POSSIBILITIES OF IMPROVING FATIGUE PROPERTIES OF MACHINE ELEMENTS BY PNEUMATIC SHOT PEENING

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SUMMARY

In this paper, an essence of dynamic burnishing process called pneumatic shot peening developed in the Technical University of Rzeszow, a method of accelerated fatigue test, and some selected results of fatigue tests as well as of surface layer investigations have been presented. The following grades of steel have been tested: 50HF, H10N7K9M5, 12H2N4WA, 30HGSA with chromium galvanic plating, 40HMNA with plasma sprayedmolybdenium coating, and titanium alloy TiA15.5-Cr2SiO,2Fe1. The obtained results show, that using the pneumatic shot peening it is possible to increase the fatigue strength limit by 15 - 30%. The achieved strain hardening rate is well correlated with process parameters, its intensity and surface layer parameters what enables the process control to be simplified and fatigue strength of processed elements to be forecast

KEYWORDS

Dynamic burnishing, pneumatic shot peening, fatigue strength, strain hardening, surface layer, surface roughness, internal stresses, alloy steels

INTRODUCTION

Pneumatic shot peening has been developed in the Technical University of Rzeszow in order to increase the fatigue strength of cylindrical and contoured elements of low and medium hardness (mainly heat treated steels and high-strength titanium alloys) in medium and small lot production. Later research works indicated that the process can also be applied to parts having higher hardness (55 - 60 RC), coated elements, and welded joints.

In contradistinction to regulr shot peening and glass bead peening, equipment for pneumatic shot peening is characterized by small overall dimensions, low costs, quite operation, and good quality of constituted surface layer. Some theoretical considerations related to the process have been presented in work [1].

PROCESS DESCRIPTION AND EQUIPMENT

Basic defferences and advantages of the pneumatic shot peening in comparison with widely used regular shot peening techniques are as follows:

a) As working medium bearing balls dia 1.5 - 4.0 mm are used, propelled at a limited speed of 4 - 9 m/sec. As a result of that, the balls do not disintegrate, maintain their high hardness, there is no dust produced during the process which could have been pressed into the surface layer (SL).

b) A smooth ball surface is projected anto the workpiece surface (WP) in the form of scale-like indentations with radii analogous to ball radius (Fig. 1).

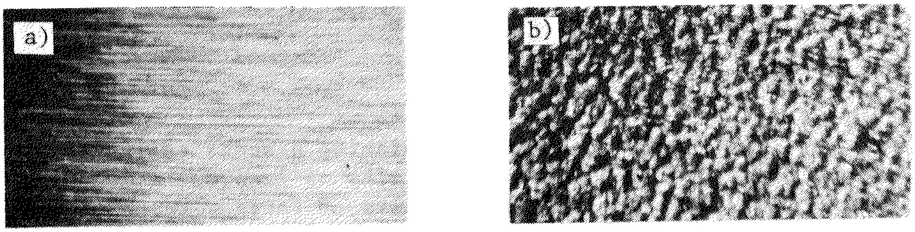

Fig. 1 Surface Photos: a) before pneumatic shot peening,
b) after pneumatic shot peening

c) Ball propelling medium is the compressed air sucking the balls from working chamber bottom through ejector nozzles (Fig. 2) and directing them onto the workpiece wherefrom, after ricochetting, the balls fall down under gravity into the suction zone eliminating thus ball transportation elements.

d) Low ball speed and their continous recirculation cause that only a small ball charge is required (1 - 2 kg for small workpieces up to 10 - 12 kg for large ones) and wear rate of nozzle bore is much lower than that for conventional peening nozzles or blasting wheels.

e) As air supply source, a regular factory internal compressed air network with pressure of 0.5 MPa can be used provided with a typical oil and humidity trapping equipment.

A diagram of the peening equipment has been shown on Fig. 3. Movement kinematics should make possible to achieve 100% coverage of the workpiece. The process itself is affected by ejector nozzle geometry and: ball diameter db, air pressure p, working nozzle to workpiece l, and peening time t.

Inspectin of parts after peening can be accomplished in the following way:

a) basing on Almen test strip mounted on a dummy workpiece,
b) basing on workpiece coverage rate,
c) basing on surface roughness changes after peening (Fig. 14)
d) on the production preparation stage, basing on surface layer measurements and fatigue strength results.

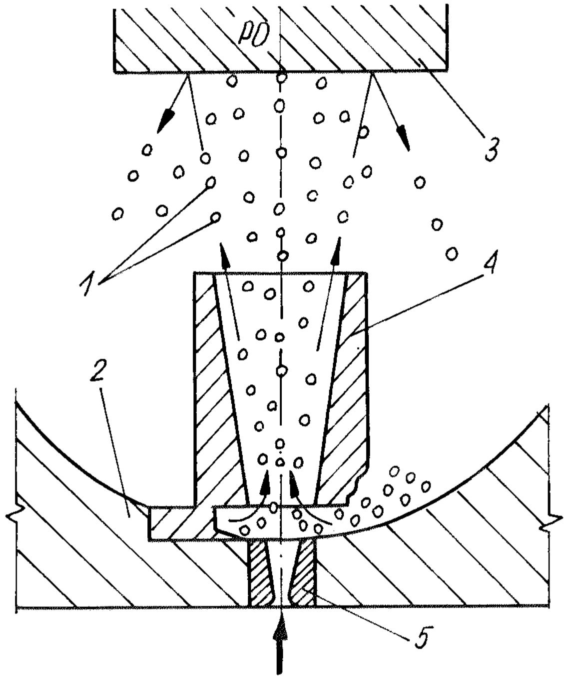

Fig. 2

Diagram of ejector nozzle and pneumatic shot peening: 1 - lower nozzle, 2 - guide, 3 - workpiece, 4 - balls, 5 - working chamber bottom

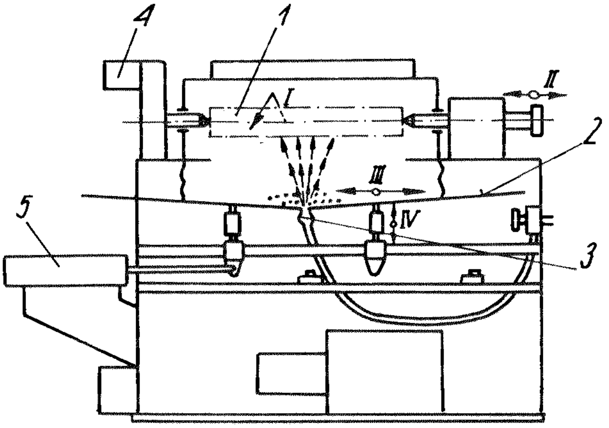

Fig. 3

Diagram of pneumatic shot peening machine: 1 - workpiece, 2 - ball container, 3 - nozzle, 4 - rotary movement drive, 5 - reciprocate movement drive [3]

Pneumatic shot peening of Almen test strip type A at $p = 0.15 - 0.25$ MPa, $t = 2 - 6$ min, and $db = 1.5 - 2.5$ mm had the following effect on intensity I determined by Almen test strip deflection:

$$I = 0.96\ p - 0.05\ t + 0.96\ db + 0.5\ p\ t - 0.084 \qquad (1)$$

Application of the pneumatic shot peening process to ground surfaces may cause even elimination of subsequent polishing operation.

FATIGUE TEST METHODS

Because the fatigue tests carried out by means of traditional methods are somewhat time- and cost-consuming, a specjal accelerated test method has been developed for quick evaluation of pneumatic shot peening effects, which can also be useful for evaluation of some other surface treatment processes. Special test pieces are used in that method having the working surface in the shape of a cylindrical section (Fig. 4) which is brought into vibration resonance motion with an amplitude assuring necessary stress level in the point of failure. Diagram of a test stand for such tests is shown on Fig. 5 and some theoretical considerations are given in [4].

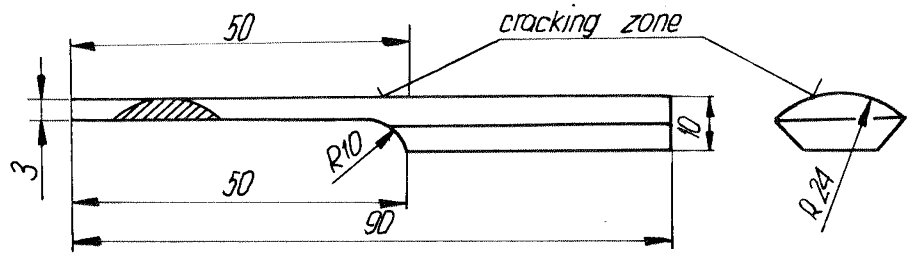

Fig. 4 Shape and dimensions of fatigue test piece

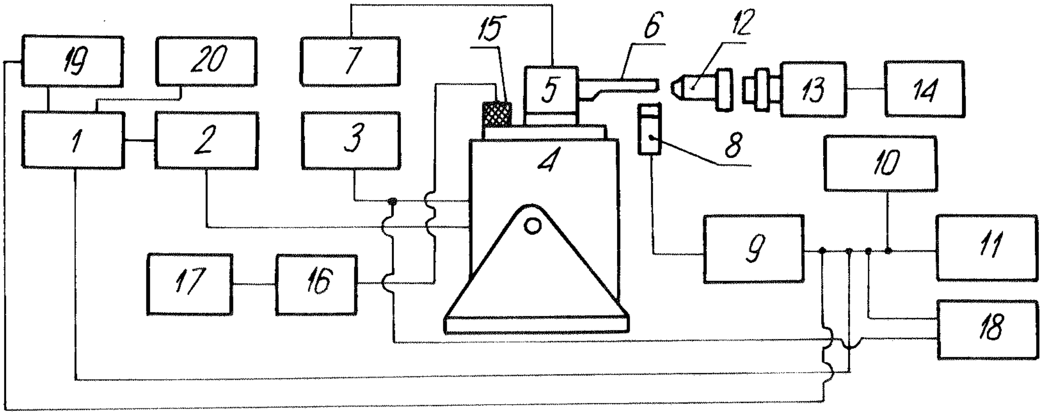

Fig. 5 Schematic diagram of specjal stand for fatigue testing at resonance frequency of loading: 1 - generator, 2 - amplifier, 3 - exciter, 4- vibrator, 5 - hydraulic holder, 6 - specimen, 7 - hand press with pressure gauge, 8 - microphone, 9 - microphone amplifier, 10 - oscilloscope, 11 - frequency meter, 12 - microscope, 13 - TV camera 14 - monitor, 15 - vibration pick-up, 16 - vibration meter, 17 - oscilloscope, 18 - automatic circut-breaker, 19 - automatic resonance corrector, 20 - load programing device

A short cycle of fatigue tests in this method has been achieved due to:

a) considerable frequency of vibrations of the test piece, preferably within 800 - 1200 Hz
b) possibility of using small test piece methods for determination of fatigue strength limit FSL (Prot, Locati) or Dixon's step method [5],
c) running the test to the first fatigue crack and its propagation to 0.1 - 0,15 mm depth rather than to full test piece failure (first crack appears as drop in free vibration frequency whereas the test stand control system must automatically maintain the resonance)

In this research work, fatigue strength limit FSL at pendulous bending Z_{gw} has been determined by a step method basing on 16 - 18 test pieces.

FATIGUE TESTS RESULTS

Pneumatic shot peening process causes an increase in fatigue stregth limit FSL due to hardening of the surface layer SL, constitution of compression stresses, and smoothening of surface undulations. An excessive intensity may cause a deterioretion of achieved results.

a) Tests on steel 50HF (42 - 44 RC). An effect of intensity measured by deflection of Almen test strip type A on fatigue strength limit FSL has been shown on Fig. 6. An increase in intensity over 30A is not recommended

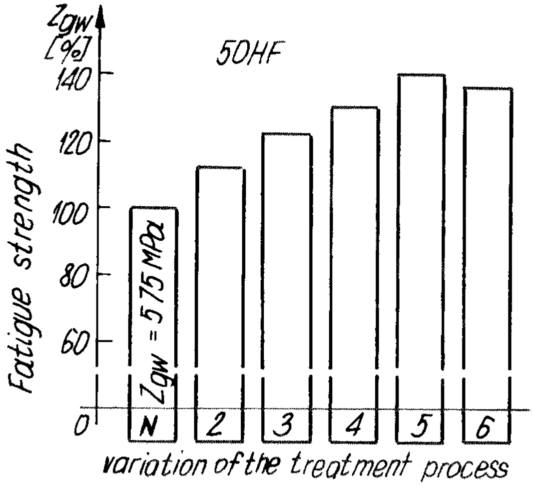

Fig. 6

Changes in FSL of steel 50HF after pneumatic shot peening with various intensity: N - without peening, PK-pneumatically shot peened to intansity: 2 - 10A, 3 - 15A, 4 - 25A, 5 - 30A, 6 - 35A

b) Titanium alloy TiA15.5Cr2Si0,2Fe1 [2].In case of this aloy, a maximum increase in fatigue strength limit FSL has been achievable at considerably lower intensity (I = 7A) whereas any further increase in intensity lowers the fatigue strength limit gain (Fig. 7)

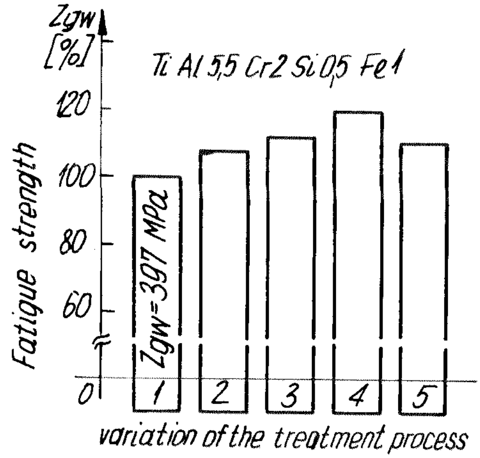

Fig. 7

Changes in FSL of titanium alloy TiA15.5Cr2Si0.5Fe1 after pneumatic shot peening: 1 - without peening, 2 - 2A, 3 - 5A, 4 - 7A, 5 - 10A

c) Maraging steel H10N7K9M5 [6]. An effect of process parameters on intensity has been presented on Fig. 8a. At the highest parameters (version 4) a decrease in FSL gain is observed. Stress distribution curves shown on Fig. 8b indicate constitution of compression stresses. For version 4, similarly to FSL, also the internal stresses are lowering. Some effects of strain hardening of a steel of this type by different methods have been presented on Fig. 9 [6]. They indicate that the pneumatic shot peening effects are comparable with other methods, however, significantly better results have been obtained by means of glass bead peening method (using Vacu-Blast equipment). An insignificant effect of peening (using Gutman equipment for carburized teeth peening) should be explained by overpeening.

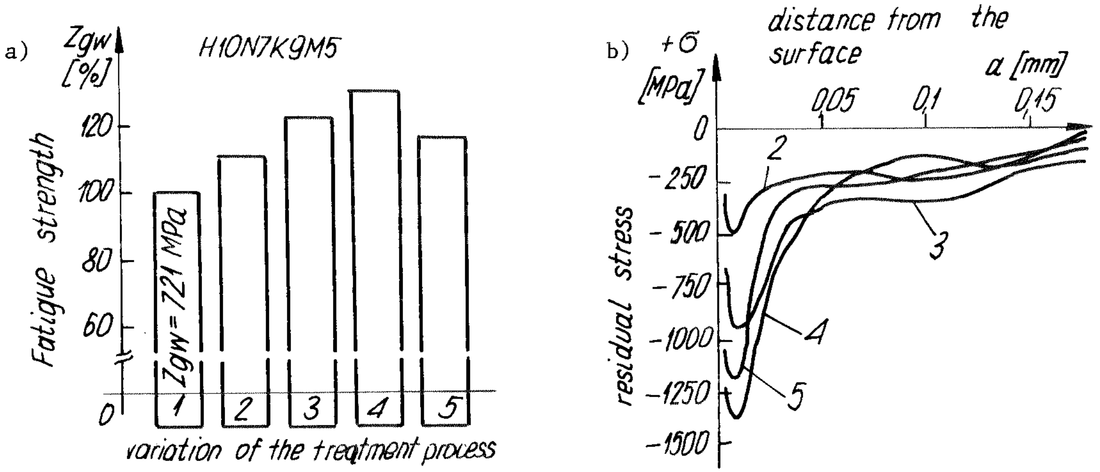

Fig. 8 Changes in FSL of maraging steel H10N7K9M5 after pneumatic shot peening a) and internal stresses distribution curves after treatment b). 1 - polishing, 2 - 5 - pneumatic shot peening at parameters: 2 - p = 0.12 MPa, t = 15 min, 3 - p = 0.12 MPa, t = 30 min, 4 - p = 0.18 MPa, t = 15 min, 5 - p = 0.18 MPa, t = 30 min

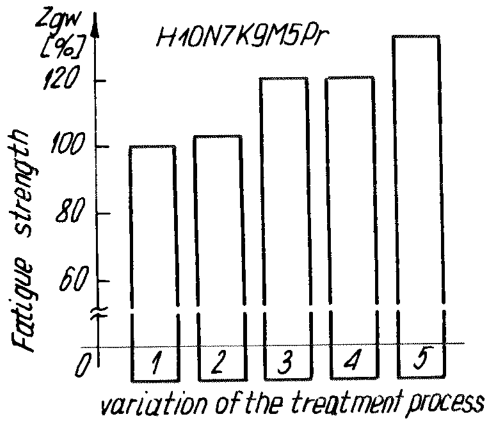

Fig. 9

Changes in FSL of maraging steel H10N7K9M5 strain hardened by various methods: 1 - polishing, 2 - peening, 3 - vibration peening, 4 - pneumatic shot peening, 5 - glass bead peening (using Vacu-Blas equipment)

e) Steel 12H2N4WA carburized and quenched (60 - 61 RC). The results have been shown on Fig. 10. Despite of a high hardness and small plastic deformations of the surface layer, an increase in fatigue strength limit FSL after the pneumatic shot peening is 15 - 18%.

f) Steel 30HGSA with galvanic chromium plating. The fatigue strength has been tested using a typical bending/oscillating equipment at the frequency of

3000 cycles/min. The results have been presented on Fig. 11. They indicate a particular usability of the pneumatic shot peening of the parent material before chromium plating application. It enables full elimination of destructive effects of chromium plating on the fatigue strength limit FSL (tensile stresses, hydrogen contents).

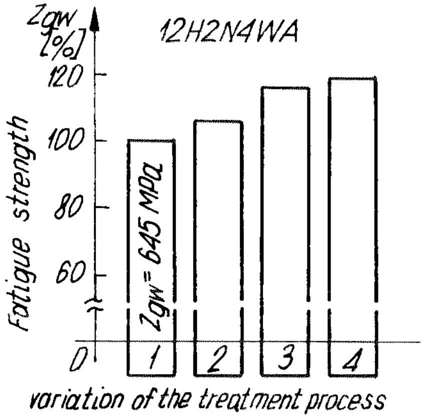

Fig. 10

Changes in FSL of steel 12H2N4WA treated by following methods: 1 - brushing 2 - polishing, 3 - brushing + pneumatic shot peening, 4 - polishing + pneumatic shot peening

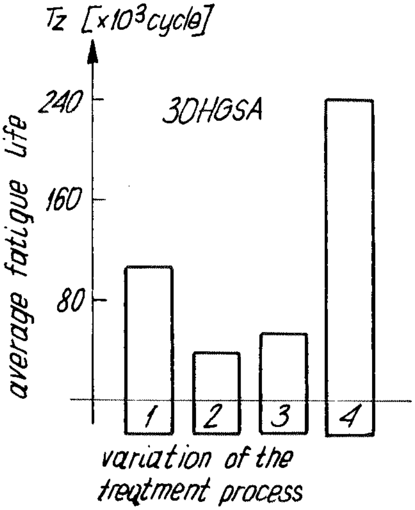

Fig. 11

Fatigue strength of test pieces made of 30HGSA steel with chromium galvanic plating: 1 - ground parent material (without plating), 2 - polished Cr plating, 3 - Cr + pneumatic shot peening, 4 - pneumatic shot peening + Cr + pneumatic shot peening

g) Steel 40HMNA with plasma sprayed molybdenium coating (using Metco eguipment) [7]. The test results are presented on Fig. 12. They indicate a negative effect of the coating on the fatigue strength limit FSL and a possibility of improvement of the fatigue strength mainly by the pneumatic shot peening of the coating (increase in fatigue strength limit FSL by 27%). Other process versions gave worse results.

ANALYSIS OF TEST RESULTS

The presented results of fatigue tests show, that by the pneumatic shot peening it is possible relatively easy to obtain some gains in FSL by 15 - 25%. The pneumatic shot peening process as its intensity increases, causes the geometrical condition of the surface layer to be changed (Fig. 13), even in the case of a higher material hardness. Those changes, within a defined intensity range, are pretty well correlated with the intensity (Fig. 14) what enables to use the mea-

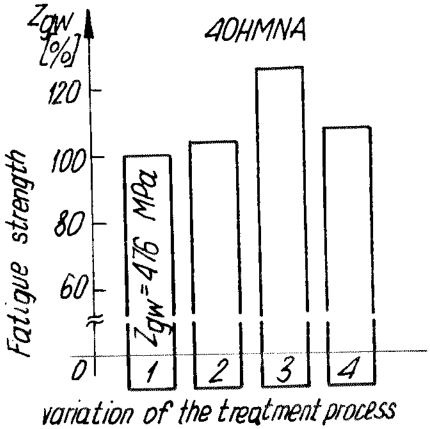

Fig. 12

Changes in FSL of 40HMNA steel with plasma sprayed molybdenium coating: 1 - both parent material and coating ground, 2 - parent material pneumatically shot peened + ground coating, 3 - parent material ground + coating pnaumatically shot peened, 4 - both parent material and coating pneumatically shot peened

surements of profile changes for a direct evaluation of the peening intensity. A high correlation with the intensity is shown by parameter (Δ_a)- Fig. 14. Correlation coefficient for the form $\Delta_a = b\ I^m$ (where I - deflection of Almen test strip A in mm, b, m - coefficients) within the range 0.853 - 0.966 whereas slightly lower parameter Ra (correlation coefficients -0.847 - -0.951). Those coefficients are slightly higher for primary surface roughness (before pneumatic

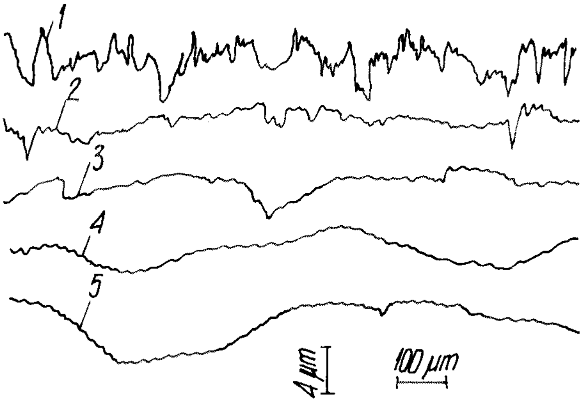

Fig. 13.

Profilographs of surface of 35HGSA steel of 50 RC hardness: a) after grinding, Ra = 1.6 - 2.2 µm, b) after pneumatic shot peening I = 0.25 mm, c) I = 0.37 mm, d) I = 0.48 mm, e) I = 0.57 mm

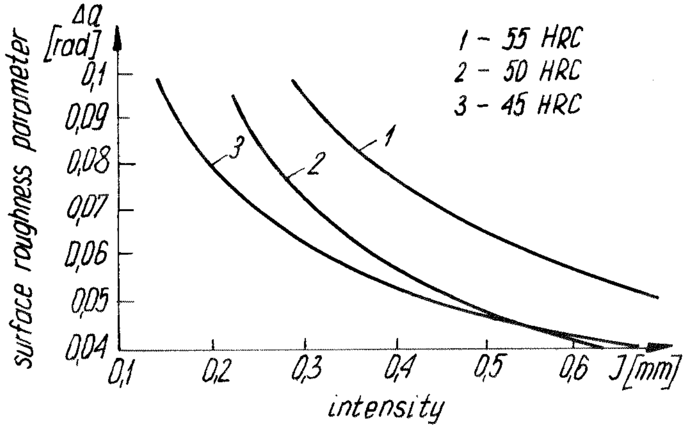

Fig. 14

Relationship between parameter Δ_a (mean profile slope to mean line) from pneumatic shot peening intensity I for Ra = 1.6-2.2 µm shot peening) Ra = 1.6 - 2.2 μm than for Ra = 0,7 - 1.2 μm. A good correlation can also be observed between more important process parameters and FSL. For example, in case of results presented on Fig. 8, a relationship between Z_{gw} and p and t can be given in the following form [8].

$$Z_{gw} = 107 + 5149.5\,p + 29.6\,t - 202.8\,p\,t \qquad (2)$$

Linear correlation coefficient between the results presented on Fig. 8 and those calculated from (2) is equal to 0.996.

A considerable correlation have also been observed between measuered values of FSL and various parameters of SL even in case of change of the peening method for another one, which also causes strain hardening. Test results of FSL (from Fig. 10) [7] together with some characteristic parameters of SL have been presented in Table 1, where the linear correlation coefficients r are indicated. They are particularly high between FSL and hardening parameters (defined by Knoop's microhardness measurements, where $H = \mu HKp100/\mu HKr$; $\Delta\mu HK = (\mu HKp - \mu HKr)$, μHKp-microhardness at the surface, μHKr - core hardness) whereas slightly lower between FSL and parameters characterizing mean internal stresses in SL of a test piece (measured on the grounds of deflection of the end of the test piece for fatigue tests f, $\sigma_{sr} = f\,E\,H_o^2 / 12(1 - \mu)\,a_o\,L^2$, where σ_{sr} - mean value of internal stresses in the layer of a_o depth determined by virtue of measurement of the depth of hardening changes, L, H_o - length and mean thickness of test piece working end, $E = 2.05\ 10^5$ MPa, $\mu = 0.3$)

Tab. 1 Test Results for Steel 12H2N4WA

Machining Version	Z_{gw} [MPa]	H [%]	$\Delta\mu$HK	f [mm]	σ_{sr} [MPa]
Brushing	645	0	0	1.869	-459.6
Polishing	688,8	3.8	24	2.17	-547.1
Polishing + glass bead peening	702.1	4.4	29	2.199	-554.4
Polishing + pneumatic shot peening	764.3	10.4	66	2.875	-966.4
Polishing + wet shot peening	732.9	6.5	45	2.312	-662.7
Brushing + pneumatic shot peening	745.6	11.3	74	2.887	-728.1

r = 0.95

r = 0.96

r = 0.85

r = 0.82

CONCLUSION

a) The presented results of fatigue tests show a wide possiblilities of use of the pneumatic shot peening method for increasing FSL of machine elements of low, medium and high hardness, as well as those with metalic platings.

b) The pneumatic shot peening process is easy to control by changing its basic parameters. It assures repeatable results to be obtained, whereas the process effects are well correlated with the parameters of constituted SL and peening intensity characterized by the process parameters.

c) There is a possibility to work out some simplified methods for current control basing on surface geometrical measurements of the surface before and after peening (Fig. 14), eliminating thus Almen test strips.

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