Research and engineering by REC "Mechanobr-technika" of additive technologies

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Abstract. Demand for additive technologies and necessity for high-quality metal powders are growed. The results of technological research of finely dispersed powders was explored. This finely dispersed powders was gotten by vibration effects to produce conditioned commercial products that meet the requirements of additive technologies. This product can be used in powder metallurgy, mechanical engineering, processing metal waste. Research is observed of application of grinding metal waste from metal processing using the example of nickel cutting and the subsequent production of metal powders.

1. Introduction
All industrial production, where the raw materials are powder materials, in acutely need of a high degree of purification when the quality of the finished product depends on the starting component.

The problem of obtaining high-quality feedstock is not ignored by additive technologies, where due to the high sensitivity to the feedstock of prototyping plants, together with the high cost and complexity of manufacturing the final parts, a number of stringent requirements are imposed on metal powders, one of which is a certain size and particle shape. The traditional method of producing metal products by sintering powder and their subsequent mechanical processing is increasingly inferior to the method of producing parts by additive technologies. They are based on methods of fusing layers of material between themselves using a 3D printer [1-3].

In strategically important industries, such as aviation, space, shipbuilding, the main material for the manufacture of parts is metal powders. Serious quality requirements are imposed the source material: high purity of the alloy, a certain size and spherical shape of the particles. Recycling of metal waste from the processing of engineering parts remains a sought-after task. When machining, about 40% of the waste is obtained, containing important expensive alloying additives of molybdenum, tungsten, chromium and others [4-8].

The Mekhanobr-Tekhnika company develops technologies and equipment based on combined physical effects - vibrational, magnetic and electrical, which allows to radically improve the quality of the obtained powders, namely: to improve fluidity due to more complete removal of very fine fractions; remove non-metallic and ferromagnetic inclusions, as well as non-spherical particles; classify powder materials by size.

As an unconventional method of producing metal powders, the method of obtaining powders from metalworking waste such as shavings, trimmings, lump scrap, briquettes, rods, wire is also of interest.
2. Technology of vibrational disintegration of metal chips

One of the main technological operations in powder metallurgy is the production of metal powders of the required dispersion and shape. The most widely used for these purposes is mechanical grinding of the starting material in vibrating or rotating ball mills. In almost all traditional devices used in world practice, the method of applying the load is concentrated, and its place of application and magnitude are random. Under such conditions, random destruction of crystalline blocks is observed, which is little dependent on defects in their structure. The abrasion effect common to all ball mills, in addition, leads to pelletizing. In general, ball grinding is very energy intensive, time-consuming and inefficient [9].

The scientific approach to the problem of the destruction of rocks as solids with a multiphase structure allowed Mechanobr to develop a vibrational disintegration method that uses in its basis heterogeneity of the material, in particular microdefects of the structure, and force action by combined vibrational compression with simultaneous shear. This method is implemented in various types of vibrating crushing and grinding machines, which include an inertial cone crusher and a vibratory mill. figure 1 and 2 [10].

For research, a basic technological scheme of disintegration was developed, including crushing of the initial chips to a particle size of less than 5 mm in a high-speed impact rotor disintegrator, followed by its mechanical processing in a cone inertial crusher (KID) and further grinding in a vibratory grinder to a particle size of less than 0.125 mm [11].

In accordance with the schematic diagram, preliminary studies of the grinding of metal chips with the help of vibrating devices were carried out. The studies were carried out on samples of an iron-nickel alloy (nickel content 70%) weighing 2.5 kg each. The closed cycle on the vibration grinder was organized by discrete circulation of a class larger than 0.125 mm in the amount of 4 cycles without adding the source material. In the process of preliminary research, testing methods, sampling and processing of samples, measurement and processing of technical and technological parameters were worked out. In the process of research, an assessment was made of the influence of the degree of vibrational impact on the material when it is crushed in a vibratory crusher KID on the efficiency of its
further grinding in a vibration grinder. The degree of vibration exposure is determined by the number of passes of the material through the crusher. Variants of the degree of vibrational impact on the material included 2, 5, and 10 passes through the vibratory crusher KID, as well as the option in the absence of such an impact. The grinding efficiency was estimated on the basis of specific indicators of the performance of the vibration mill for particle size classes less than 125 and 74 microns, as well as specific energy consumption for the production of these classes. The analysis of particle size distribution was carried out using the Analysette 22 NanoTec plus universal laser analyzer, the results are presented in the figure 3.

Analysis of the results of the research of the vibration disintegration chip revealed:

– The use of the KID vibratory crusher (depending on the intensity of exposure and the method of supplying the starting material) made it possible to increase the specific productivity of the vibration grinder by 18-29% in the class of less than 125 microns and by 22-59% in the class of less than 74 microns. At the same time, the total specific energy consumption for the production of finished products with a particle size of less than 125 and 74 microns decreased by 6-7% and 8-22%, respectively.

– The increase in grinding efficiency in the vibration grinder depends not only on the number of passes through the KID, but also on the method of supplying the starting material.

Analysis of the physical properties of the ground metal powder by narrow particle size classes showed the following:

– With a decrease in particle size in the range from 1.25 mm to 0.074 mm, the effective viscosity decreases from 5.0 to 3.6 E -9. Thinner classes are characterized by an increase in viscosity to 5.42 (for the class 0.074-0.044 mm) and a complete lack of fluidity for the class less than 0.044 mm.

– In the range of narrow size classes from 1.25 to 0.25 mm, the pour density increase from 2.63 to 3.45 g/cm³. In particle size classes less than 0.25 mm, a decrease in particle size gradually reduces pour density from 3.33 to 2.08 g/cm³.

– The shape of the particles varies depending on the size class: in the size range from 1.25 to 0.5 mm there are particles of a scaly shape, in the size classes from 0.5 to 0.18 mm the number of particles of a rounded shape with smoothed edges and surface is growing. In the particle size classes less than 0.125 mm contain more particles of an angular shape, particle sizes less than 0.074 mm are almost entirely composed of shard particles. In the particle size classes less than 0.125 mm contain more particles of an angular shape, particle sizes less than 0.074 mm are almost entirely composed of shard particles.

![Figure 3. Granulometric composition of nickel powder after vibration disintegration.](image-url)
The results showed that the average particle size of the obtained powder, \( d = 100 \text{ microns} \), and a particle content of less than 10 microns is only 3%. This particle size distribution meets the requirements of additive production, since the content of fine particles of more than 10% leads to a deterioration in the fluidity of the powder and its sticking in the feed system. Atomization must be carried out to obtain a spherical particle shape.

This study showed an energy-efficient method for processing metal waste to produce powders for the traditional method of manufacturing parts and additive technologies.

3. **Improving the quality of finished metal powders**

Production, where the feedstock is powder materials, is in urgent need of a high degree of purification, because the quality of the finished product directly depends on the material.

Getting high-quality raw materials for powders is a big problem. This also applies to such a dynamically developing industry as additive technologies. A number of stringent requirements are imposed on metal powders, the main ones of which are a certain particle size and shape. This is due to the method of manufacturing parts, the high cost and complexity of manufacturing the final parts.

This article presents the results of experimental studies that show the possibility of improving the quality of powder materials.

The object of research was finely dispersed metal powders of various compositions and fractions of highly alloyed alloys. In order to bring fine powders to the required quality, each powder was investigated separately, depending on the tasks formulated from the composition of the initial powder and the contaminants contained in it.

One of the tasks is the removal of non-metallic inclusions and particles of non-spherical shape obtained from high-speed steel, which are formed during production, from a finely dispersed metal powder with a fraction of 0-200 \( \mu \text{m} \) [12]. The developed technological scheme for refinement of metal powder to a commercial product included two stages: preliminary removal of non-metallic inclusions by low-intensity magnetic separation in an inhomogeneous magnetic field with a magnetic induction of 0.35 T and removal of non-spherical particles on a developed and manufactured prototype electrostatic separator with power supply to mode of vibrational fluidization of the material. The developed device allows you to separate powder materials by particle shape and uses its work in a combination of gravitational and electrical effects. Moreover, to select the optimal separation mode, the determining factor was the magnitude of the electric field \( U, \text{kV} \). Analysis of the separation products was carried out visually, using a Bresser Science MTL-201 metallographic microscope, as well as by the yield of the finished commercial product.

The principle of separation on the developed device: using a vibrating feeder, the material was fed to a horizontal deck performing asymmetric reciprocating movements under the action of an eccentric or unbalanced (inertial) drive. Above the deck is a high-voltage electrode connected to an external high-voltage source. It allows you to adjust the magnitude of the electric field in the range from 0 to 45 kV. Particles of the material have different electrical properties and differ from each other in shape, transported along the deck, forming two fans of separation products and unloaded in the respective collections. The separation results are presented in figure 4 and table 1.

![Conditioning powder](image1.png) ![Non-spherical particles](image2.png) ![Non-metallic inclusions](image3.png)

**Figure 4.** Results of the separation of finely divided metal powder obtained from high speed steel.
Table 1. The results of the separation of finely divided metal powder from high speed steel.

| Material                        | Mass recovery, % |
|--------------------------------|------------------|
| Conditioning powder            | 73.2             |
| Non-spherical particles        | 10.4             |
| Non-metallic inclusions        | 16.4             |
| Grand total                    | 100.0            |

As a result of experimental studies on fine-tuning finely dispersed metal powder of excess cutting steel fractions of 160-200 microns, it was possible to obtain a commercial grade product with a mass recovery of 73.2%.

Of increasing interest is the manufacture of polymetallic products using additive manufacturing methods. This allows you to get parts or individual elements that differ in composition and properties from the base material [13]. A number of advantages:

- the use of a lighter alloy in the basis of the product allows to reduce the mass of the developed design;
- the production of specific sections of parts from carbide metals can improve the strength properties and save on material.

For the study, a mixture of Inconel 718 metal powders and CuSn5Pb5Zn5 (ratio \( \approx 50/50 \) by weight) was provided.

Size distribution is Inconel718 0-50 \( \mu \)m; CuSn5Pb5Zn5 0-80 \( \mu \)m. Visual difference in color: gray/brown.

The separation was carried out on an electromagnetic separator EVS10/5. The separation principle is based on the difference of powders by magnetic properties.

Principle of operation: the initial power enters the working area of a strong magnetic field formed by the surfaces of the roll and the pole piece. Weakly magnetic particles are carried out by a rotating roller into the zone of a weakened magnetic field, where they come off to form a wide fan: smaller particles and particles with greater magnetic susceptibility fly further and fall into the last compartment of the separation product collection. Non-magnetic particles slide along the pole piece and fall into the first compartment.

Studies of the received separation products of the Inconel 718- CuSn5Pb5Zn5 were carried out using a Jeol JSM-6490 scanning electron microscope with an INCA Energy energy dispersive X-ray analyzer. The images of the particles of the powder mixture and the results of microanalysis are shown in table 1. The particles of CuSn5Pb5Zn5 powder are highlighted in red, green, Inconel 718 powder particles.

The results received indicate that the impurities of one component in another are not more than 2.5%. 100% separation can be achieved by increasing the number of rewashing.
Figure 5. Images of the powder mixture and the results of microanalysis: a, b - before analysis; c, d - after analysis.

4. Conclusions
Studies have shown the possibility of obtaining high-purity conditioned metal powders, obtained mainly by magnetic and electrical methods in combination with vibration effects. It should be noted, that all the equipment used for research is characterized by high performance, low energy consumption and environmental safety.

A technological scheme of vibration disintegration was developed and preliminary studies were carried out on the grinding of metal chips from highly alloyed alloys based on vibratory crushing, grinding, and vibration classifying technological equipment from the initial size to fineness of less than 0.125 mm.

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