The influence of vibratory shot peening on the selected properties of the surface layer elements made of cast iron

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The results of experimental investigations influence of vibratory shot peening on surface roughness and residual stress of spheroidal graphite cast iron objects were presented. The surfaces before vibratory shot peening were milled using different feed. After vibratory shot peening surface roughness $Ra = 0.7\div0.9\ \mu m$ was obtained and in surface layer compressive residual stress, with the maximum (absolute) value from 170 MPa to 330 MPa at a depth 0.4\div0.7 mm have been formed. For accepted vibratory shot peening condition it was recommended to use time of about 8 minutes.

KEYWORDS: spheroidal graphite cast iron, vibratory shot peening, surface layer, surface roughness, residual stress

Introduction

Cast iron can be classified as casting materials widely use in machine construction. Nodular cast iron are characterised by good resistance and plastic properties. They are used for manufacturing of, among other things, machine components - such as camshafts or gears - exposed to variable loads during operation.

Fatigue resistance of machine components depends on condition of their surface layer, in particular on residual stress formed in this layer. Due to fatigue resistance, residual compressive stresses resulting from shot peening machining are favourable. Residual compressive stresses shaping is correlated to increase of defect density of the crystal structure in layer surface burnished items, which is confirmed by tests carried out with annihilation techniques on various steel grades [10].

Machine elements can be burnished or shot peened [4]. Cast iron burnishing by burnisher equipped with rolling elements (rolls, discs, balls) caused a decrease of surface roughness, tribological wear and coefficient of friction [2,5]. Due to cast iron shot peening by centrifugal heads [1,5] has been obtained an improvement of layer surface properties of workpieces. For shot peening of machine components with a complex shape is generally used dynamic dispersed shot peening, which can be carried out by stream of shot peening elements impacting in treated surface (stream shot peening) or by workpieces setting and loose balls in working vibration chamber (vibration shot peening). An increase of fatigue resistance and reducing the occurrence of casting defects of cast iron due to stream shot peening confirms in publication [3]. Previous own studies on the influence of vibration shot peening on layer surface properties and fatigue resistance was carried out mainly on steel and titanium alloys samples [7–9]. The results of the research on the impact of vibratory shot peening on surface roughness and hardness of gray cast iron bodies are presented in publication [6].

The aim of this article is to discuss the impact of vibratory shot peening time of nodular cast iron samples on surface roughness and residual stress distribution.
Test methodology

Tests performed on samples with dimensions 4 mm × 15 mm × 100 mm, made of nodular cast iron EN-GJS-400-15. Before shot peening samples were milled with head diameter 100 mm with sintered carbide inserts K10. Cutting depth \( a_p \) was equal to 1 mm, and cutting speed \( v_c \) = 90 m/min. Feed \( f_z \) was variable parameter and was equal to 0.05; 0.13 and 0.26 mm/ per tooth.

In order to carry out the shot peening, samples were mounted on the bottom of working chamber, which was placed on a kinematic vibrator, and then shot peening steel balls were poured into chamber. During vibrator operation, the balls hit the samples surfaces causing a strengthening of the surface layer. Vibratory shot peening parameters were as follows:

- Vibrator vibrations amplitude \( a = 58 \) mm,
- Vibrator frequency \( \nu = 7 \) Hz,
- Shot peening balls diameter \( D = 6 \) mm,
- Shot peening time \( \tau = 0.5; 2; 8; 24 \) min.

Surface roughness and topography test were carried out with a profilometer 3D T8000 RC 120-400 from Hommel-Etamic. Average of profile ordinates \( Ra \) and maximum height of roughness profile \( Rz \) were measured. Roughness was measured in perpendicular direction to machining marks after milling.

Residual stress was based on the sample deformation during removal of next material layers, in which these stresses exist. Material layers were removed by chemical pickling in a 4-percentage of nitric acid solution. Charts illustrating distribution of residual stress as a function of distance from the surface were drawn - on that basis determines the absolute value of maximum compressive residual stresses \( |\sigma_{\max}| \) and the depth of these compressive stresses \( g_{\alpha} \). Individual measurements have been reproduced five times. Based on the obtained results, average values and standard deviation were calculated.

Tests results

Results of the surface roughness tests after milling with variable feed are given in table. As expected, with the increase of feed \( f_z \) increase values of parameters \( Ra \) and \( Rz \).

| \( f_z \) [mm/ per tooth] | 0.05 | 0.13 | 0.26 |
|-------------------------|------|------|------|
| \( Ra \) [µm]           | 0.68±0.09 | 0.95±0.13 | 1.55±0.14 |
| \( Rz \) [µm]           | 4.08±0.79     | 5.71±0.89     | 8.58±0.66     |

The impact of vibratory shot peening time of milled samples with variable feed on surface roughness parameters \( Ra \) and \( Rz \) is shown in fig. 1.

The surface roughness of milled samples with feed \( f_z = 0.05 \) mm/ per tooth after shot peening during 0.5 min increased by 30÷40%. The extension of the shot peening time up to 2 min. was caused the surface roughness reduction to a value close to the roughness before shot peening, but further time extension did not have any significant effect on surface roughness (fig. 1a).

In the case of milled samples with feed \( f_z = 0.13 \) mm/ per tooth, shot peening time extension up to 8 min (fig. 1b) was caused the reduction both parameter \( Ra \) (by 21%), and \( Rz \) (by 30%). A clearer changes of surface roughness was related to samples shot peening with feed \( f_z = 0.26 \) mm/ per tooth (fig. 1c). After 8 min shot peening, parameter \( Ra \) value has been reduced by 51%, and parameter \( Rz \) by 55%. The extension of the shot peening time up to 24 min. has not changed surface roughness parameters.

The topography of samples after milling and vibration shot peening is shown in fig. 2. In the milled surface (fig. 2a) there are marks next passes of cutting tools (small marks curvature is related to large radius of milling head). It may also be noted insignificant workpiece material blisters. After vibration shot peening took place complete removal of micro-inequalities created during milling. Due to shot peening balls impact on treated surface formed cavities characteristic for directional spot of geometric structure (fig. 2b).
Distribution of residual stress in the surface layer of samples after milling with feed \( f_z = 0.26 \text{ mm/ per tooth} \) and vibration shot peening during 8 min. is shown in fig. 3. In the surface layer of milled samples have been formed small residual compressive stresses in depth approx. 0.1 mm. Vibration shot peening cause a significant increase of absolute value of residual compressive stresses and their deposit depth.

Fig. 1. Influence of vibratory shot peening time on surface roughness of milled samples with feed: \( a) f_z = 0.05 \text{ mm/ per tooth}, b) f_z = 0.13 \text{ mm/ per tooth}, c) f_z = 0.26 \text{ mm/ per tooth} \) (designations: 1 – milled samples, 2 – samples after vibratory shot peening during 0.5 min, 3 – samples after vibratory shot peening during 2 min, 4 – samples after vibratory shot peening during 8 min, 5 – samples after vibratory shot peening during 24 min)

With increasing shot peening time, increase both the absolute value of maximum compressive residual stresses \( |\sigma_{\text{max}}| \), and the depth of these stresses \( g_\sigma \). This increase is more visible in range of shorter burnishing time, e.g. increase of the burnishing time form 0.5 min to 8 min caused an increase \( |\sigma_{\text{max}}| \) in 60%, and extension of this time from 8 min to 24 min – 7-percentage increase \( |\sigma_{\text{max}}| \), which is maintained within the measurement errors. Similar correlations can also be observed for deposits depth of compressive residual stresses \( g_\sigma \).

Fig. 2. Topography of sample surfaces: \( a) \) after milling with feed \( f_z = 0.26 \text{ mm/ per tooth}, b) \) after vibration shot peening during 24 min
Fig. 3. Distribution of residual stress $\sigma_w$ in the surface layer of samples after milling with feed $f_x = 0.26$ mm/per tooth (a) and after vibratory shot peening during 8 min (b).

![Graph showing distribution of residual stress]

Fig. 4. Impact of vibration shot peening time on the absolute value of maximum compressive residual stresses $|\sigma_{\text{max}}|$ and the depth of these stresses $g_\sigma$ (designations: 1 – milled samples, 2 – samples after vibratory shot peening during 0.5 min, 3 – samples after vibratory shot peening during 2 min, 4 – samples after vibratory shot peening during 8 min, 5 – samples after vibratory shot peening during 24 min).

Time is one of the important parameters of vibration shot peening. If it's too short, then in the surface layer there is no (sufficiently) favourable - due to exploitation durability - properties changes, and may even worsen the surface roughness. The extension of shot peening time is not recommended, because it increases unnecessarily machining costs, and in addition can result in deterioration of surface layer properties. Results of this study seem to indicate that for the adopted process parameters of vibration shot peening can be recommended the time aprox. 8 min for shot peening of nodular cast iron EN-GJS-400-15.
Conclusions

On the basis of studies relating to the impact of shot peening time for nodular cast iron samples EN-GJS-400-15, milled with different feed value, on surface roughness and distribution of residual stress can be made the following conclusions:

- vibration shot peening allowed to obtain a surface roughness of approx. $Ra = 0.7 \pm 0.9 \, \mu m$ regardless of the surface roughness before shot peening, which varied within the limits of $Ra = 0.6 \pm 1.7 \, \mu m$;
- in the surface layer of samples during vibration shot peening have been developed residual compressive stress, which the absolute maximum value varied within the limits from 170 MPa to 330 MPa; deposits depth of this stress was $0.4 \pm 0.7 \, mm$ depending on shot peening time;
- with increasing shot peening time, increase the absolute value of maximum compressive residual stresses and the depth of these stresses, while increasing shot peening time, this increase dynamic is definitely smaller;
- considering properties of the surface layer changes taking place during vibration shot peening, and also costs of this process, it can be assumed that shot peening time of approx. 8 min is sufficient (for adopted other shot peening parameters).

REFERENCES

[1] Kęsy M. „Problemy kształtowania warstwy wierzchniej żeliwa szarego dynamicznymi metodami nagniatania”. Inżynieria Materiałowa. 5 (2005): 755–757.
[2] Laber S. „Właściwości tribologiczne żeliwa sferoidalnego ferrytycznego EN-GJSF warunkowane stanem technologicznej warstwy wierzchniej”. [W:] Przybylski W.: Współczesne problemy w technologii obróbki przez nagniatanie. T.3. Gdańsk: Politechnika Gdańsk, 2011, 257–267.
[3] Ochi Y., Masaki K., Matsumura K., Sekino T. “Effect of shot peening treatment on high cycle fatigue property of ductile cast iron”. International Journal of Fatigue. 23 (2001): 441–448.
[4] Przybylski W. „Technologia obróbki nagniataniem”. Warszawa: WNT, 1987.
[5] Tubielewicz K. „Technologia nagniatania żeliwnych części maszynowych”. Częstochowa: Wydawnictwo Politechniki Częstochowskiej, 2000.
[6] Wieczorowski K., Legutko S., Matusiak-Szaraniec A., Siecla R. „Nagniatacie wibracyjne odlewanych korpusów żeliwnych”. [W:] Przybylski W. Współczesne problemy w technologii obróbki przez nagniatanie. T.2. Gdańsk: Politechnika Gdańsk, 2008, 143–150.
[7] Zaleski K. „Modelowanie chropowatości powierzchni i stopnia umocnienia warstwy wierzchniej stali 30HGSa po nagniataciu wibracyjnym”. Mechanik. 3 (2007): 194–198.
[8] Zaleski K., Skoczylas A. “Effect of vibration shot peening parameters upon shapes of bearing curves of alloy steel surface”. Advances in Science and Technology Research Journal. 9, 25 (2015): 20–26.
[9] Zaleski K. “The effect of shot peening on the fatigue life of parts made of titanium alloy”. Eksploatacja i Niezawodność – Maintenance and Reliability. 4, 44 (2009): 65–71.
[10] Zaleski R., Gorgol M., Zaleski K. “Positron annihilation lifetime study of steel surface modification by shot peening”. Physics Procedia. 35 (2012): 92–97.