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doi:10.15199/48.2019.05.10

Application of explosion treatment methods for production Items of powder materials

***Abstract**. The article gives the peculiarities of the compaction of the sintered powder blanks at a high impact energy effect by the hot isostatic pressing, intensive plastic deformation twist extrusion and explosion pressing. The ways of increase of the mechanical properties of powder parts are shown. The results of the experimental researches on the explosive compacting from the tested powder blanks after preliminary sintering are given.*

***Streszczenie**. W artykule podano specyfikę zagęszczania spiekanych półfabrykatów proszkowych przy silnym wpływie energii uderzenia przez gorące prasowanie izostatyczne, intensywne odkształcenie plastyczne, wytłaczanie skrętne i wytłaczanie eksplozyjne. Pokazano sposoby zwiększania mechanicznych właściwości części proszkowych. Przedstawiono wyniki badań eksperymentalnych zagęszczania eksplozyjnego badanych półfabrykatów proszkowych po wstępnym spiekaniu.(**Zastosowanie metod eksplozyjnych do produkcji sproszkowanych materiałów**)*

Keywords: sintering, explosion, compacting, powder parts.
Słowa kluczowe: spiekanie, eksplozja, zagęszczanie, części proszkowe.

Introduction

To successfully solve a set of interrelated tasks to maintain competitiveness in the world market, increase labor productivity, use capital efficiency and maintain high rates of economic development, the major role belongs to the methods of the powder metallurgy. These methods, due to a number of advantages, in comparison with the other methods of metal working find wide application in the production of blanks and parts of gas turbine engines, cutting and stamping tools, energy conversion and generation systems, surgical implants, etc.

At the present time, the compaction of powder materials is most efficiently performed using the high-energy methods of deformation and shaping, such as: the hot isostatic pressing, intensive plastic deformation, dynamic pressing, isothermal stamping into a closed volume, explosive pressing, etc. [1]. The main disadvantage of the blanks obtained by all known methods of the powder metallurgy is the residual porosity, which reduces the mechanical and physical properties and performance characteristics of the resulting parts. To further maintain the high growth rates of key sectors of production and economy it is necessary to find methods to improve the mechanical properties of blanks and parts of the powder metallurgy.

The pulse methods of the metal working in a series of cases allow either significantly improve the quality indices of parts wedging in the existing methods or entirely substitute them. For instance, in case an additional pulse effect of insignificant intensimty is made on the workable blank during the hot isostatic pressing after the primary sintering, then the parts will have the structure with the unsurpassed density [2]. The mechanism of obtaining the dense structures is theoretically and experimentally grounded by the authors [2, 3].

Research methods

In the explosive pressing the density of the products obtained practically reaches the density of a solid. However, at the explosive pressing there occur great difficulties associated with obtaining an even density distribution over the cross section of the blank [1]. The explosive treatment results in a significant increase in the chemical and cathodic activity of a number of powder materials in comparison with the initial ones. This results in an increase in the adsorption of halogens and oxidation of the materials forming the finished part and also reduces its qualitative indices.

Many studies are devoted to improving the performance characteristics of the products obtained from the powder materials. The most common in the industry are the surface modification methods, i.e. the ion-beam treatment, laser hardening, electric explosive and explosive alloying. The need for such studies is due to the fact that the technology of the hot isostatic pressing is effective for the workpieces obtained by sintering the metal powders. The main task of the hot isostatic pressing is to eliminate porosity and increase the homogeneity of the material structure [1]. However, the hot isostatic pressing is effective only if the defects of the workpiece being treated (pores, friability, shells) are internal and not related to the surface of the workpiece [4, 5]. The greatest effect in the synthesis and development of new technologies can be obtained when creating the combined treatment methods. During the explosion treatment the superdense structures can form in a small time interval of the impulse action. The intention of the authors was to compact or strengthen the finished products. There are still no reliable theoretical dependencies of the degree of compaction of the treated material on the indicated parameters and factors. Therefore, there was a need for a complex of experimental studies. In the experiments the sintered cylindrical samples 5 mm in diameter with a length of 50 mm, prismatic ones with a size of 50x10x10 mm, 6.5x6.5x44 mm and blanks from the sintered powder materials were explosively treated (Fig. 1).

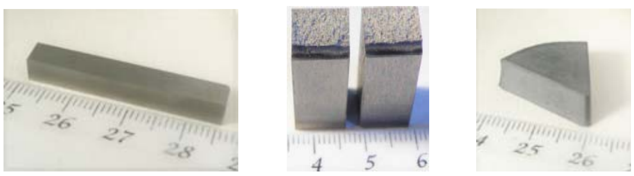


Fig. 1. Samples from powder materials after preliminary sintering

The cylindrical samples were placed in a copper shell and loaded with a "traveling" shock wave according to the scheme (Fig. 2).

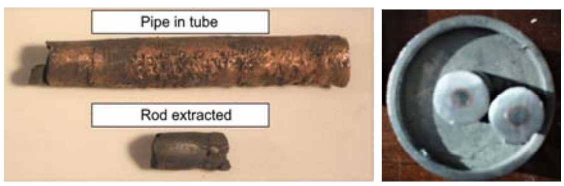


Fig. 2. Samples in shells

Also such a scheme is used in the explosion welding in the production of the nanocrystalline materials (Fig. 3) [6].

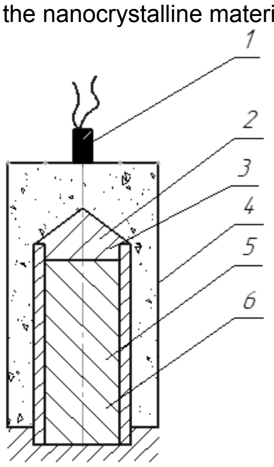


Fig. 3. The scheme of the explosive compaction of cylindrical samples: 1 – the detonator; 2 – the charge of the explosive; 3 – the generator of a plane shock wave; 4 – the shell for the explosive; 5 – a sample; 6 – a copper shell

Therefore, it was completely justified to place the sample being compacted in a shell of a ductile metal (copper, aluminum). In addition, with the explosive loading it is possible to realize many variants of the force loading schemes, such as a flat and "traveling" wave under the contact explosion, flat and "traveling" shock waves from the collision with the thrown plate (Fig. 4), multiple compression of the strengthened material with the reflected shock waves, (Fig. 5) convergent shock waves in various transmitting mediums, cavitation hardening, combined hardening [7 – 9].

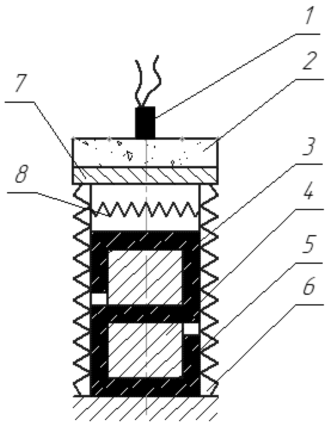


Fig. 4. The scheme of the compaction by throwing the striker: 1 – the detonator; 2 – the explosive; 3 – copper shell; 4 – samples; 5 – a copper shell; 6 – the corrugated support; 7 – the striker; 8 – the elastic screed

The pressure at the explosive loading ranged from 30 to 70 GPa. The samples were made of the titanium, tungsten carbide with cobalt powders, etc. The results of the investigations of the microstructure of the samples after the explosive loading made it possible to determine that the porosity in the surface layer did not exceed the porosity of the parts manufactured in the production [10, 11]. At pressures above 40 GPa, inclusions of fine-grained diamonds were observed in the samples made of the carbide-containing powders. However, the density of the samples did not exceed the density of the parts obtained by the hot isostatic pressing. All the samples were welded to the copper shell in case the special techniques were not used [12 – 14].

The explosion strengthening by converging shock waves and the cavitation strengthening did not give positive results for the pre-compression of powder materials. The explosion stamping of a small part was carried out in the pool (on depth of 2 m). The mass of the charge was 5 g. The best results were obtained with the pressure in the liquid of 0.2 MPa and the use of a shell made of a sand-resin mixture of a cold curing. For the experiments a universal loading scheme was used in a closed volume of a liquid, in a pipe (Fig. 6).

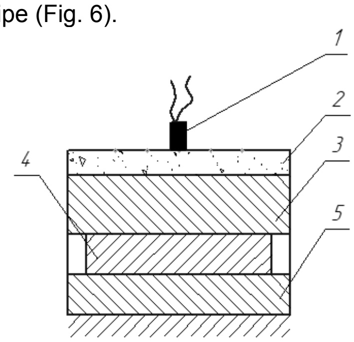


Fig. 5. The scheme of the explosive compaction by a repeated compression: 1 – the detonator; 2 – the explosive; 3 – the plate with a greater acoustic rigidity; 4 –sample; 5 – the plate with a lower acoustic rigidity

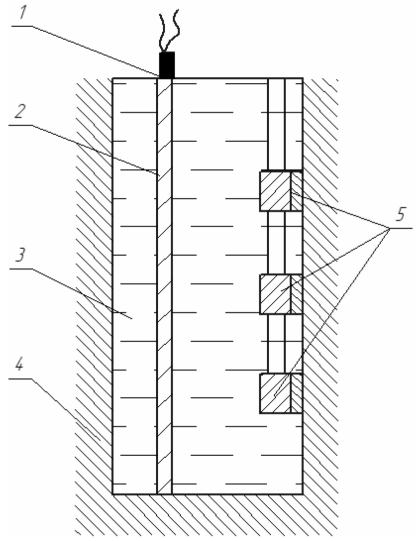


Fig. 6. The scheme of hardening in a closed volume: 1 – the detonator; 2 – the detonating cord; 3 – the transmission medium; 4 – the rigid walls; 5 – the compacted samples

The minimum explosion distance was selected from the condition that samples were not destroyed. Then it increased.

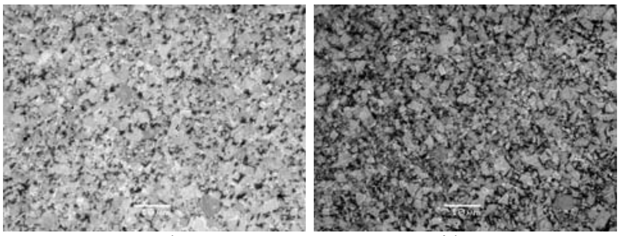
Experimental research results

The samples treated with the blast energy have passed the final sintering procedure at the temperature of 1380 °C. After grinding the samples the following studies were carried out: 1) the determination of the hardness; 2) the bending test; 3) the determination of porosity; 4) the analysis of the microstructure. The results of the studies are given in table 1.

Table1. Mechanical tests

Sample No.	Ultimate flexural strength (σ_{flex}) [MPa]	Hardness [HRA]	Porosity [%]	Note
1	2.202	90	0.02	Serial technology
2	1.568	90	0.02	
3	1.691	90.5	0.02	
4	2.484	89.5	0.002	Impulse working
5	2.43	89.5	0.002	

The microstructure studies were carried out with an optical microscope with an increase of 500 and a Jeol JSM3060LA scanning electron microscope with an increase of 1500. The microstructure of the sample manufactured by the serial technology is shown in Fig. 7, a. It was evaluated on the basis of GOST 9391-80. The grade of porosity was estimated on the scale A and corresponds to A 0.02% (TT GOST 4872-75 for VK-8 grade, the porosity is not more than 0.2%). Free carbon is not detected (according to GOST no more than 0.2%). The η-phase (double tungsten carbide with cobalt) is revealed in the form of "lakes" and "lace". The presence of η-phase TT GOST 4872-75 is not allowed [15 – 17].



a) b)

Fig. 7. Microstructures of the samples: a – sample made according to the serial technology; b – sample after a low-intensity impulse loading

In Fig. 7, b the microstructure of the sample is shown after the explosion treatment. The porosity was evaluated on scale A and corresponds to A 0.02%. The unwanted η-phase is not detected, a distinct tendency is observed to obtain a more dense structure [18].

The results of the research formed the basis for the technology for producing gas turbine engine parts from alloyed powders, and also are used in the manufacture of the cutting tools from hard alloys (Fig. 8).

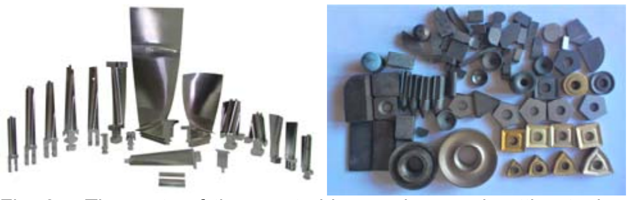


Fig. 8 – The parts of the gas turbine engines and cutting tools of powder materials obtained by the new technology.

Theoretical research

Modeling the process of the pulse deformation of powder materials, which is based on the equations describing the law of conservation of mass, momentum, energy and the state of the elastoplastic porous disruptible medium also does not answer the question of anomalously high compacting of the medium at the pulses of small amplitude. The most adequate result was obtained using the determining relations for the inelastic strain rate in the form of Gilman-Johnston

(1) $$\dot{\varepsilon} = bc_s\left(n_o + 0,75m\varepsilon\right)\exp\left[-2\left(D + 0,75H\varepsilon/\sigma\right)\right]4/3$$

where ε – the deformation; $\dot{\varepsilon}$ – the deformation velocity or volume change velocity; b – the average distance between pores; c_S – the speed of the sound in the transverse direction; n_0 – the average statistical initial pore density; D – the empirical constants; m – the coefficient of pore multiplication; H – the hardening constant, σ – the stress intensity.

In the Gilman-Johnston's dependence the authors proposed to use instead of the interatomic distance (modulus of the Bygers vector) the average distance between the pores of the powder material after the primary sintering. The initial density of dislocations is replaced by the specific average statistical density of the pores. The hardening constant of the powder material is determined experimentally [19].

For the fixed values of the stress intensity the relation (1) has an extremum

(2) $$\dot{\varepsilon}_i = \frac{4}{3m}\left(\frac{\sigma_i}{2H} - n_o\right).$$

When the extremum $d\dot{\varepsilon}/d\varepsilon = 0$ is reached, the value of the deformation rate corresponds to one of the conditions for the localization of deformations the loss of stability of the pore wall. In the first case the pores merge with each other and their concentration is in the middle of the sample. In the second the pores go out on the free surface and the compaction of the porous material occurs. This explains the fact that the coating of samples with materials of different acoustic rigidity affects the process of compaction of the porous blank. High pressures lead to the acceleration of the tentative shell of the pore. At the velocities of the shell that are comparable with the sound velocity of the gas filling the pore cavity, the shock waves are generated inside the porous material of the sample or blank. The additional shock-wave action during the collapse of the pores results in the formation of cracks and destruction of the pressed material.

Conclusions

The pulse loading of low intensity in a closed volume with a liquid the pressure of which is equal to two atmospheres of the powder blanks after the primary sintering at the frequency characteristics corresponding to the lower threshold of the sound frequencies (4 - 8 Hz) leads to the production of nonporous structures while the solid alloys (WC + Co) acquire the plastic properties and the alloys based on the titanium and alloyed titanium powders acquire the plasticity exceeding the initial by 12 – 15 % and an increase of 24 – 27 % of the bending strength of the finished products.

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