PHYSICS AND CHEMISTRY OF SOLID STATE
V. 25, No. 1 (2024) pp. 127-135

Section: Technology

DOI: 10.15330/pcss.25.1.127-135

Vasyl Stefanyk Precarpathian National University

ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
Т. 25, № 1 (2024) С. 127-135

Технічні науки

UDC 621.921.762: 533.924

ISSN 1729-4428 (Print)
ISSN 2309-8589 (Online)

David Sakhvadze[1], Gigo Jandieri[1,2], Besik Saralidze[3], Giorgi Sakhvadze[4], Anzor Kuparadze[5], and Nata Sulaqvelidze[5]

Universal Portable Unit for Hydro-vacuum Dispersion of Metallic Melts: Improvement of the Technological Process

[1]R. Dvali Institute of Machine Mechanics, Tbilisi, Georgia
[2]Independent Investigator, Leipzig, Germany, gigo.jandieri@gmail.com
[3]F. Tavadze Institute of Materials Sciences and Metallurgy, Tbilisi, Georgia
[4]Metal Powder Ltd., Tbilisi, Georgia
[5]G3D Ltd, Kutaisi, Georgia

The development of the technology and techniques of dispersing metal alloys is important both from the point of view of improving the quality of powders, as well as increasing the volume of production and increasing the economic and ecological safety of the technosphere. Metal powder is an indispensable functional component for many modern branches of industry. Against the background of the growing demands for the production of metal powders, we have developed and optimized a new device for hydro-vacuum dispersion of melts, the essence of innovation and advantage of which lies in sucking and dispersing the melt in the direction opposite to the action of the force of gravity, under 150-200 g gravity overload conditions, where the main work is performed by hydraulic rarefaction resulting from a sharp (on 162°) refraction of direction and rapid expansion of a high-pressure water annular flow, with the superimposition of spatial shock- pulsating waves generated in the outer shell of the formed cone-shaped vortex. The device is characterized by high production and low energy costs, while powders - by increased specific surface, improved purity and high activity.

Keywords: Hydro-vacuum dispersion; Metal powder; Simulation; Optimization.

Received 25 November 2023; Accepted 4 March 2024.

Introduction

Among the numerous methods of dispersing metal melts into functional powders, today, the most widespread in industrial practice is the technology of high-pressure water or gas jet spraying (atomization) of the melt [1]. Nevertheless, due to the difficulty of mastering the technological process and the limited functional capabilities of the equipment (periodic work cycle, technical service difficulty, low productivity, harmful effects on the environment [2], [3]), the issue of industrial unification and large-scale implementation of the mentioned technology remains a problem. Due to the peculiarities of the technological process, it is practically impossible to process melts of different types (of different chemical composition and viscosity) with one plant. In each individual case, the equipment needs to be retooled, to change working nodes and their operating modes. In addition, in the large-scale production of powders (for example, the production of iron powder), operational management of the efficiency of the melt sputtering process, including stabilization of the conditions of formation into individual granules, long-term maintenance of operational properties, elimination of the problem of oxidation, gas saturation and reduction of pyroporosity, has remained an unsolved task until now [4]-[6]. As a result, the powders obtained by this method are inevitably subjected to additional sorting-mechanical crushing in an inert gas environment, as well as to further thermal, hydrogen-reducing treatment [7], [8].

Similar problems exist in the relatively less common centrifugal dispersion and ultrasonic disintegration processes of atomization metallurgical melts [9]-[11]. In all cases, the powders require a finishing thermomechanical (activation) treatment. Without this step, the powders remain in a passive (chemically low-activity) phase. Therefore, their direct use in mining and metallurgical, machine-building, construction and other fields is less effective. The need to optimize the alloy dispersion process and hydrogen reduction treatment of the obtained powders is especially acute when dispersing active metal alloys such as aluminum, magnesium, Armco-Iron, low-carbon alloyed steels, modified cast iron, etc. Due to all of the above, the process of dispersing metallurgical melts into functional powders is considered one of the most high-tech, expensive and difficult production processes, which requires further research and optimization.

We, the team of authors of the proposed short scientific report, consider one of the most effective ways of solving the mentioned problem to be the further research and development of the innovative method of hydro-vacuum dispersion of melts developed by us and protected by Georgian patents [12], [13] and the pilot plant necessary for its implementation (Figure 1), first of all, for the conditions of serial (continuous) production of a wide range of iron and aluminum powders, which are most demanded in the world market. Solving the posed problem is aimed at improving the functional capabilities of the mentioned device, - at giving it a high degree of flexibility (universality), - managing the granulometric composition of the produced powders, as well as - at improving their physico-chemical purity and the quality of mechanical activation. Achieving the set goal will be especially interesting for production facilities focused on metallurgical processing of secondary metals or melts lacking free production capacities and financial capabilities, to replace the production process of semi-finished products, bars or other types of products with the production of high-tech powder products with high added value.

The structural design and specification of the main technological unit of the device for hydro-vacuum dispersion of metal melts is illustrated in Figure 1. On the other hand, the visual image of its simulation model and the research experimental prototype in semi-industrial conditions are presented in Figure 2.

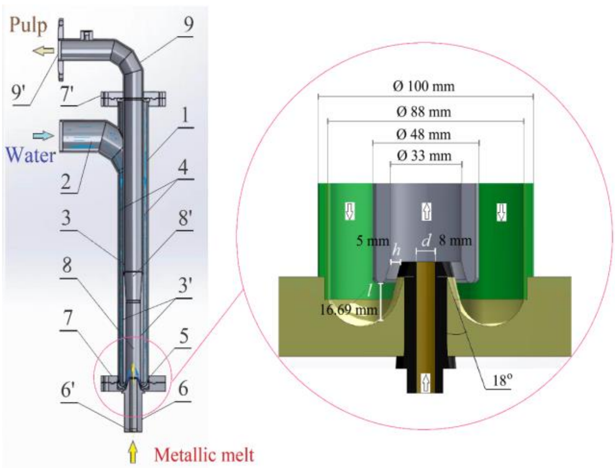

Fig. 1. The main technological unit of the device for hydro-vacuum dispersion of melts**.**

The unit contains: the body/housing 1 with a lateral high-pressure water tangentially delivery elbow pipe 2; the Venturi tube of relatively small dimeter and length 3 concentrically mounted in the body 1, with bottom position of the inlet duct 3' and the circular collector channel 4 formed between the inner surface of the body/housing 1 formed and shell of Ventura tube 3, coupled with the high-pressure water delivery lateral elbow pipe 2; the semi-toroidal internal (convergent-divergent) confuser 5 formed through the lower end of the Venturi tube 3-3' and the collector channel 4 in the extreme lower peripheral part of the body/housing 1; the convergent sucker 6 axially placed from its inner surface at a (l) longitudinal and (h) transverse distance with a cylindrical perforation 6' (d); lower 7 and upper 7' flat toroidal flanges for sealing the water-injection hydraulic system (body 1, annular duct 4); in the converging duct 3' of the Venturi tube 3, the dispersion chamber 8, formed on the top of the sucker 6 with the diffuser 8'; the pulp discharger 9 within the diffuser 8' flexibly connected to the upper end of the pipe 3, and the guiding channel 9' in its hydrocycline-type collector-settler (not shown in the diagram).

I. Technological features and advantages of the hydro-vacuum dispersion process

In contrast to the traditional methods of production of functional powders of metallurgical melts for various purposes [1]-[3], [9]-[11], the essence of the innovativeness and advantage of our proposed technology lies in the suction and dispersion of metallurgical melts in the opposite direction of the force of gravity, under 150-200 g gravity overload conditions, where the main work performs the rarefaction formed in the vortex core of the conical profile formed as a result of the rapid expansion of the annular flow delivered by high pressure and the sharp 162^{o} change of the flow direction in a closed space (hydraulic vacuum). The shear forces (tensile stresses) vertically, bottom-up created on the surface of the cylindrical jet of melt absorbed in the vacuum action zone, inclined to each other by 360, and directed upwards by 720 from the horizontal plane, create fundamentally different and hydrodynamically optimized conditions of melt dispersion. At the same time, intense processes of hydraulic friction, hydromechanical adhesion and capillary disintegration take place, where, in contrast to traditional technologies, the impact of hydrodynamic flows of water with increasing angular acceleration on the particles (droplets) taken from the dispersed melt continues until they solidify and enter a special collector. This additionally conditions large-scale 3D twisting-deformation and intense micro-volume cavitation-impulse (ultrasonic acoustic) treatment of the formed particles, thus achieving the irreversible effect of their microstructural segregation, gradient migration and tension (mechanoactivation). Consequently, targeted powders are obtained with improved purity, increased surface area and activity.

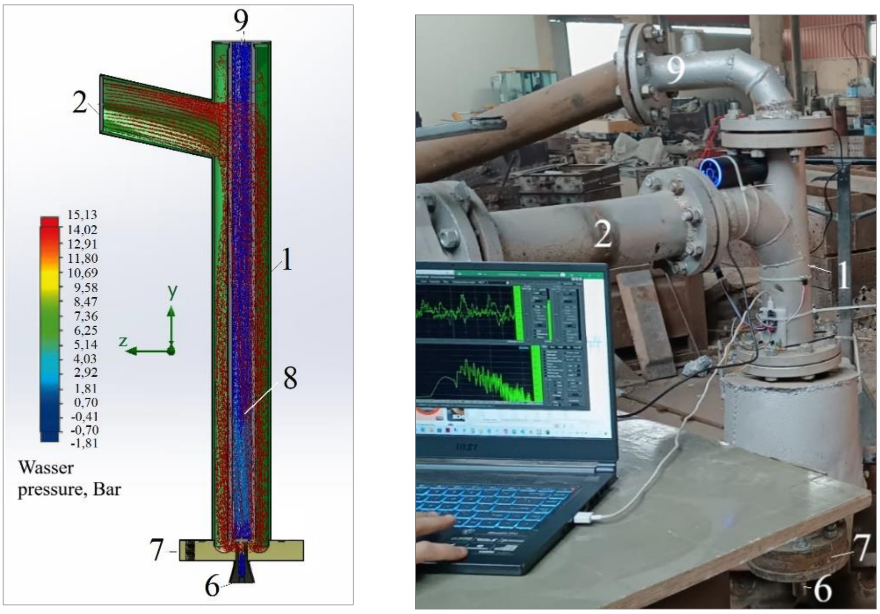

Fig. 2. A graphical simulation model of the hydro-vacuum dispersion process and experimental research prototype in semi-industrial conditions.

In order to clearly illustrate the effect of microstructural segregation, gradient migration and non-equilibrium stress obtained in powder particles, Figure 3 presents a typical microstructure of a hydro-vacuum dispersed secondary duralumin (AW-2017A - $AlCu_4MgSi$) powder particle, where microcavitation-perforation pits are also abundantly noted.

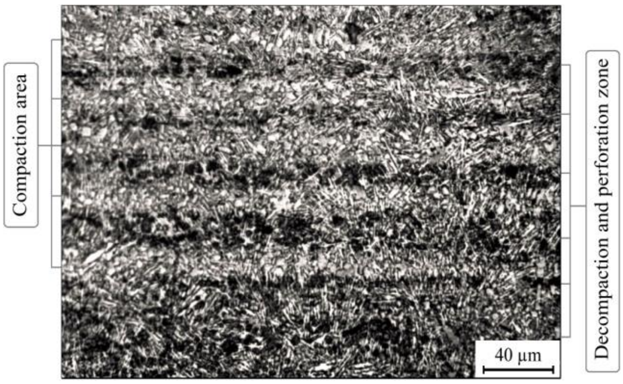

Fig. 3. Microstructural segregation, gradient migration and non-equilibrium stress in duralumin powder particles dispersed by hydro-vacuum method.

In contrast to traditional technologies, in the process of hydro-vacuum processing of melts, the surface of the dispersible melt jet is completely isolated from both atmospheric air and long-term effects of steam generated during the processing. As a result of all of the above, the intensity of damage and porosity of granules due to atmospheric oxygen oxidation, water vapor and gases resulting from its dissociation is reduced. As a result, the finishing stage of powder production is limited to low-temperature (40-150^{0}C) drying. The need for hydrogen-reducing thermal and granulometric homogenizing and chemically activating mechanical processing is completely excluded.

The technological system implementing the mentioned process (operating plant, water circulation mechanism, pulp separator, etc.) is distinguished by its compactness and mobility. It can be used practically in metallurgical production of any scale for large-tonnage production of activated, functional powder from any type of molten metal [14]-[16].

In order to regulate the granulometric composition of the powder particles, the device also provides for the regulation of the rarefaction formed in the core of the vortex of the melt suction cone profile, both by controlling the speed and pressure of the water supplied to the device, and also by changing the vortex profile (shape and height), which is achieved by a semi-toroidal confusor that vertically sprays water supplied by pressure in the body of the device by adjusting the section (dimensions l, h) of the confuser (convergent-divergent) nozzle (5).

These innovative solutions represent an important scientific and technical innovation, since they have no analogues in the case of dispersing alloys. Implementation of such a fundamentally different controlled process provides the possibility of continuous production of absolutely homogenized pulp, and therefore, relatively homogeneous, free of harmful impurities highly activated functional powders.

The proposed technology is environmentally safe. No smoke, steam or dust is released during the work process, because the water circulating in the technological system itself performs the function of both an air filter and a steam condenser. The device operates quietly and without significant vibrations, is compact and easy to install (installation is not related to significant reconstruction of the smelting plants or foundry area). The technical water used in the working area circulates in its own pipe system and also does not pollute the environment. The technology is energy-efficient, eliminates high-temperature heat treatment of the received powders in a regenerating environment. Therefore, it is highly profitable and cost-effective.

II. Research methodology and materials

The computer software module Solidworks Flow Simulation [17] based on the laws of theoretical hydrodynamics and hydromechanics was used for the simulation modeling of the device. When modeling, the flow rate (velocity) of the water supplied to create a hydro-vacuum in the device was used as a variable parameter, the range of variation of which was within the limits of 0.015-0.029 $m^3 \cdot s^{-1}$. During the calculations, variation of the geometrical parameters (l, h) of the semi-toroidal confuser (5) forming a conical vortex from the water supplied at high pressure from the circular collector channel (4) of the dispersion-diffusion chamber (8-8′) of the body (1), from the (initial) values l = 16.69, h = 5 mm, within ±50% deviation limits, obtained when making design solution. At the same time, the reference pressure of the water supplied in the circular collector channel (4) of the device was varied in the range of 4-23 bar. Through the comparative analysis of the modeling results carried out as a result of the mentioned approach, the optimal values of the construction and technological parameters necessary and sufficient to ensure the desired theoretical value of hydro-vacuum (-1 bar) were determined.

In order to evaluate the accuracy and effectiveness of the data obtained as a result of the modeling, standard methods and tools of hydrometry were used for the experimental research, including a digital water pressure measuring manometer with an electronic transmitter PTL-25 A (measurement range 0-25 bar) and a vacuum meter Leybold THERMOVAC TTR 91 (measurement range 5.10^{-4}÷1000 microbar).

For recording vibrations of the hydro-vacuum dispersion chamber, a digital gyroscope mounted on the device, a noise meter (Integrating Sound Level Meter) for recording the acoustic spectrum, including the ultrasonic range of acoustic noise, liquid metal temperature measuring contact thermocouples with digital galvanometers, etc. were also used. Accumulation and processing of experimental data was carried out online, directly during the conduct of experimental studies, through the use of a special experimental computer platform Grab ExP.

Experimental studies were conducted, alternately, both using a high-purity aluminum of the 1000 series and - aluminum scrap. An induction furnace Termolit ICMEF-0.06 was used for melting. Structural and metallographic studies were performed using a metallographic microscope Neophot 32 (Carl Zeiss).

To evaluate the quality of the activity of the obtained powder, a special tool - a FANN-432 model manometric calcimeter [18], with an automated magnetic stirrer and an automatic sodium hydroxide supply function was used, which led to the rapid removal of the oxide film from the surface of the investigated particles and an increase in the rate of hydrogen release from dissociated water molecules.

III. Results and discussion

Simulation modeling showed that in order to operate the device with the maximum possible efficiency, which was expressed in the condition of providing technical -1 bar power vacuum with minimum expenses (water pressure), it is necessary to reduce the parameters h and l of the semi-toroidal mixer (Figure 1) to the optimal values obtained by the simulation model. These values are: $h_{opt}=3.24$ mm, $l_{opt} = 8.75$ mm.

It was determined that, as a result of the optimization of the mentioned parameters, in order to obtain -1 bar rarefaction in the hydro-vacuum dispersion chamber (Figure 1, pos. 8), in exchange for the supply of water at a rate of 0.029 $m^3 \cdot s^{-1}$ into the circular collector channel (4) with a pressure of 16-20 bar used by us so far it will be enough to develop a speed of 0.022 $m^3 \cdot s^{-1}$ and a pressure of 13.2 bar. The effectiveness of the mentioned solution is clearly proven by the results of the report on the acceleration rates of the melt particles absorbed/dispersed under the influence of the pressure drop and created rarefaction in the confuser-diffuser pair (5-8), which is presented in Figure 4 in the form of diagrams.

From the diagrams presented, it can be seen that the reduction of the height (h) of the confuser (5) by 35% and the thickness (l) by 47% increases the pressure drop rate in the mentioned transition zone from 11 to 8 bars and increases acceleration of the water-carried metal particles from 3-3.5 to 4.1-4.3 $m \cdot s^{-1}$, which also leads to a change in the amplitude-frequency characteristic of shock waves generated in the device. This is one of the key factors in terms of improving the intensity of melt dispersion and the kinetics of mechanoactivation of the formed powder particles.

From the diagrams showing the results of the reporting data, it can also be seen that as a result of the optimization of the geometrical parameters of the confuser (5) in the diffuser part of the hydro-vacuum device 8-8', the amplitude of the shock-wave impact generated on average decreases from 0.35 to 0.065 units. On the other hand, it is observed that the frequency decreases by 40% after reaching the height of 120 mm, and in the optimized case, on the contrary, it increases sharply after reaching the height of 180 mm. In addition, it can be seen from the diagrams that if in the first case the zone of active dispersions is located in the height range of 25-180 mm, as a result of parametric optimization, the height of this zone increases to 250 mm. This also indicates the activation of cavitation processes and the strengthening of shock waves accompanying the rarefaction front.

By checking the adequacy of the obtained results, which was carried out by modernizing the structural elements of the device in accordance with the simulation model and a new trial-experimental investigation, we were convinced of the high (≈ 95%) accuracy and efficiency of the latter. This is clearly confirmed by the graphic material constructed as a result of the experimental research data presented in Figure 5, where it can be seen that as a result of the parametric optimization of the device and process, similar to the simulation model, the amplitude of the vibrations of the dispersion chamber decreases, and the frequency increases, so that the gravitational overload, that is, the average rate of the vacuum suction-acceleration of the dispersed particles decreases relatively insignificantly, by 0.004 $m \cdot s^{-2}$.

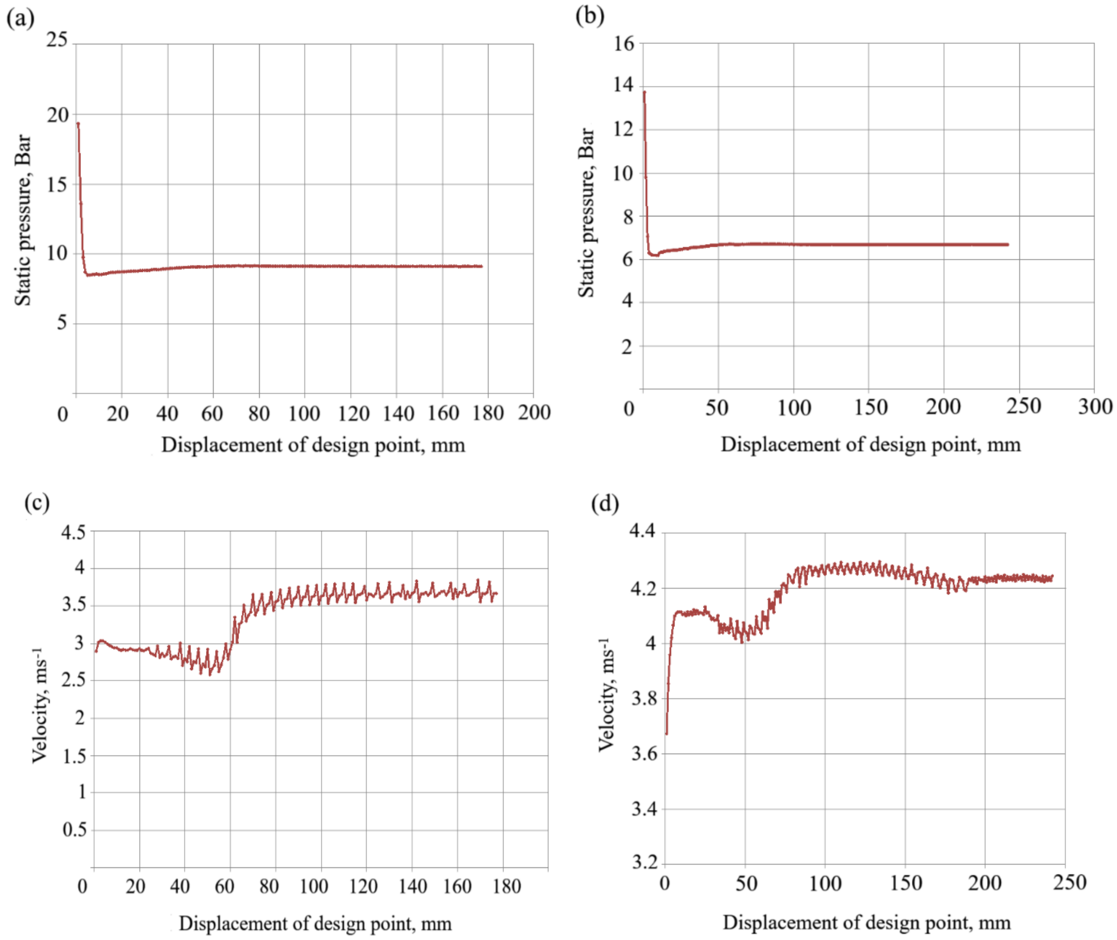

Fig. 4. Results of the simulation study: indicators of pressure drop and velocity increase of the water supplied to the dispersion chamber in relation to its vertical location, before optimization ((a), (c)) and after optimization ((b), (d)) of the dispersing process.

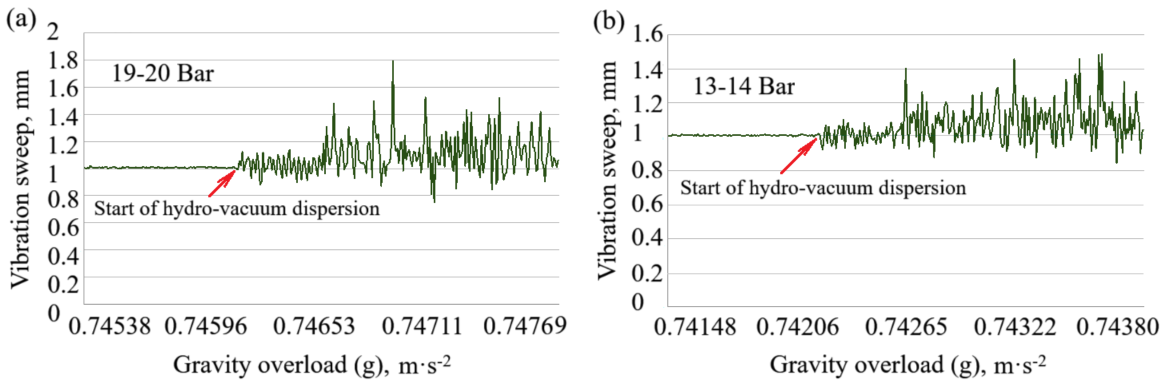

Fig. 5. Vibration of the dispersion chamber of the hydro-vacuum machine before and after the working process. (a) Vibration's sweep, mm and overload dynamics before optimization of operating parameters and water pressure, (b) after optimization (Aluminum, dispersion temperature 740°C).

The above is further supported by the data recorded by the digital audio recorder and the acoustic spectrograms obtained as a result of their processing in Figure 6 and Figure 7. In particular, it can be seen from these spectrograms that after parametric optimization of the hydro-vacuum device, the power of the noise emitted during its operation, i.e. the density of its spectrum, decreases at the expense of reducing the amplitude of acoustic waves, i.e. the kinetic energy. This leads to the ability to transfer the potential energy accumulated in these waves to a greater distance (height), and this is very important in terms of increasing the efficiency of cavitation currents acting on dispersed particles, i.e., secondary mechanoactivators. The said is also quite similar to the results of the above-mentioned simulation modeling (Figure 4, d) and supports it.

In order to compare the hydromechanical processes generated in the dispersion chamber of the device, in particular, the model and actual profiles of the force hydrodynamic currents, during the experimental work, the procedure of artificial freezing of the jet sucked into the device was carried out, which was carried out by means of

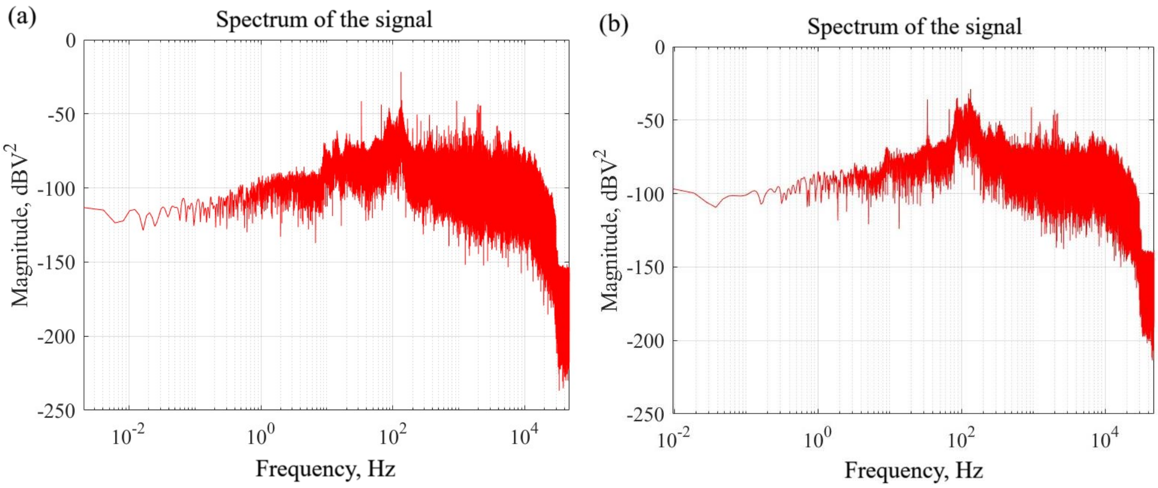

Fig. 6. Amplitude spectrum of the audio signal before and after pumping the melt into the dispersion chamber: (a) spectrum before optimizing the geometrical parameters of the converging duct (5); (b) after optimizing.

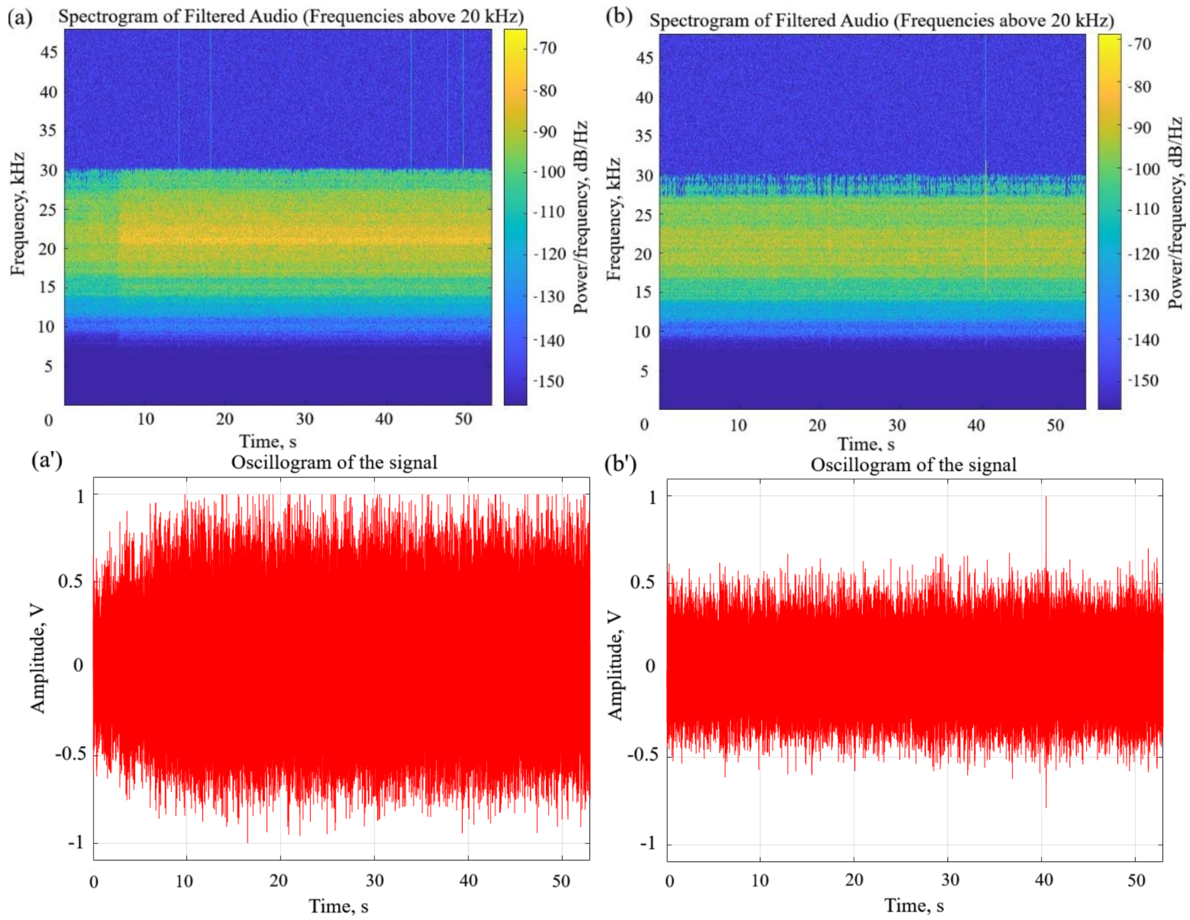

Fig. 7. Acoustic spectrum of the hydro-vacuum dispersion process of aluminum in the established operating mode of the equipment: (a, a') before optimization and (b, b') after it.

a gentle reduction of the water pressure and braking of the dispersion process.

Based on the imprint (Figure 8) left on the peripheral layers of the cylindrical flow of molten metal absorbed by the hydrodynamic shell of the vortex of water sucked into the disperser and conically ejected from the confuser (5), there is no doubt that the ejected water shell, passing through the 36º inclined skirts of the conical cap of the suction nozzle (6), experiences angular acceleration corresponding to the direction of negative rotation of the water tangentially delivered from the tube (2) in the circular collector channel (4), identical to the forces shown in the graphical simulation model (Figure 2).

It is noteworthy that according to the existing imprints, the actual indicator of the inclination of the vector of the angular movement of the hydrodynamic vortex of water was the value provided by the design $\alpha \approx 18\pm0.5^{\circ}$, which indicates the operation of the device in conditions as close as possible to the optimal ones. Deviation from the optimal values of the technological regimes for the larger value (water pressure 13.2 bar, velocity 0.022 $m^3 \cdot s^{-1}$) led to a decrease in the mentioned angle, and to a small value, on the contrary, to an increase.

From the material illustrated in Figure 8, b, it can be seen that the powder particles obtained as a result of hydro-vacuum dispersion of aluminum are characterized by an elongated shape with a predominantly smooth surface morphological structure, which have clearly defined zones of relative elongation and narrowing developed as a result of hydromechanical stretching and twisting.

The study of the granulometric composition of the obtained powders, the results of which, in turn, are presented in the form of histograms illustrated in Figure 9, showed that the dominant fraction of particles obtained after the optimization of the hydro-vacuum dispersion process is 100-150 μm, which is on average 60-80 μm less than the fraction formed before the optimization of the process. In addition, its specific share has increased from 10-15 % to 25-34 %.

The laboratory analysis performed on the manometric calcimeter determined that the reduction of the dispersity of the obtained aluminum powder particles led to an increase in the content of active particles from 95-96 % to 99 %, which is explained by an increase in the specific surface of the latter and the degree of mechanoactivation, that is, in the concentration of the hidden physico-chemical energy accumulated in them.

Experimental studies also revealed the need to manage the technological parameters having a significant influence on the granulometric composition of powders, such as: the initial temperature of the melt and the speed of its absorption in the disperser. It is significant that the diameter of the inner cylindrical channel of the suction nozzle is the key factor in regulating the speed of melt absorption, i.e. dispersion cost. It was determined experimentally that in the case of hydro-vacuum dispersion of aluminum, the rational value of the ratio "melt speed: water speed" is 1:20÷1:23. Therefore, in the case of a water velocity of 0.022 $m^3 \cdot s^{-1}$, the optimum speed of aluminum supply to the disperser shall be 0.0011-0.00095 $m^3 \cdot s^{-1}$, which in mass units corresponds to a speed of 2.5-3 $kg \cdot s^{-1}$.

Experimental studies have shown that this ratio changes depending on the initial temperature and viscosity of the melt. In particular, - an increase in the alloy temperature leads to an increase in the mentioned ratio, and vice versa, - a decrease - to a decrease.

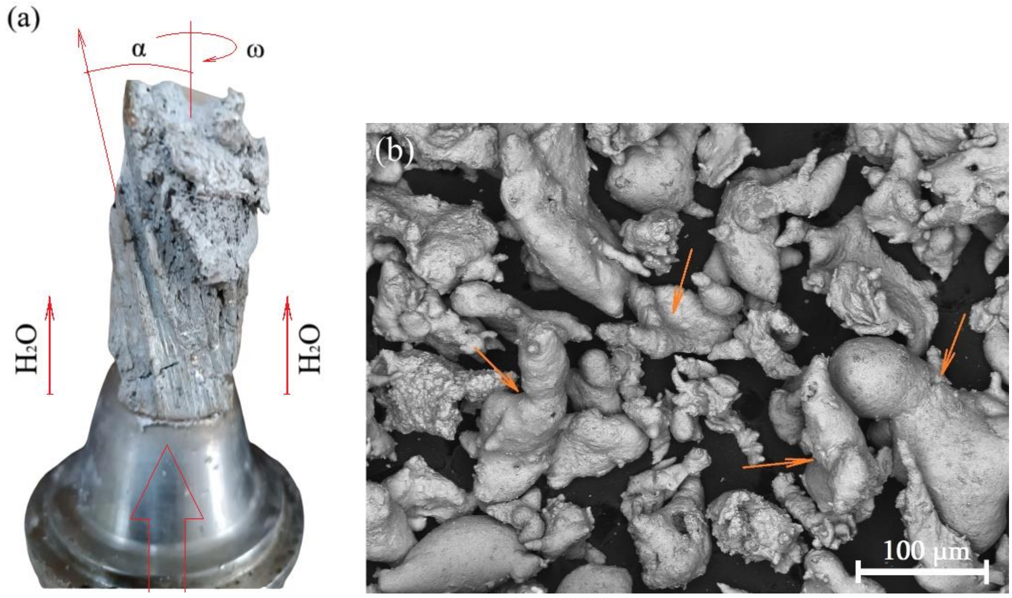

Fig. 8. (a) Effect of hydromechanical impact on the flow stream of the sucked metal, and (b) powdery particles obtained as a result of dispersion, fraction 10-100 μm.

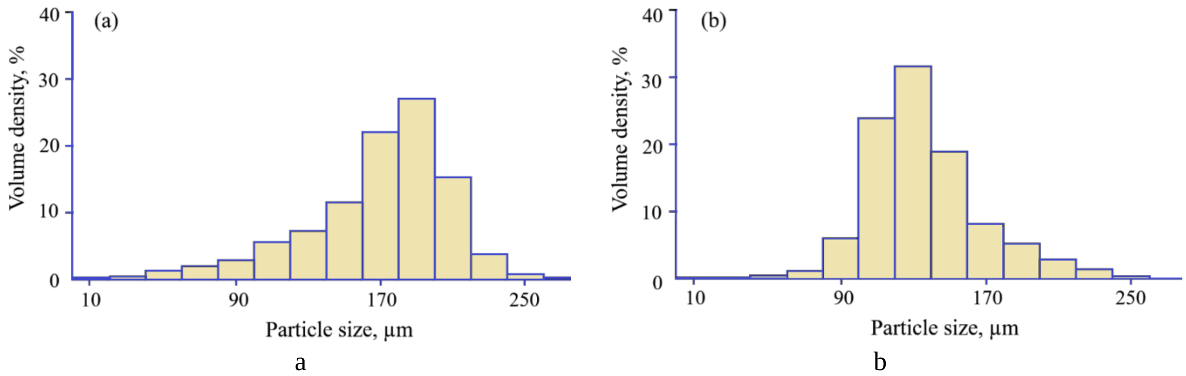

Fig. 9. Granulometric composition of obtained powders before (a) and after (b) optimization of the hydro-vacuum dispersion process.

The operational management of the process is carried out through a programmed operating computer/laptop, where the function of the supporting signal is performed by the operationally controlled granulometric composition of the produced powder. In case of deviation from the latter's target indicators, a control impact signal is generated by means of a special portable express analyzer integrated with a computer with a special controller, based on which the computer program using the MATLAB simulation modeling database automatically makes a decision to manage the dispersion process, in particular, the suction speed of the molten metal, by appropriate adjustment of the pressure and consumption of the water tangentially entering in the circular collector channel (4) and semi-toroidal convergent-divergent confusor (5).

Conclusions

A systematic analysis of the results of experimental studies allows us to conclude that:

1. Continuing the research and taking into account the essential parameters in the simulation model, such as the initial temperature of the melt, its viscosity and the actual weight ratio is metal/water, will give us the opportunity to reveal all the technical conditions necessary for the optimization of hydro-vacuum dispersing modes for melts of practically any type and technological complexity without conducting preliminary experimental studies.

2. The wave (hydromechanical) impact generated by the water acting on the molten metal jet with increasing angular acceleration in the universal portable device for hydro-vacuum dispersion of metal melts, which continues until the dispersed metal particles completely solidify and enter the special cooler, leads to the spatial (3D) twisting of the formed powder particles and intense cavitation-pulsation treatment, thus achieving the irreversible effect of their microstructural segregation, gradient migration and mechanoactivation. As a result, the obtained powders are distinguished by increased surface area, improved purity and high physico-chemical activity. It is possible to obtain metal powders with a weight content of active particles of 98-99 %.

3. The optimal operating modes of the hydro-vacuum device for dispersing metal melts are: water pressure - 13.2 bar, water supply rate - 0.022 $m^3 \cdot s^{-1}$, thickness of the outlet neck of the annular confuser for the reverse (on 162°) ejection of water - 3.24 mm, the suction speed of the melt - 2.5-3 $kg \cdot s^{-1}$, which, when working on aluminum melts, is provided by the suction cylinder nozzle with the inner channel diameter of 8 mm.

Acknowledgements

The research was financially supported by the Shota Rustaveli National Science Foundation of Georgia, Grant No. AR-22-1495. For technical support, the authors also acknowledge the directors of the R. Dvali Institute of Mechanics of Machines and GeoEnterprise LLC, Mr. Tamaz Natriashvili, Academician of the National Academy of Sciences of Georgia, and Mr. Zurab Magradze.

Sakhvadze David – Dr., R. Dvali Institute of Machine Mechanics, Scientific director of the grant;
Jandieri Gigo – Dr., Grant coordinator and lead investigator;
Saralidze Besik – PhD, Researcher of the F. Tavadze Institute of Materials Sciences and Metallurgy;
Sakhvadze Giorgi – *Eng.* Metal Powder Ltd, Tbilisi, Georgia;
Kuparadze Anzor – Soft Eng-s G3D Ltd, Kutaisi, Georgia;
Sulaqvelidze Nata – Eng. Metrologist - G3D Ltd, Kutaisi, Georgia.

[1] J.J. Dunkley, Metal Powder Atomisation Methods for Modern Manufacturing: Advantages, limitations and new applications for high value powder manufacturing techniques, Johnson Matthey Technolology Review, 63(3), 226 (2019); https://doi.org/10.1595/205651319X15583434137356.
[2] I. Korobeinikov, A. Perminov, T. Dubberstein and O. Volkova, *Modification of Liquid Steel Viscosity and Surface Tension for Inert Gas Atomization of Metal Powder*, Metals, 11(3), 521 (2021); https://doi.org/10.3390/met11030521.
[3] C. Fredriksson, *Sustainability of metal powder additive manufacturing*, Procedia Manufacturing, 33, 139 (2019); https://doi.org/10.1016/j.promfg.2019.04.018.
[4] D. Powell, E. W. Rennie Allan, L. Geekie and N. Burns, *Understanding powder degradation in metal additive manufacturing to allow the upcycling of recycled powders*, Journal of Cleaner Production, 268, 122077 (2020); https://doi.org/10.1016/j.jclepro.2020.122077.
[5] J. Grubbs, B.C. Sousa and D. Cote, *Exploration of the Effects of Metallic Powder Handling and Storage Conditions on Flowability and Moisture Content for Additive Manufacturing Applications*, Metals, 12, 603 (2022); https://doi.org/10.3390/met12040603.
[6] A. Vignes, A. Krietsch, O. Dufaud, A. Santandréa, L. Perrin and J. Bouillard, *Course of explosion behaviour of metallic powders – From micron to nanosize*, Journal of Hazardous Materials, 379, 120767(2019), https://doi.org/10.1016/j.jhazmat.2019.120767.
[7] A.V. Baranovskiy, G.A. Pribytkov, M.G. Krinitcyn, V.V. Homyakov and G.O Dankovcev, *Mechanical activation of self-propagating high temperature synthesis in titanium, carbon black and iron-based alloy powder mixtures*, AIP Conference Proceedings, 2167 (1),. 020031(2019); https://doi.org/10.1063/1.5131898.
[8] X. Liu, X. Zhang, J. Li, Q. Zhu, N.G. Deen and Y. Tang, *Regeneration of iron fuel in fluidized beds Part II: Reduction experiments*, Powder Technology, 420, 118183 (2023); https://doi.org/10.1016/j.powtec.2022.118183.

[9] A.E. Zverovshchikov and G.S. Bolshakov, *Simulation of the kinematics and gas dynamics of the centrifugal dispersion stand*, Journal of Physics: Conference Series, 2094, 042046 (2021); https://doi.org/10.1088/1742-6596/2094/4/042046.

[10] S.A. Cegarra; J. Pijuan and M.D. Riera, *Cooling Rate Modeling and Evaluation during Centrifugal Atomization Process*, Journal of Manufacturing and Materials Processing, 7, 112 (2023); https://doi.org/10.3390/jmmp7030112.

[11] P. Kustron, M. Korzeniowski, A. Sajbura, T. Piwowarczyk, P. Kaczynski and P. Sokolowski, *Development of High-Power Ultrasonic System Dedicated to Metal Powder Atomization*, Applied Sciences, 13(15), 8984(2023); https://doi.org/10.3390/app13158984.

[12] D. Sakhvadze, G. Jandieri, T. Tsirekidze, I. Gorbenko, *Device for producing metallic powder from melt*, GE Patent 20156384B, Oct. 12, 2015.

[13] D. Sakhvadze, G. Sakhvadze, G. Jandieri, *Method for metallic powder preparation and device for implementation thereo*f, GE Patent 20207078B, Mar. 10, 2020.

[14] D. Sakhvadze, G. Jandieri and J. Bolkvadze, *Novel technology of metal powders production by hydrovacuum dispersion of melts*, Journal of Machines, Technologies, Materials, 12(6), 236 (2018); https://stumejournals.com/journals/mtm/2018/6/236.

[15] G.V. Jandieri, I.F. Gorbenko, D.V. Sakhvadze and T.I. Tsirekidze, *Innovative hydrovacuum technology of granulation of metal melts*, Electrometallurgy Today, 4 (133), 70 (2018); https://doi.org/10.15407/sem2018.04.06.

[16] D. Sakhvadze, G. Jandieri, G. Jangveladze and G. Sakhvadze, *A new technological approach to the granulation of slag melts of ferrous metallurgy: obtaining glassy fine-grained granules of improved quality*, Journal of Engineering and Applied Science, 68, 22 (2021); https://doi.org/10.1186/s44147-021-00019-7.

[17] J.E. Matsson, *An Introduction to SOLIDWORKS Flow Simulation*, Stephen Schroff publisher, USA: SDC Publications, ch. 3, 57 (2022).

[18] I.V. Bazhenov, *Automated complex for determination of aluminum activity and gas release kinetics*, Construction Materials, 8, 16 (2015); (in Russ.). Accessed: 10.10.2023. [Online]. Available: https://journal-cm.ru/images/files/2015/2015_08_016-017.pdf.

Давид Сахвадзе[1], Гіго Джандієрі[2], Бесік Саралідзе[3], Георгі Сахвадзе[4], Анзор Купарадзе[5] та Ната Сулаквелідзе[5]

Універсальна переносна установка для гідровакуумного диспергування металевих розплавів: удосконалення технологічного процесу

[1]Інститут механіки машин Двалі, Тбілісі, Грузія
[2]Незалежний дослідник, Лейпциг, Німеччина, gigo.jandieri@gmail.com
[3]F. Тавадзе Інститут матеріалознавства та металургії, Тбілісі, Грузія
[4]Metal Powder Ltd., Тбілісі, Грузія
[5]G3D Ltd, Кутаїсі, Грузія

Розвиток технології і техніки диспергування металевих сплавів важливий як з точки зору підвищення якості порошків, так і збільшення обсягів виробництва і підвищення економічної та екологічної безпеки техносфери. Металевий порошок є незамінним функціональним компонентом багатьох сучасних галузей промисловості. На фоні зростаючих вимог до виробництва металевих порошків ми розробили та оптимізували новий пристрій для гідровакуумного диспергування розплавів, суть інноваційності та перевага якого полягає у всмоктуванні та диспергуванні розплаву в напрямку, протилежному напрямку. дії сили тяжіння, в умовах гравітаційного перевантаження 150-200 g, де основну роботу виконує гідравлічне розрідження, що виникає внаслідок різкого (на 162°) заломлення напрямку та швидкого розширення кільцевого потоку води високого тиску, з накладення просторових ударно-пульсуючих хвиль, що генеруються в зовнішній оболонці утвореного конусоподібного вихору. Апарат характеризується високою продуктивністю і низькими енерговитратами, а порошки - підвищеною питомою поверхнею, підвищеною чистотою і високою активністю.

Ключові слова: Гідровакуумне диспергування; металевий порошок; моделювання; оптимізація.