Model for high-pressure water atomization of metal melt using a vortex type jet

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Abstract: *In this paper the physical model for high pressure water atomization of metal melts using hydraulic nozzle of a vortex type was proposed. The developed model assumes, that due to high speed water flow with significant centrifugal component of its velocity vector the rarefaction is formed, which causes intensive air suction leading to the formation of rotating gas (vapor-air) layer of toroid-like shape, providing a gap between the water flow and the metal stream. Thus water stream is separated from the heated surface of metal stream and the formation of particles during crystallization of melt droplets occurs due to surface tension mainly in this vapor-air layer. The cooling of melt droplets in the gas-water leads to the formation of spherical powder particles. The proposed model correlates well with the known experimental data on the production of spherical powders using a vortex-type annular hydraulic nozzle.*

Keywords: *model, metal powder, water atomization, nozzle, melt, jet, swirling, crystallization, gas ejection, particles.*

1. Introduction

One of the most common methods for producing of metal powders in large-scale production is water atomization of the melt [1]. The process of water atomization of liquid metal with using of a ring nozzle according to the standard scheme has been widely studied experimentally and theoretically [1-3]. When using this technology in a wide range of technological parameters of the process, the powder particles acquire an irregular shape, which partially limits their scope, in particular due to the relatively low yield.

As a result of a change in a number of basic parameters of the atomization process, namely, the angle of attack of the water flow causing it to "twist", the authors [4] and later [5] proposed and experimentally substantiated a method for producing powders whose quality is fundamentally different from that characteristic for traditional water atomization schemes.

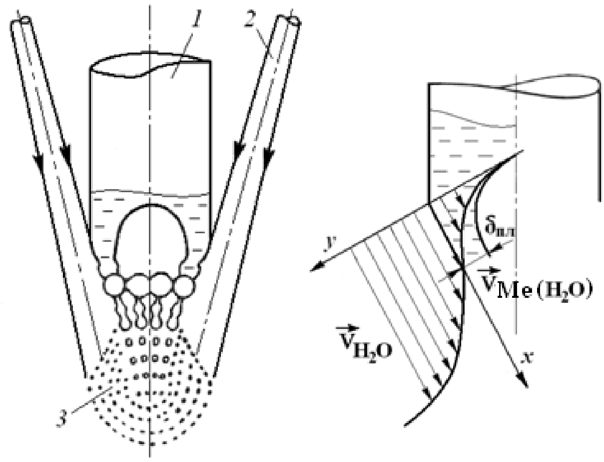
This method was the basis of technologies that received the name, respectively, "atomization of melts with high-pressure water in air-water whirlwing" or «ultra high pressure swirl water atomization».

In [6] we showed that the atomization of melts with high-pressure water in whirlwing conditions is a promising scheme for the production of metal powders with increased bulk density and fluidity up to the production of spherical powders. At the same time, if the theoretical foundations of processes are sufficiently deeply developed for traditional schemes for melts water and gas atomization, and atomization using centrifugal forces, then information on the particle formation mechanism for the scheme for atomization of melts with water "in whirlwing conditions" is practically absent in available literature sources.

Thereby, the aim of the present work was to analyze the known experimental data and develop a schematic model of the mechanism of formation of powder particles using a melt atomization scheme that ensures the formation of a rotation of the water flow in the nozzle area.

2. Research results and discussion

In [2] the model of the process of atomization the melt with high pressure water [2] was presented, which was tested for the manufacturing of high speed steels, ferroalloys, complex alloys, aluminum alloys powders. The model includes the following steps (fig. 1): transformation of the initial metal stream upon contact with the water stream into a conical film converging to the axis of the stream; development of longitudinal and transverse waves on the film surface; instability and decay of the end of the film into droplets. Drops of metal are intensively cooled in the spray zone in a water-vapor medium and crystallize quickly without reaching geometric equilibrium in the form of coral-shaped particles (fig. 2).



a *b*

Fig. 1. *Model scheme for atomization of liquid metal jet (a) and velocity distribution in a water-metal system (b): 1 - stream of metal; 2 - annular flow of water; 3 - cooling zone of metal droplets;V_{H2O} - water flow speed; $V_{Me\ (H2O)}$ - speed of metal stream; δ_{pl} - metal film thickness*

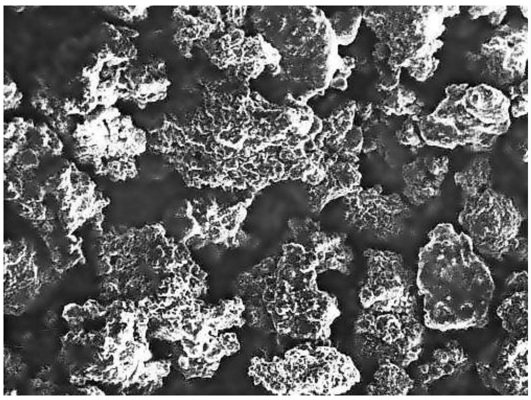


Fig. 2. *Coral-shaped particles of 50Mn-12Si-17Ni-9Fe powder*

The formation of coral-like particles is caused by the action of dynamic water flow, as well as by the boiling of water droplets formed when water enters the melt, which confirms the structure of the surface layer of the crystallized plume section in the atomization unit (fig. 3).

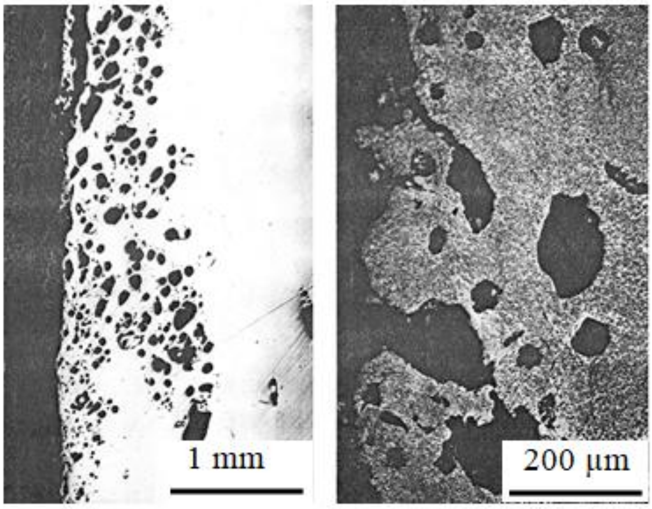


Fig. 3. *Macro (a) and microstructure (b) of the subsurface layer of crystallized section of melt jet flame for water atomization of P6M5 high speed steel*

As it had been shown by the results of theoretical and experimental studies of the traditional process of water atomization, with an increase in water consumption, its flow rate and the temperature of the melt overheating, which contributes to a decrease in its viscosity, the likelihood of obtaining finer powders at a given thickness of the metal jet increases. However, it is not possible to affect the particle shape of the main powder fraction during atomization according to this mode.

Unlike the traditional water atomization process, the feature of “tornado” atomization technology in the is the atomization of liquid metal jet of a vortex-type annular hydraulic nozzle (fig. 4,a), which supplies a high-pressure water jet along its axis while rotating it around metal stream. This character of the jet flow is ensured by the set of the nozzle’s special design, which provides for a change in the direction of the axes of the nosepieces in such way that the horizontal component of the water jet velocity vector in each nozzle is directed at an angle $\omega>0$ relative to the radial direction (fig. 4,b).

The rotational movement of the water stream causes the formation of the centrifugal component of the velocity vector of its movement, which leads to the formation of rotating water stream in the form of a hyperboloid (fig. 4,c), into the cavity of which a metal stream is fed.

Moreover, while using traditional methods for producing powder by high-pressure water atomization of the melt, the powder particles have a predominantly coral-like shape (fig. 5,a), the use of a ring nozzle with rotating jet results in powder particles of a spherical or spheroidal shape (fig. 5,b).

The results of experimental studies of real processes of melts atomization using of hydraulic nozzle of a vortex type with application of high-speed filming made it possible to propose a physical model of atomization in the following mode.

When a water jet contacts a surface of melt jet heated by more than 550-600 °C, the so-called film boiling occurs, when water is separated from the heated surface by a continuous film - vapor shell. Moreover, in the area of the neck of the hyperboloid (fig. 5,c) and below, due to the presence of significant centrifugal component of the water flow velocity vector, the rarefaction is formed, which causes intensive air suction leading to the formation of rotating gas (vapor-air) layer, providing a gap between the water flow and the metal stream of order of thickness of about 10^{-3} m (fig. 6).

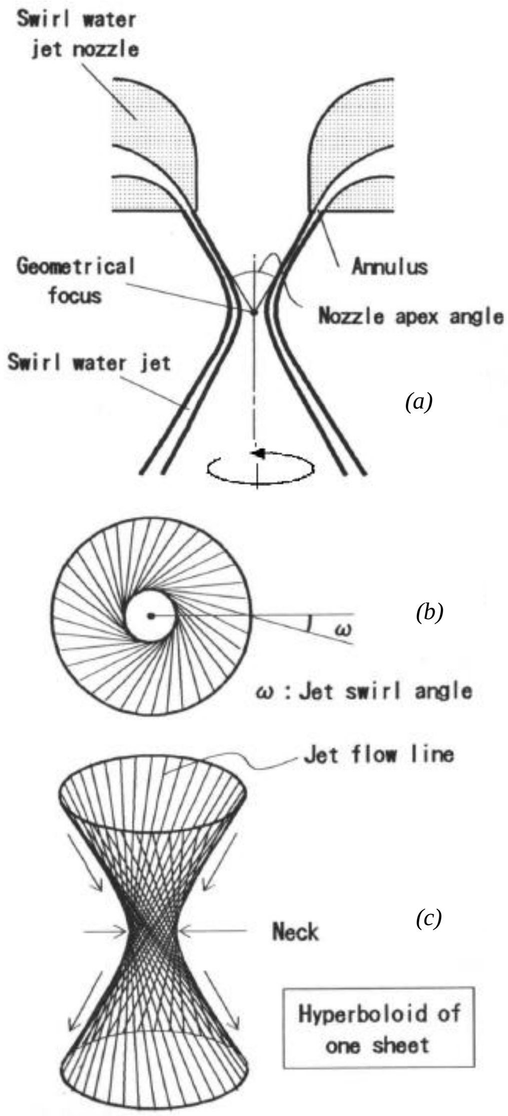


Fig. 4. *Schematic cross-section of water jet for water atomization in air-water whirlwing (a) and schematic diagram of air-water stream (b, c) [7]*

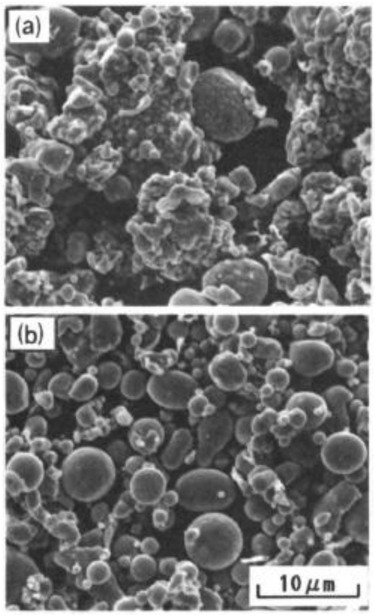


Fig. 5. *SEM micrographs of Cu-10 % Sn alloy powders produced by high-pressure water atomization using traditional technology (a) and ring nozzle with rotating jet (b) [7]*

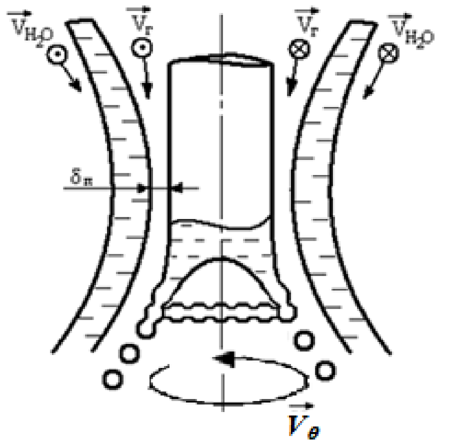


Fig. 6. *Flow separation scheme for atomization using a vortex type nozzle:V_{H2O} - velocity of the water conical stream; $V_г$ - velocity of the ejected gas (air); $\delta_п$ - the gap between the water and the jet of melt; V_θ - circular rotation velocity of the air-water stream*

Under the influence of gas-dynamic vacuum generated in the region of the vapor-air layer, the initial cylindrical stream of liquid metal is deformed: a hollow liquid-metal cone is formed from it, thinned in its lower part to the film-like thickness. At the same time, oscillatory processes develop in a thinning melt film due to the instability of its motion as a result of small-order disturbances. Roughnesses and roughness of the nozzle surface, irregular hole geometry, pulsations in the liquid, etc. can serve as a source of the latter. Initial perturbations favor the formation of waves, which, in turn, increase, first contribute to the formation of a liquid toroidal thickening along the periphery of the film, and then to pinch the jet and separate it into separate strands - melt micro-jets flowing from the periphery of the film. The latter, in turn, under the influence of disturbing forces break up into droplets.

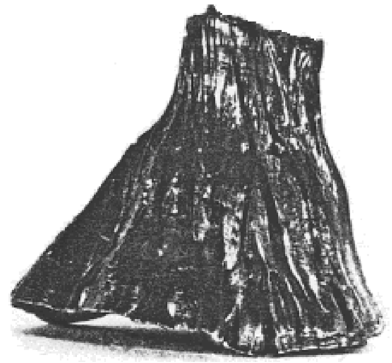
The spherical shape of the obtained powder particles in this case is explained by the fact that the formation of particles during crystallization of the melt drops occurs mainly due to surface tension in the vapor-air layer, when the rotating stream of water from the nozzle does not touch the metal stream but only the final solidification and cooling of the powder particles occurs in water.

Such a cooling regime significantly changes the thermophysical characteristics of the process compared to conventional methods of water atomization, since the vapor-air layer, due to the reduced heat transfer coefficient, removes heat much worse than water, which leads to a significant decrease in the crystallization rate.

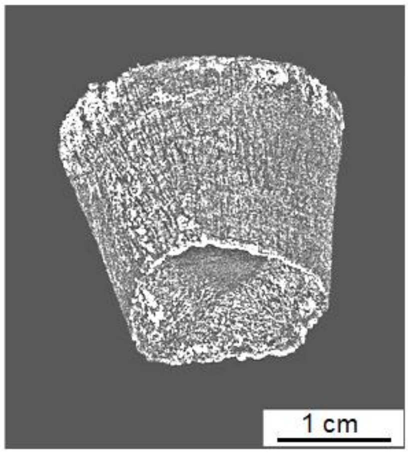
In addition, due to the rotational component of the flow rate and the absence of direct contact of the melt jet with water, the particles collide less with each other and experience less deforming effect on their shape.

The speed of the gas column is determined by the flow rate of water V_{H2O} (fig. 6) and significantly decreases with distance from the surface of their contact. Therefore, the thickness of the gas layer $\delta_п$ is of great importance, which is ensured by a combination of the geometric parameters of the nozzle for the diameter of the metal jet. To ensure effective atomization, it is necessary to achieve some optimal (minimum) value of $\delta_п$, at which the gas flow rate will correspond to the velocities characteristic of gas atomization. The angle of attack of the water flow, as well as the angle of its swirling, are in this case those parameters that determine the location and depth of the created vacuum, and therefore the magnitude of the ejection and the flow rate of the sucked gas.

The indirect confirmation of the adequacy of the proposed model is the appearance of the crystallized section of the torch of the melt jet, which remains after the completion of the atomization process using a vortex-type nozzle (fig. 7, a), which differs significantly from the similar portion of the torch obtained using a direct-flow nozzle (fig. 7, b).



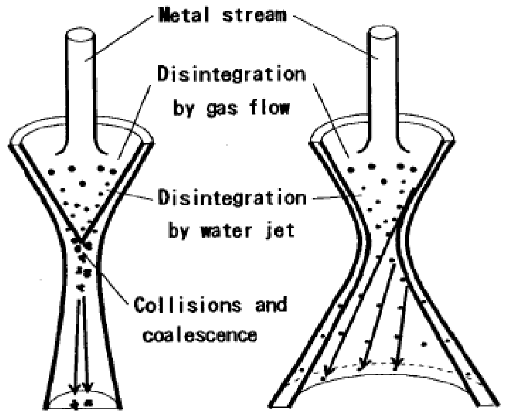
(a)



(b)

Fig. 7. *Crystallized section of melt jet flame for atomization using a vortex-type nozzle (a) and with using of a direct-flow nozzle (b)*

The results presented on fig. 7 also correlate well with the model of water atomization in a vortex flow proposed in [7], which is conditionally displayed in fig. 8.



(a) *(b)*

Fig. 8. *Models of high-pressure water atomization using a direct-flow nozzle (a) and a vortex-type nozzle [7]*

Thus, the proposed model allows us to conclude that atomization under the conditions of vortex motion of an energy carrier jet is essentially gas-like atomization with gas moving at a speed and in the direction determined by the flow of water, which also determines the temperature gradient of the gas layer.

However, the analysis of the microstructure of powder particles obtained using this technology indicates substantially cellular nature of the structure (fig. 8), which indicates high crystallization rates, significantly exceeding the crystallization rates during traditional (water free) gas atomization. The reason for the noted effect is the presence in the gaseous layer of significant amount of microscopic drops of water, which lead to quenching of the metal drops during their crystallization, which was shown earlier in [8].

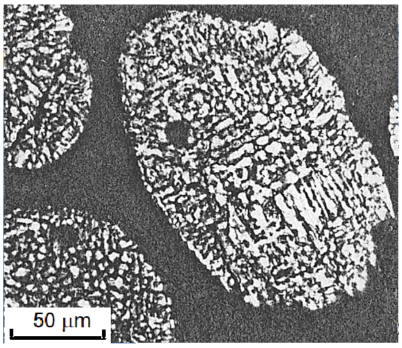


Fig. 8. *The microstructure of ferromanganese powder produced by water atomization using a vortex type nozzle*

3. Conclusions

1. Using of hydraulic nozzle of a vortex type for high-pressure water atomization of the melt provides spherical shape of powder particles.

2. The physical model of atomization using hydraulic nozzle of a vortex type was proposed. In accordance with this model, water stream is separated from the heated surface of metal stream with a continuous film - vapor shell and the formation of particles during crystallization of melt droplets occurs due to surface tension mainly in this vapor-air layer.

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