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A fractal approach to estimating the durability of critical parts

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The method of evaluating the effectiveness of strengthening technologies for increasing the durability of hydraulic hammer parts by means of detonation spraying is considered. Indicators of crack resistance in the controlled cross-section of the striker and peaks during strengthening by this material increases by 1.3-2.4 times compared to the initial state without spraying. For an express analysis of the mechanical properties of the striker and the hydraulic hammer pick after detonation spraying, the fractal formalism was applied, which made it possible to predict the strength index σ_B for the body at the pair correlation coefficient R^2 =0.8351, for $\sigma_{0.2}$ – at R^2 = 0.7534, and the plasticity index for the pick with R^2 = 0.7827, hardness – with R^2 = 0.8682. The fractal dimension of the microstructure was calculated at a magnification of 100.

Keywords: detonation treatment, fractal, structure, strength, hydrohammer, mathematical model.

Фрактальний підхід до оцінювання довговічності відповідальних деталей. *А.В. Ужва, О.В. Орел, Д.Б. Глушкова, В.М. Волчук*

Розглянута методика оцінювання ефективності зміцнювальних технологій підвищення довговічності деталей гідромолота шляхом детонаційного напилення. Показники тріщиностійкість у контрольованому перерізі бойка і піки при зміцненні шляхом при цьому матеріалу підвищується в 1,3-2,4 рази у порівняння з початковим станом без напилення. Для експрес-аналізу механічних властивостей бойка і піки гідромолота після детонаційного напилення застосовано фрактальний формалізм, що дозволило прогнозувати показник міцності σ_B для корпусу при коефіцієнті парної кореляції R^2=0.8351, для $\sigma_{0.2}$ – при R^2=0.7534, а показник пластичності для піки при R^2=0.7827, твердості – при R^2=0.8682. Фрактальна розмірність мікроструктури розраховувалася при збільшенні 100.

1. Introduction

The choice of processing methods plays a decisive role in the formation of the set of properties of the original part, especially the methods of surface processing [1-3]. Detonation coatings [4-6], as a type of gas-thermal coatings, due to the highest characteristics, are increasingly used in various industries. Due to the highest characteristics (bonding strength to the substrate up to 250-280 MPa), detonation spraying [7-9. can be better for strengthening and restoring the most responsible and loaded parts and assemblies. Detonation spraying increases the mechanical properties of various parts of a responsible purpose, the surface of which wears out during operation.

2. Materials and methods

Evaluation of the mechanical properties of parts after detonation spraying using non-destructive control methods based on structure analysis is complicated due to the complex configuration of the shape of its components. A heterogeneous and geometrically complex structure is characteristic of many surfaces after various types of treatments, including spraying [10-13].

In the work, it is proposed to apply the theory of fractals to evaluate the mechanical properties of hydraulic hammer parts [14-16].

In general, detonation installations consist of unit 4 of powder supply, which includes a powder feeder and a dosing device; unit 1, serving to form the necessary gas mixtures and fill the barrel of the detonation unit with them at a given speed; ignition unit 3 and igniter 2, designed to initiate the explosion of the working mixture; barrel 5, which is a pipe with a diameter of 20-50 mm, a length of 1-2.5 m and intended for the directed propagation of an explosive wave towards the open end of the barrel (Fig. 1).

The principle of operation of the installation is as follows. From block 1, the gas mixture is fed into barrel 5. At the same time, from the powder feeder through the dosing device (block), nitrogen gas or air is blown in specified portions - finely dispersed powder into the gas mixture immediately before its ignition, then the gas mixture is ignited with igniter 2. As a result of ignition and movement along the channel of the combustible mixture, it explodes with the release of a significant amount of heat and the formation of a detonation wave, which accelerates and is transferred through the barrel to the surface of the part 6 of the particles 7 that are sprayed, with a speed determined by the geometry of the barrel and the composition of the gas.

Cleaned working surfaces of hydraulic hammer parts without preliminary treatment were strengthened by detonation sputtering of VK25 alloy (80%) and PT-NA-01 binder (Ni 91%, Al 9%). The VK 25 powder used is a tungsten-cobalt carbide (WC- Co) containing up to 25% cobalt, and is used for work in fretting corrosion, abrasive wear at normal and elevated (up to 650°C) temperatures. Powder with a grain size of 20-100 μm was used; which was melted in an oxygen-acetylene flame and transferred to the surface of the part by the gas flow. The thickness of the sprayed layer is 0.1 mm. The ratio of oxygen content to acetylene content was 12; powder loading depth 300 mm, spraying distance 150 mm, powder weight 200 g, barrel length 1.6 m, barrel diameter 16 mm.

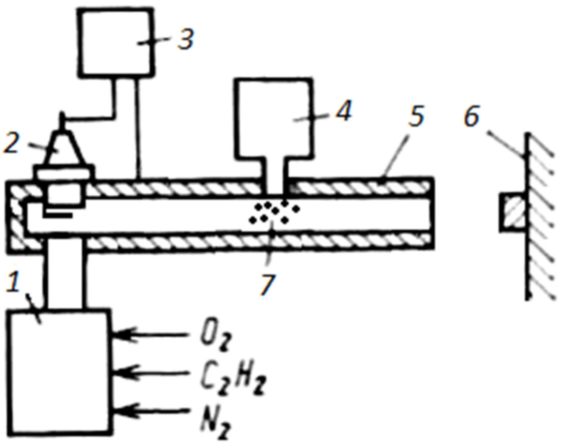


Fig. 1. The scheme of the detonation device consists of: 1 - block from which the gas mixture is supplied; 2 – igniter; 3 - ignition block; 4 – unit of the dosing device; an employee for the formation of the necessary gas mixtures; and the igniter; of the barrel 5 – the barrel (a pipe with a diameter of 20-50 mm, a length of 1-2.5 m); 6 - the surface of the part; 7 - sprayed particles

3. Results and discussion

The surface roughness of the parts before spraying was Ra 0.35-2.5. As a result of spraying, the roughness of the working surfaces of the parts increased to R values of 4.8-5.4 on the body and sleeve and to 2.8-3.7 on the striker and peak.

The initial signs of failure of the reinforced layer were detected at the peak after 400 load cycles. Risks - burrs in zones “M” and “F” on the striker (Figure 2) appeared after 1300 cycles, on the sleeve after 1050 load cycles and on the body after 1700 cycles. The test was carried out in the amount of 1800 cycles. Measurements of the tested parts show that the indicated diameter of the channels in the cut zone has increased to 125.2 mm The striker was worn by 0.25 mm, the peak in the “M” and “F” zones received a wear of 1.2 mm The appearance of damage to parts strengthened by detonation spraying is shown in In general, detonation installations consist of unit 4 of powder supply, which includes a powder feeder and a dosing device; unit 1, serving to form the necessary gas mixtures and fill the barrel of the detonation unit with them at a given speed; ignition unit 3 and igniter 2, designed to initiate the explosion of the working mixture; barrel 5, which is a pipe with a diameter of 20-50 mm, a length of 1-2.5 m and intended for the directed propagation of an explosive wave towards the open end of the barrel Fig. 2 and Fig. 3.

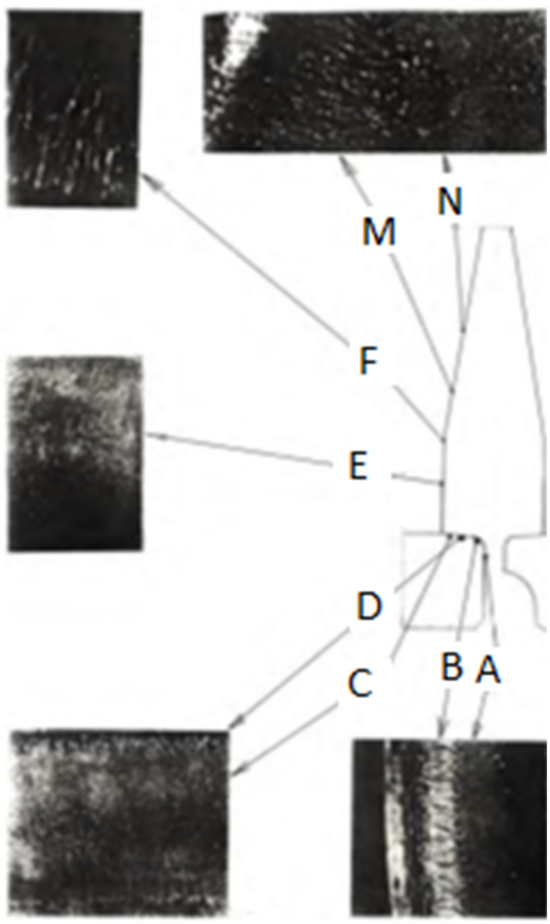


Fig. 2. Damage to the peak and sleeve strengthened by detonation spraying , ×3

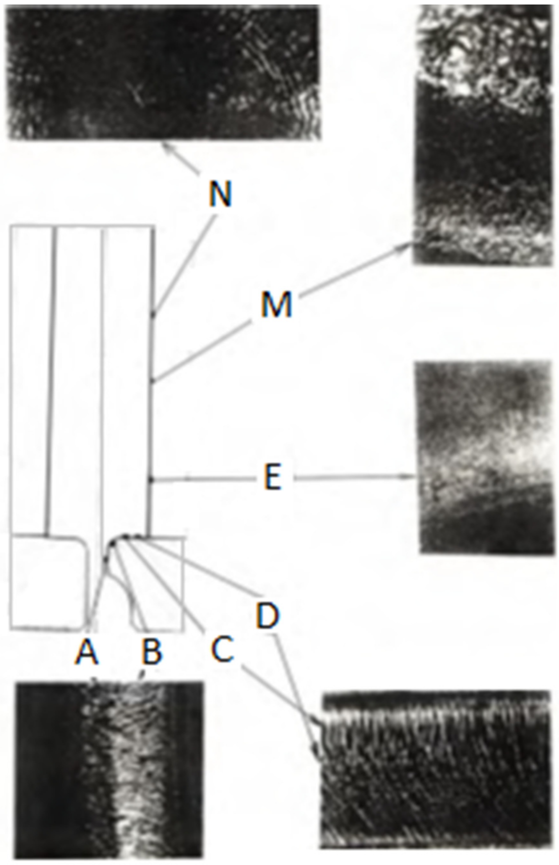


Fig. 3. Damage to the hull and striker, strengthened by detonation spraying , ×3

The location and nature of damage to the surfaces of the parts are identical to those observed on the previously investigated device sets. Such characteristic signs of degradation of the surface volumes of the material of the parts as wear, smearing, plastic deformation with the formation of radial grooves, surface oxidation are noted on the body and sleeve. In zone “A” on the body there is wear and tear, on the sleeve there are characteristic shear lines.

In zone “B” on the body, there is a weakly pronounced fold-like relief, on the sleeve, the relief of the furrow is smoothed to the base, so that a pattern of wave-like crumpling zones is observed. Peeling of the surface layers of the metal in the “C” zone differs on the sleeve, on the body - a smooth surface. In zone “D” there are traces of surface treatment.

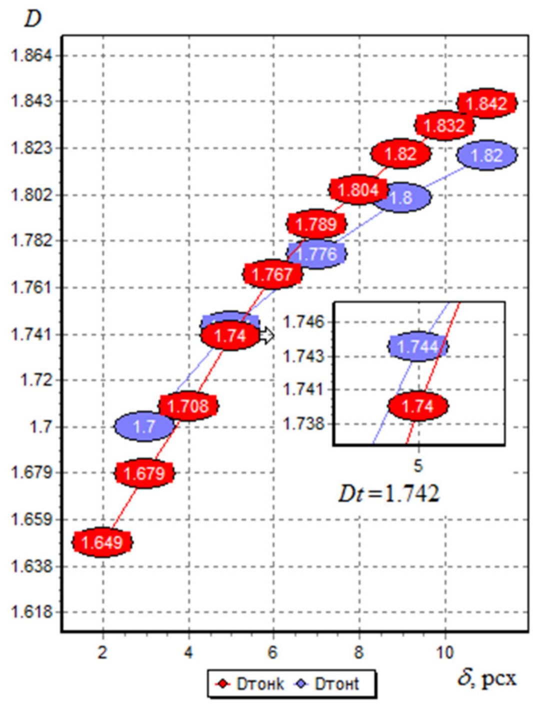
The pattern of wear of the pick and pick is typical. In the presence of a central spot and grooves in the peripheral part of the “N” zone, a fold-like relief of the grooves in the “M” zone, wear and plastic deformation with the formation of a rough, flaking surface in the “F” zone and wear with slander in the “E” zone, it is noted less “roughness” of the terrain and greater smoothness for the fight and spades. In combat, the degree of damage is lower.

The body and the striker are characterized by the presence of darker colors on the surface.

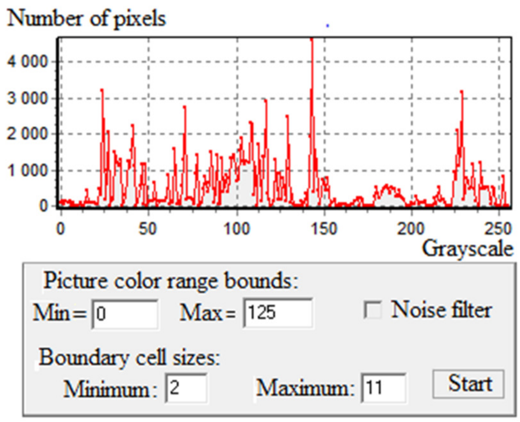
During the test, cracks formed in all the examined parts of the device. On the sleeve, the cracks up to 0.05 mm deep are single and are observed only in the “Z” zone (Figure 4). On the case, cracks are visible in zones “A”, “B” and “Z”, respectively, with a depth of 0.25 mm, 0.4 mm and 0.1 mm (Fig. 5). There are no cracks in zone “D”.

on the battlement and peak in the “N” zone. There are cracks 0.3–0.4 mm deep in the “M” zones of the striker and peaks. Cracks with a depth of 0.1 mm are in the F zone of peaks and 0.15 mm - a crack. Cracks were found both in the zones of structural changes and outside them.

In the working zones of all the investigated parts of the device during the test, almost complete wear of the detonation coating occurred (see Figure 4 and Figure 5), only in the “M” zone of the case and the bushing are the remains of



a



b

Fig 6. The search for the convergence of the fractal dimension of the sorbite structure in fig. 5 c, calculated by the cell and point methods (a) and the color distribution of the structure in the 256-color drawing with shades of gray (b)

the coating up to 20 μm thick. The same single plots are on the battlefield in zone “F”.

Structural changes of the base metal were found in the damage zones of all parts. On the body and sleeve, structural transformations are observed in zones “A” and “B” to a depth of 0.2 mm on the body and 0.15 mm on the sleeve.

The hardness of the material in these zones on the body is HB 414-540 and HB 414-645 on the sleeve. In the “C” zones of the case and sleeve, the depth of structural transformations does not exceed 0.05 mm (HB 460–480). At the peak and peak, structural changes of the metal are observed in the “M” zone to a depth of 0.25–0.3 mm and in the “F” zone to a depth of 0.1–0.15 mm (for both) at a hardness of HV 340–475 (in places at the peak of HB 560-675). There are no structural changes in the “E” zones at the peak and peak and in the “N” zone of the peak. At the peak in this zone, the depth of structural changes is 0.15 mm (HV 340-560).

of sorbitol -type parts with a finely dispersed structure.

The fractal dimension D of the structure of the hammer and the peaks of the hydrohammer after detonation spraying at a magnification of 100 was calculated by the Hausdorff formula [17. (2) (cellular dimension) (1) and by the point dimension formula (2):

$$D = -\lim_{\delta \to 0} \frac{\ln N(\delta)}{\ln \delta}. \qquad (1)$$

where $N(\delta)$ is the number of cells with linear size d that cover the object under study.

The point method is an alternative approach to the cell method when calculating the fractal dimension. For its implementation, the entire fractal is covered with a square grid. The nodes of this grid will be called cells. Each cell that has a non-empty intersection with the fractal will be considered as one point. The point method is fundamentally different from the cell method: in the first, the number of points in each cell is counted, while in the second, the number of cells needed to cover the fractal. To simplify the calculations, we will consider the cells to be square. The cell size L is taken as the number of cells on each side of the fractal. Let’s limit ourselves to odd values of cell size L; in this case, the central cell of the cell will be equidistant from all sides. First, let’s calculate the probability $P(m,L)$ that the size cell L contains m points (cells) of the fractal. To do this, around each point of the fractal, assuming it to be the central one, we will build a size cell L and count the number of points that fall into it. Suppose that the fractal contains M

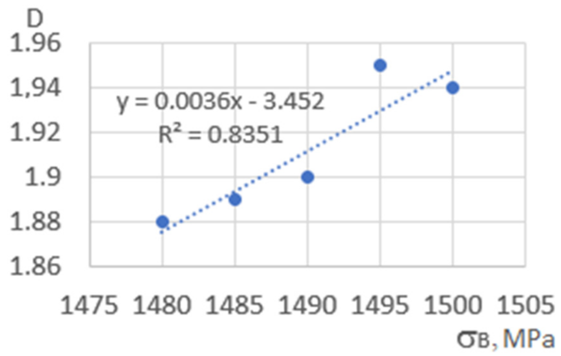


Fig. 7. The relationship between the fractal dimension of the body surface D and the strength limit σ_B for axial samples

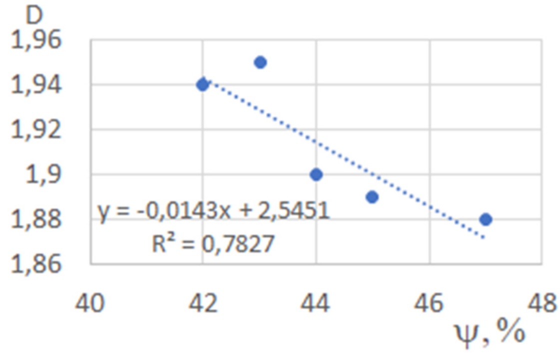


Fig. 8. Correlation between the fractal dimension of the D peak surface and the relative narrowing for tangential samples

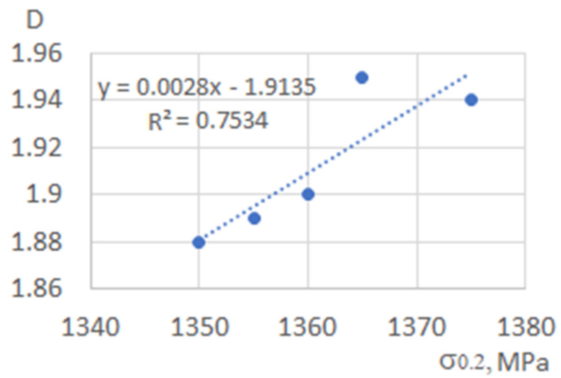


Fig. 9. The relationship between the fractal dimension of the body surface D and the yield strength σ0.2 for axial samples

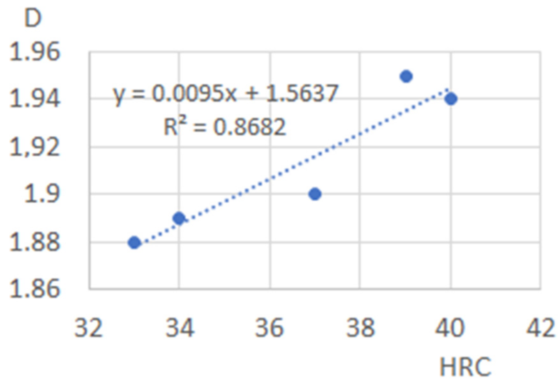


Fig. 10. The relationship between the fractal dimension of the surface of peak D and its HRC hardness in the tangential direction

the point $m = 1,...,M$. Then $P(m,L)$ is equal to the ratio of the number of cells containing m points, $m = 1,...,M$, divided by M . It is worth noting that the sum of all probabilities is equal to one:

$$\sum_{m=1}^{M} P(m,L) = 1 ,$$

The number of cells N with the size L that contain m points is equal to $(M/m)P(m,L)$:

$$N(L) = \sum_{m=1}^{K}(M/m)P(m,L) = M\sum_{m=1}^{K}(1/m)P(m,L)$$

where is K −the possible number of points in the cell. Accordingly, the average value was used to estimate the fractal dimension D:

$$\tilde{N}(L) = \sum_{m=1}^{K}(1/m)P(m,L) \sim L^{-D} \qquad (2)$$

The stages of determining the fractal dimension of microstructure elements are shown in Fig. 6. Dependencies D1 and D2 describe the fractal dimension of the sorbitol structure by cellular (1) and point methods (2). Their convergence is observed at the seventh step of calculations, hence their average value is Dt =1.898+1.897=1.898. The fractal dimension of photographs of the fracture surface was calculated by software after setting the range of colors of the structural components in gradations of gray (Fig. 6).

Results describing the influence of the fractal dimension of sorbitol the structure of the peak and the body on the mechanical properties are shown in Fig. 7 - Fig. 10.

Analysis of ratios between fractal dimensions sorbite structure and characteristics of the strength and hardness of the body (Fig.7, Fig. 9) and peak (Fig. 10) show that the increase in the fractal dimension of sorbite is caused by the increase in strength and hardness indicators. The connection between the microstructure of materials and their properties is confirmed in works [18-20]. An increase in hardness indicators leads to a decrease in plasticity indicators, which is confirmed by the results of a decrease in the fractal dimension of the sorbite structure in Fig. 8.

5. Conclusions

Hydraulic hammer parts has been created and tested, which is based on testing parts after various strengthening options and provides action during the loading process of pressures and gas-dynamic characteristics that simulate the relevant parameters of operational loads.

2. Tests of parts strengthened by the researched methods showed that, compared to the initial version, a significant increase in wear resistance is achieved:

- in the controlled cross-section of the fight and peaks during strengthening by detonation -gas surfacing, while the crack resistance of the material increases by 1.3-2.4 times compared to the initial state.

3. Mathematical models were obtained, which makes it possible to carry out an operational forecast of the mechanical properties of hydraulic hammer parts strengthened by detonation spraying based on the analysis of their fractal structure within an error of up to 6%.

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