ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1213759

PARAMETERS SELECTION OF SHOT PEENING GEARS OF CARBURIZED AND HARDENED STEEL 21NICRMO2

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Abstract

This article presents the methodology of shot peening gears' parameters selection used in agricultural tractor transmission. The gears made of steel have been treated with 21NiCrMo2 thermal-chemical consisting of carburization to the depth of 0.8 mm and subsequently hardened. The hardness of the side teeth surface after hardening was 58 HRC. The same process of thermo chemical was used for flat samples with dimensions 120×12×5 mm. Prepared samples were divided into two series. First shot peening was treated with spherical pellet with a varied diameter from 0.4 mm to 2.5 mm. For second series samples additional treatment of shot peening was not carried out. Then micro-hardness, roughness and longitudinal and transverse residual stresses were measured. As a result of the studies, there were selected parameters of shot peening, exerting the greatest influence on favourable residual stresses distribution in the surface layer of material and an increase in microhardness. At the same time, particular attention was paid to the morphology of samples surfaces after shot peening. There were rejected the parameters of shot peening, which caused damage to the surface in the form of visible cracks and craters. Based on the analysis presented in this article there were selected shot peening parameters, which will be applied during the additional dynamic surface processing of gears, used in the tractor's drive system.

Keywords: *materials engineering, shot peening, vehicles, gears*

1. Introduction

The shot peening process scope is to cause plastic deformation surface layer by the tool action on a component hard surface. There are many ways to implement shot peening, but the aim of each treatment is strengthens, lapping, or both [1].

Shot peening is the subject of many studies conducted in research centres around the world. Over the past decades, we developed new technologies and recommendations on the implementation of this treatment for various materials, especially those characterized by high hardness, such as ceramics. Publications on shot peening relate in particular to study the physical processes that occur during processing, the material properties change after the procedure, the theoretical models describing the process and still developed shot peening surface technology [2-7].

More and more attention is paid to the state of the machines surface layer during manufacture that is in operation to natural wear. In the course of cooperation gears work force, which can lead to adverse effects, causing the partial or complete loss of the ability to continue working. Gears strength deterioration can be caused by tribological wear such as pitting, fretting and all kinds of surface layer fatigue, which may result in loss of exploitation properties acceleration. In the case of gears shot, peening improves the surface layer state and its geometric structure [8-10].

This technology introduces favourable changes in the surface stress state layer of the teeth. Tensile stress turn into compression, while hardening the material and changing the geometric surface structure. Shot peening is used increasingly as a final gear machining, in particular those that are exposed to high loads. This is a process carried out in the cold, which in addition to improving the fatigue strength can be used for finishing and cleaning surfaces [1-5]. Shot peening consists in firing work surface with small balls made of hard materials. Balls' kinetic energy is caused by the compressed air hose with balls, which exits the orifice and gives them appropriate speed. Schematic diagram of the shot peening gear process is shown in Fig. 1.

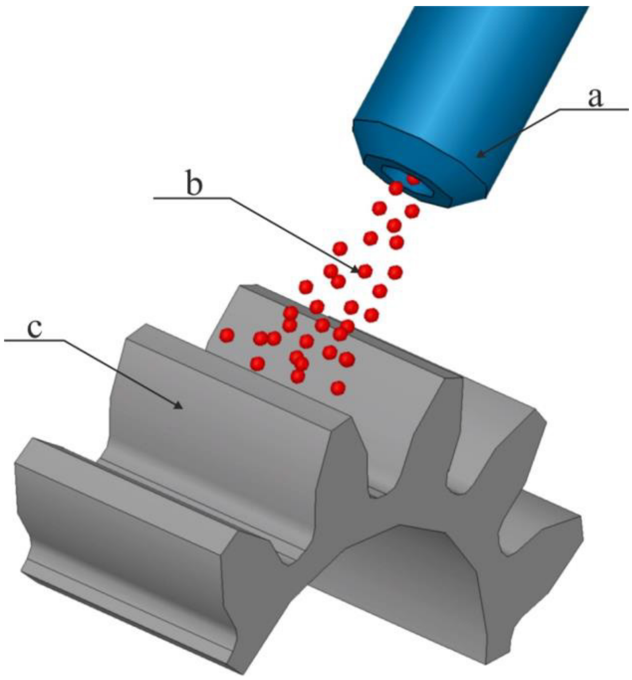

Fig. 1. Schematic diagram of the shot peening gear process, a – orifice, b – stream of balls, c – gear [36]

Each hit balls on the tooth's lateral surface introduces stresses, which exceed the gear's yield stress. The result of these strokes is micro indentation entail a change in the tooth's surface geometric structure.

Shot peening process increases the fatigue strength through the introduction of compressive residual stresses and strengthen the material surface layer. It is assumed that the increase in strength as a result of shot peening is proportional to the increase in the material hardness. Another factor determining the fatigue strength increase is compressive stress occurring in the surface layer. A linear relationship was found between fatigue strength increase and value of compressive stress and surface defects reduction of such as burns, scratches or burrs in relation to the disadvantages after other surface treatments.

2. Parameters Selection shot of peening gears

Shot peening is applied to processing gears made of steel 21NiCrMo2 after thermal-chemical treatment, which consist in carburization to a depth of 0.8 mm, and subsequently hardening. The hardness of tooth side surface after hardening is 58 HRC. The same process of thermo-chemical used for flat samples with dimensions 120×12×5 mm, Fig. 2.

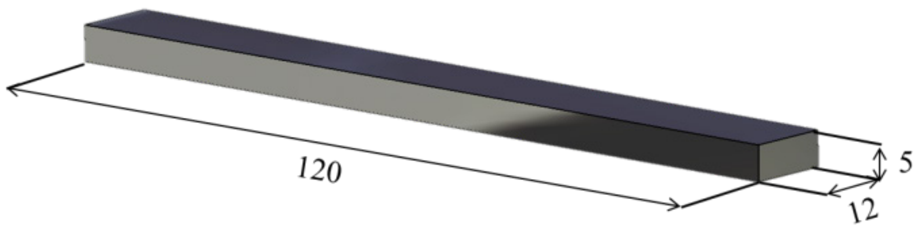

Fig. 2. The sample flat made of steel 21NiCrMo2

The prepared samples are divided into two series. The first shot peening was treated spherical grit of varying diameter according to the diagram shown in Fig. 3.

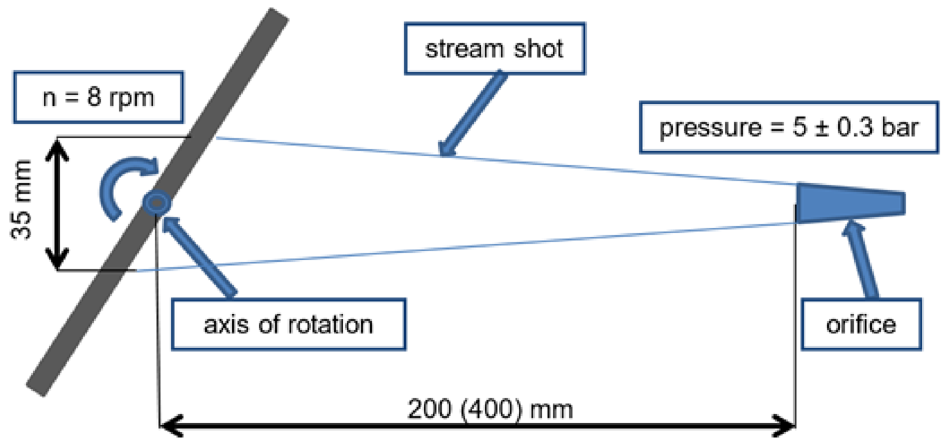

Fig. 3. Schematic diagram of the flat samples shot peening process

During shot, peening the sample for pivotal movement relative to the axis of rotation indicated in Fig. 3 at a speed of 8 rpm. Spherical shot subjected to a pressure of 5±0.3 bar exit from the orifice, which was located at a distance of 200 mm from the sample's centre of rotation. The exception was shot peening buckshot with a diameter of 2.5 mm away when the orifice was 400 mm. The zone of action shot diameter with an assumed energy shot peening was 35 mm.

The parameter with which the shot peening process was carried out is shown in Tab. 1.

Tab. 1. The parameters of shot peening samples flat

Shot diameter [mm]	Shot hardness [HV]	Orifice distance [mm]	Shot peening time [min]	Shot peening intensity [mm]
2.5	750-800	400	10	$f_C = 0.28$
1.2	640	200	4	$f_C = 0.2$
0.8	640	200	4	$f_A = 0.2$
0.6	640	200	4	$f_A = 0.4$
0.4	640	200	4	$f_A = 0.34$

For shot peening were subjected to a series of samples, some of which has been subjected to a double shot peening as shown in Fig. 4.

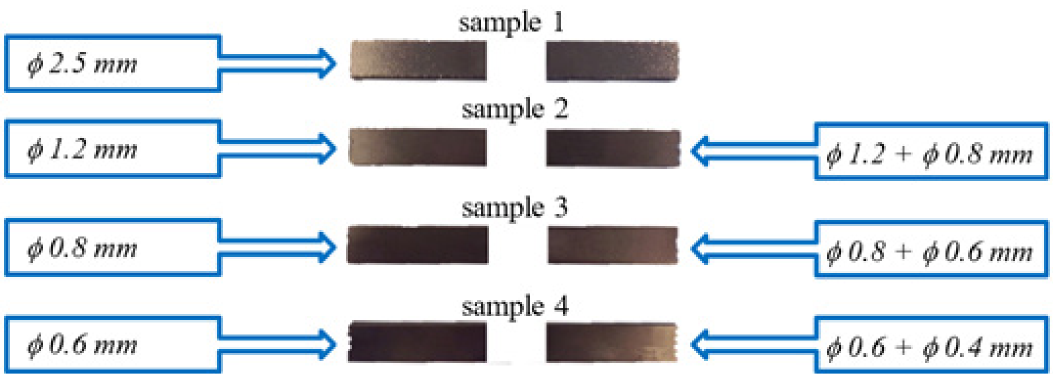

Fig. 4. Flat samples series, which was subjected to shot peening with different parameters

Second series samples have not been subjected to shot peening. Then studied micro-hardness, longitudinal and transverse roughness and stresses were measured.

3. Micro-hardness measurement

Microhardness tests were carried out by HV0.2 to achieve a minimum first imprint depth from the surface. The minimum depth at which they were able to measure the microhardness in each case is approximately 50 µm. Measurements were carried out to a depth equal to 1.2 mm in order to investigate the effect of heat treatment-chemical, which is made at a depth of 0.8 mm. Microhardness measurement results shown in Fig. 5.

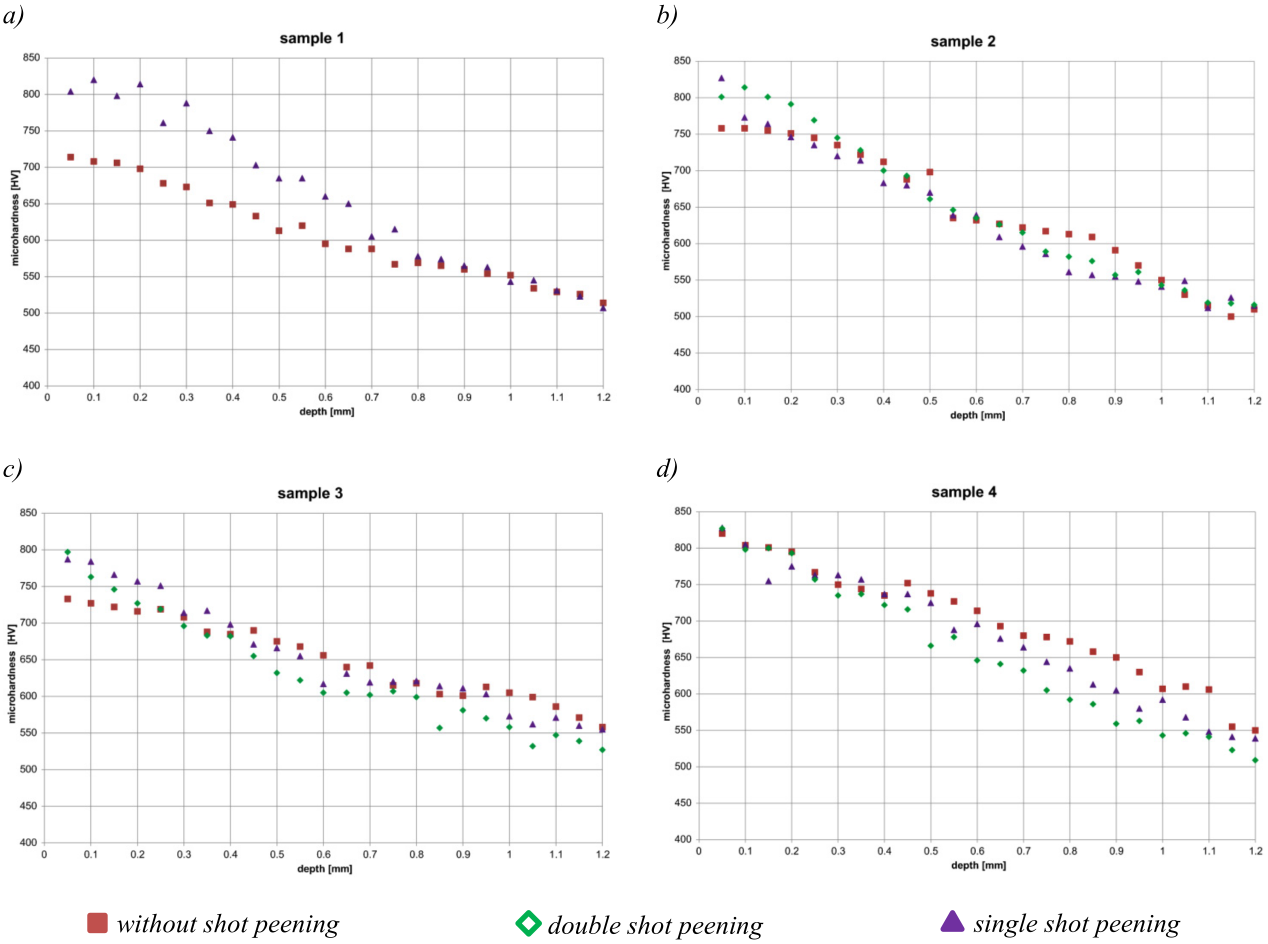

Fig. 5. Graphs of microhardness changes obtained by shot peening with buckshot of varying diameter, a) ϕ 2.5 mm, b) ϕ 1.2 mm and ϕ 0.8 mm, c) ϕ 0.8 mm and ϕ 0.6 mm, d) ϕ 0.6 mm and ϕ 0.4 mm

Analysing the curve shapes on graphs microhardness it can be seen, the use of buckshot with a diameter $\phi = 2.5$ mm in the greatest increase in hardness. This is due to the largest kinetic energy balls, which is converted into material deformation during treatment implementation. Strengthening with buckshot having a diameter of $\phi = 0.6$ mm and $\phi = 0.4$ mm was carried out with the lowest energy, and in this case there was no noticeable increase in hardness.

4. Roughness measurement

Surface roughness of flat specimens was measured using a confocal microscope. Shown in Fig. 3, manner of performing treatment does not ensure constant angle of incidence of buckshot on the sample surface. It may affect different surface roughness values in different areas of the sample. In order to assess the effect of shot peening angle on the sample surface roughness measurements were made around the pivot axis and the edge of sample. The results are presented in Fig. 6.

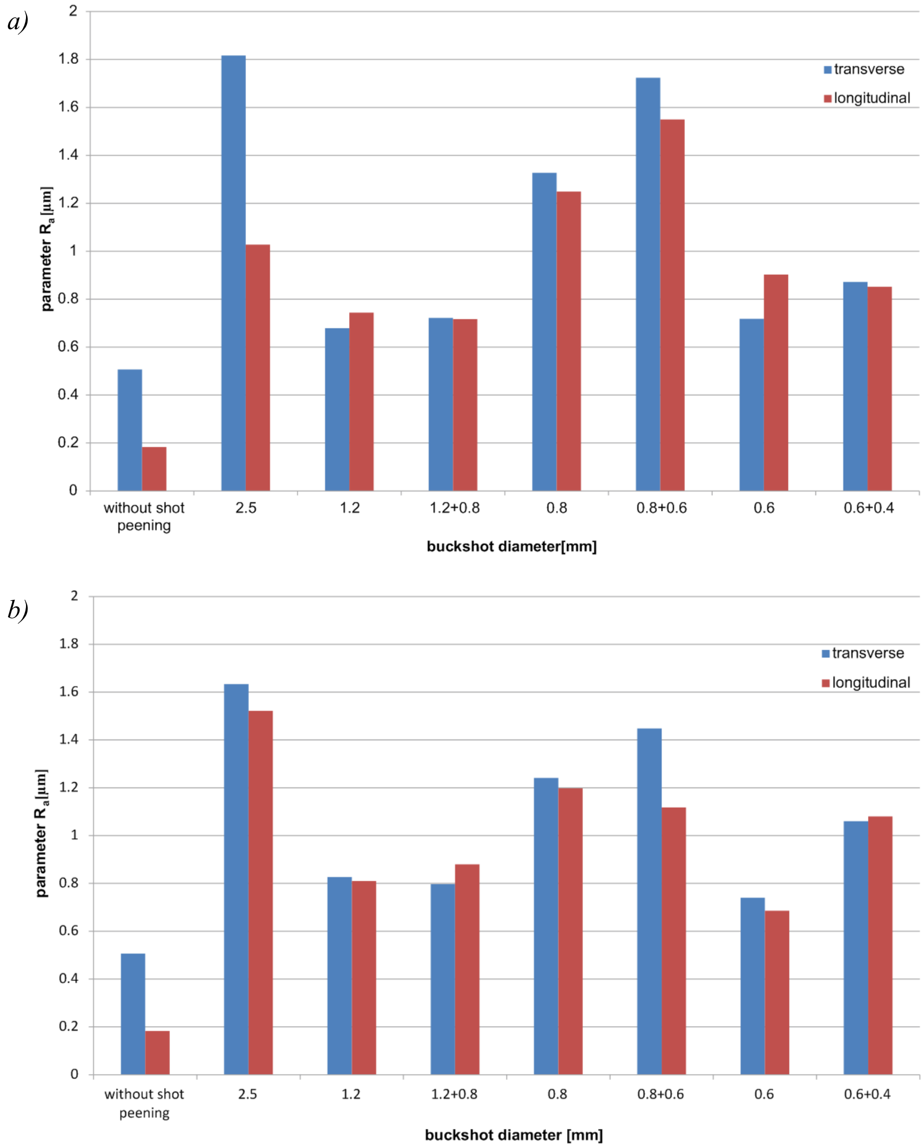

Fig. 6. Graphs linear roughness change obtained by shot peening buckshot of varying diameter, a) close to the axis of rotation, b) close to the edge

The smallest linear roughness of the samples subjected to shot peening characterized by the samples were assayed under single treatment buckshot having a diameter of 1.2 mm, 0.6 mm and double shot peening with buckshot diameter of 1.2 mm and 0.8 mm.

Surface morphology analysis showed however, that the surface of sample subjected to the shot peening buckshot having a diameter of 2.5 mm are macroscopic defects in the form of flaking material.

5. Residual stresses measurement

Determination tensor stresses in the material's surface layer is made of X-ray diffraction technique using a diffractometer Bruker D8 DISCOVER. The study confirmed the results of measurements taken assumption $\sigma_{33} = \sigma_{13} = \sigma_{23} = 0$. The measurement of stress direction, used to principal stresses calculation, made $\sin^2\psi$ technique for three angle ψ values at the sample surface, based on the observation of reflex Fe 211. Adopted the following X-ray elastic constants: $E_{\mathrm{Fe}\ 211} = 220$ GPa, $\nu_{\mathrm{Fe}\ 211} = 0.3$. Stress values occurring on the sample surface is presented in the form of components σ_x and σ_y according to Fig. 7.

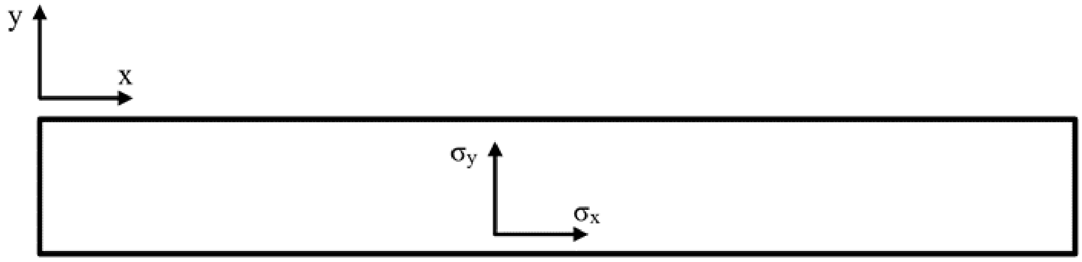

Fig. 7. Directions stress measured in the tested samples

The results of surface stresses measurements are presented in the bar graphs including the uncertainties of measurements plotted in Fig. 8.

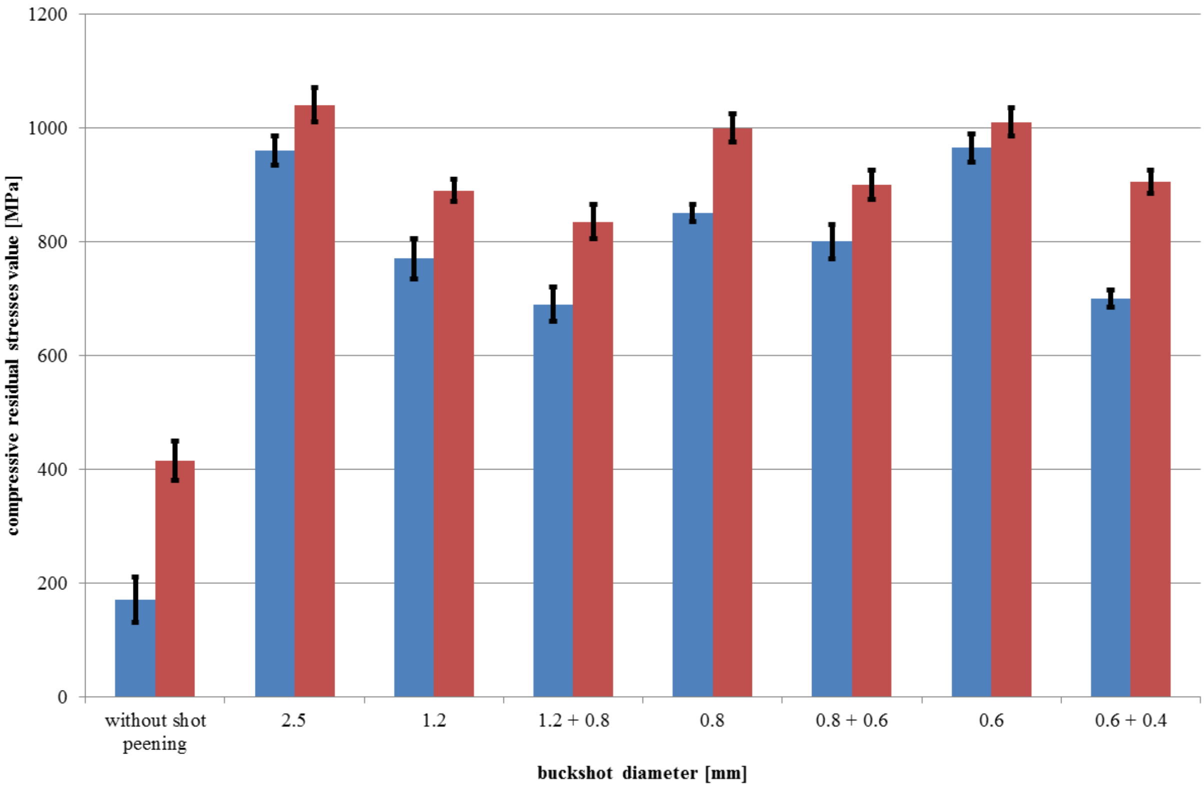

Fig. 8. Surface residual stresses values of flat samples

When measuring the residual stresses in each case found to contain only compressive stresses. In the case of the samples subjected to shot peening these stresses exceed the value of even five times the value of the stress in the samples without any additional treatment.

6. Summary

Microhardness samples after shot peening results measurements analysis indicates that the greatest influence on the hardness increase occurred as a result of shot peening buckshot with a diameter of 2.5 mm. The samples were subjected to double shot peening buckshot having a diameter of 1.2 mm and 0.8 mm, and shot peening a single buckshot of 0.8 mm are also noticeable increase in hardness to a depth of 0.3 mm from the surface. The increase in hardness at points distant about 50 μm from the surface of these samples in both cases was about 60 HRC. The use of buckshot having a diameter of 0.6 mm and 0.4 mm did not affect the increase in hardness of the sample.

Roughness measurements and samples' surface morphology analysis showed that the largest reaching roughness Ra = 1.8 occurred on a sample after shot peening buckshot a diameter of 2.5 mm.

Furthermore, on the sample's surface occurred peeling of material, which disqualifies the use of buckshot with a diameter of 2.5 mm to shot peening gears. The lowest values of Ra occurred on samples after single shot peening buckshot 1.2 mm and double shot peening buckshot 1.2 mm and 0.8 mm.

Surface residual stress measurements results indicate the largest increase in compressive stress in the sample subjected to the shot peening buckshot with the largest diameter. It was noted there appears in each case an adverse decline in the value of compressive stress by exposing samples after double shot peening.

Basing on the measurements it was found that the best was a single shot peening with buckshot having a diameter of 0.8 mm. The choice of this diameter affects a significant increase at the same time in surface layer hardness and compressive stresses on sample's surface. In this case, the maximum value of roughness parameter Ra ≈ 1.3 reaches an acceptable level for the gears. In addition to that, spherical buckshot with a diameter of 0.8 mm complies with the general recommendations for the type and diameter used to shot peening gears, the recommended value for cast steel of buckshot should be in the range from 0.3 mm to 1.0 mm [8].

References

[1] Aggarwal, M. L., Agrawal, V. P., Khan, R. A., *A Stress Approach Model for Predictions of Fatigue Life by Shot Peening of EN45A Spring Steel*. International Journal of Fatigue 28, 2006.

[2] Kirk, D., *Development of Shot Peening Control and Residual Stress Patterns*. Europe-USA Seminar on Shot Peening 29-30 Sept. 1992, Cincinati, Ohio, USA – 14 Oct. 1992, Grenoble, France.

[3] Kirk, D., *Shot peening. Aircraft Engineering and Aerospace Technology*, pp. 71, No. 4, 1999.

[4] Kukiełka, L., *Teoretyczne i doświadczalne podstawy powierzchniowego nagniatania tocznego z elektrokontaktowym nagrzewaniem*, WSI, 1994 (in polish).

[5] Kukiełka, L., Kułakowska, A., Patryk, R., *Problematyka kształtowania jakości technologicznej części w procesie nagniatania powierzchniowego*, Pomiary, Automatyka Kontrola, 2008 (in polish).

[6] Majzoobi, G.H., Azizi, R., Alvi, Nia, A., *A three-dimensional Simulation of Shot Peening Process Using Multiple Shot Impacts*, Journal of Materials Processing Technology, pp 164-165, 15 May 2005.

[7] Meister, J.T., Eckersley, J.S., *Improving Fatigue Life of Gears by Shot Peening*, Advances in Gear Technology. A Symposium on Gear Manufacturing Through Powder Metallurgy, 1998.

[8] Nakonieczny, A., *Dynamiczna powierzchniowa obróbka plastyczna kulowanie*, Instytut Mechaniki Precyzyjnej, Warsaw 2002 (in polish).

[9] Przybylski, W., *Technologia obróbki nagniataniem*, WNT, 1987 (in polish).

[10] Radziejewska, J., *Laserowa modyfikacja właściwości warstwy wierzchniej wspomagana nagniataniem*, Instytut Podstawowych Problemów Techniki Polskiej Akademii Nauk. Warsaw 2011 (in polish).

[11] Schulze, V., *Modern Mechanical Surface Treatment*, States, Stability, Effects, Wiley-VCH 2006.

[12] *Shot Peening Applications*, Metal Improvement Company, Inc. New Jersey 1992;

[13] Suh Nam P., *Tribophysics*, Prentice Hall 1986.

[14] Tubielewicz, K., *Analiza zjawisk towarzyszących odkształceniu warstwy wierzchniej w procesie nagniatania*, Wydawnictwo Politechnika Częstochowska, 1990 (in polish).

[15] Tubielewicz, K., *Technologia nagniatania żeliwnych części maszynowych*, Wydawnictwo Politechnika Częstochowska, Częstochowa, 2000 (in polish).