NANOPOWDERS PRODUCTION BY ELECTRICAL EXPLOSION OF WIRES: ENVIRONMENTAL APPLICATIONS

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Abstract

The possibility of application of nanopowders for solution of ecological problems is discussed in this paper. The dispersed, phase and chemical compositions of nanopowders produced by electrical explosion of aluminium wires in water depending on electrical parameters were investigated. Very active oxide-hydroxide phases can be used for water purification from ions of heavy, radioactive metals, organic compounds. Another product of interaction of aluminium particles with water is production of hydrogen with the transformation ratio 100 % without special additives. The tribological characteristics of industrial oil after treatment with electrical explosion of copper wires were studied. It was obtained decrease of the friction constant to 40 %. Use of nanopowder can lead to increasing lubricating oil time and prevent pollution of environment.

Keywords: *nanopowder, electrical explosion of wires, water purification*

Introduction

Nanosized powders due to their specific properties are more and more widely used as basic materials for production of ceramics and composites, filters, lubricant additives, for solution of ecological problems as catalysts, sorbents, etc.

One of the ways of nanopowder production is electrical explosion of wires (EEW). It is a process of explosive destruction of a metal wire under the action of great density current ($>10^6$ A/cm^2) [1]. EEW is characterized by the following peculiarities: time of explosion is $10^{-5}…10^{-8}$ s; temperature at the moment of explosion can reach the value more than 10^4 K, pressure ~ 10^9 Pa; velocity of product recession is from 1 to 5 km/s. Material of the wire transmutes into particles of nanosized range (10…100 nm) in accordance with certain conditions. Extremely nonequilibrium conditions of EEW cause some unusual properties of nanopowders.

Electroexplosive nanopowders have as a rule the spherical form of particles, they are steady against oxidation and sintering at room temperature and characterized with high diffusion activity at the heating. The threemodal particle size distribution is formed under the process of EEW. Dispersed composition is one of the most important parameters that determine their technical characteristics (packed density, flow rate, slope angle, and others), and, hence, their range of use.

The dispersed composition and other characteristics of nanopowders depend on all conditions of explosion – firstly, on the electrical parameters (energy consumed by wire before explosion, energy of arc stage, the velocity of energy input or power density. The nature of wire metal and its geometry (length and diameter of wire), microstructure and substructure of wire metal, environmental properties – pressure and kind of gas, introduction of chemically active gases in inert gas also have influence on the dispersiveness and other properties of nanopowders [2-4].

An important advantage of EEW technology is the adjustability of properties of EEW products by means of electrical parameters. Low energy consumption (< 10 kWh/kg) is due to direct heating of wire by electric current without heat carriers and due to high heating rate (> 10^7 K/s) that provides adiabatic conditions of energy transmission to wire. Yield of nanopowders on the basis of aluminum is 50 g/h, on the basis of tungsten – 300 g/h under production using one set. This technology is environmentally benign one: the process of nanopowder production is carried out in closed chamber, there is no technological emission.

EEW in inert gases or hydrogen is used to produce powders of metals, alloys, and intermetallic compounds. EEW in chemically active ambient is used to produce nanopowders of chemical compounds of metals: oxides, nitrides, carbides, etc.

In this paper the phase and chemical compositions of nanopowders produced by electrical explosion of wires in water and industrial oil are presented. The ways of application of electroexplosive nanopowder are shown.

Experimental Technique

The principal scheme of the experimental installation for producing electroexplosive powders in liquid ambient is shown in the Figure 1. The installation works as follows. The capacitor battery 2 is charged from the high-voltage power source 1. The wire driving mechanism 3 is used for automatic feed of the exploding length of wire 4 in the electrodes gap. When the wire reaches the high-voltage electrode 5, the commutator 6 operates, and the electric discharge of the capacitor battery occurs on this length of wire – the wire explodes.

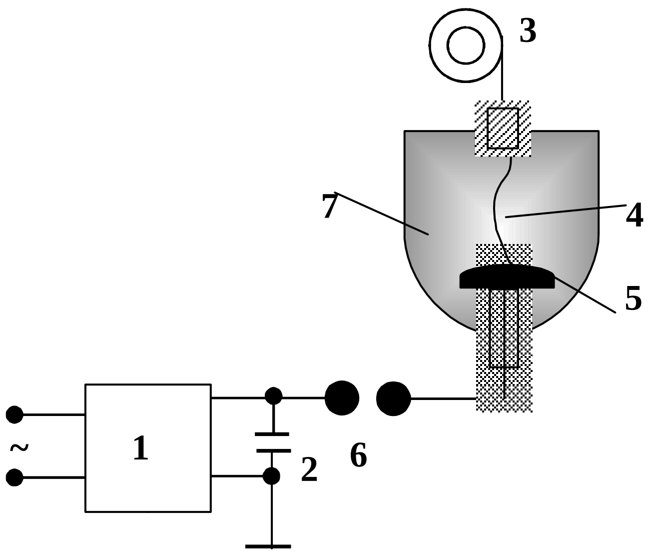

Figure 1. Principle scheme of experimental setup: 1 – high-voltage power source, 2 – capacitor battery, 3 – wire supply unit, 4 – exploding wire, 5 – high-voltage electrode, 6 – commutator, 7 – explosion chamber filling with liquid

The aluminium wires with diameter *d*= 0.25 mm and length *l*= 40…200 mm were used in the experiments. Electrical explosion of wires was carried out under conditions of “fast” explosion with an arc stage or with infinite current pause when almost all accumulated in capacitor energy was consumed by wire before explosion. Energy parameters of EEW were regulated with change of charging voltage and geometric characteristics of exploding wires. The specific electrical energy input in the wire (e) was changed from 0.4 to 1.8e_s (e_s is the sublimation energy of the wire material); the energy of the arc stage (e_a) – (0.7…1.7)e_s. Parameters of electric circuit: capacitance C= 2.25 μF; charging voltage U= 15…30 kV; inductivity L= 0.8 μH.

The phase analysis of the obtained powder was performed using CuKα-radiation of a DRON-3.0 X-ray diffractometer. Particle shapes and the dispersiveness were determined by means of a JSM-840 scanning electron microscope. The determination of specific surface area (S_{sp}) was carried out by using a method of low temperature nitrogen adsorption (BET). The differential-thermal analysis (DTA) and thermogravimetric analysis (TGA) was performed with apparatus Q-1000. The method of radiation probing (electron paramagnetic resonance) was used for quantitative determination of aluminium oxide-hydroxide phases in product of EEW.

Experimental results and discussion

Nanopowders produced by electrical explosion of aluminium wires in water are different crystal modifications of aluminium oxides: $Al(OH)_3$, γ-Al_2O_3, α-Al_2O_3.

According to the X-ray data, the main product formed by the electrical explosion of the aluminium wire in water is low-temperature modification γ-Al_2O_3. A content of residual aluminium decreases with the rise of energy consumed by wire and is about 15 % at e_a/e_s> 1.5. Dependence of abundance of residual aluminium Al^0 и γ-Al_2O_3 in the EEW products is shown in the Figure 2. A drastic decrease of residual aluminium is observed in the range e/e_s~ 0.9…1.1. Similar dependencies were discovered previously by the investigation of EEW in gases [2, 3]. Formation of size composition is the result of two mechanisms: dispersion of liquid metal and condensation of vapor phase. A metal part transforms to vapor phase rises sharply at e/e_s> 1.0. Electrical explosion of aluminium wires in water at e/e_s= 1.0 and arc stage (e_a/e_s= 1.3) results in complete oxidation of metal to γ-Al_2O_3.

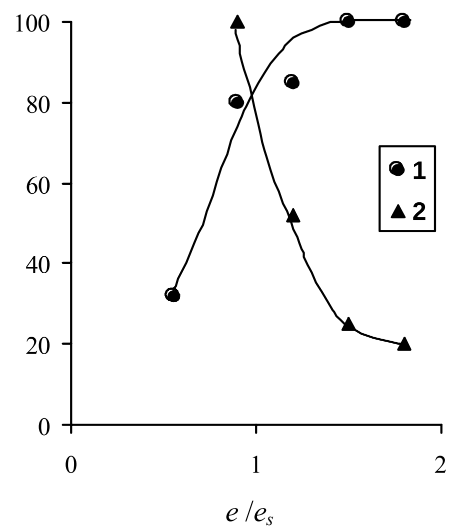

Figure 2. Dependence of the 100 %-X-ray diffraction patterns intensities on the energy input in the wire: γ-Al_2O_3(1) and Al^0(2)

The powders consist of spherical particles as shown in the Figure 3. The measured specific surface area S_{sp} of the aluminium oxide powder sample produced by EEW in water at e/e_s= 1.5 was 36.3 m^2/g. The average surface particle diameter calculated for this value of S_{sp} was 33 nm.

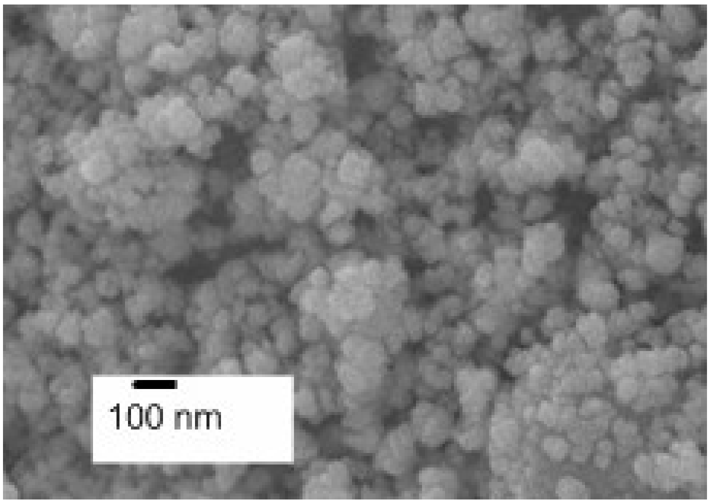

Figure 3. Micrographs of the powders produced by electrical explosion of aluminium wires in water at e/e_s= 1.2

Content of aluminium oxide and aluminium hydroxide in the product of EEW was determined using the method of radiation probing (electron paramagnetic resonance). The results are presented in the Table 1. These experimental data were tested by thermogravimetric analysis. The mass decrease at the heating the EEW products to 950 єC due to removal of sorbate water and fixed water was 2 and 5.3 % for the sample produced at e/e_s= 1.2; 2.3 and 17 % – for the sample produced at e/e_s= 0.5.

Table 1. Aluminium oxide and hydroxide content
in the products of wires electrical explosion in water

№	e/e_s	Ratio oxide-hydroxide phases, %	
		Al_2O_3	$Al(OH)_3$
1	0,6	25 %	75 %
2	1,20	80 %	20 %

Very active oxide-hydroxide phases can be used for water purification from ions of heavy and radioactive metals. The possibility of purification from chrome and copper ions was studied [5, 6]. Aluminium EEW was carried out directly in model solution. The specific electrical energy input in the wire was $0.9e_s$. In this case the main product of aluminium EEW, as it was shown earlier, is $Al(OH)_3$. The results of experiments are shown in the Table 2.

Table 2. Dependence of impurities removal on the concentration of aluminium

Initial concentration of metals in water, mg/l		Concentration of aluminium, mg/l	Residual concentration of pollution, mg/l	
Cr	Cu		Cr	Cu
1,00	5,00	20	0,70	0,90
1,00	5,00	30	0,20	0,60
1,00	5,00	50	0,03	0,05
1,00	5,00	150	0,00	0,00

The residual content of chrome and copper ions in water was determined by photocolorimetric method. Practically total purification from pollutants ions is achieved when input amount of aluminium is 50…150 mg/l.

Another perspective application of aluminium EEW in water is production of hydrogen which is a gaseous product of interaction reaction of aluminium particles with working ambient. Hydrogen is considered to be a most likely fuel in the future.

Hydrogen can be obtained in the process of interaction of aluminium nanopowder previously produced by EEW in inert gas, for example, in argon. This method needs a heating of water to 60–80 єC. In result of passivation of metal nanopowder the oxide layer on particles surface forms and quantity of metal decreases. Moreover, aluminium nanopowders coagulate, conglomerate and their chemical activity decreases.

We propose to use electrical explosion of aluminium wires directly in water. Solid products of EEW can be different depending on experiment conditions, first of all depending on electrical parameters – the specific electrical energy input in the wire $e/e_s$and the arc stage energy e_a/e_s:

$$2Al + 3H_2O \rightarrow Al_2O_3 + 3H_2\uparrow$$
$$2Al + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2\uparrow.$$

In the case of $e/e_s > 1.5$ or$e_a/e_s = 1.2$ the transformation ratio approaches 100 % without special additives.

One of the applications of electroexplosive nanopowder is their use as the additives in lubricating oil for improving the tribological characteristics and increasing the wear-resistance of the machine parts. For example, copper nanopowder and fullerenes can be used as such additives. The tribological characteristics of industrial oil after treatment with electrical explosion of copper wires were studied. The copper wires with diameter d= 0.2 and length l= 50…120 mm were used in experiments. The specific electrical energy input in the wire was 1.2e_s. Suspension of copper nanopowder with concentration 0.05 mass.% was obtained in result of the treatment. To obtain suspension of carbon clusters (fullerenes) copper nanopowder were separated from oil with special centrifuge.

The dependences of friction constant on load for initial mineral oil, oil contained copper nanopowder, and oil contained carbon clusters are shown in the Figure 4. Decrease of friction constant occurred to 40 %, if the oil contained copper nanopowder and the oil contained carbon clusters were used.

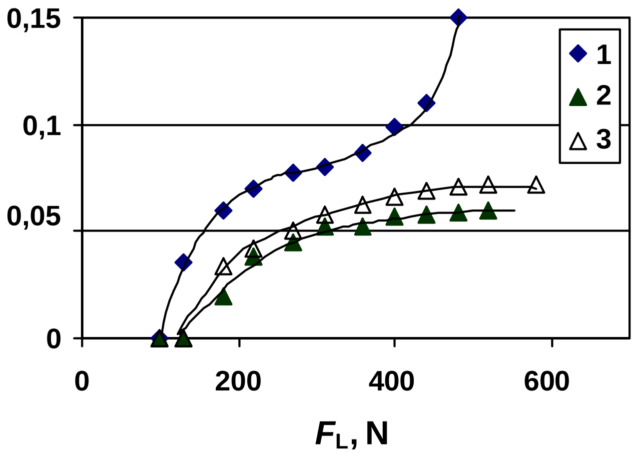

Figure 4. Dependences of friction constant on load for initial mineral oil (1), oil contained copper nanopowder (2), and oil contained carbon clusters (3)

Treatment of industrial oil with electrical explosion of copper wires as well as use of nanopowders and fullerenes increases the working time of oil and helps to prevent the pollution of environment.

Conclusion

Phase and size compositions of nanopowders prepared by electrical explosion of aluminium wires in water and copper wires in industrial oil were investigated. Control factors were electrical parameters, characteristics of wires.

The main product of aluminium EEW in water at the energy input in the wire ~ 0.6…0.9e_s is $Al(OH)_3$. The rise of energy input in the wire to 1.8e_s leads to formation of low-temperature modification γ-Al_2O_3. The arc stage of discharge results in obtaining high-temperature modification γ-Al_2O_3 and transformation ratio about 100 %. The possibility of water purification from heavy metals and other impurities was shown.

The tribological characteristics of industrial oil after treatment with electrical explosion of copper wires were studied. Copper nanopowder and carbon clusters (fullerenes) were obtained in result of EEW. Decrease of friction constant occurred to 40 %.

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