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Strengthening surfaces of machine components by treatment using loose solid balls

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ABSTRACT

Purpose of this paper is to develop mathematical models of the treatment methods using loose solid balls. Analysis of treatment with the use of loose solid balls behaviour is carried out for modelling. The operating factors such as geometrical parameters of a nozzle, distance to the treated surface, and pressure of compressed air and outlet factors such as level of strengthening, depth of hardened layer are determined. It is proposed to put into basis of the mathematical models the energy conception that permit for unification and simplification of mathematical description of the processes. The level of strengthening, and depth of hardened layer are estimated for the plain surfaces by means of created mathematical models.
Design/methodology/approach: The main methods used for the theoretical research are mathematical modelling, integral calculus, fundamentals of analytic geometry, theory of probability, hydraulics of multiphase flow. The main methods used for the experimental investigations were conducted by receiving diagrams of surface roughness, microhardness of the oblique slices of the treated samples, speckle interferograms of the surfaces treated using loose solid balls.
Findings: A method of mathematical modelling for treatment with the use of loose solid balls is developed based on the energy conception. The mathematical model is created and allows calculating the characteristics of surface quality depending on the technological modes of treatment.
Research limitations/implications: It is planned to develop and improve the methods of mathematical modelling of the treatment using loose solid balls in future research by extending them for the curvilinear treated surfaces, which are characterised by a movement relative to the nozzle.
Practical implications: have the applied software, elaborated on the basis of the models, that allows providing for automation of calculations of the characteristics of surface quality depending on the technological modes of the treatment.
Originality/value: It is pioneered to receive functional dependences between depth of a hardening layer, changing microhardness, degree of hardening and the parameters of equipment, blast of loose solid balls, and working medium. The created functional dependences take the distribution of characteristics of working medium into account (mass and velocity) all along the cross-sections of the blast.
Keywords: Surface treatment; Loose solid balls; Strengthening; Modelling

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1. Introduction

A requirement in the effective and cheap methods of treatment of metallic machine parts with the complicated configuration grew along with development of production and creation of enterprises in machine-building industry of different types and expansion of nomenclature of wares. Lots of progressive technological processes are developed for providing necessary cleanness and quality of their surfaces. Technology of clean treatment of details for machines with the use of effect of the shock impulsive operations made on the surface of blast of loose solid balls belongs to them. Necessity to reduce in a price machining, promotes its productivity and efficiency, and also dissociates a metal-cutting tool from a tool holder, carriage and machine-tool for avoidance of heating and vibrations, brought about creation of methods treatments, in which an instrument does not have mechanical connection with a machine-tool.

Essence of treating with loose solid balls consists in that blast of loose solid balls which are impinged of the surface of detail and during a collision work, changes the state of this surface, and it is sent at high speed (50...80 m/s) on the treated surface. As a rule, loose solid balls gather speed by the means of the compressed air.

Every ball in a shot blast keeps a reserve of kinetic energy which grows into work of cutting and is sufficient for dissociating from the treated surface of microswarf. Thus, a surface acquires an original kind, characteristic only for this process (Fig. 1).

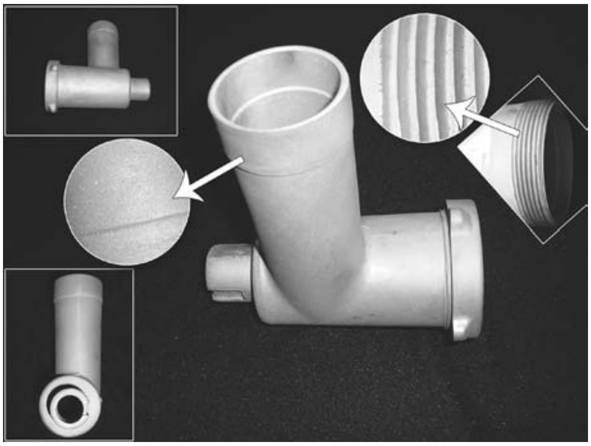

Fig. 1. Components treated by the blast of angular abrasive

Processes that use the effect of impinging loose solid balls at the treated surface will be realized in number of different ways:

- an impact is actually carried out by the ball (mechanical shot peening);
- an impact is carried out by an liquid jet or jet of the compressed air or jet of the steam which contains abrasive grains (air shot-peening, glass beads cleaning, sand blasting treatment, abrasive blasting treatment);
- influence on the treated surface is carried out by slurry, which consists of the abrasive uniformly distributed in the special emulsion, and sprayed by compressed air with the use of the jet nozzles (wet shot-peening, wet abrasive blasting treatment).

Such methods of treatment are applied in aircraft, automobile, instrumental, repair industries of machine-building for grinding and polishing of details that have specially complicated configuration (stamps, press-forms, blades of pumps, shaped casting, and the like), and also while necessary receipt of clean surface without the directed tracks of treatment, increase of durability of springs and teeth of cog-wheels, increase of firmness of tool piece, receipt of surfaces at high capillarity and increase of their wear resisting property, improvement of antirust properties and adhesion with galvanic coverages and paints, delete of dross, corrosion, removal of rough edges after tooling. Processing is possible for both simple surfaces (flat, cylinder) and formed surfaces of the wares. Efficiency for using different kinds of treatment with loose solid balls grows with the increase of size complicating the configuration of details.

Taking advantages of such treatment into account, problems should be pointed out which are related to its realization, in particular ecological ones. A quartz or metallic dust, its maintenance, both in the area of breathing of worker and in a workshop, considerably exceeds possible sanitary norms (for a quartz dust - 2 mg/m^3, for a metallic dust - 10 mg/m^3) [1], appears during work of plants, without regard to application of powerful ventilation. Considerable noise is another negative factor. The listed factors are insalubrious for serving personnel of the plants. The large charges of air for acceleration and transporting of working medium to the surfaces of the details increase the prime cost of the process.

The analysis of literary sources points out on that both Ukraine and abroad, plenty of experimental researches of the technological methods of treating with loose solid balls, directed on the decision of the concrete applied tasks are conducted [2, 3, 4].

The basic scientific approaches of theoretical description and research of processes of treating with loose solid balls laid the foundation of Sh.M. Bilyk, and were considerably extended and improved by A.E. Provolotskiy [5, 6]. Functional dependence which allows approximately to estimate interrelation between the size of linear removal of material and the parameters of shot-peening treatment was offered to them. The simulation of interaction between the single ball and the treated surface was conducted for research changing of the linear sizes of the surface and roughness during shot-peening with the use of angular abrasive. The various constructions of nozzles and heads subjected to shot peening were described, and a form and properties of shot blast, which formed by them, were analysed. In scientific works [7-9] the authors conducted the sophisticated and depth analysis of processes of wet abrasive-blasting treatment with the use of extra high pressure, and new complex approach was offered in the theory of hydro-cutting; basic principles of constructing of hydro-cutting equipment were expounded. Research of the methods of shot-peening by foreign scientists, as a rule, is experimental and touches its influence on physical and mechanical properties of separate groups of metals and alloys [10-12]. Treatment of surfaces of machine parts is examined by the flooded abrasive blasts in the separate works [13].

The analysis of the scientific research conducted in this branch allows to draw the following conclusions:

- the process of treating with loose solid balls is examined, mainly, only in the aspect of cutting of metals, without the account of mechanisms of surface plastic deformation;

- in the offered models, distributing of the parameters of working medium is not taken into account in the cross-sections of the blast and, accordingly, on track of the blast on the treated surface;
- models which allow to predict спрогнозувати the results of stream treatment for the surfaces of the complicated configuration absence.

Leading to the mathematical model of parameters which describe the mechanism of the surface plastic deformation will allow to get an idea of the phenomena which take place during treatment using loose solid balls. Taking into account the distribution of the parameters of a working medium in the cross-sections of the blast, and accordingly, on track of the blast on the treated surface, it will enable to provide evenness of treatment and high-quality characteristics both for the flat and for the formed surfaces of wares.

Therefore, it is important to perform detailed research and mathematical description of the mechanisms which forms quality of the surfaces of wares while processing with loose solid balls on the basis of which the technological providing can be developed for applying the process in industry, optimization of the technological modes is executed for decreasing contamination of environment and increasing dirigibility by the process, its reduction of prices, development of recommendations to perform automation of the process.

2. Description of the approach

To develop the mathematical models of the process it is needed to consider the mechanisms by which forming of microrelief and stress is in the treated surface. They go as follows:

- micro-cutting, tracks which are looked over on the electronic pictures of the treated surfaces. At the mass operation of the balls on the surface a highly developed mat surface without the directed tracks of treatment appears that gives to it valuable operating properties;
- brittle failure of the surface which is caused by repeated impacts of the balls;
- surface plastic deformation during which compressed stress is formed on the surface;
- hydro-molecular destruction, as result of Rebinder effect, takes place during penetration of the liquid components of working medium in highly developed microcracks on the surface [6].

Determining mechanisms which substantially influence on physical and mechanical properties of the treated surfaces and evenness of removal of the material is micro-cutting and surface plastic deformation.

Predominance of that or another type of plastic deformation depends on placing of the nozzle and the treated surface. During treatment an impact blast (β = 90º, Fig. 2) basic part of energy which the balls has is outlaid on the deformation of the subsurface layer and the balls that the mechanism of surface plastic deformation prevails in this case. During treatment a sliding blast (β = 0º) energy of the balls is outlaid on increasing speed of sliding balls on the surfaces. The deformation of chipping and shearing is small in both cases. They become maximal, when the blast is directed to the treated surface at the angle β = 45º [5].

Micro-cutting is a prevailing mechanism of forming of microrelief and stress on the surfaces in this case.

Technological destruction of the surface of the machine components, caused by micro-cutting, and their strengthening, caused by surface plastic deformation, is determined by lots of the controlled and uncontrolled parameters. Their interrellations and influence on forming of the surface during treatment with using loose solid balls are represented on Fig. 3.

The initial parameter of the mathematical model which describes treatment by loose solid balls from the point of view of micro-cutting, and it can be utilized for setting of the stocks, is the depth taken off the balls of layer of material from the surface of the detail. Initial parameters which are characterized by the results of treatment by loose solid balls from the point of view of the stress change of subsurface layers of details are the depth of hardening layer, a change of microhardness, degree of hardening, distribution of residual stresses on the surface.

In the scheme (Fig. 2) an instrument is presented as a cone of working medium without breaks in it. Solid components of the blast are modelled balls with a diameter, even the diameter of grains of basic fraction of abrasive, or shot. While creating a mathematical model with not separated balls, packages of working medium are considered which have certain mass and speed and, accordingly, kinetic energy. The treated surface is broken on separate areas and accepted so that on every area of the surface for time unit which gets one package of working medium that has kinetic energy and executes work on the change of characteristics of the surface.

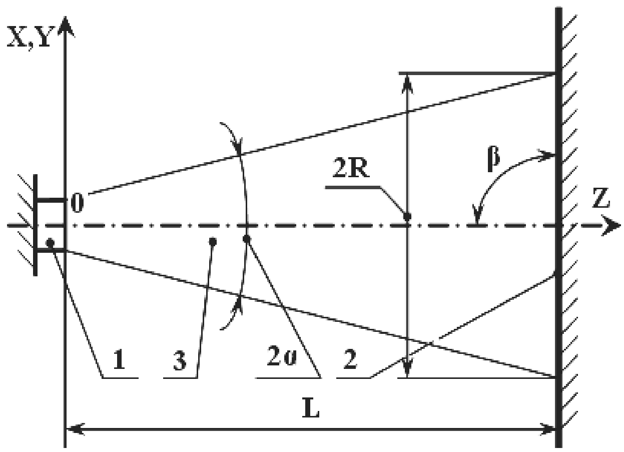

Fig. 2. Scheme of the blast that run out of the nozzle with circular cross-section: 1 - nozzle; 2 - surface; 3 - blast; 2α - cone angle; β - impinging angle; R - radius of the shot track on the treated surface; L - perpendicular length between treated surface and end of the nozzle

Energy concept, after which energy, giving working medium by the nozzle, except for its losses on the different stages of the treatment, transferring into work on the change of form and stress state of the treated surfaces, is fixed in basis of the mathematical model of treating by loose solid balls [14].

Going out from general equation of energy balance the simplified equation by which the simulation of the process is carried out on that basis is the following:

$$\frac{M_{i,j} \cdot V_{i,j}^{2}}{2} - \left(E_{op} + E_{tr.s}\right) = \frac{\left(A_{pl.d} + A_{ruyn}\right)}{\left(1 - k_{vtr}\right)} \quad (1)$$

where: $M_{i,j}$ - distribution of mass of the working medium on the treating surface, kg; $V_{i,j}$ - distribution of velocity of the working medium on the cross-section of the blast, which is congruent with treated surface, m/s; E_{op} - loss of energy by the blast on overcoming forces of air resistance, J; $E_{tr.s}$ - loss of energy on overcoming forces of friction in the blast, J; $A_{pl.d}$ - work, outlaying on the surface plastic deformation of the surface, J; A_{ruyn} - work, outlaying on destruction of the treated surface by micro-cutting, J; k_{vtr} = 0.1…0.15 - a coefficient of losses of energy during interaction of the balls with the treated surface.

For determination of distributing the mass of working medium $M_{i,j}$ “mechanical” interpretation of distributing of the system that consists of two random quantities is utilized, as to distributing of single mass on the plane of treatment and dependence is following:

$$M_{ij} = Q_m \cdot \int_0^t \int_{x_i}^{x_{i+1}} \int_{y_j}^{y_{j+1}} f(x, y)\,dydxdt \quad (2)$$

where: Q_m - productivity of the nozzle or charges of working medium, the masses shown in units, kg/s; t - duration of treatment, s; f (x, y) - density of distributing of mass in a point (x, y); x_i, x_{i+1}, y_j, y_{j+1} - coordinates of ij-area on the treated surface, m.

Coming from physical maintenance of the process of treatment by loose solid balls and experimental information, shown in [6], for the nozzle with circular cross-section as a subintegral function is accepted normal law of distribution of packages of the masses of working medium in plane XOY, to perpendicular to the axis of the blast:

$$f(x, y) = \frac{1}{2\pi\sigma_x\sigma_y} \cdot e^{-\frac{(x-a_x)^2}{2\sigma_x^2} - \frac{(y-a_y)^2}{2\sigma_y^2}} \quad (3)$$

де a_x, a_y - centres of dispersion (mathematical hopes) on axes OX and OY, accordingly; σ_x, σ_y - standard deviations.

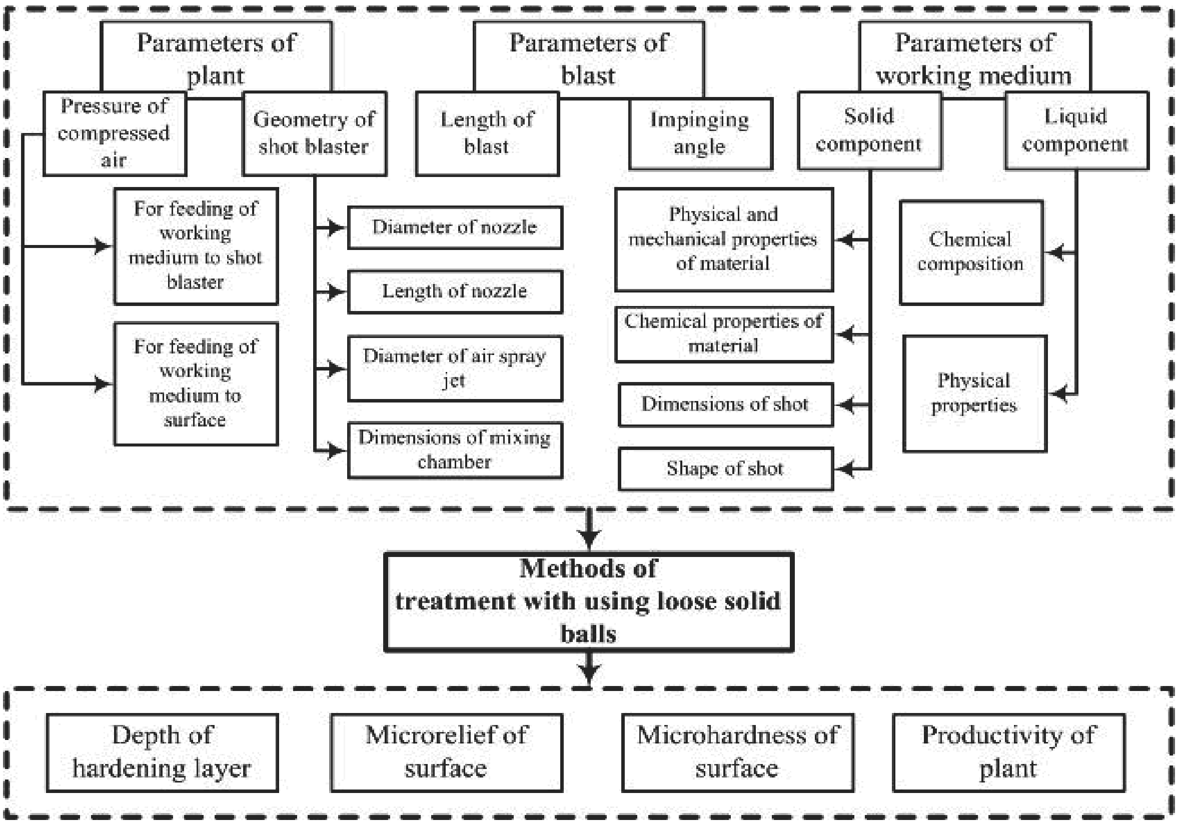

Fig. 3. Parameters of treatment with loose solid balls, and quality characteristics of the machine parts surface

Standard deviations for the nozzle with circular cross-section are determined, following a rule of "three sigma" and going out from the geometrical reasoning:

$$\sigma_x = \sigma_y = \frac{(L + 0.145\frac{d_c}{a}) \cdot tg\alpha}{3} \quad (4)$$

where a - coefficient of turbulence of the blast; L - the perpendicular length between treated surface and the end of the nozzle, m; α – cone angle of the blast, rad.

Utilizing a scheme, resulted on Fig. 4, analytical dependence which allows to define influence of geometrical parameters of chambers of the nozzle of ejector type on his productivity is set:

$$Q_m = \left(\frac{5\cdot\pi}{2}\right)\cdot\mu\cdot d_c^2\cdot\sqrt{\frac{2\cdot p_{zh}\cdot d_{zh}^2\cdot l_{zh}\cdot\rho_T\cdot\rho_P}{\left(x_T\cdot\rho_P+\rho_T\cdot(100-x_T)\right)\cdot d_{kz}^2\cdot l_{kz}}} \quad (5)$$

where μ - coefficient of charges of working medium through the nozzle; d_c – diameter of the nozzle with circular cross-section for creating the blast, m; d_{zh} - diameter of the air spray jet, m; d_{kz} - diameter of the mixing chamber, m; l_{zh} - length of the air spray jet, m; l_{kz} - working length of the mixing chamber, m; p_{zh} - pressure of the compressed air on the air spray jet of the nozzle, Pa; x_T - concentration of the solid components in the working medium, the masses shown in units, %; ρ_T - density of the solid components in the working medium, kg/m^3; ρ_P - density of the liquid components in the working medium, kg/m^3.

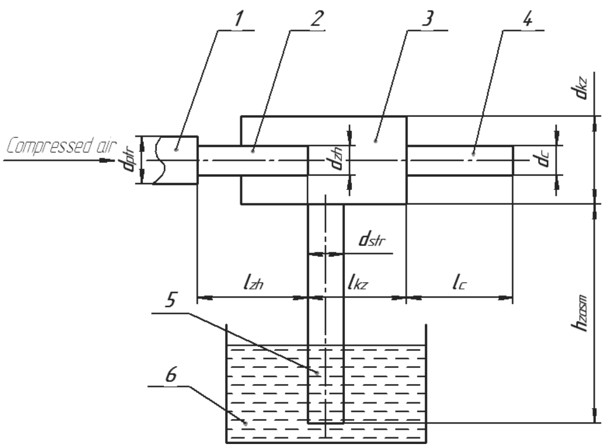

Fig. 4 Scheme of the nozzle: 1 - input pipe line for compressed air; 2 - air spray jet; 3 - mixing chamber; 4 - nozzle for creating the blast; 5 -input pipe line for working medium; 6 - storage tank for working medium

For investigations of distributing velocity along the cross-sections of the blast semi-empiric dependence is utilized:

$$V_{i,j} = V_0\frac{0{,}96}{\frac{2aL}{d_c}+0{,}29}\cdot\left(1-\left(\frac{r}{R}\right)^{k_1}\right)^{k_2} \quad (6)$$

where: V_0 - velocity of the blast outlet the nozzle, m/s; r - distance from the axis of the blast to the examined point of the cross-section, m; R - maximum radius of the blast or distance from the axis of the blast to the points with a zero velocity, m.

Distributing velocity goes along the cross-section of the blast, received on the basis of this dependence is presented on Fig. 5.

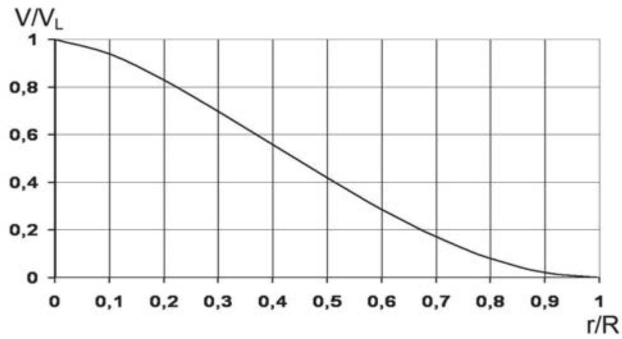

Fig. 5. Distribution diagram of velocity along the cross-sections of the blast

For determination of velocity of the blast on an exit from the nozzle of ejector type on the basis of scheme, presented on Fig. 4, the following analytical dependence is got:

$$V_0 = \frac{0.497}{d_c^2}\sqrt{\frac{\mu_{zh}^3\cdot d_{zh}^6\cdot p_{zh}^{1,5}\cdot\rho_{air}^{1,5}+\mu_{str}^3\cdot d_{str}^3\cdot p_{kz}^{1,5}\cdot\rho_c^{1,5}}{\mu_{zh}\cdot d_{zh}^2\cdot p_{zh}^{0,5}\cdot\rho_{air}^{0,5}+\mu_{str}\cdot d_{str}^2\cdot p_{kz}^{0,5}\cdot\rho_c^{0,5}}} \quad (7)$$

where: ρ_c - density of slurry, kg/m^3; ρ_{air} - density of air, kg/m^3.

It is set at the analysis of dependences (6) and (7), that (6) cannot be utilized for the calculation of distributing velocities in the cross-sections of blast for distances from the nozzle to the treated surface less 0.05 m, but the change of values of coefficients of k_1 and k_2 conduces the forms of epure of velocities to the change, allowing to do it more concave or convex, form areas with the permanent value of velocities in central part of epure or on its periphery. It allows adequately to describe distributing of velocities for the initial, transitional and basic areas of blast.

For implementation of calculations of distributing masses and velocities of working medium in the cross-sections of the blast an algorithm is made and the application program is realized in mathematical editor MathCAD.

After calculations, distributing masses and velocities of working medium in the cross-sections of the blast, it was found work, outlaying on the surface plastic deformation $A_{pl.d}$ and work, outlaying on destruction of the treated surface A_{ruyn} following the formula (1). At the normal corners of attack of the blast to the treated surface (90°) there is only surface plastic deformation, the quality characteristics of the surfaces for which are the depth of hardening layer, changing microhardness, degree of hardening.

It is recommended to determine the depth of hardening layer following the formula:

$$h_n = 20.966 \cdot \sqrt[4]{\frac{A_{pl.d.1} \cdot d_{T.T.}}{n_d^3 \cdot \omega_a \cdot G}} \quad (8)$$

where; $A_{pl.d.1}$ - work which is executed by the balls for strengthening the subsurface layer on a thickness h_n, J; $d_{T.T.}$ - diameter of the ball, m; $n_d^3 \cdot \omega_A$ - empiric coefficients which take the microstructure of the treated material into account; G - module of shearing, N/m^2: G = 8×10^{10} N/m^2 for steels.

Degree of hardening is determined as:

$$\varepsilon = \sqrt[4]{\frac{A_{pl.d.1} \cdot d_{T.T.}}{262 \cdot 10^{-7} \cdot n_d^3 \cdot \omega_a \cdot G}} \quad (9)$$

Microhardness of the surface after strengthening is determined as:

$$H\mu = \frac{H\mu_0}{100} \cdot \sqrt[4]{\frac{A_{pl.d.1} \cdot d_{T.T.}}{262 \cdot 10^{-7} \cdot n_d^3 \cdot \omega_a \cdot G}} + H\mu_0 \quad (10)$$

where: $H\mu_0$ - microhardness of the surface before strengthening, Pa.

In dependences (8)-(10) work which is executed by the balls on creation of strengthening on the treated surface can be defined, coming from the work of surface plastic deformation of $A_{pl.d}$, which is executed by the package of working medium.

Formulas (8)-(10) allow to calculate the parameters of the stress state in the treated surface for the normal corners of attack of the blast to the surface. Realization of algorithms for determination of distributing of the masses and the velocities of working medium in the cross-sections of the blast allows to get the discrete distributing of these parameters as matrices for each of packages of working medium on the entire treated surface.

In an order to provide the removal of material at the treatment by loose solid balls, it is necessary to utilize different from normal corners of attack of the blast to the treated surface. At all of corners of attack, different from normal, the blast creates tracks in form ellipses on the treated surface which conduces to the necessity the account of this factor in the offered higher mathematical model.

As at the corners of attack of the blast to the surface, different from normal, there is destruction of the treated surface, for determination of intensity of removal material from a surface its dependence is taken into account on the technological modes of treating by loose solid balls, set A.E. Provolotskyy:

$$h_p = d_{T.T.} \cdot \left(\frac{5 \cdot \pi \cdot \rho_T \cdot (1 - \mu_p^2) \cdot V^2 \cdot \sin^2 \beta}{4 \cdot E}\right)^{\frac{2}{5}} \quad (11)$$

where: μ_p - coefficient of Poisson: for steels μ_p = 0.28; E - module of elasticity, Pa: for steels E = 20.6×10^{10} Pa.

The method of simulation of the treatment by using loose solid balls for flat surfaces at the corners of attack of the blast, different from normal, can be utilized in transition to the simulation of treating curvilinear surfaces.

To simplify and speed-up calculations after the method, offered in this section, an application software is made on the basis of influence of the technological modes of the treatment by using loose solid balls which was investigation on the quality characteristics of the treated surfaces.

3. Description of achieved results of internal researches

For such technological modes of the treatment by loose solid balls:

- duration of the treatment - 30 s;
- parameters of the nozzle: length of the chamber of the air spray jet - 0.09 m, diameter of the air spray jet – 0.006 m, working length of the mixing chamber - 0,065 m, diameter of the mixing chamber - 0.035 м, diameter of the nozzle with circular cross-section for creating the blast - 0.01 м, diameter of the input pipe line for working medium - 0.016 m, pressure of the compressed air on the air spray jet - 0.5 MPa;
- parameters of blast: the perpendicular length between treated surface and the end of the nozzle - 0.1 m, impinging angle – 90°;
- parameters of working medium: material of solid component is river sand which have grains of round shape, density of the solid components in the working medium - 2400 kg/m3, diameter of grains of basic fraction of the material - 0.15×10-3 м, material of liquid component is water, concentration of the solid components in the working medium, the masses shown in units - 37.5 %;
- parameters of the treated surface: the material is Steel 30 GOST 1050 - 88, limit of fluidity of material during tensile deformation - 300 MPa, initial microhardness of the treated surface -800 MPa; the calculation of quality characteristics is executed for a flat surface.

The results of calculations are presented on Fig. 6. For this case a maximal microhardness is after the treatment $H\mu$ = 845.865 MPa at initial hardness $H\mu_0$ = 800 MPa; maximal degree of hardening ε = 5.733%, the difference of levels is maximally possible between the nozzle and tank for storage of slurry makes 1.431 m.

The analysis of distribution diagrams of quality characteristics on the treated surface for the different modes of the treatment by loose solid balls, gives next conclusions. At the increase of distance from the end of the nozzle to the treated surface, diameter of the nozzle for creating the blast and cone angle standard deviation which determines the form of the graphs of distributing of the quality characteristics on the surface is increased, that distribution curves become more flat, that conduces to the improvement of evenness treatment with the simultaneous decline of its intensity. At the increase of vacuum in the chamber of mixing of the nozzle and coefficient of charges of working medium, which depends on the geometrical parameters of chamber of mixing and the nozzle, kinetic energy of blast, and accordingly intensity of treatment, grow, the unevenness of treatment grows however.

For verification correctness of the mathematical model the flat polished plates of square form that had dimensions 150×150 mm and thickness 3.5 mm were treated. Measuring of roughness, microhardness, thickness of the strengthened layer took place after treatment on each of the marked out squares at regularity 10 mm. Roughness was measured on profilometer 201 at a horizontal increase - 20, vertical increase - 2000. Determination of the depth of hardening layer, degree of hardening and microhardness took place measuring on slanting cuts in the probed squares of plates. After the scission of plate slanting cuts were got grinding on a cast-iron slab by a unit for providing its receipt under the set corner. Microhardness was measured on the device of PMT-3 at loadings 0, 2...1 N and higher, even 487. A corner of cut was within the limits of 1°30´...3°. The depth of hardening layer was calculated after the known formula depending on distance between the point of measuring of microhardness and beginning of slanting cut and a value of a cut corner.

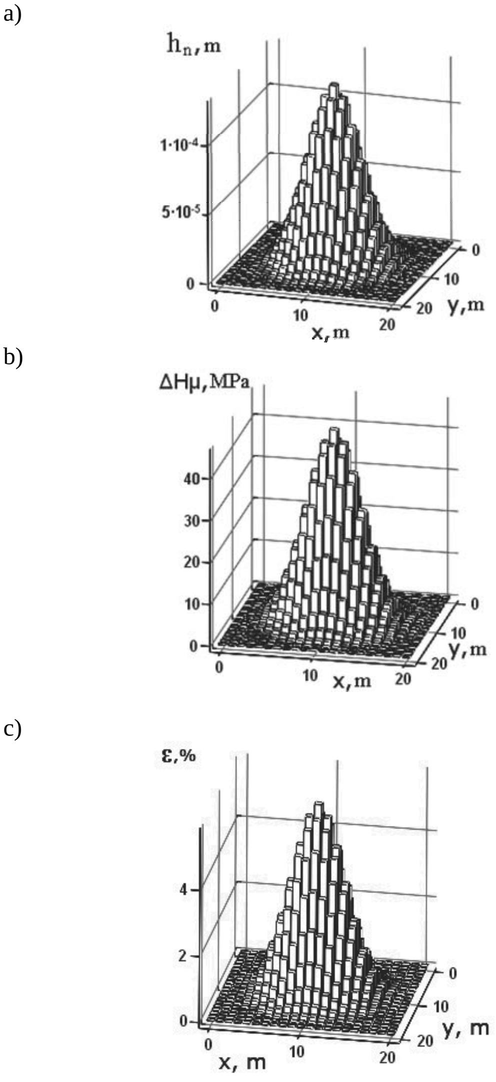

Fig. 6. Distribution diagram of quality characteristics on the surface after treatment with loose solid balls: a) depth of hardening layer h_n, b) change of microhardness Δ Hμ, c) degree of hardening ε

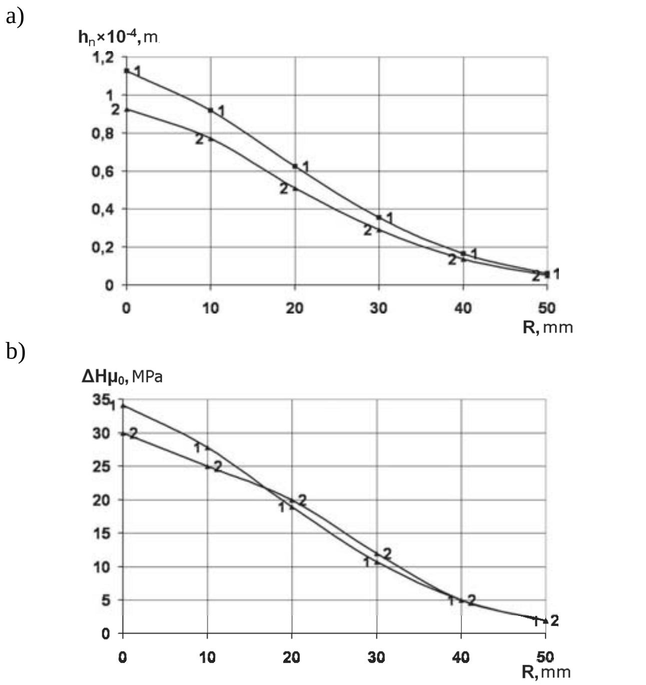

Fig. 7. Distribution diagram of the depth of hardening layer h_n, and changing of microhardness ΔHμ along the blast track on the treated surface: 1 - theoretical data; 2 - experimental data

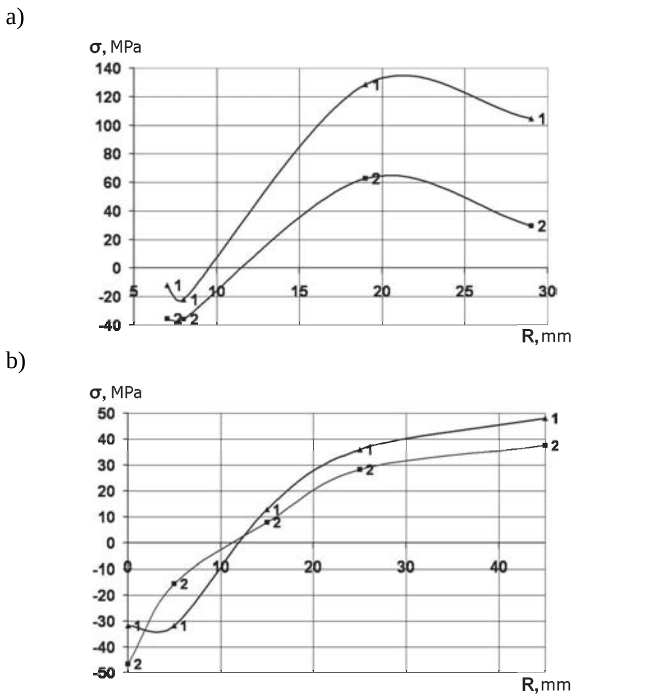

Fig. 8. Distribution diagram of residual stresses along the blast track on the treated surface: 1 - residual stresses σ_{xx}; 2 - residual stresses σ_{yy}: a) processing time - 10 min; b) processing time - 20 min

The degree of hardening was determined following the known formula depending on the change of hardness of the treated surface.

Research results are presented in Fig. 7. Divergence of experimental values with theoretical does not exceed 19 %. For such modes a model describes the real process of the treatment by loose sold balls adequately.

For measuring the residual stresses there are a few different alternative methods [15, 16]. Here for researches, the method of laser speckle interferometry was chosen, which allowed to get distributing esidual stresses on track which forms the blast on the treated surface (Fig. 8).

Maximal values of stresses are fixed in a centre of the plates. They are equal σ_{xx} = - 11.82 MPa; σ_{yy} = - 35.43 MPa for duration of treatment t = 10 min; σ_{xx} = - 31.81 MPa; σ_{yy} = - 46.49 MPa for duration of treatment t = 20 min at the modes of treatment indicated as higher. An error of measurements is 6 % from limit of fluidity of material during tensile deformation that is ± 15 MPa.

4. Conclusions

- Theoretical generalization is executed and the scientific task of the technological providing the quality of surfaces of wares is untied for the treatment by loose solid balls which enable to inculcate this operation in a technological process as alternative operation of the finishing, which provides high characteristics quality of wares surfaces, in particular roughness, depth of hardening layer, degree of hardening, microhardness, distributing residual stresses. Efficiency of its usage grows at treatment of the shaped surfaces, and also at the observance of the optimum technological modes of treatment.
- The mathematical model of the treatment by loose solid balls is created for an unmoved nozzle at the normal cone angles of blast to the treated surface describes interaction between the technological modes of process and quality characteristics, got as a result of treatment: depth of hardening layer, degree of hardening, change of microhardness. To simplify and speed-up, software application calculations is made on the basis of which it is possible to investigate influence of the technological modes on the characteristics quality of the treated surfaces.
- By modelling it is set on the basis of the created mathematical model: for the typical modes which are utilized in industry, at duration of treatment of t = 30 min, for the material like steel 30 GOST 1050-88, maximal depth of hardening layer in central part of track of blast h_n = 0.129 mm; a maximal microhardness after treatment is Hμ = 845.865 MPa at initial hardness of $H\mu_0$ = 800 MPa; maximal degree of strengthening ε = 5.733 %.
- It is set as a result of experimental researches of the process treatment by loose solid balls that intensity of the treatment for an unmoved nozzle at the normal cone angles of blast to the treated surface is diminished from the centre of blast to his periphery. For the diameters of nozzles d_c = 0.006 m; 0.008 m; 0.010 m; 0.012 m and diameters of air spray jets d_{zh} = 0.006 m; 0.008 m; 0.010 m; 0.012 m are set that an error between theoretical calculations and results of experiment for depth of hardening layer does not exceed 19 %, for the change of microhardness of the treated surface ΔHμ a maximal error is within the limits of 14 %. It is experimentally confirmed at research of distributing residual stresses that the treatment using loose solid balls forms an area with prevailing compressed stress in the subsurface layers of steel details which have the value to 50 MPa, and removes tensile stress, got on previous operations that promote resistance to cracking and fatigue strength of machine parts.

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