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CHARACTERISTICS OF THE OUTER SURFACE LAYER IN CASTS SUBJECTED TO SHOT BLASTING TREATMENT

CHARAKTERYSTYKA WARSTWY WIERZCHNIEJ ODLEWÓW PODDANYCH OBRÓBCE STRUMIENIOWO-ŚCIERNEJ

Surface treatment utilising the dynamic abrasive action of the stream of a cleaning agent is applied to ensure the required surface parameters and quality. Under the action of the cleaning agent the properties of the surface layer are changed and the treatment method is commonly referred to as shot peening. It is used to improve the mechanical resistance, hardness, resistance to corrosion and fatigue endurance of casting products.

To evaluate the scale of changes of the material parameters and surface properties, the test castings made from typical foundry materials and then shot-peened are thoroughly examined as regards their surface quality and micro-hardness, for the precisely controlled peening intensity. Testing was done in a set-up incorporating an industrial shot blasting machine where the intensity (speed) of the cleaning agent and its impact conditions (the angle of incidence) can be precisely controlled.

Finding the properties of the surface layer for the precisely controlled process parameters allows for identifying the hitherto undefined results of treatment in sand blasting machines.

Obróbka strumieniowo-ścierna przy użyciu czyściwa jest prowadzona ze względu na wymagany stan powierzchni. Wskutek oddziaływania czyściwa występują zmiany własności warstwy powierzchniowej, charakterystyczne dla procesu znanego również jako kulowanie. Proces ten jest stosowany dla poprawy własności mechanicznych, twardości, odporności na korozję i zużycie zmęczeniowe.

Dla oceny zakresu zmian stanu i własności przeprowadzono badania odlewów testowych z tworzyw odlewniczych poddanych oczyszczaniu strumieniem śrutu. Przeprowadzono ocenę jakości powierzchni oraz pomiary mikrotwardości dla ściśle określonej intensywności oddziaływania strumienia czyściwa. Badania prowadzono na stanowisku przemysłowej oczyszczarki zmieniając intensywność (prędkość) czyściwa i warunki jego oddziaływania (kąta padania).

Wyznaczenie własności warstwy wierzchniej dla określonych warunków prowadzenia obróbki strumieniowo – ściernej pozwoliło na sprecyzowanie, dotychczas nie określanych, efektów stosowania oczyszczarek i skutków oczyszczania odlewów.

1. Characteristics of the shot blasting and shot peening processes

The chief purpose of the cleaning process is to remove the contaminants from the surface of castings in order to prepare them for use or for further finishing treatment: painting, enamel coating or mechanical treatment. Sand blasting processes are typically done by rotor machines where the stream of the cleaning agents (steel grain or iron shots) are ejected by a rotor blades and bombard the surface of the casting. Shots fed onto the rotating blade are ejected at high speed, under the action of the centrifugal force [3÷5,9].

The shot peening method is also applied to produce the surfaces with required parameters [2, 9].

Shot peening, involving the dynamic cold plastic treatment of the surface layer in metals, is applied to modify its parameters. Due to work hardening of the outer layer, the metal is strengthened, its physical and chemical parameters are changed and its service life and fatigue parameters are improved [1,2,8].

The difference between the processes discussed here lies in that products to be sand blasted include castings products obtained in sand moulds and metal moulds. Sand blasting is intended to given them a good appearance, to ensure the required surface quality and conditions. Metal products are typically treated by shot – peening, including castings after mechanical treatment, polishing or thermal and chemical treatment [6]. The main objective of shot-peening is to improve their fatigue endu-

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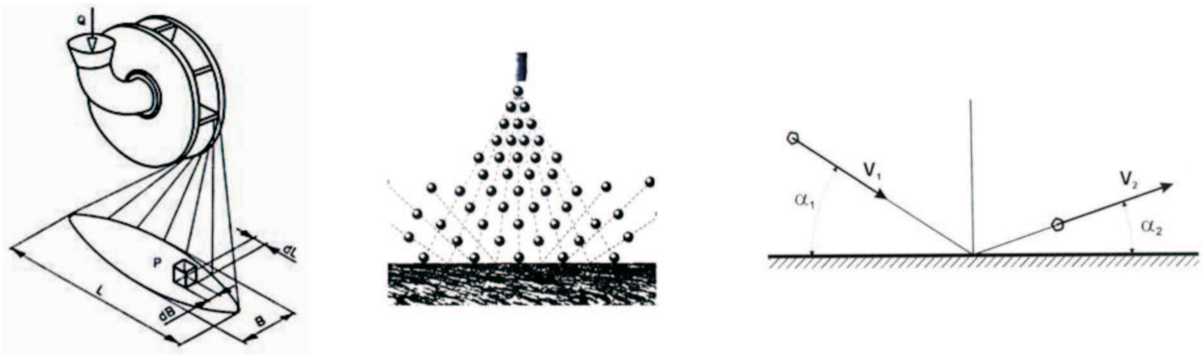

Fig. 1. Schematic diagram of abrasive grain impacting on the surface to be cleaned [7, 8]

rance, resistance to erosion and cavitation wear as well as corrosion resistance. Sand blasting and shot-peening procedures require that the stream of cleaning agent (grain or shots) should have the required level of kinetic energy and should impact on the entire surface to be covered.

2. Effectiveness of the shot blasting processes

The analysis of effectiveness of the cleaning treatment [3, 10] reveals that shots hitting the targeted object play the double role: they clean it both by hitting and abrasive action. The difference in hypothetical impacts produced by the stream of shots hitting the castings surface results from the differences in the speed v of shots or grain and the incidence angle α (Fig. 1). It is recommended that the rotors should be used that should blast the cleaning agent at different angles.

The extent of surface impacts and their quantitative description is provided by the the-ory of J.G. Bitter, dealing with erosion wear [7] and based on mechanics of elasticity and plasticity of solids. Erosion wear involves both abrasive action associated with the impacts produced when shots hit the surface at small angles (micro-machining) and crushing and chipping caused by shots bombarding the surface at large angles.

For machining wear experienced when abrasive grains scratch the surface forming 'micro- chips', referred to as 'small angle impacts' [7]:

$$W1 = \frac{2 \times m \times C \times (v \times \sin\alpha - K)^2}{\sqrt{v \times \sin\alpha} \times} \left(v \times \cos\alpha - \frac{C \times (v \times \sin\alpha - K)^2}{\sqrt{v \times \sin\alpha}} \times E_{j.skr} \right). \tag{1}$$

For machining wear experienced when abrasive grains machine-cut the surface tearing off 'micro-chips', referred to as 'large angle impacts' [7]:

$$W2 = \frac{m \times \left(v^2 \times \cos^2\alpha - K_1 \, (v \times \sin\alpha - K) \right)^{3/2}}{2 \times E} \tag{2}$$

For crushing wear, when $\alpha \leqslant 90^\circ$ [7]:

$$W3 = \frac{m \times (v \times \sin\alpha - K)^2}{2E_{j.krusz}}. \tag{3}$$

where:

α – incidence angle of abrasive grain; deg,

m – mass of grains; g,

v – speed of cleaning grain; cm/s,

$E_{j.skr}$ – energy required to machine-cut a unit volume of material, $E_{j.krusz}$ – energy required to crush a unit volume of material, C, K, K_1 – parameter associated with abrasive ability. Abrasive wear (expressed in mm3) of soft and hard materials is shown graphically in Figs 2 and 3 [7].

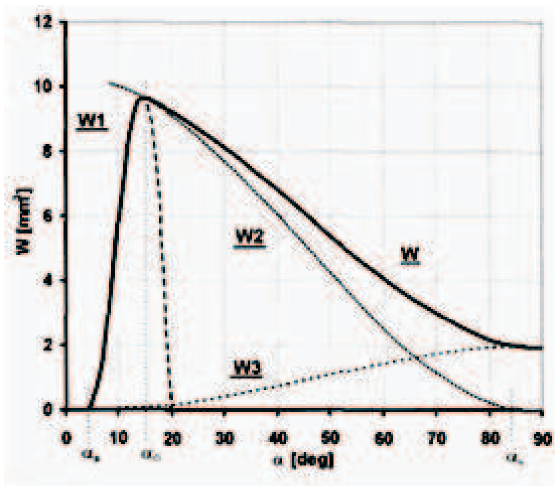

Fig. 2. Component functions of the erosion treatment for soft materials, according to Bitter

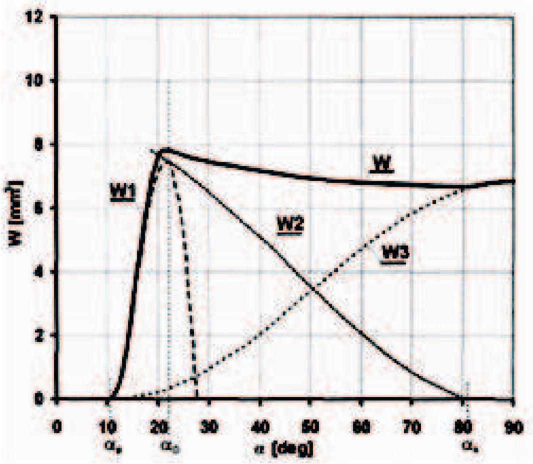

Fig. 3. Component functions of the erosion treatment for hard materials, according to Bitter

Cleaning effects are achieved both through cutting and chipping of contaminants from the surface by the impacting grains. The efficiency of shot peening treatment of casting products is evaluated basing on the mass loss in relation to the process parameters and parameters of the treated material and of the cleaning grain. The comparison is also made of the surface conditions (surface roughness).

As regards shot peening, it is required that the stream of shots should be well concentrated so that the process should be restricted to local impacts applied normal to the surface of the treated products, prompting the change of surface conditions and the conditions of the sub-surface layers.

The stream of shots ejected by jet rotors forms a scattered beam and, in consequence, hits the surface under different angles. That is the consequence of the nature of the stream of shots, which is dispersed because individual shots leave the rotor blades at different times and their velocities, mass and shapes may differ, too.

The stream of grain is dispersed both in sandblasting and shot peening processes, both are used to meet specific surface condition requirements. Dynamic surface treatment of metal products causes the surface condition to change [1,2,8,9]. Compressive stresses are generated to compensate for stresses induced by manufacturing processes. Internal compressive stresses will appear because the deformed layer tends to increase its volume and this process must be counteracted by elastic, deeper-situated layers of metal.

The mechanism generating the compressive stresses in the surface layer is associated with the properties of treated materials. In the case of hard materials (HV⩾600), these stresses are generated by forces acting normal to the treated surface. The maximal tangent stresses $\tau_{\max}$ due to normal stresses are situated underneath the surface, at the depth of $z = 0.47 \times a$ (Fig. 4a).

In the case of plastic (low-hardness) materials, such as aluminium alloys (HV ⩽300), considerable plastic strains are generated near the surface. The increase of the size of the shot-peened layer A is counteracted by the layer B, which in consequence produces the internal stress distribution (Fig 4b). The maximal value of compressive stress is registered on the surface of the worked product. Thus generated state of stress will cause the changes in the structure of the surface layer, depending on the type of the worked material.

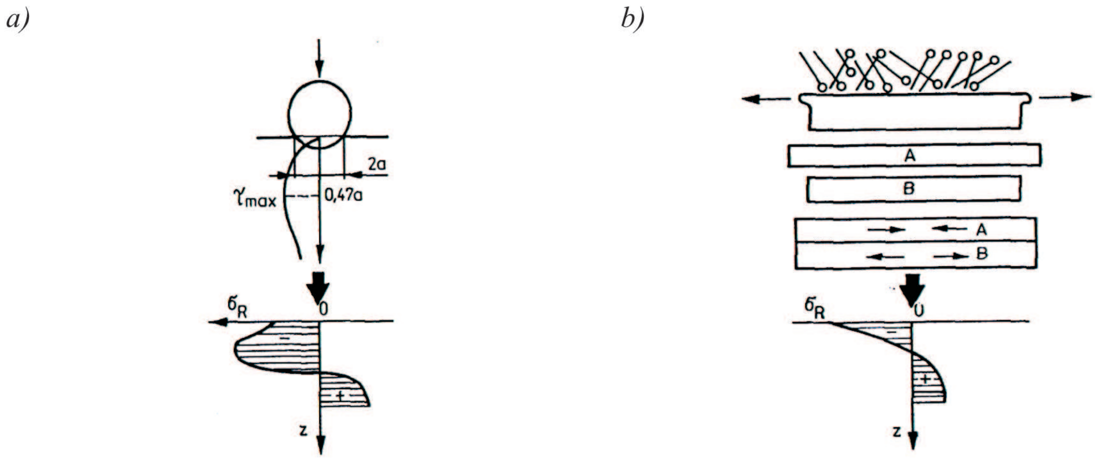

Fig. 4. Model of compressive stress generation as a result of shot-peening process [8]: a – hard materials HV>600; b – plastic (HV<300); a) the pressure effect in accordance with the Hertz model, b) the effect of plastic deformation of the surface layer

3. The scope of the research program and methodology

The influence of the process parameters on the efficiency of cleaning treatment of cast-ing products is investigated by the collaborating research teams from the Laboratory of Mechanisation, Automation and Design of Foundry Plants at AGH-UST and the PPP Technical company, the domestic manufacturer of sand blasting and peening machines [10]. The research data will be used by the manufacturer and the users for the purpose of optimisation of the technical and operating parameters of sand-blasting and peening processes to improve the efficiency of the applied treatment and to help define the process conditions to achieve the required effects.

The purpose of this study is to define the surface condition requirements in relation to the process parameters: intensity of the abrasive grain and the treatment time. The evaluation procedure involves the surface condition and the properties of the outer layer.

Testing was done on a in the table - type airless shot blasting machine OWS-1000. Worked products are placed on a rotary bench of diameter 1000 mm. The stream of shots is ejected by two rotors: the upper and the side ones (Fig. 5). The rotor's rpm speed during the tests can be varied between 1500 and 3000 rpm and the shot feeding rate may range from 50 to 150 kg/min. The shots used in the tests are made of cold rolled spring steel, grain size d = (1÷2) mm, d_r=1.45 mm.

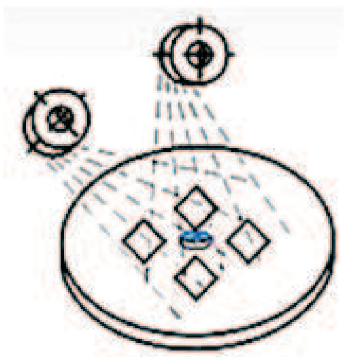

Fig. 5. Layout of rotors with respect to the rotary bench in the shot blasting machine OWS-1000

The shot stream intensity in the rotary peening machine is determined by the indirect method involving the measurement of kinetic energy of grains. The applied method is referred to as Almen test [1,8,10]. During the test steel strips, standardised in terms of their size, material and manufacturing method, are subjected to shot peening. The strips (76±0.2×19±0.1 mm) are fixed in holding fixtures and their curvature becomes the measure of the shot peening intensity. Type A and C strips are used in the testing.

Measurements were taken of the load exerted by the stream of shots upon the worked surface using extensometer sensors placed under the cover of the measuring device of the outside diameter 300 mm, targeted by the shot stream. Depending on the selected process parameters, the loading force were registered of up to 60 N [9].

Alongside the strip deflection f_A, f_C the surface coverage factor was determined, ex-pressed as the proportion of the surface area targeted by the shot stream to the total surface area of sample for the Almen test or the total area of the test castings.

Shot peening efficiency is measured by the loss of mass of test castings. Their surface condition is evaluated by finding the arithmetic mean deflection of their profile from the mean level line – R_a. The irregularities are mapped using a contact device.

To find the characteristics of the surface layer, the micro-hardness has to be deter-mined in the samples' cross-section. The load to be applied is chosen depending on the type of material and the depth of plastic deformations. Micro-hardness is determined by the Haneman method, utilising an optical microscope Neophot 32.

4. Results and discussion

These test results were collected in an experimental setup using one (upper) rotor placed above the immobile bench. The intensity of ejected shot stream was $\dot{m}$ = 66 kg/min.

Sample castings used in the tests were made of alloys typically used in foundry engineering, such as AM5 and CuZn34 (aluminium- copper and brass). Tests were also done on samples made of bronze, alloy cast steels, cast iron. Each time the test castings were cast in sand moulds, made of synthetic sand mix with bentonite with the silica sand base.

Tests results are shown in Figs. 6÷9. The upper rotor was switched on during the shot-peening

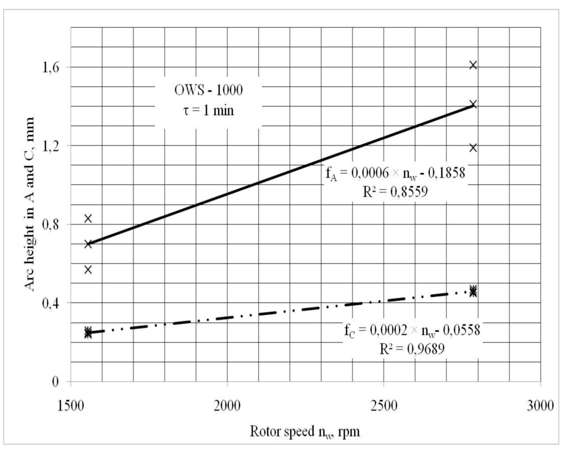

Fig. 6. Intensity of shot stream depending on treatment time and on the rotor speed

process whilst rough castings were placed on the immobile bench.

Figure 6 shows the intensity of shot stream hitting the Almen control strips when only one rotor was on.

The condition of surfaces subjected to the shot-peening treatment is obtained by finding the deviation of its profile from the mean level line R_a. For the sake of comparison, the rough-ness of untreated surface is determined, too.

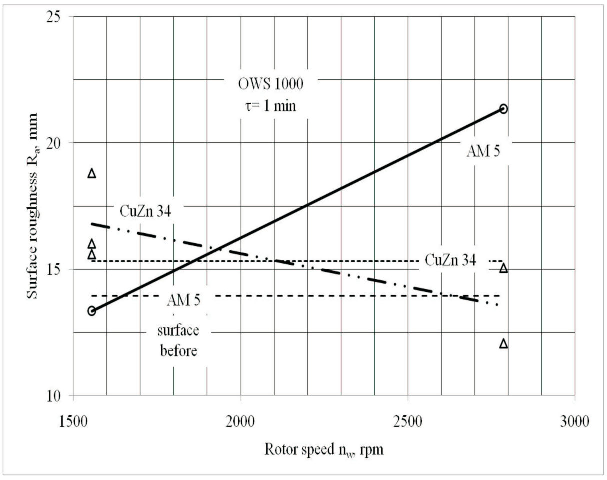

Fig. 7. The change of surface roughness of shot-peened samples made of AM5 and CuZn34 in relation to the rotor rpm speed

Fig. 8 and 9 show the hardness of surface layer in selected casting products. Comparing these values with hardness levels before the treatment, we obtain the extensiveness h of the surface layers in castings made of alloys AM5 and CuZn34.

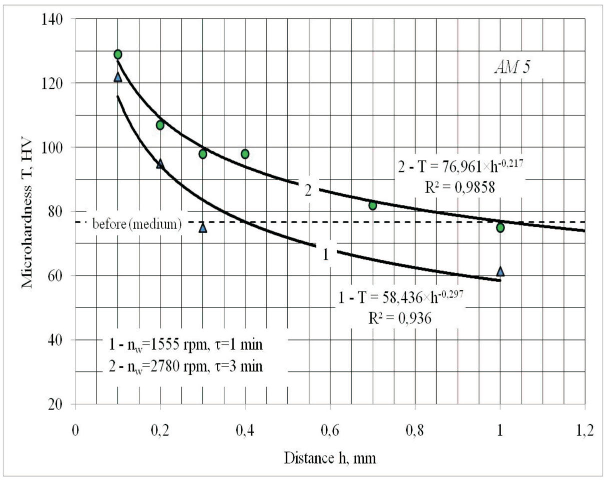

Fig. 8. Hardness measured in layers of AM5 samples, depending on rpm speed of the upper rotor and the treatment time

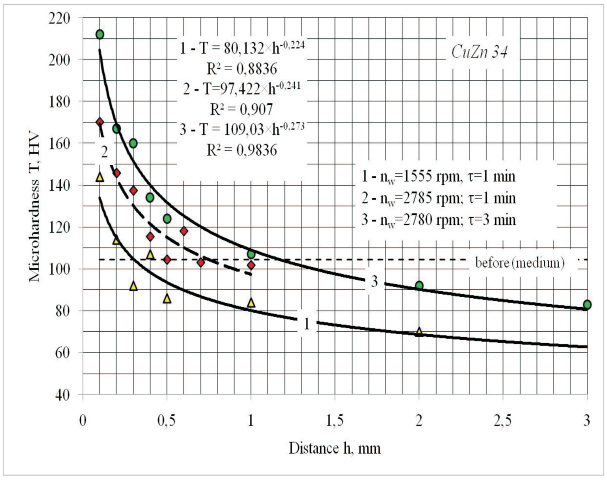

Fig. 9. Hardness measured in layers of CuZn 34 samples, depending on rpm speed of the upper rotor and the treatment time

Test data show how the hardness of the surface layer in the castings should change de-pending on the shot peening intensity (expressed as the rotor rpm speed) and the treatment time.

The expertise gained to date was employed to define the conditions for hardening the components of the shot-peening machines made of high-chromium cast irons, achieving the 20% improvement of their hardness and of their fatigue endurance, too.

5. Conclusions

Sand-blasting and shot peening methods are used for aesthetic reasons and to modify the surface conditions. Under the action of the abrasive grain, the properties of the surface layer of the treated product are changed, so its functional and endurance parameters are vastly improved. The methodology outlined in this study enables us to find the extent of the covered surface layer in the function of process parameters (rotor rpm speed and the treatment time).

Results of testing done on shot-peened castings are further utilised to determine the requirements for the hardening of elements exposed to fatigue hazard. When the rotor blades made of high-chromium cast iron are shot-blasted, the hardeness of their active surface is enhanced from 47 to 67 HRC.

Most manufacturers of the castings do not present all advantages of sand blasting and shot peening treatment, though they should perhaps emphasise that castings cleaned by those methods have the surface layers of very good quality. The improved surface condition is achieved alongside the improved state of stress, improved corrosion resistance and enhanced hardness of the surface layers, which have a beneficial effect on functional quality of casting products.

In order to meet the surface condition requirements, the process parameters have to be precisely controlled: intensity of the shot stream (measured with the use of control strips) and the treatment time. It is required that process conditions should remain stable, which necessitates the regular monitoring and control of process parameters and the condition of the clean-ing agent.

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