	1.005	215	216
3	77	505	509	507	1.005	216	218
4	77	500	504	502	1.005	221	222
			diameter	505	1.005	222	220

Table 9. Hardness values of Sample 3

No. of puncture	D [mm]	d1 [μm]	d2 [μm]	d [μm]	K	HV30tab	HV30calc
1	77	501	502	502	1.005	221	222
2	77	505	506	506	1.005	217	219
3	77	509	509	509	1.005	215	216
4	77	492	516	504	1.005	219	220
			diameter	505	1.005	220	219

Table 10. Hardness values of Sample 20

No. of puncture	D [mm]	d1 [μm]	d2 [μm]	d [μm]	k	HV30tab	HV30calc
1	77	477	484	481	1.005	222	242
2	77	484	490	487	1.005	235	236
3	77	493	497	495	1.005	227	228
4	77	504	493	499	1.005	223	225
			diameter	490	1.005	223	233

Table 11. Hardness values of Sample 24

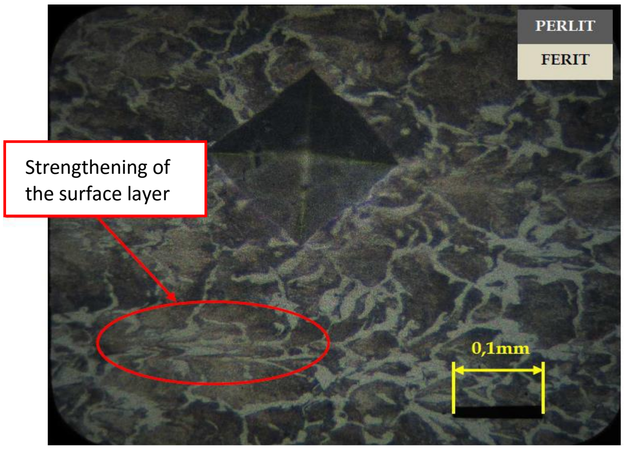

Figure 9. Metallographic structure of Sample 24 surface with marked strengthening of the surface layer (enlargement 250x)

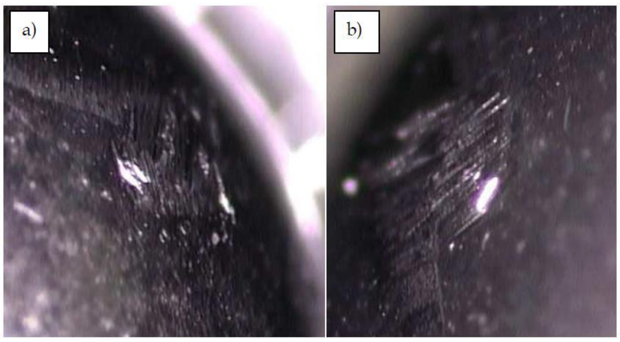

Figure 10. Forming element wear – steel ball a) d=6 mm, b) d=8 mm

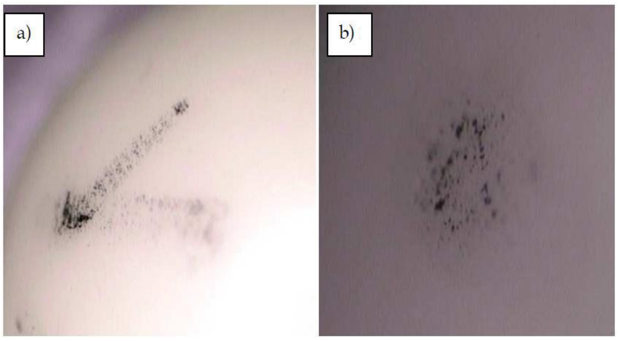

Figure 11. Forming element wear – ball made of Si3N4 d=6 mm, b) d=8 mm

6 EXPERIMENT RESULTS DISCUSSION

Roughness values that we have reached with static shot peening confirmed the assumption regarding smoothing the microinhomogenities of the chosen sample - reducing the surface roughness value. The low values of surface roughness, while maintaining its strength, were shown by the strengthening element made of cutting ceramic (silicon nitride), confirming its very good physical properties. Thanks to the advantageous properties of cutting ceramics such as high hardness, resistance to high temperatures, durability, cutting, wear and mechanical stress resistance, we have reached the better surface roughness with the lowest forming force than at strengthening with the steel ball. We confirmed also that the resulting average surface roughness is better at the lower device movement (f = 0.08 mm). This condition is confirmed in particular by the sample strengthened with silicon nitride at d = 6 mm and f = 0.11 mm. Increased roughness was caused mainly by the high pressure of the forming element, due to the high forming force, the inability of ceramics to deform plastically and a small radius of the strengthening element. The best surface roughness values were achieved at the shot peening with silicon nitride at d = 8 mm, f = 0.08 mm and forming forces of 700 and 1000 N (0,23 μm resp. 0.27 μm values). We have reached the highest hardness of the surface with the sample No.24, while the sample had the lowest roughness. We performed metallographic scratch pattern of the surface. The structure of the sample is documented on Fig. 9. The microstructure of the sample analysed is formed by pearlite (dark grains). Perlite originated from the original austenite grains as a product of eutectoid transformation. Perlite grains are lined by proeutectoid ferrite (bright fields). In Fig. 9 in the marked area there are deformed ferrite grains clearly identifiable in one direction. We assume that this deformation of ferrite grains is a direct result of the static shot peening and caused hardness increase. Forming element wear is shown in two figures, Fig. 10 and Fig. 11. The strengthening element wear was seen the most at using the steel balls. The wear of the strengthening element made of cutting ceramic is substantially lower due to the high stiffness of the material at high temperatures and wear resistance, which guarantees its greater durability.

7 CONCLUSIONS

The operational characteristics of metal components are determined also by their surface condition. At mechanical loading of elements the surfaces condition has a strong influence, especially at cyclic loading, on the occurrence and spread of surface cracks and the contact fatigue. Therefore it is necessary to pay attention to the knowledge of the surfaces properties as well as to their improvement. The importance of parts surfaces is evidenced by the number of theoretical and experimental works which characterize the constant interest in the issue. Invented and manufactured device was verified, the samples were evaluated so we can conclude that our research in this area is useful. During the implementation of the experiments the new insights were obtained that broaden the area of surface layers quality influence. It can be stated that the issue of improving the quality of equipment parts will be actual for the future as well. The opportunities are mainly in the further use of simulation programs applications. For the creation of logistic models it will be needed to use the latest and broader interdisciplinary knowledge of the actual implementation engineering processes and technologies.

ACKNOWLEDGMENTS

This paper was written in frame of the work on the projects VEGA 1/0936/15

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