High-Speed and High-Temperature Powder Metallurgy for Energy Efficiency and Environmental Protection

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Abstract: - The article examines various approaches to creating industrial products from metal powders using powder metallurgy methods. The advantages of powder-metallurgical methods for the production of details in comparison with classical methods are cited. Innovative grinding bodies and grinding media are presented. Possibilities of adding micro and nano elements are considered. A high-speed and high-temperature technology for obtaining wear-resistant materials is described. Possibilities for the utilization of waste materials - glass and electronic boards - were discussed. Applications in industry, medicine, and agriculture are presented.

Key-Words: - metal powders, innovative grinding bodies, innovative grinding media, powder metallurgy, high-speed compacting, high-temperature sintering, waste processing, energy efficiency.

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1 Introduction

Globally, 20% of the extracted energy is used for crushing and grinding processes. The use of innovative grinding bodies and grinding media makes grinding energy efficient. Also, the processes of chip removal, forging, and similar have high energy costs and high losses, especially for metal products. Some waste products are harmful, break down slowly, and pollute the environment. The processing of other waste materials (glass, electronic boards) contributes to environmental protection.

Mass-spread methods for thermal and chemical-thermal treatment of tool and structural steels are gas carburizing and gas nitrogen carburizing. Shaft furnaces are used with external indirect heating of the products in retorts. Other additional equipment is used for tempering, including second-heat tempering furnaces, conveyors, oil baths, degreasing equipment, retort furnaces, etc. These methods are characterized by several disadvantages such as high consumption of reactive gases, non-uniformity of the diffusion layers, a high degree of environmental pollution due to the release of poisonous gases during quenching, the presence of technological waste from the quenching oil, and the need to degrease the products after quenching by using organic and inorganic degreasers, partial decarburization and oxidation of the surface of the products during transportation in a heated state.

The high efficiency of powder metallurgy (PM) lies in the production of materials or products that are technologically impossible or economically unprofitable to produce by other methods. A feature is that the products are produced using practically waste-free technologies, [1], [2], [3]. Regardless of the higher price of powders than that of cast metals, the price per PM unit is lower than that of cutting, stamping, milling, etc. With PM, the coefficient of use of materials is in the range of 95-97%, while with processing by cutting, this value is only 50-60%. The small number of operations (3-5), allows for the concentration of the production of parts in one place, and this is related to increasing productivity and automation, reducing energy losses and the number of staff. As a result - lowering the price of the final product. When working with automatic presses, the amount of powder needed to obtain a blank with a certain density is precisely dosed, avoiding material losses inevitable in the mechanical processing of cast parts. The method is unique in the production of composite materials on a metal or ceramic basis: copper-graphite for current-carrying parts, WC-Co for metalworking tools, W-Cu alloys, and many more. Others, [4], [5], [6]. These materials include the methods proposed for development with the inclusion of micro and nano elements - based on titanium carbide (TiC) and based on boron carbide (B4C).

In the paper, we offer the following innovations:

- obtaining metal powders through innovative grinding,
- obtaining blanks from metal powders by high-speed impact pressing,
- production of powder-metallurgical details by high-temperature sintering,
- obtaining powders from other materials - broken glass, broken electronic boards.

2 High-Speed Metal Powders Compacting

The developed product represents an innovative technology for obtaining metal products by the methods of powder metallurgy. The innovative technology involves the energy-efficient production of fine metal powders by grinding using patented innovative grinding bodies (Reuleaux tetrahedron* - Figure 1, [7] in mills with patented innovative grinding media (Reuleaux triangle lifters** - Figure 2, [8]. The inclusion of micro- and nano-elements (for example, titanium carbide or boron carbide) in the metal powder material is planned to increase the hardness and wear resistance of the parts.

Fig. 1: Reuleaux tetrahedron

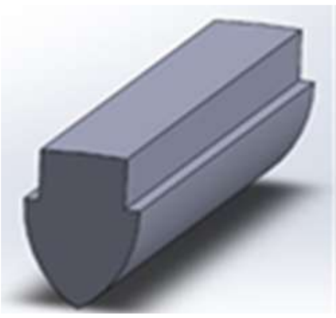


Fig. 2: Lifter with a section triangle of Reuleaux

**Reuleaux tetrahedron – has the largest area of all convex 3D figures with equal volume*

***Reuleaux triangle – has the largest perimeter of all convex 2D figures with equal area.*

The energy efficiency and better quality of the metal powder are demonstrated by using a ball mill - tandem with one drive on two drums - Figure 3. In one drum are placed the innovative tetrahedrons of Reuleaux and in the other - traditional spherical grinding bodies. At the same speed and the same grinding time, the size of the particles from the two drums and their size distribution are compared with a laser nano-granulometry unit with a lower limit of 10 nanometers - Figure 4. If the uniform particle size is required, it is proven that with the innovative grinding bodies, this is achieved in a shorter time, correspondingly with less energy consumption.

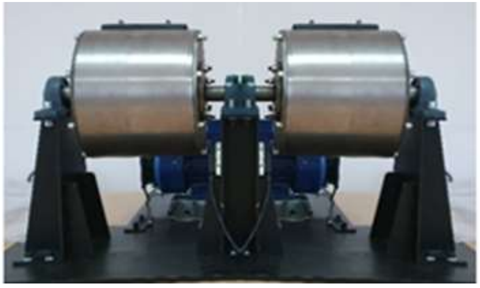


Fig. 3: Ball mill – tandem

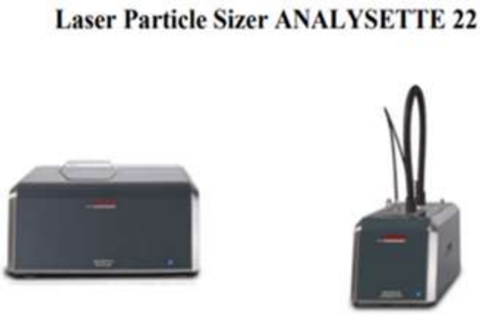


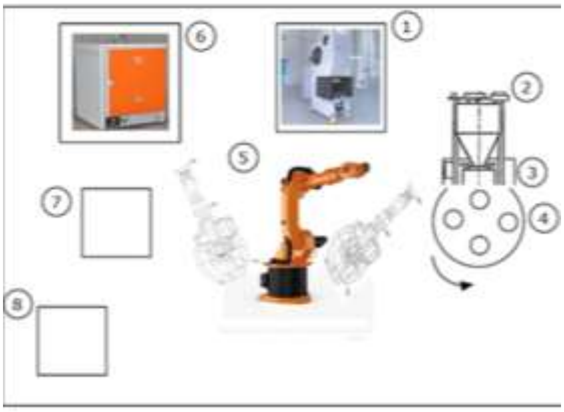
Fig. 4: Laser nano granulometry unit

The obtained metal powders by grinding or atomization [9], [10] are placed in test matrices of different shapes and compacted by a high-speed impact press with frequency control and the ability to set the number of impacts - Figure 5. The blanks thus obtained are sintered in an oxygen-free environment in a muffle furnace up to 1700-1800 ^{0}C - Figure 6. If hardening is required, the parts are annealed to 900 ^{0}C and reheated in an electric furnace to 1100-1200 ^{0}C.

Fig. 5: Impulse impact press hammer

Fig. 6: Muffle furnace

In Figure 7 the structure diagram of the developed innovative technology is shown. Metal powders obtained by innovative grinding (possibly with added micro and nano elements) are poured from a dosing device into special matrices. The matrices are located on a four-position rotary table. A robot takes the completed matrices and places them in a high-speed press, where the metal powder is compacted into blanks. The blanks are placed in a high-temperature furnace, where they are sintered.



1-Impulse press hammer
2-Bunker for metal powder
3-Dosing device
4-Rotary table
5-Stationary robot
6-High-temperature furnace
7-Table for details
8-Control panel
Fig. 7: Innovative technology for obtaining metal powder products

3 High-Temperature Metal Powders Sintering

We also offer an innovative high-temperature technology (over 2000 ^{0}C) for active sintering of high-temperature wear-resistant boron carbide materials using a technological line with a graphite Tamanov furnace - Figure 8. The Taman furnace is a thick-walled graphite tube, short-circuited to a powerful current source. In the Work Zone, the walls are thinned, the resistance is greater and the zone heats - max. up to 2300 ^{0}C, a temperature that only graphite can withstand. Graphite ships are pushed through the Work Zone from the conveyor with a pusher rod - Figure 9, filled with mixtures of metal powders that are melted and homogenized.

Fig. 8: Technological line with graphite Tamanov furnace

Fig. 9: Graphite ship

In the hierarchy of materials in terms of hardness, boron carbide ranks third after artificial diamonds and the cubic modification of boron nitride, but the synthesis of B4C proceeds relatively easily. The synthesis of (BN)c from (BN)h takes place under higher temperatures and pressure than the synthesis of diamonds from carbon materials. In addition to super hard (~40 GPa), boron carbide also belongs to hard-melting (2450 ^{o}C) materials.

The applications are:
The B4C is used in the manufacture of the nuclear reaction control systems, [11]. The B4C is used also in military technology for making bulletproof vests, and armor for tanks and helicopters. Calipers, templates, sharpening tools, thermocouple guards, mortars, etc. are made from boron carbide. Boron carbide produces high-quality sandblasting and shotblasting nozzles with diligence in metallurgy,

engineering, shipbuilding, architecture, and dentistry. B4C is used for nozzles instead of Al2O3, in tumor diseases instead of BNC, [12]. The high thermal and chemical stability determine the application of B4C in the architecture of fuel cells as a catalytic carrier, [13].

4 Processing of Other Waste Materials

Another innovation is grinding instead of melting a waste product - broken glass and the idea is to use the resulting fine glass powder in construction in the production of concrete. The quality of the obtained material is established through research in specialized laboratories. Glass waste (flat glass, bottles, jars, household baking dishes, LCD screens, etc.) is very suitable for processing in ball mills. Depending on the operating modes of the ball mill and the duration of grinding, products of different shapes and sizes can be obtained. Larger products with a size of 4 - 20 mm are used as substitutes for gravel. Products with smaller sizes are used as substitutes for sand or cement (< 48 µm).

It is also an innovation to grind other ecologically harmful waste products - crushed electronic boards, from which metal powder can be separated from the busbars and other metal elements using a cyclone-type separation and filtering through water instead of direct disposal. Metal powders are sifted in a system of precision sieves.

5 Conclusion

Innovative grinding bodies and innovative grinding media enable energy-efficient production of metal powders. The addition of micro and nano elements in metal powders, high-speed impact pressing, and high-temperature sintering make the products harder and wear-resistant. The reduction of waste products, as well as the disposal of other waste materials, contribute to the protection of the environment.

Materials with high hardness and wear resistance, produced with energy-efficient technologies, can be used in various industries, for example, for elements in the construction of large buildings in agriculture – greenhouses, and hothouses in crop production, stables and cowsheds in animal husbandry, etc. Materials produced from waste products such as glass can also be used in these industries, [14], [15].

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