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PROBLEMS AND POSSIBILITIES OF LASER SYNTHESIS OF METAL POWDERS IN ADDITIVE TECHNOLOGIES

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Abstract:

Objective. To carry out research on the production technology of powder materials used in the production of products with additive technology, to apply the obtained results for the purposes of powder metallurgy.

Methods. The mechanical methods of obtaining metal powders are studied in the article, and the properties of formation without significant changes in the chemical composition of the powder material are highlighted.

Results. Depending on the aggregate state of the initial components in the reaction zone, results were obtained for three main types of the reaction process: solid-phase, non-gaseous and gaseous types. It was found that during the solid phase reaction, the metal particles in the powder mixture retain their original size. It was found that the reaction rate of gasless combustion does not depend on pressure and the constant mass of the formed particle is maintained. The dependence of the gas combustion reaction rate on pressure and the change in the mass of powder particles during the process were determined.

Conclusion. In the process of mechanochemical synthesis, it is necessary to take into account the increase in the volume fraction of the three-sided bond boundary with the decrease in the size of the particles.

In the process of preparing the powder material, its positive feature is its low temperature and high speed fusion, while maintaining its plasticity with the reduction of the particle size. The reduction of the particle size reduces the porosity of the powder, which increases the density and strength of the prepared product.

Keywords: additive, ultraviolet, laser, powder, synthesis, layer, particles, growth, mechanochemical, combination.

Introduction. Currently, humanity is entering the period of the fourth industrial revolution, which is characterized by the structure of cyber-physical systems in production processes. The natural, biological and digital integration of scientific technology is making new breakthroughs in fields such as artificial intelligence, robotics, nano and biotechnologies, energy, materials science and others. The process of layer-by-layer melting of metal powder from these technological bases is carried out in an automated mode, according to a computer model. In this case, for obtaining and for resources, except for the intermediate stages of production and mold production, there is no parting and finishing labor cost of loading [1].

Literature analysis. Advanced industrial enterprises are conducting scientific research studies on the technological processes of layer-by-layer synthesis of metal, metal-ceramic and nanostructured powder compositions.

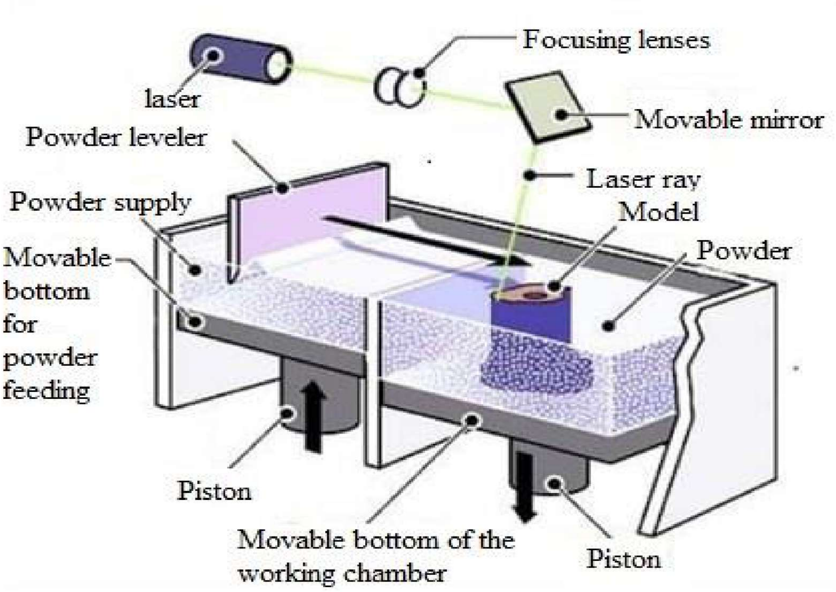
The first creative approach to additive technology began in 1956 with the production of a method of selective (layer-by-layer) synthesis of transparent photographic emulsion by Professor Otto Munz of the University of California. In 1981, R.F. Housholder proposed a method of forming a thin layer of powdered material on a flat platform by water. support this year Hideo Kodama announced the support of the first functional photopolymerization systems using ultraviolet light and laser. In 1982, A.J. Herbert created 3D models using an ultraviolet lamp and a system of mirrors along the X-Y coordinate axes.

In the mid-1990s, the first stereolithographic (SLA machines) laser machines were developed, followed by powder (SLS machines). These machines were mainly used in research and development related to the defense industry, because the cost of the machine was too expensive, which changed the cost of production. , in 1995, MIT students Jim Bredt and Tim Anderson pioneered the development of this technology by introducing layer-by-layer material production into a traditional desktop printer body [1,2].

Therefore, industrial enterprises are actively adopting additional technologies. In this scientific research work, in architecture and design offices, in design studios, and in individual personal development of individual products. Additive in many colleges and universities (layer-by-layer growth machine) machines or 3D printers are an integral part of the curriculum for professional engineering education.

Research object and methodology. With SLA (Steriolithography Apparatus), laser stereolithography - photopolymerization technology: it is possible to obtain a high-resolution basic model of a casting detail, thin-walled body details of micro-instruments and high-resolution membranes (valves). This technology is also very promising in the current situation. The continuous development of photopolymer materials, which are the main raw materials, allows to obtain more details with different technical characteristics.

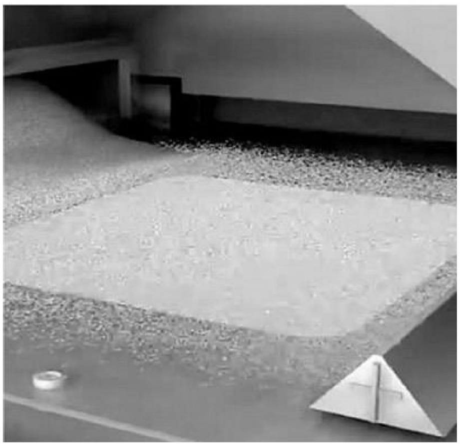
The principle of operation of this technology is that the material is introduced into the annealing chamber in the form of powder, and the minimum material layer is leveled with a roller to the permissible thickness, then the laser melting process begins by heating the material up to the melting temperature, after which the powder layer corresponding to the geometry of the part shape is selected with laser beams. during the melting stage, the shape of the detail on the sample is grown to a height equal to the thickness of the powder layer (Picture. 1).



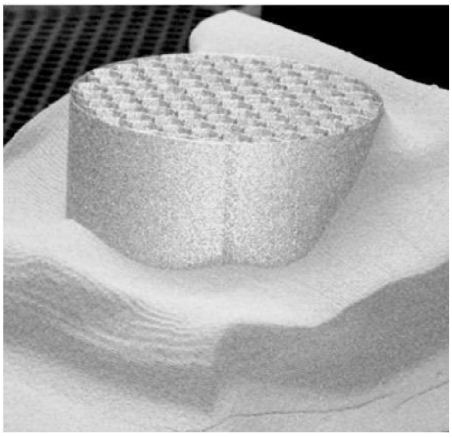
Picture 1. Scheme of the process of growing a three-dimensional model by the method of laser stereolithography

At the next stage, a new layer of powder is introduced into the heating chamber, the stage of selective melting of the layer with laser beams is repeated, and the section of the detailed shape is grown to a height equal to the thickness of another layer of powder. Thus, the detail is grown layer by layer until the complete shape is formed. In the process of product preparation with additive technology, the conditions and method of growing the detail form are described through the source of energy, processing speed, physico-chemical properties of the material and other indicators (Picture. 2).

There are no established standards for the production of powder materials used in the production of products with additive technology, and there is no possibility of application due to the presence of anisotropy in materials obtained by traditional technologies. A general requirement for a powder material is the spherical shape of the particles.



a)



b)

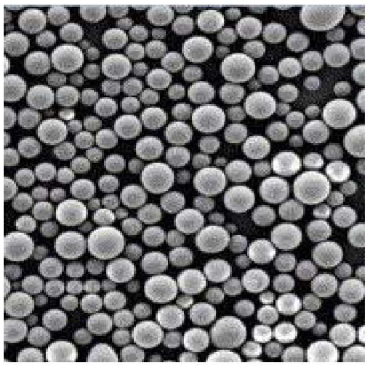
Picture 2. Preparation of products from powder material by the method of selective laser melting: a - spreading a layer of powder on the work surface; b - the process of layer-by-layer growth of the detail form

The spherical shape ensures a more compact distribution of particles of a certain size, as well as uniform flow of powder material into the working chamber with minimal resistance [3].

The problem of obtaining powder materials is relevant not only for the development of additional technologies, but also for the purposes of powder metallurgy. Metal powder compositions are used in high-tech industries such as aircraft engineering, space technology, shipbuilding, energy, military and instrument engineering.

Analysis and results. There are physico-chemical and mechanical methods of obtaining metal powders in industry: - the chemical composition and structure of the powder is significantly different from the original material. Mechanical methods ensure the production of powder from raw materials without significant changes in chemical composition. Mechanical methods include many types of grinding, such as grinding in mills, as well as dispersion of solutions using a gas or liquid stream, a process also called atomization. Particles of powder obtained by mechanical grinding have a fragmented, irregular shape. The produced powder contains a relatively large amount of foreign impurities, so these methods are not used to obtain powders used in additional technologies (Picture. 3a).

a)



b)

Picture 3. Depending on the method of obtaining the powder material, the appearance of the morphology and texture of the particles: a) obtained by a mechanical method powder particles; b) powder particles obtained by melt dispersion method

Melt dispersion is the most economical and effective way to obtain small and medium-sized metal powders. 60-70% of the volume of all industrial powders is obtained by this method. Atomization is widely used in the production of powders of multi-component alloys with an amorphous structure, which makes it possible to achieve the same chemical composition in the main alloy component of the composition, even if the composition of the alloy components is above the solubility limit. . In addition, powder particles obtained using melt dispersion methods have a spherical shape [3,4].

The size, morphology and texture of the particles differ depending on the technological parameters of the nanomaterials production process (Picture. 3a,b).

As the particle size decreases, the volume fraction of the triple junction boundary increases, and the volume fraction of triple junctions with particle sizes below 10 nm increases significantly. It has a significant effect on the properties of the structure determined by the methods of preparation of nanocrystalline materials (particle size, percentage of junction boundaries, porosity, etc.). Reduction in particle size while maintaining its plasticity, its strength increases, the effect of superplasticity is manifested at low temperatures and high speeds (Picture. 3b).

A macro picture describing the process of synthesis of metal compounds is typical for "cold" and "high temperature" synthesis. The difference between "high-temperature" synthesis and "cold" synthesis is that as a result of "high-temperature" synthesis, favorable conditions for spontaneous combustion are created, and the subsequent synthesis process is carried out due to the heat of the chemical reaction [5,6].

Let's consider the simplest case, when the synthesis process is carried out in the form of a single compound between two components: A+B→AB. We conditionally define the melting and boiling points of the initial components, respectively TAmelting, TVering, TAboiling, TBoiling, combustion temperature - Tyonish, depending on the ratio of Tyonish to Dialing and Boiling, the aggregate state of the initial components changes and the reaction is different mechanisms can be implemented.

Depending on the aggregate state of the initial components in the reaction zone, there are three main types of reaction processes: solid-phase, non-gaseous and gaseous.

Solid phase combustion mechanism. A characteristic feature of solid-phase reactions is that the reaction takes place only in the solid phase, without the participation of liquid, and the reaction rate is extremely low. According to the aggregate state of the reactions, the transition condition of the solid-phase reaction is as follows: Tyonish < TA. This combustion mechanism is carried out in carbides, borides, silicides and intermetallic compounds. Most often, the solid-phase combustion mechanism occurs in systems containing hard-to-melt metals such as tungsten, tantalum, molybdenum, and niobium. Hardly soluble metals (Ta, Nb, Mo), mixed with boron and carbon were detected in the powder in the process of self-propagating high-temperature synthesis (CBC) in the solid-phase gasless combustion method [8].

During the solid-phase reaction, deep synthesis does not occur, the metal particles in the powder mixture retain their original size. It was found that the combustion mechanism in the solid state without gas is very sensitive to changes in operating parameters at the site of the reaction process (deterioration of the interaction between particles, an increase in the size of particles and a decrease in the combustion temperature) [5,6,7].

Gasless combustion engine. The peculiarity of this mechanism is that the speed of the synthesis reaction during the process does not depend on the pressure and the constant mass of the formed particle is maintained. Depending on the ratio of cooling of the initial components depending on the melting and boiling temperatures, the process takes place in different ways, in which we consider two cases:

Case A. nA + mB = AnBm reaction participants react in the liquid phase with the condition (n, m ≥ 1). The transition condition for such a reaction is TAerish < Tyonish > TVerish, Tyonish > TAVerish. is represented by the inequality This case includes the following compounds: borides (TiB, TiB2, ZrB2, HfB2, VB2, CrB2, NiB), silicides (Ti_5Si_3, Zr_2Si, Zr_5Si_3, ZrSi), NiAl intermetallic compound, and MnS sulfide. State A is characterized by the release of heat as a result of the formation of some compounds, which is sufficient not only to melt the initial component, but also to convert it into a vapor state. For example, the temperature during combustion of Ti +2B mixture

Temperature rises to 2927oC. Thus, with high values of Tyonish, when the pressure of one of the components exceeds atmospheric pressure, the vacuum allows to "turn off" the explosive mechano-chemical synthesis of a hard-to-dissolve compound.

Case B. One of the participating components reacts in a liquid state, and the other in a solid state. The transition condition for this state is represented by TAerish<Tyonish<TVerish. This situation is most typical for the formation of titanium, zirconium, hafnium and silicon carbides. As a result of the carbide synthesis reaction, the metal melts and the carbon becomes solid. In the case of the self-propagating high-temperature synthesis (CBC) process, the interaction of the liquid metal with the carbon creates a capillary diffusion effect, which results in a dramatic acceleration of the burning rate. According to the conducted studies, mixtures burning with the effect of capillary diffusion have the highest propagation speed of the combustion wave, which in some cases leads to thermal explosion. At the same time, it is clear from the calculated and experimental results that during the explosive mechano-chemical synthesis, the temperature sufficient to melt titanium actually occurs.

Gas combustion engine. A characteristic feature of this combustion mechanism is the dependence of the combustion speed on the pressure and the change in the mass of the reagents during the process, in which we consider two cases:

Case A. The conditional regime in the form of TAboiling < Cooling < TVboiling can be performed in Me–gas (N_2, H_2, O_2) systems, as well as in Me–S, Me–P systems.

Case B. A conditional mode of rest > TAB can also be performed in the Mg + S system.

The gaseous combustion mechanism can be performed only for some nitrides, sulfides, as well as oxides. In the case of (CBC), most of the nitrides are synthesized using this mechanism, the mechanochemical synthesis of nitrides is carried out under nitrogen atmospheric pressure. The gaseous combustion mechanism in the (CBC) process has been developed for most nitrides, hydrides, and oxides. In mechanochemical synthesis, according to explosive kinetics, the interaction of metal with gas was determined only in the environment of interaction of metals with oxygen [9,10,...16].

Conclusions. Based on the results of the studied and conducted research, we make the following conclusions: - the technical requirement for the particles of the powder material is that they should be spherical in shape. The spherical shape of the particles ensures uniform distribution of a powder layer of a certain volume and uniform flow transfer to the working chamber with minimal resistance;

- in the process of mechanochemical synthesis, with a decrease in the size of the particles, the volume fraction of the three-way junction boundary increases, the volume fraction of the three-way junctions increases significantly with particle sizes less than 10 nm;

- as a result of the significant influence on the characteristics of the structure (particle size, compound boundary fraction, porosity, etc.) determined during the preparation of the powder material, the strength increases while maintaining the plasticity with the reduction of the particle size, low temperature and high speed the effect of plasticity is manifested;

- the reduction of the particle size reduces the porosity of the powder, which increases the density and strength of the prepared product.

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