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CHARACTERISTIC OF A SHOT STREAM IN A ROTOR CLEANING MACHINE

CHARAKTERYSTYKA STRUMIENIA ŚRUTU W OCZYSZCZARCE WIRNIKOWEJ

Indicators of the surface quality after treatment include the shot peening intensity and surface coverage factor.

Peening intensity is understood as joint forces of cleaning grains acting on the surface of castings. Grains (or shots) have individual geometric parameters and the trajectories of their motion when blasted will differ, too. In order to consider those impacts, it is required that average values be taken into account.

Peening intensity is evaluated basing on measurements of the pressure force and Almen strip deflection readings (Almen test). Application of the Almen strips allows for finding grain interactions within the impact zone, the effects of shot peening and the magnitude of applied pressures. This test has been widely used in foundry engineering though its applicability range, process conditions and requirements have never been investigated in great detail. Defining the process conditions enables a comparative analysis of the constructional and operational factors affecting the quality and efficiency of the cleaning treatment.

The Almen test allows for process optimisation, involving:

– selection of the peening time;

– evaluation of process efficiency associated with selection of the cleaning agent and its condition after repeated use;

– controlling the positions and movements of castings to be treated;

– selection of the number and capacity parameters of the blasting rotors;

Apart from the selection of the peening time the Almen test enables the determination of conditions ensuring repeatability of effects.

Keywords: shot peening, intensity of the grain stream, surface coverage factor

Podstawowymi wskaźnikami, wiążącymi się ze stanem końcowym powierzchni, są: intensywność oddziaływania strumienia śrutu oraz stopień pokrycia powierzchni.

Intensywność oddziaływania to łączne, siłowe oddziaływanie na powierzchnię odlewu, zbioru ziaren. Ziarna zbioru charakteryzują się indywidualnymi parametrami zależnymi od ich geometrii, ale również przebiegu ruchu w elementach zespołu rzutowego. W związku z łącznym wpływem tak wielu czynników możliwa jest jedynie uśredniona ocena wielkości.

Charakterystykę intensywności oddziaływania oparto o pomiar siły naporu oraz wyniki odkształceń płytek kontrolnych (test Almena). Stosowanie płytek kontrolnych pozwoliło określić siłowe oddziaływanie ziaren śrutu w polu rozrzutu strumienia oraz skutki oddziaływania, ilość i wielkość śladów uderzenia (odcisków). Jest to próba, której praktyczne możliwości i szczegóły stosowania dotychchzas nie omawiano i nie stosowano w praktyce odlewniczej. Opracowanie warunków stosowania tej próby pozwala na porównawczą analizę wpływu parametrów konstrukcyjno-eksploatacyjnych procesu oczyszczania i ustalania ich związków z efektami.

Próba Almena daje możliwość optymalizacji procesu między innymi poprzez:

– dobór czasu obróbki,

– ocenę skuteczności obróbki związaną z doborem czyściwa i jego stanem w wyniku wielokrotnego używania,

– wybór położenia obrabianych odlewów i ich ruchu,

– dobór wydajności i ilości pracujących wirników rzutowych.

Oprócz doboru czasu obróbki strumieniowo-ściernej próba Almena daje możliwość ustalenia warunków celem zapewnienia powtarzalności efektów.

1. Introduction

Cleaning treatment of casting products is applied to remove the remnants of adhering core mix and sand from their surface and to improve their surface quality [8]. In 1979 a monograph by J. Łempicki and J. Paradysz was published: "Cleaning and finishing treatment of iron and steel castings", that dealt exclusively with those problems. Since then no publications on that subject have appeared

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that would address the problems involved in control and optimisation of sand blasting and shot peening processes in a comprehensive manner.

Basically, the cleaning treatment uses a stream of cleaning agent (metal or glass grains) that bombard the targeted surfaces. Shot peening is effective provided that:

– constructional requirements of the blasting mechanisms are fully satisfied,
– the cleaning agent has the required specifications and parameters,
– the stream of grains (shots) is optimally controlled in terms of its geometry and kinematic and dynamic behaviour,
– operating conditions of the stream of grain are such that the entire target surface is covered.

Casting products are mostly cleaned by mechanised systems employing the impact methods (Fig. 1).

In accordance with the definition given in the standard PN-EN ISO 8504-2:2000, the shot blasting treatment methods “use the abrasive action of the high-energy stream of a cleaning agent which bombards the targeted surface”.

In the shot blasting treatment processes casting fettling and finishing are singled out. Crude castings from sand and metal moulds are subjected to fettling while castings after a mechanical treatment (e.g. grinding) or heat-chemical treatment (e.g. carburizing) are subjected to finishing by shot peening.

Shot peening involves cold working of metal surfaces changing the surface condition. As the result of cold working of the surface layer, the metal is strengthened and its physical and chemical properties are changed [10].

During the shot peening process, shots bombard the targeted surface at the speed of up to 80 m/s, producing dimples on the surface and, in consequence, generating the new state of stress in the surface layer. Preliminary compressive stresses generated in this process relieve peak tensile stresses occurring during the exploitation, increasing the durability of peened elements [10]. Instruction concerning the shot peening technology appeared in the USA in 1952. Dimensions of Almen strips, workshop drawing of fixing Almen strips, measuring instrument for checking the strips deflection are presented, among others, in this Instruction.

The test was developed by J.O Almen to measure the shot peening intensity in order to ensure constant parameters of the hardening working and to ensure the required surface quality of the entire batch of worked products. Parameters that are compared basing on the Almen strip deflection readings include peening intensity and the surface coverage factor.

Peening intensity is determined by the deflection of free-formed, peened Almen strips, manufactured to the specification given in the standard SAE J444 (Cast shots and grit for peening and cleaning, 1969) and BN-80/1062-01 (Shot peening. Guidelines for peening treatment, 1980).

Three types of Almen test strips: N, A, C are in widespread use, depending on the applied peening intensity range. Of their several parameters the most noteworthy are the permitted flatness and hardness variations (Table 10). Their application range is shown in Table 2. Dimensions of Almen test strips are summarised in Fig. 2. Selection of the strip type (C,A,N) is based on parameters of the peening process, particularly on the grain size distribution, shot velocity and on the type of the worked material.

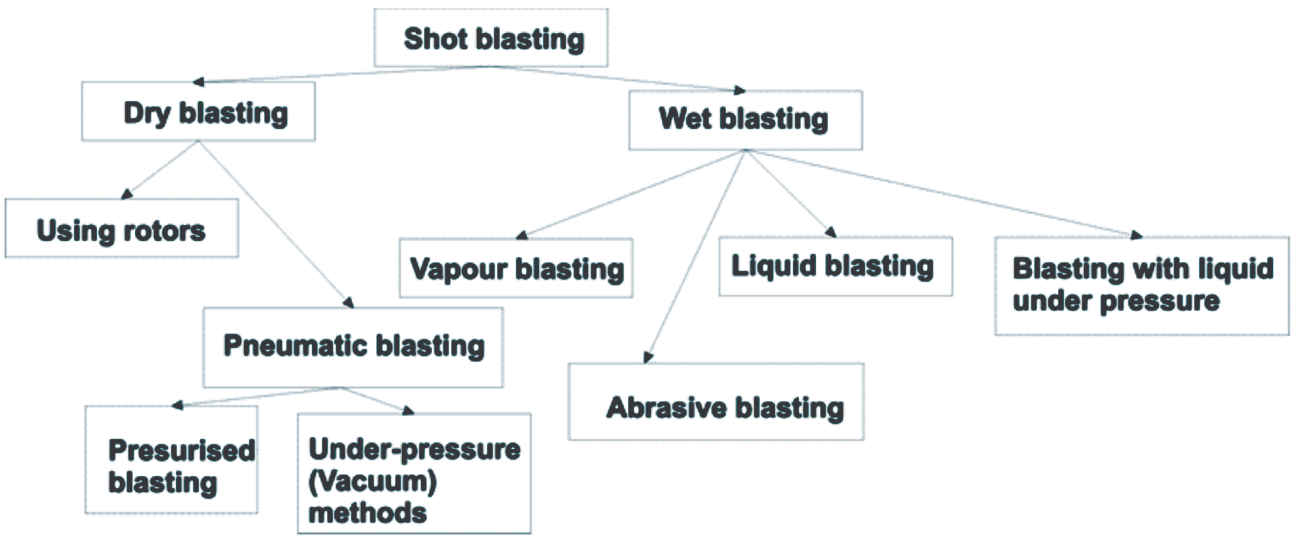

Fig. 1. Shot blasting methods according to the standard PN-EN ISO 8504-2:2000 [11]

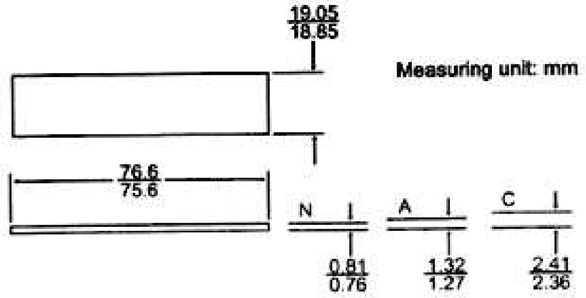

Fig. 2. Test strip dimensions [10, 12]

Measurements of strip deflection are taken with the Almen gauge, in accordance with the procedure set forth in the standard SAE J442 or BN 80/1062-01 (Fig. 3).

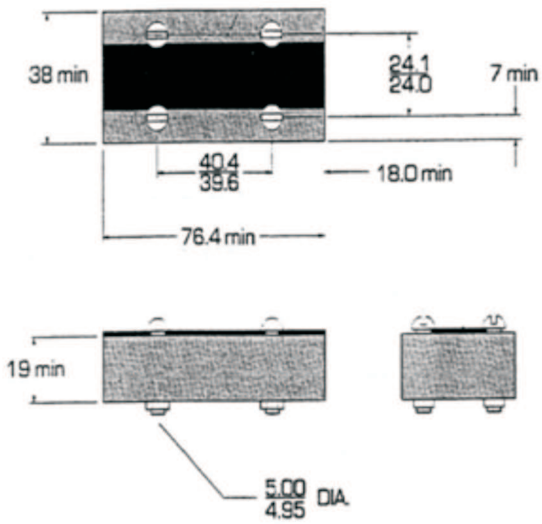

Fig. 3. Strip dimensions and the holding clamps [12]

TABLE 1

Almen test strips [10, 12]

Designation	Strip type	Flatness, mm	Hardness, HRC
A1-S	A	0.0127	45÷48
A1-B	A	0.0254	45÷49
A-1	A	0.0254	44÷50
A-2	A	0.0381	44÷51
A3-55 HRC	A	0.0254	53÷56
A3-60 HRC	A	0.0254	58÷62
C1-S	C	0.0127	45÷48
C1	C	0.0254	40÷50
C2	C	0.0381	40÷51
N1-S	N	0.0127	45÷48
N1	N	0.0254	44÷50
N2	N	0.0381	44÷51

TABLE 2

Applicability range of test strips [10]

Strip type	Thickness s, mm	Applicability range
N	0.8±0.02	For low – intensity working, deflection of test strip A < 0.15 mm
A	1.3±0.02	Medium intensity of working, deflection of test strip A 0.15-0.60 mm
C	2.4±0.02	High – intensity working, deflection of test strip A > 0.60 mm

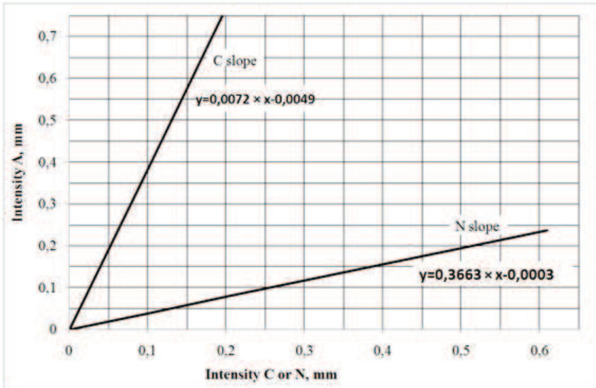

Fig. 4. Characteristic of test strips: deflection of test strips C and A with respect to A

To establish the best intensity, the relationship is found between the test strip deflection and working time in the form of a plot, as shown in Fig. 5. In practice, it is recommended to establish the peening time in such a way as to fulfill the condition: $\varepsilon = {}^{a}/_{10}$ and the time ascribed to the point A on the curve is taken as the peening time. Above the point A (b zone) large increments of time correspond to very small deflections.

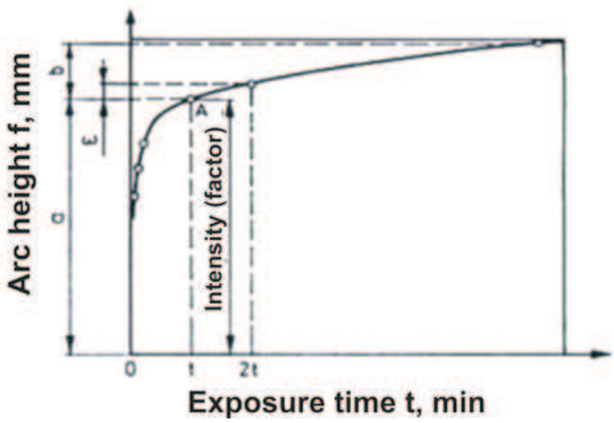

Fig. 5. Peening intensity curve: a- zone of fast variability of strip deflection; b- zone of slow increase of strip deflection [10, 12]

The surface coverage factor of Almen test strips as well as the product surface quality are parameters strictly related to the intensity of peening and the quality of the performed process. The treatment degree determines also the density of grains bombarding the surface.

The surface coverage factor is expressed as the proportion of the surface area subjected to peening action to the total area of the Almen test strip or the surface area of the worked specimen. The American Standard SAE J443 (Procedures for using standard shot peening test strip, 1968) provides the equation by means of which it is possible to determine the coverage of the worked surface area [10, 12]:

$$C = 1 - (1 - C_1)^n , \qquad (1)$$

where: C – coverage of the worked surface after n cycles; %,

C_1 – coverage of the worked surface after 1 cycle; %,

n – number of working cycles (the cleaning agent passing through the rotor).

Control patterns were also developed enabling the evaluation of the condition of a peened surface (see Fig. 6).

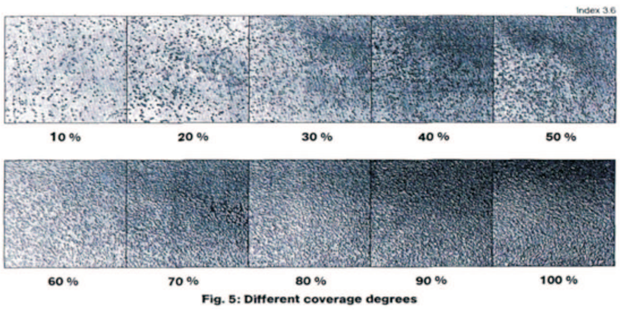

Fig. 6. Surface patterns [12]

2. Experimental

The basic parameters of the shot stream: peening intensity and surface coverage factor (density of shots) and the scatter of the shot stream can be determined by the test strip deflection readings.

Experimental tests involved the quantitative and qualitative evaluation of shot blasting parameters and characteristics.

Experimental methods are focused on improving the methodology of finding the shot stream parameters and their respective variability ranges. Testing was done on an industrial shot blasting system OWS-1000 (Technical), incorporating two blasting rotors of controllable flow rate. The castings to be worked are placed on an immobile bench. The applied constructional solutions and frequency converters allow to establish and record the shot blasting machine parameters. The experimental setup is shown in Fig. 7.

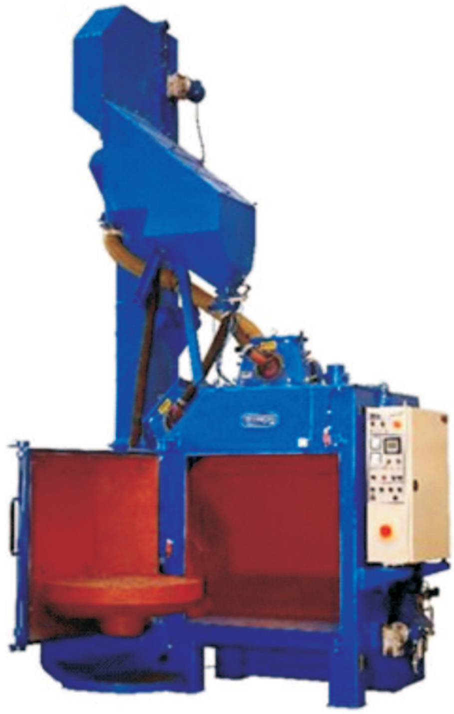

Fig. 7. Rotary shot blasting machine OWS- 1000 manufactured by the Technical Company [21]

The shot type used is designated as CS, made of cast steel, spherical, the nominal grain size d_{90}=0,42÷2,0 mm, specific density 7,9 g/cm^3.

Measurements of the shot stream intensity were taken with a sensor, fabricated specifically for the purpose of this research program (Fig. 8). The sensor is aided by the computer with a dedicated software to register the force patterns in the function of time. The sensor incorporates a cover, a base, a hollow and a mandrel. Three openings are made in the base to house three sensors. Signals from the sensors are transmitted to the control card and then recorded on the computer. Shot intensity measurements are recorded in the real time and measurement data are stored in the graphic form, as time patterns of shot intensity.

For this research the sensor was placed at the distance of 1185 mm from the rotor's outlet. The sensor was positioned inside the machine's working chamber, on the bench. Testing was done for the blasting turbine and the immobile bench.

The shot peening tests were performed in a setup shown in Fig. 7. Only one blasting rotor, above the working bench, was switched on during the test. The other rotor, incorporated in the blasting system and located on the side wall, remained switched off.

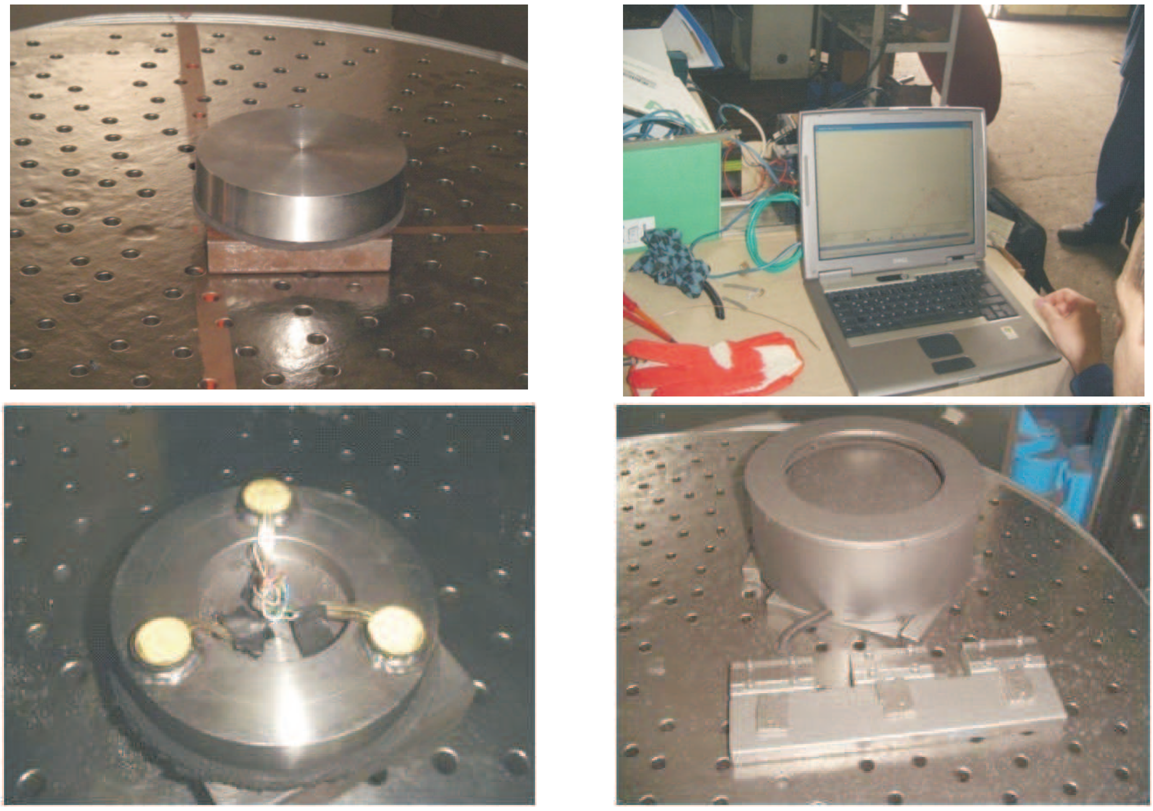

Fig. 8. Sensor for measuring shot intensity in the blasting machine [20]

3. Experimental results

The first stage of investigations comprised measurements of stream force values at the angle setting of the immobile regulatory sleeve being 20°. Measurements were performed for the peening times: 1, 3, 5 min, using spherical, cast steel shots. The selected graph of the measured pressure force of the shot stream in a sand blasting system OWS- 1000 is shown in Fig. 9.

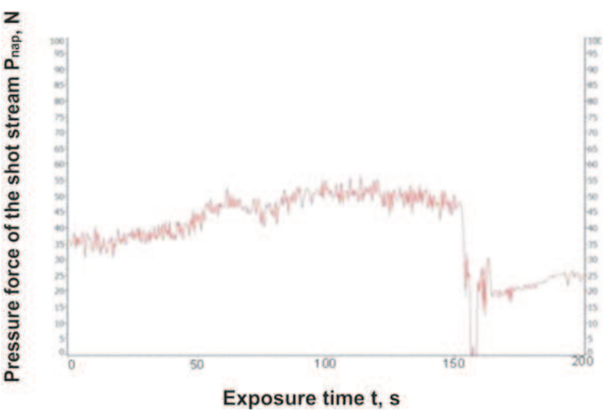

Fig. 9. Pressure force of the shot stream using shot S280, $\dot{G}$ = 220 kg/min, t = 3 min, n = 2929 rpm [20]

The relevant plots reveal that the pressure force of the stream of shots falls in the range from 5 to 80 N. Geometrical dimensions and exploitation parameters such as: blasting rotor efficiency, angle setting of immobile regulatory sleeve, blasting rotor rotational speed, kind and grain size of abrasive, distance between a measuring sensor and blasting rotor outlet as well as the surface area (of sensor) affected by the shot stream – are influencing the pressure force of the shot stream. As the result of own investigations no influence of the treatment time on the obtained shot stream forces was found.

During the peening tests, Almen test strips were held down with specially designed clamps. Strips held down by the clamps were placed on the working bench. The strips were then peened using spherical, cast steel shots S280, S330, S550 (Wheelabrator Allevard). The applied treatment times: 1, 3, 5 min. Testing was done for the minimal, intermediate and maximal rpm speed of the blasting turbine. Furthermore, each test was performed for the minimal and maximal flow rate delivered by the rotor. Depending on the shot type and grain size distribution, the flow rates delivered by the rotor were obtained as follows: S280 – $\dot{G}$ = 100 kg/min, $\dot{G}$ = 220 kg/min; S330 – $\dot{G}$ = 66 kg/min, $\dot{G}$ = 162 kg/min; S550 – $\dot{G}$ = 48 kg/min, $\dot{G}$ = 180 kg/min.

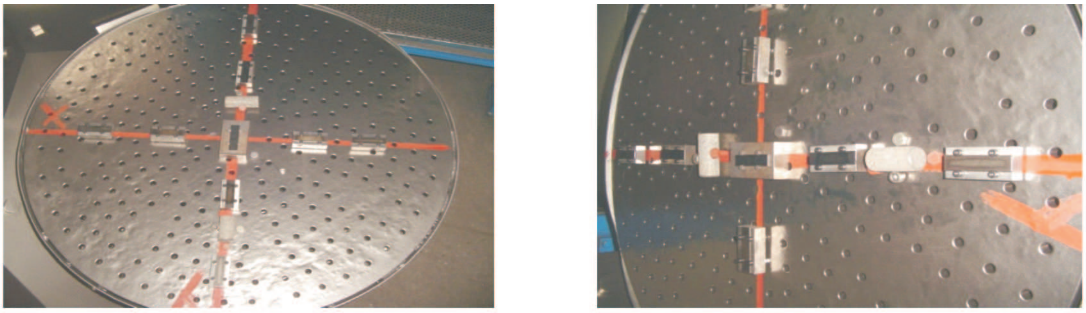

Fig. 10. Position of castings and Almen test strips in the working chamber [20]

For better clarity, tests results are presented in the graphic form in Figs. 11 and 12.

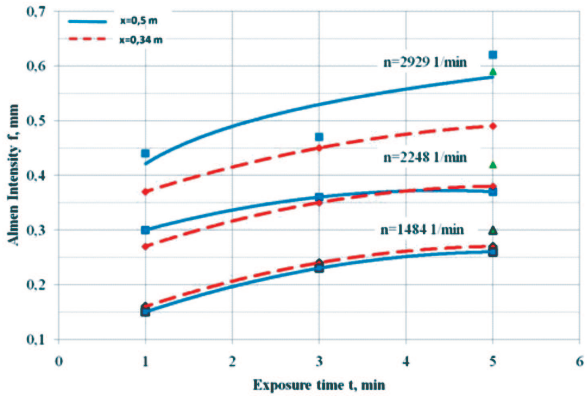

Fig. 11. Effect of exposure time, rotor's rpm speed and test strip position on deflection of the C-type test strip; $\dot{G}$ = 100 kg/min, shot type S280 [20]

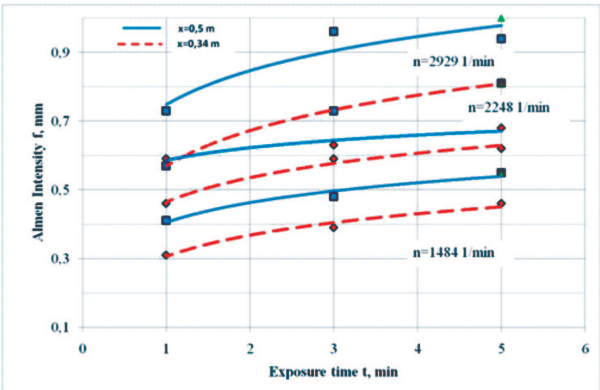

Fig. 12. Effect of exposure time, rotor's rpm speed and test strip position on deflection of the C-type test strip; $\dot{G}$ = 180 kg/min, shot type S550 [20]

The Almen test strip after the shot blasting treatment is shown in Fig. 13.

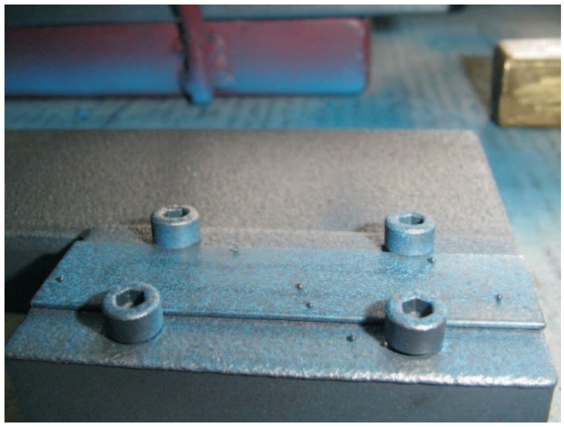

Fig. 13. Almen test strip after shot peening [20]

The covered surface area is determined as well as the number of traces left by shots within the specified area. For that purpose, shot blasted test strips were examined using a scanning electron microscope JEOL JSM-5500LV and an optical Leica microscope. The selected image surface of an A-type test strip is shown in Fig. 14.

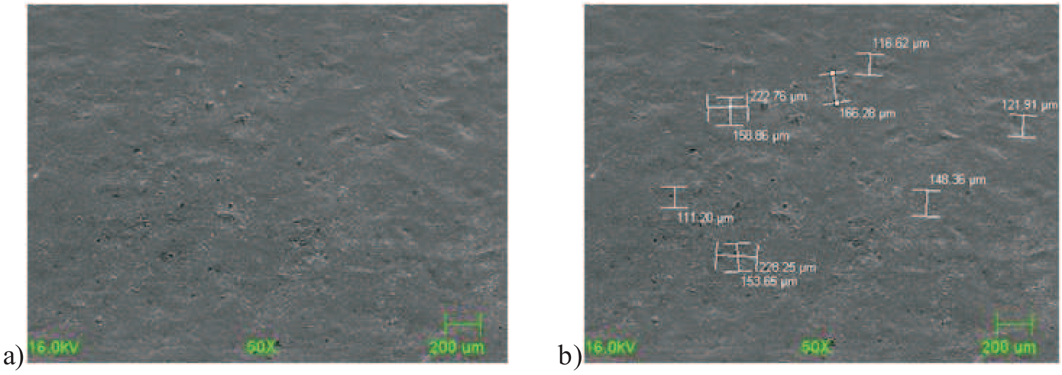

Fig. 14. Surface of the A-type strip, n = 1486 rpm, t = 1min, $\dot{G}$ = 162 kg/min; a) surface without dimensioned shot traces, b) dimensioned shot traces [20]

The surface coverage factor for the peening time t= 1min is shown in Fig. 15.

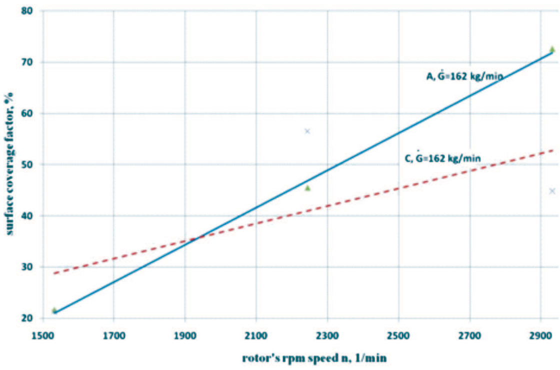

Fig. 15. Surface coverage factor vs rotor's rpm speed; test strip A (blue) and C (red); t=1 min [20]

4. Conclusions

The basic indicators of the surface quality include the peening intensity and the surface coverage factor.

Peening intensity is understood as joint forces of cleaning grains acting on the surface of casting products. Grains have individual geometric parameters and the trajectories of their motion when blasted will differ, too. In order to consider those impacts, it is required that average values be taken into account.

Peening intensity is evaluated basing on measurements of the pressure force and Almen strip deflection readings (Almen test). Application of the Almen strips allows for finding grain interactions within the impact zone, the effects of shot peening and the magnitude of applied pressures.

The pressure force of the shot stream varies depending on the point where the measurements are taken. The stream of grain (shots) is dispersed and non-homogeneous, which enhances the cleaning action. Typically, castings are placed within the zone impacted by a compact stream.

Strip deflection reveals the joint influence of a great number of constructional and operational factors.

The estimation of the intensity of the shot stream influence determined by means of test strips deflection (Almen test) was the main aim of the author's own investigations. The surface coverage factor of the area treated by shots was also estimated. These estimations were done on the basis of equation (1) and measurements performed by means of the optical and scanning microscopes. This method is in accordance with the measuring methodology described in the specialist references [10, 12]. However, no dependence between the Almen strip deflection and the surface coverage factor is provided in these references. Determinations of these relations, which are variable due to the process and controlled by service men, with not variable constants (often considered as limitations) will be the subject of further studies of the author.

Another parameter closely associated with peening intensity and affecting the surface condition is the surface coverage factor, which determines the density of shot bombarding the targeted surface. The surface coverage factor, expressed as the proportion of the surface area subjected to peening action to the total area of the Almen test strip or the surface area of the worked specimen, should range from 50% to 80%, depending on specific surface requirements.

Dimensions of shot traces as well as their shape on the strip surfaces confirm that shot influences the surface not only as impact but mainly as machining. Irregular traces appear because the shots bombard the worked surface at different angles and with different speed, which is associated with a shot stream scatter.

Measurements of strip deflection and examination of the surface condition by relating it to the surface coverage patterns are combined to develop a simple and reliable method of controlling the peening efficiency and quality. The method takes into account joint effects of major factors involved: shot type and dimensions, rpm speed of blasting rotors, air pressure, nozzle diameter, distance between the outlet nozzle and the targeted surface, angle of shot hitting the surface, peening time.

The analysis of the chemical composition of the Almen strip was performed (within own studies) and pointed out that it corresponds to a carbon spring steel.

The characteristic feature of dynamic treatments is, apart from force variability during the treatment, a periodically intermittent contact of the strengthening element with the surface being treated. A character of this contact is dynamic since strengthening elements are striking the surface returning the kinetic energy, which is transferred into the plastic deformation energy in the strengthening zone.

REFERENCES

[1] P.N. A k s j o n o w, Oborudowanije litejnych ciechow. Izdatielstwo "Maszinostrojenie". Moskwa, 1977.

[2] P.N. A k s j o n o w, Theory of Foundry Machines-Selected Problems. Wydawnictwo "Śląsk" Katowice, 1965.

[3] T. B u r a k o w s k i, T. W i e r z c h o ń, Metal Surface Engineering. Wydawnictwa Naukowo Techniczne, Warszawa 1995.

[4] R. C h u d z i k i e w i c z, Mechanisation and Automation of Foundry Plants. Wydawnictwa Naukowo - Techniczne. Warszawa, 1980.

[5] L.A. D o b r z a ń s k i, Control of the Structure and Properties of Metallic Materials. Wydawnictwo Politechniki Śląskiej, Gliwice 2007.

[6] A. F e d o r y s z y n, T. P i o s i k, P. Z y z a k, Methodology of peening intensity evaluation Fasing on the Almen tests. Archives of Foundry Engineering **9**, 4, Katowice-Gliwice, 246 (2009).

[7] J. K i l a r s k i, A. S t u d n i c k i, J. S u c h o ń, D. B a r t o c h a, Application of Bittner's Theory to Evaluation of Materials Used to Manufacture Machine Components Exposed to Abrasive Wearing. Przegląd Odlewnictwa 4, 284 (2005).

[8] J. Ł e m p i c k i, J. P a r a d y s z, Cleaning and Finishing Treatment of Cast Steel and Iron Castings. WNT. Warszawa, 1979.

[9] B. M a ł e c k i, Cleaning Agents Used Rotor Machines and Methodology of Testing. Przegląd Odlewnictwa, 45 (1963).

[10] A. N a k o n i e c z n y, Dynamic Plastic Working-Shot Peening. Instytut Mechaniki Precyzyjnej. Warszawa 2002.

[11] T. P i o s i k, Shot – Blasting Rotor Machines. Materiały Sympozjum "Metody i środki do strumieniowo-ściernego przygotowania podłoży metali pod powłoki ochronne". Instytut Mechaniki Precyzyjnej. Hajnówka, 89 (2001).

[12] Pr. Zbiorowa, Shot Peening. A Dynamic application and Its Future. Wydawnictwo Metal Finishing News (MFN). Wetzikon, 2006.

[13] Pr. Zbiorowa, Guide to Foundry Engineering. Wydawnictwo Naukowo-Techniczne. Warszawa, 1986.

[14] Z. S a m s o n o w i c z, Effects of Cleaning Treatment Methods on Mechanical Properties of Iron Castings. Praca doktorska. Politechnika Wrocławska, Katedra Odlewnictwa, Wrocław 1961.

[15] Z. S a m s o n o w i c z, Effects of Sand Mix Properties on Surface Quality of Cast Iron Products. Praca habilitacyjna. Zeszyty Naukowe Politechniki Wrocławskiej, Mechanika XVI, nr 110, Państwowe Wydawnictwa Naukowe Oddział Wrocławski, 1965.

[16] R. W r o n a, E. Z i ó ł k o w s k i, M. Ś l a z y k, P. Z y z a k, Determining the Shot Stream Geometry in Rotor Machines by Experimental and Analytical Methods. IX Konferencja Odlewnicza TECHNICAL 2006 : Odlewnictwo XXI wieku – Technologie, Maszyny i Urządzenia Odlewnicze: Nowa Sól 08-09. 06 2006 r. Biuletyn Konferencyjny s. 25.

[17] J. B. Z a j g e r o w, Masziny i Avtomatyzacja Litiejnogo Proizvodstwa. Wydawnictwo Wyższaja Szkoła. Minsk, 1969.

[18] P. Z y z a k, Testing of Cleaning Treatment on the Laboratory Stand. XXXII Konferencja Naukowa z okazji Święta Odlewnika 2008. Materiały Konferencyjne. Wydział Odlewnictwa AGH, Oddział Krakowski STOP, s.103, Kraków 2008.

[19] P. Z y z a k, Evaluation of Surface Quality after Sand Blasting using an OLYMPUS microscope. XI Konferencja Odlewnicza TECHNICAL 2008. Biuletyn Konferencyjny, s.73, Nowa Sól 2008.

[20] P. Z y z a k, The Effects of Shot Stream Parameters on Surface Quality of Castings PhD dissertation. Faculty of Foundry Engineering, Kraków 2010.

[21] www.technical.com.pl

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