NATIONAL TECHNICAL UNIVERSITY OF UKRAINE
«IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE»
Faculty of welding
Surface engineering department

INCREASING THE EFFICIENCY OF CLADDING OF POWDER BY CATHODIC ARC DEPOSITION

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Actuality

The method of coatings formation from the flow of metallic plasma of the vacuum arc due to its technological capabilities is most promising in the area of deposition coatings of composite powders of different dispersions. This method differs by its simplicity of realization of evaporation and the condensation of the vapour of the material on the surface and through the high level of ionization of the plasma flow, it can be applied to various structural materials, significantly improving the performance of these material, and provides them with new physic-mechanical properties.

Thereby, the study of the improvement and optimization of the technological process of cathodic arc deposition of films on powder materials is relevant and aimed at creating new composite powder material with high quality for its further use, including for thermal spraying coating of various functional properties.

Purpose and tasks

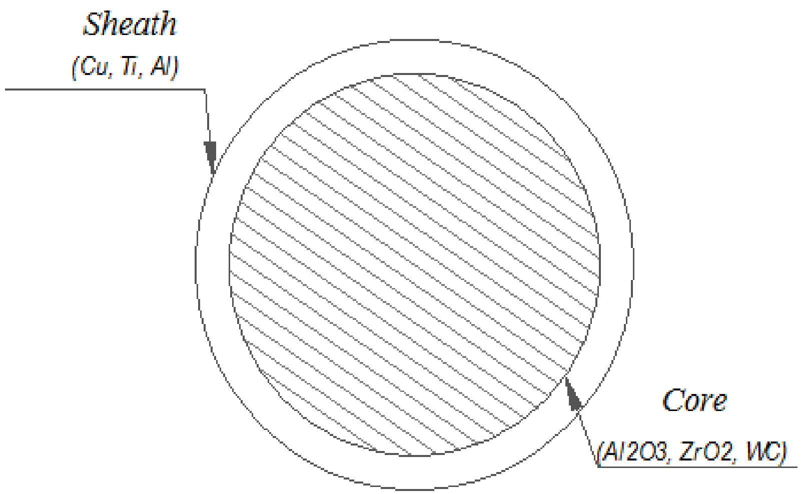
The aim of the master's thesis is to analyze the factors that influence on the quality and efficiency of the powder cladding process by the cathodic arc method for choosing the optimal modes for cladding of powder.

To achieve this goal, were defined the following tasks:

- to study, based on the literature data, the structure of composite powders, methods for obtaining coatings on powders, their properties and applications;
- to define the dependencies that allow to determine the optimal time of metallization required to achieve a given temperature of the surface on powder particle and to obtain a desired thickness of metal film;
- to analyze the influence of the choice of the material of the ceramic base for the composite particle on the productivity of the metallization process;
- to investigate the physical and chemical processes on the surface of powder particles
- to analyze the influence of the thickness of the coating of the clad particle on the modes of the application of functional thermal spraying;
- to develop basic requirements for labor protection, fire and environmental safety

The powders as objects for metallising, in contrast to the thick materials, have a number of the following technological special features in deposition of the coatings:

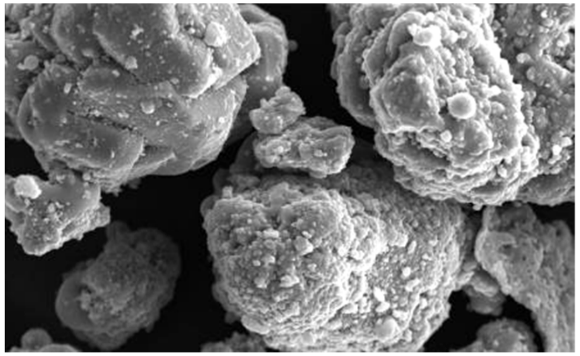
- Firstly, the powders, especially the fine fraction powders, are able to 'sticking' which becomes more intensive with the vapour flow so that it is necessary to take special measures to prevent aggregation of the particle;
- secondly, since the process of heat transfer in vacuum is complicated, the powder particles may be overheated as a result of the generation of condensation heat of the metal;
- thirdly, the developed surface of the powders is a source of generation of the adsorbed moisture and gases. This influences the pumping process and formation of deep vacuum.



Schematic illustration of clad ceramic particle

Examples of microstructures and micro slips of titanium-coated aluminium oxide particles and copper-coated tungsten carbide

A



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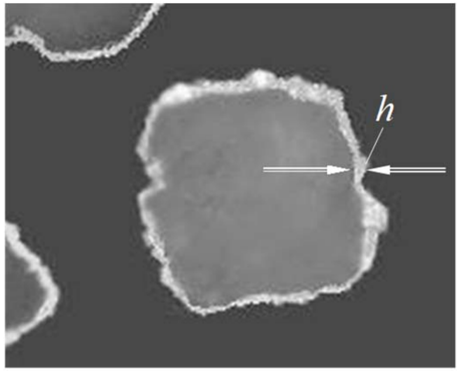
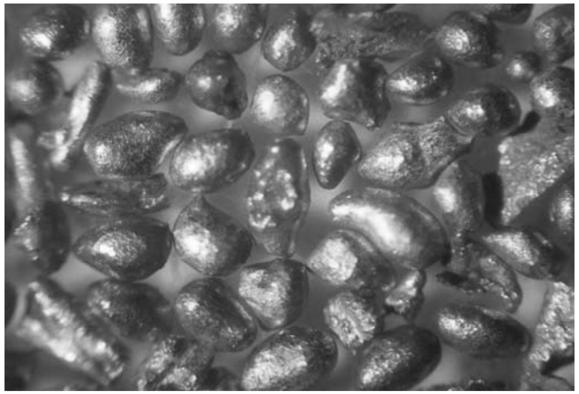
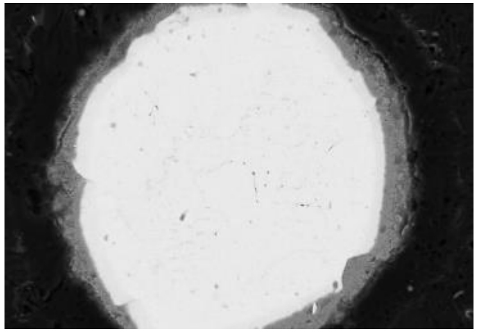


C

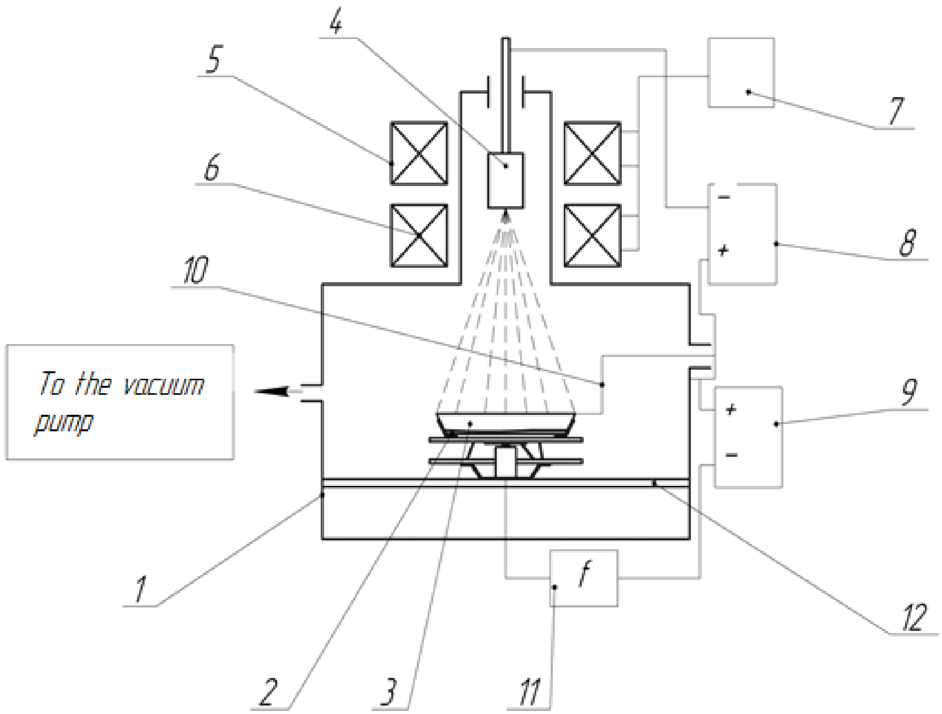


D



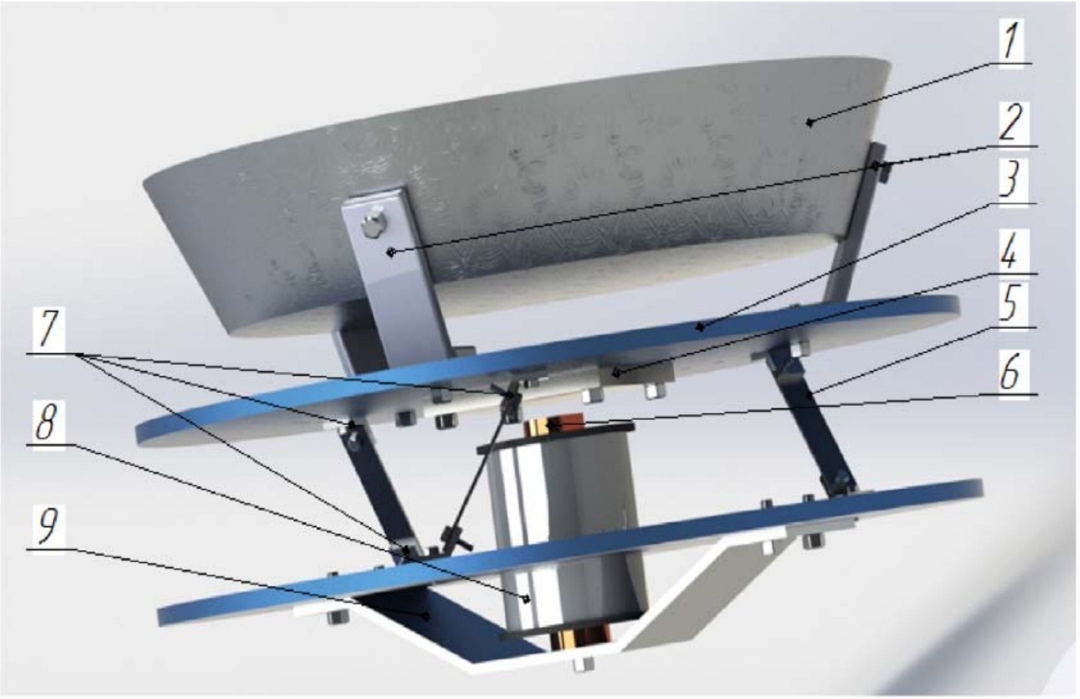
A – the microstructure of Al_2O_3 particles covered by Ti;
B – croslip of Al_2O_3 particles covered by Ti;
C – microstructure of WC particle covered Cu;
D – microslip of WC particle covered by Cu

Scheme of the main elements of the PVD installation



1 - vacuum chamber;
2 - the powder that is cladding;
3 - mixer device;
4 - cathode;
5 - stabilizing coil;
6 - focusing coil;
7- power supply for the stabilizing and focusing coil;
8 - power supply unit of the evaporator ВДУЧ - 315;
9 - high-voltage power supply;
10 - capacity supply to the mixer device;
11 oscillation generator;
12-plate for placing the mixer device in the chamber.

Mixing device for powder cladding in vacuum



1 - container for powder;
2 - bearing angles;
3 - support platform;
4 - plate;
5 - flat springs;
6 - core of the coil;
7 - angles;
8 - magnetic coil;
9 - support element

Scheme of the device for mixing

Due to the frequency signal applied to the magnet coil, the result of which is the formation of a frequency magnetic field, that creates vibration of the layer of powder in the reservoir. While the formation of horizontal rotation allows the powder to stir and move in a circle at a speed of 4-5,5 cm/sec.

Mathematical modeling

Complicated and the most important is the assessment of the temperature of the powder particles during the metallization. During applying the coating in a vacuum there is a increased heating of the substrate surface, which can cause undesirable structural changes and composition of the material.

It is possible to estimate the surface temperature of a the core of clad powder by the equation of thermal balance, which for a spherical powder particle will have the form:

$$\frac{\pi d^2}{4} P_{sp} = cm \frac{dT_s}{dT} + \left(T_s - T_0\right) I\left(d\right),$$

where d, c, m - respectively, the diameter, heat capacity and the mass of powder particles; P_{SP} - specific absorption power; T_S - temperature on the surface of powder particles.

Mathematical modeling

After conducting a series of substitutions and simplifications, we obtain

$$t = \frac{1}{a}\ln\left(\frac{aT_s + b}{aT_0 + b}\right).$$

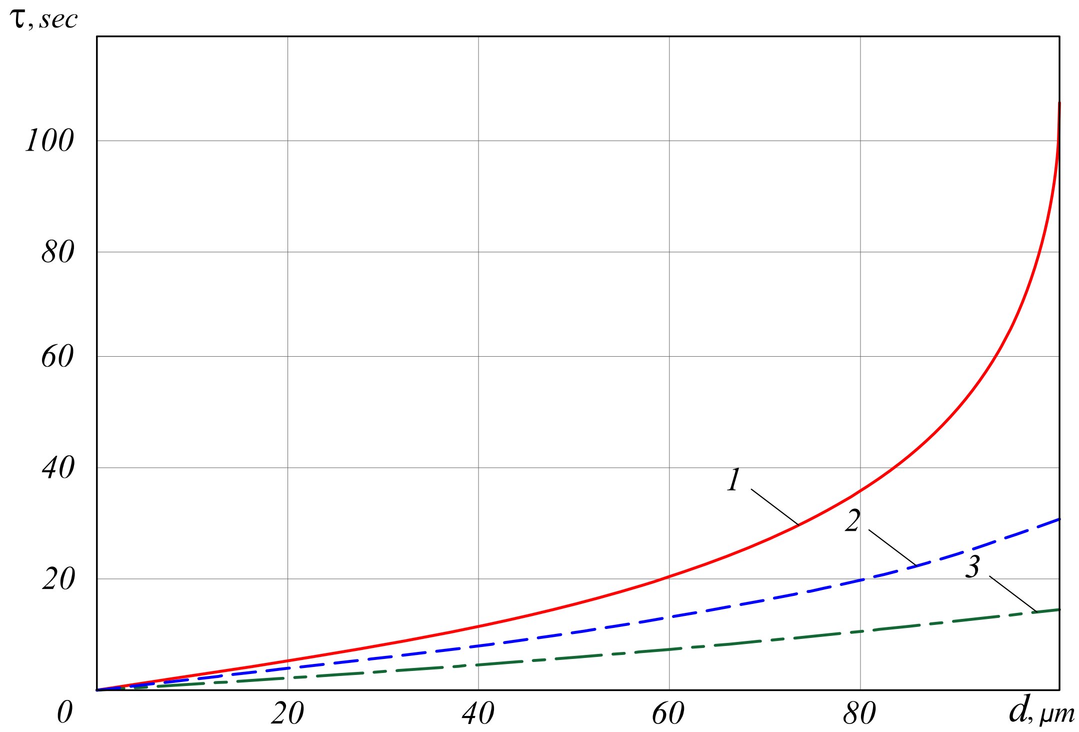
where

$$a = -\frac{6\lambda_1\lambda_2}{c\rho h^2\left(2\lambda_1 + \lambda_2\right)}\left(1 + \frac{\lambda_1}{2\lambda_2 + \lambda_1}\ln\frac{2\lambda_2}{\lambda_1}\right);$$

$$b = -aT_0 + \frac{3}{2c\rho d}P\,.$$

λ_1, λ_2 – the thermal conductivity of the particle of powder and of the environment respectively

Mathematical modeling



The theoretical dependence of the metallization time on the diameter of the powder of aluminum oxide upon reaching the following temperatures on the surface of the particle*:*

1 – 300 °C;
2 – 250 °C;
3 – 200 °C

Mathematical modeling

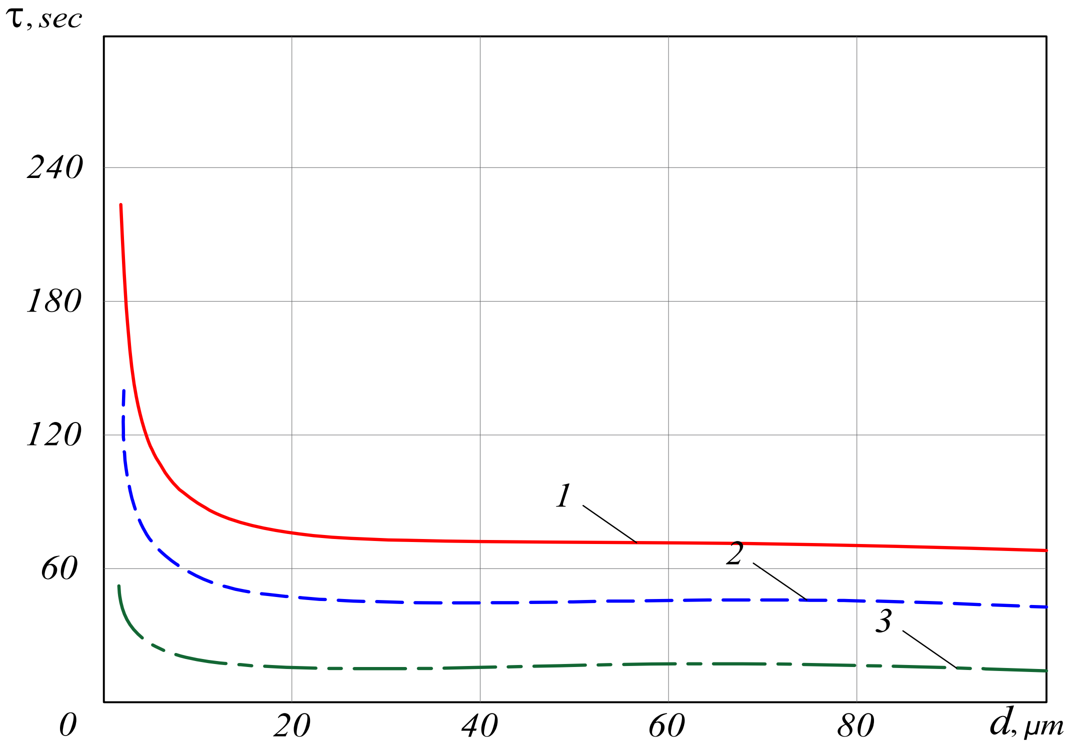
$$\tau = \int_0^h \frac{dh}{v_{ef}} = \int_0^h \frac{M_p S_{part}}{M_{part} S_p v_c} dh,$$

where h - thickness of the film on a powder particle, µm;
v_c – rate of metal condensation of a film on a flat surface, µm/min;
S_p, S_{part} – the area corresponding to the powder layer and the surface of the individual particle, mm^2 ;
M_p, M_{part} – the mass of the loading powder and the particle, g

By accepting the spherical form of the particles, after appropriate substitutions and integrals we obtain:

$$\tau = \frac{M_p}{\rho S_p v_c} \left(\frac{R + h}{R} \right)^3$$

Mathematical modeling



Theoretical dependencies of metallization time on the diameter of particles of aluminum oxide powder (1), zirconium oxide (2) and tungsten carbide (3)

Mathematical modeling

One of the important factors in optimization of the powder cladding process is the productivity. In addition to choose the optimum spray modes, the choice of core material of the clad particles leads to increase the efficiency and, as a result, time saving.

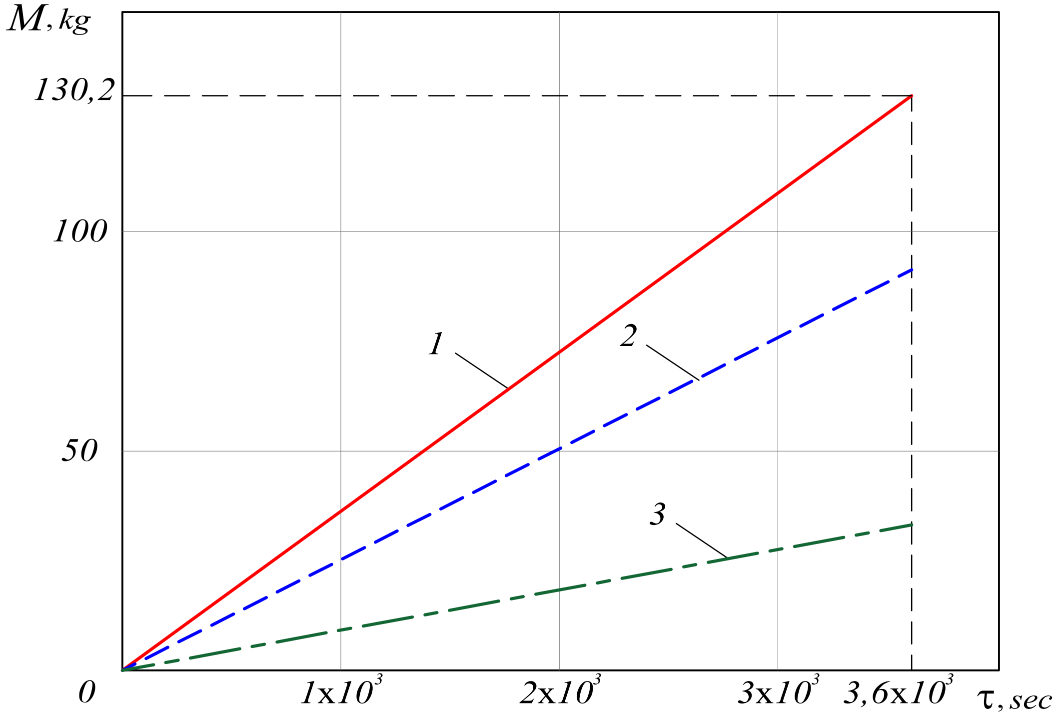
From the reference count evaporation rate under the given conditions:

$$U_s = \frac{0.1196}{133} 1.33 = 1.196 \times 10^{-3} \quad \frac{kg}{m^2 \cdot sec}$$

Modeling conditions for the metallization process for selected Al_2O_3, ZrO_2, and WC powders:

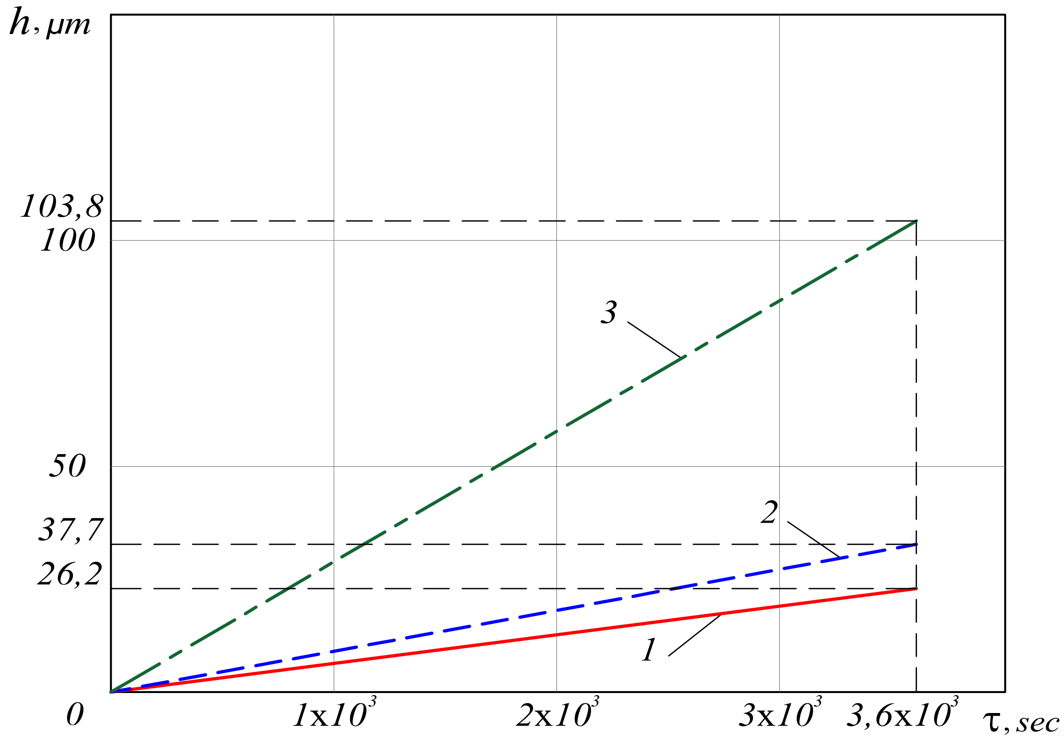
- cladding time - 1 hour,
- mass of powder - 1 kg
- coating material – Cu
- the diameter of the particles - 50 microns,
- pressure of the chamber - 1.33 Pa

Mathematical modeling



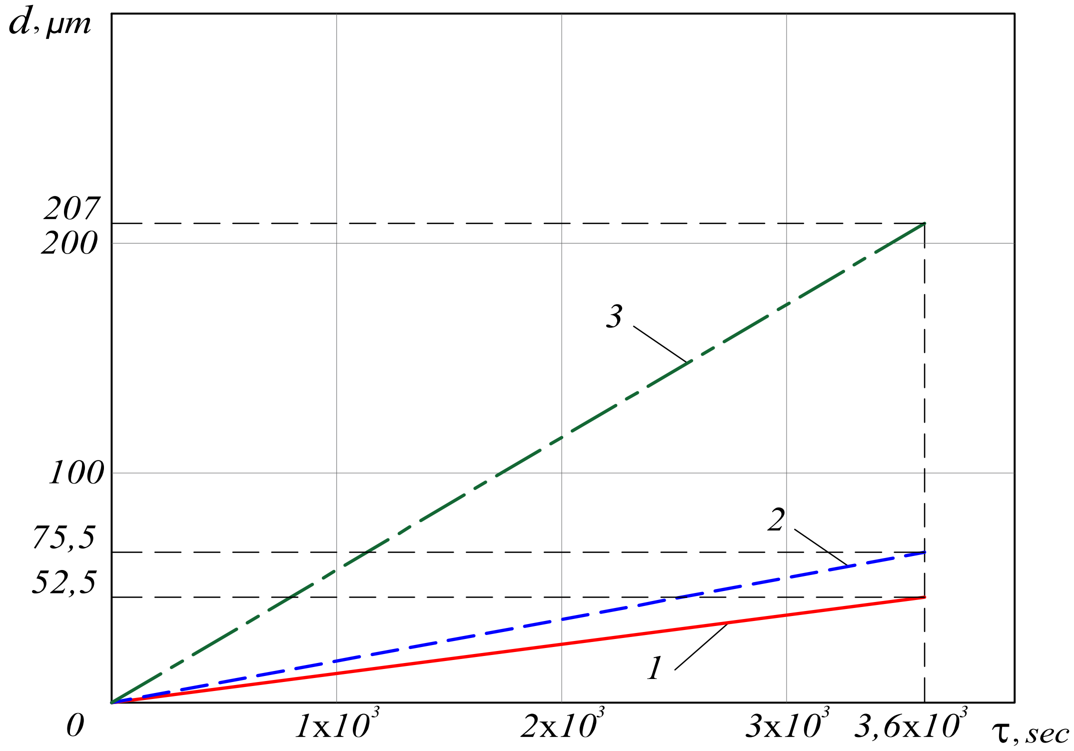
The theoretical dependence of the change in the total Cu coating mass from time for Al_2O_3 (1), ZrO_2 (2) and WC (3) with the same mass of powder and metallization time

Mathematical modeling



The theoretical dependence of the change in the thickness of the coating from time for Al_2O_3 (1), ZrO_2 (2) and WC (3) with the same powder mass and metallization time

Mathematical modeling



The theoretical dependence of the change in the diameter of the clad particles from time for Al_2O_3 (1), ZrO_2 (2) and WC (3) with the same powder mass and metallization time

GENERAL CONCLUSIONS

1. In the master's dissertation, on the basis of literary data, the types of composite materials, conditions for the formation of clad materials, their properties and applications are investigated. It is revealed that the most widespread use is the use of deposited powders on the basis of ceramic materials coated with more melting metals (Al, Cu, Ti, etc.). The analysis of the basic methods of obtaining clad powders has been made, from which it is concluded that it is more promising to obtain coatings on powders by vacuum-arc spraying methods, since in comparison with others it is possible to cover a larger range of coating materials.

2. According to the results of work, mathematical models were proposed that allow to determine the time of achievement on the surface of powder particles of a given temperature, as well as the duration of the metallization process to obtain a film of a certain thickness for three different materials (Al_2O_3, ZrO_2, WC), which allows to adjust the technological regimes vacuum - metallic metallurgy, depending on the weight of the loaded powder, its fractions and evaporator performance. On the basis of mathematical calculations, an analysis of the influence of the choice of the base material for the deposited particle on the performance of the metallization process and the growth of the thickness of the coating at the same powder volumes and time of spraying was carried out. It was established that with the same volume of powder and metallization time, the growth rate of the thickness of the coating is greater in WC than in ZrO_2 and Al_2O_3. This is due to the fact that, with the same volume of powders and different densities, the WC particles in comparison with other materials are less and correspondingly one particle has more coating material.

GENERAL CONCLUSIONS

3. An analysis of the physico-chemical processes occurring on the surface of the trapped particle was performed and the chemical interaction of the material of the nucleus of the trapped particle and the coating material was investigated. According to the results of the study, the oxygen and aluminum concentration, corresponding to 8.4% and 5.6% for titanium and 2% and 2.5% for copper, were determined. It has been found that at the temperature of 573 K the calculated values of the concentration of oxygen and aluminum in copper are very small compared with the solubility of these components in titanium.

4. Investigation of the dependence of the thickness of the coating of the deposited particle and the temperature parameters of the gas-thermal spraying was carried out. A mathematical model has been developed, according to which, for a particle of aluminum oxide with a diameter of 50 microns of clad copper, the thickness of the coating at which the particle acquires the maximum temperature corresponds to 1.5 microns. By mathematical calculations, the change in the maximum particle temperature was studied by changing the thickness of the coating and its corresponding change in the temperature of the plasma stream.

5. The master's thesis provides the basic requirements for labor protection, fire and environmental safety when working with vacuum equipment. Developed measures and facilities for the creation of safe working conditions on a research facility.