

NOVEL TECHNOLOGY OF METAL POWDERS PRODUCTION BY HYDRO-VACUUM DISPERSION OF MELTS

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Abstract: A novel technology for producing metal powders is presented, the distinctive feature of which are the conditions of forming of powder particles. In particular, under the proposed technology the melt is sucked bottom-up by the vacuum produced by the toroidal vortex of the discharged nucleus of high-pressure water flow in the two-layer cylindrical shell cavity, where it is being dispersed as metallic particles and carried over from the working medium to a special store. The so produced powders have a particular morphology and structure, increased specific surface area and microhardness.

KEYWORDS: METAL POWDERS, MELT, SPRAYING, DISPERSION, PULP

At present, dispersion of melts by the high-pressure water is the most popular technology for producing metal powders. The essence of this process consists in the fact that the falling down vertical flow of metal is dispersed by the cross-sectional high-pressure water flows [1-3]. At high dispersion speeds also great are the aerodynamic forces contributing to the formation of a significant part of oxides (formation of the primary oxide film occurs practically instantaneously). As a result of the dissociation of water vapors at high temperatures, the formation of oxygen is also possible in the spraying area. After the process of spraying and temperature reduction is over, the dissolved oxygen is extracted from metal, becoming the reason of porosity of the sprayed powders and articles therefrom. It is noteworthy that nitrogen also gets into the melt in all the technology stages. It dissolves well in iron and other metals with the production of nitrides, which leads to the increasing the hardness and reduction of the plasticity of powders. Therefore, the dispersion-produced powders are subjected to recovery annealing, the purpose of which is not only the recovery of oxides, but also the improvement of the such technological properties of the powders as compressibility, sintering ability, etc. [4-6]. The same takes place during the centrifugal, ultrasound and other methods of dispersion.

In contrast to the available technologies, the developed one provides for dispersion of melts by the technological operation of hydro-vacuum pumping [7]. The functional scheme of the technological process of hydro-vacuum dispersion of melts is

shown in Fig. 1. By supplying high-speed water flow in the closed system of special ducts, a discharge is generated in the area of the bottom edge joint if these ducts at the upper head projecting on the external face of the cylinder nozzle body, by the force of which suction of the melt toward the area of high-speed hydrodynamic volume effect is taking place. The proposed technological solution principally differs by its functionality, stability and low price, where the common high-pressure process water circulating by the closed path serves as an energy carrier. The principal functional feature of the hydro-vacuum suction device can be considered its ability to create a volume toroidal vortex with the discharged nucleus, at the expense of which the suction and primary fragmentation of the trapped and vertically movable (against the force of gravity) melt take place (see Fig. 2). Since the contact of melt drops with the air in the dispersion device is excluded. The process of oxidation of particles is also prevented. It should also be mentioned that the high-vacuum melt dispersion technology is ecologically safe, because no dust and gas emission to the environment takes place and the water itself does not require to be filtered from solid impurities, since the dispersion in our case is carried out without employment of special spray jets. All this offers additional advantages to the technology under consideration.

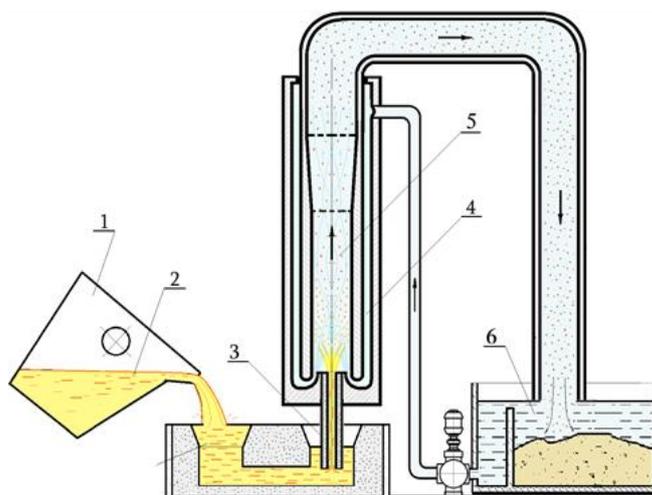


Fig. 1: Functional scheme of the process of hydro-vacuum dispersion of a melt

1-ladle; 2-melt; 3-suction head;
4-high-pressure water; 5-pulp;
6-powder store

Experimental studies, which were carried out at water pressure of 16 kg/cm², which, in turn, created in the bottom head of the cap vacuum - 0,8 kg/cm², demonstrated that the mechanism of practical implementation of the proposed method and of the device of hydro-

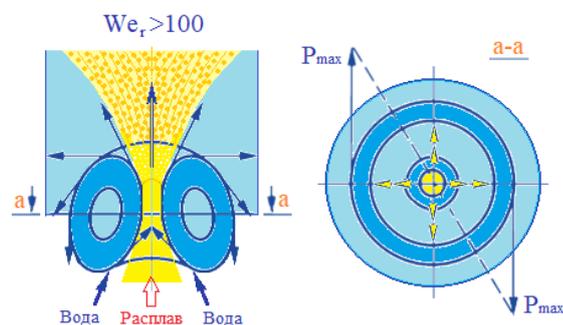


Fig. 2: Hydrodynamic structure of the produced toroidal vortex, where We_r is the rotary Weber number

vacuum suction of melts principally differs from the water dispersion mechanism. Upon hydro-vacuum suction, from the moment the melt jet gets into the inlet box of the end head, where it is surrounded by a circular high-pressure water flow, produced by

the mentioned toroidal vertex (Fig. 2). This force hydrodynamic effect forms the vertically directed cone flow with the angular acceleration, with the corresponding tangential and radial stresses, as a result of which the flow abruptly widens and is diminished by the flush (cavitation) mechanism of the layer-by-layer disruption of the cone flow. Under the values $We > Re^{0.5}$, the destruction will be of the explosive spattering nature (speed > 500 m/s).

On the surfaces of the crushed and supercooled metal water vapor bubbles are immediately formed, frequently producing a vapor film; while not being accumulated, they are removed from the working area occasionally with the formed dispersed particles. However, the bubbles/films, because of fast condensation of their

water vapor and abrupt fall of the internal pressure, quickly collapse (close up) and form hydraulic micro-shocks, which, in turn, conditions secondary destruction and deformation of case-hardened metal shards. In the end, the output generally consists of mechanically strengthened (mechanically activated), tempered powders of a complex flaky shape/form, with increased specific surface. Evidence of this are figures 3 and 4, demonstrating the surface morphology and micro-hardness of the particles produced by the proposed method. For clarity, Fig. 5 individually shows microfractographs of synthetic cast iron of different dominating fractions.

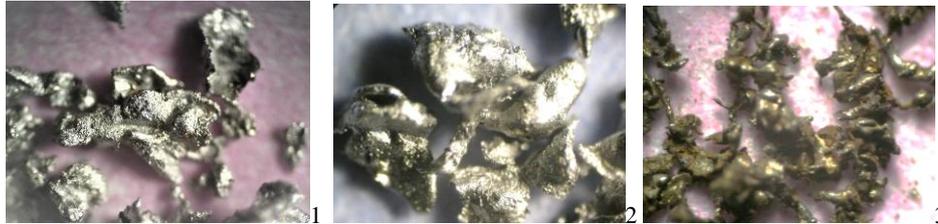


Fig. 3. Morphology of surface of the powders produced by the technology of hydro-vacuum dispersion of melts. 1) Al, 2) Mg 90-Al 10%, 3) C 3.5% C, $\times 40$

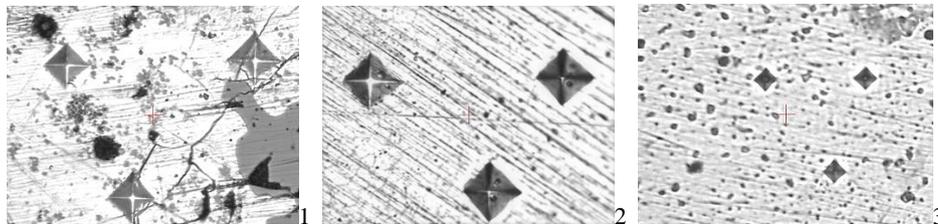


Fig. 4. Powder micro-hardness, load on indenter 200 mN. 1) Al - 164 HV, 2) alloy MgAl - 118 HV, 3) cast iron - 880 HV



Fig. 5. Microfractograph of the powders of gray cast iron 3.5% C of different fractions, μm ($\times 25$). 1) +800-1000; 2) +500-800; 3) +200-500

Experimental studies revealed that the crystallization of liquid metal drops (flakes) is carried out at significant overcooling of the melt and high speeds of cooling within: 10^3 - 10^4 °C/c. Metallic powder particles are represented by a highly refined cellular-dendritic microstructure. The size of cells and distances between secondary axes of dendrites constitute

1-5 μm , depending on the cell sizes. The carbide phase in the form of a thin net is located along the cell borders and interaxial sections of dendrites, the carbide phase representing a peculiar reinforcing, wear-resistant framework, retaining the shape and strength/solidity of powder particles (Fig. 6).

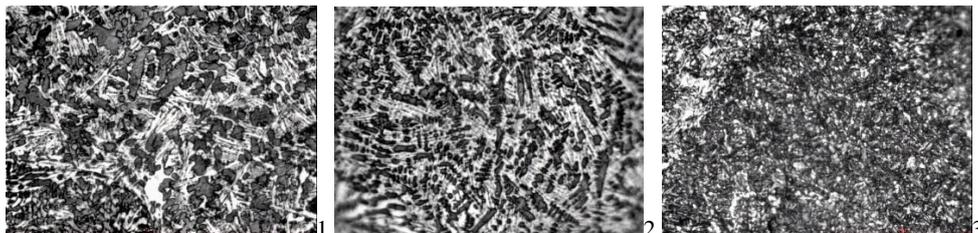


Fig. 6. Microstructure of hydrodynamically dispersed synthetic cast iron ($\times 1000$). Dispersion, μm : 1) +800-1000; 2) +500-800; 3) +200-500

For a deeper investigation of the phase composition of powders an X-ray spectrum analysis of the phase composition was used (Fig. 7). It was found that iron, instead of the expected cementite and ferrite phases – the solid solution of carbide implantation in α -iron with volume-centered lattice, is represented by the phase of cementite and austenite – the solid solution of carbide implantation in γ -iron with the face-centered cubic lattice. For the purpose of a comparative analysis of the phase composition of the powder produced by us with the widely distributed *Hoganas* metal powder, Fig. 7 presents the X-ray spectrum analysis of this powder, where γ -iron is completely absent and the phase is represented exclusively by α -iron, which can be explained by the significantly different conditions of hardening and temperature of

cooling being formed during dispersion of the particles of our powder. It should be noted in favor of the proposed method that the produced powder does not require the restoration of oxides and is subjected to drying only at 130 °C, fully preserving the unbalanced structure with γ -iron. Accordingly, it is chemically more active than the *Hoganas* powder, fire-reduced and with α -iron. In Fig. 7, the blue (lower) contour describes the phase composition of our powder before drying, while the red (upper) contour describes the phase composition after drying. Both are identical. This factor can be distinguished as one of the most important distinctive features and obvious productive advantages as compared with the existing methods of dispersion of metal melts.

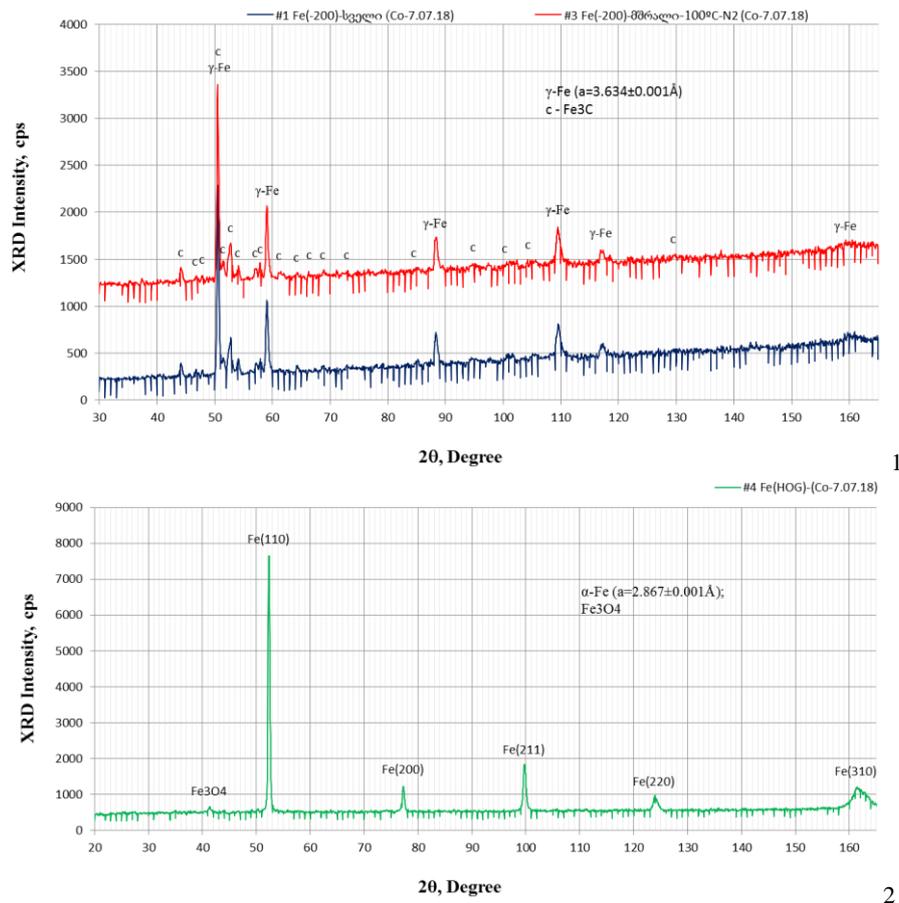


Fig. 7. X-ray spectral analysis of synthetic cast iron powders before and after drying in the CO_2 protective atmosphere. Dispersion - 200 μm

1) Powder produced by hydro-vacuum dispersion; 2) *Hoganas* powder

2)

Experiments demonstrated that the melt's superheat value, suction rate, pressure and water temperature generated by the hydro-vacuum suction determine dispersion of the produced powder. The maximum production of the process during dispersion of aluminum makes 120 kg/min, and 425 kg/min – in the case of cast iron. The exclusion of the need to restore oxides makes the technology highly profitable. Since no

vapor, dust and gases are emitted into the air, the technology can be regarded as environmentally friendly. In its turn, the production tools are distinguished by their compactness, ergonomic characteristics, low noise level, as well as a possibility of controlling the technological parameters and the process. The structural process control model is illustrated as a process chart in Fig. 8.

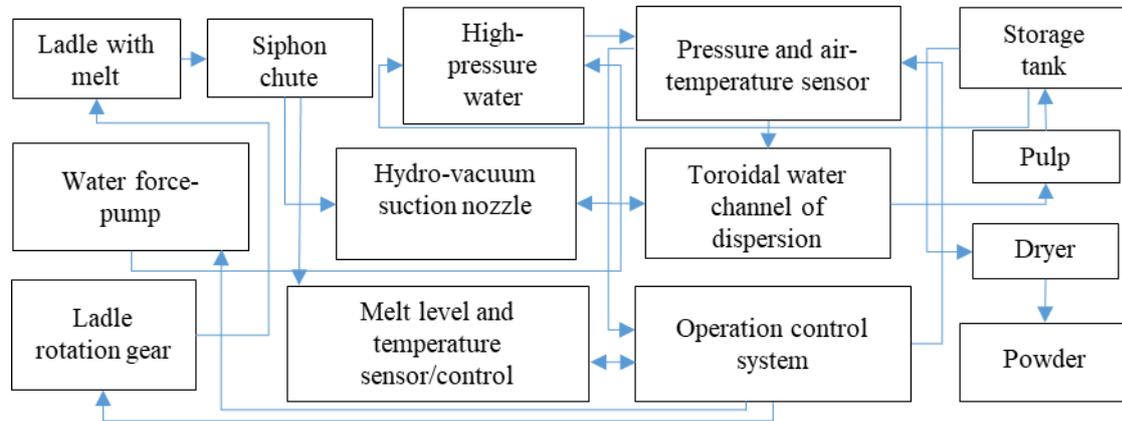


Fig. 8. Process chart of production of disperse metal materials by hydro-vacuum dispersion of melts

The melt flows from the ladle to a special siphon chute, where it is purified from non-metallic impurities and goes as a laminar flow to the hydro-vacuum suction nozzle. From the nozzle, by force of the in-channel vacuum generated by the toroidal vertex of high-speed water flow, the melt is sucked-off within the dispersion area, where it is subjected to the hydrodynamic volume action, decomposition/break-up and mixing with water, by the flow of which is then delivered as a pulp to the storage tank. After deposition and drying in the protective atmosphere (without reducing firing), the powder of the intended fractions ready for purposeful use is produced. The fractional composition can be regulated by controlling the melt suction temperature and rate, as well as the circulating water pressure and temperature, for which purpose the system is provided with controls/sensors of the melt level and temperature in the siphon chute and of the pressure and water temperature in the water channel of dispersion. Electronic signals from the sensors are integrated in the operations control system, where the current indications/data are compared with the reference data. In case of necessity, a respective control signal is developed and communicated to the actuators. The rotation gear drive of the pouring ladle and the electric motor serve as the actuators. Thus, an on-line correction of the production cycles and quality control of the produced powder is carried out.

A systems analysis of the foregoing functional peculiarities and results of experimental studies of the technology of hydro-vacuum dispersion of melts shows that the following technical advantages can be cited for substantiating high performance of the proposed technology:

1. The possibility of exclusion of a contact of particles with the atmosphere in the course of the powder forming and cooling;
2. The condition of particles' forming in the force field directed against the gravitational force;
3. Formation of particles with an increased specific surface.

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