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Use of waste production of crystalline silicon in the production of vacuum insulation

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Abstract. The purpose of the study is to consider the possibility of using microsilica - waste of aluminum production, as filler in a vacuum insulation panel. The properties of silicon dioxide powder have been studied, and compositions and manufacturing technology of vacuum thermal insulation panels on its base have been developed. Differential thermal analysis of powders is carried out; the curves of differential thermal analysis and thermogravimetric analysis, x-ray phase analysis are obtained. The microstructure of the samples is investigated. The thermal conductivity of the manufactured panels is measured. The test results suggest that for the manufacture of low–vacuum insulation panels of microsilica powders, waste production of crystalline silicon can be used. The use of waste in the future can become the basis for the production of high-quality vacuum insulation with low cost.

1 Introduction

According to current estimates, only 2% of natural consumed resources are converted into final products. More than 80 billion tons of waste is accumulated in Russia [1]. Especially acute environmental problems are manifested in cities, oversaturated with industrial enterprises (Novokuznetsk, Bratsk, Chelyabinsk, Krasnoyarsk, etc.), where significant environmental pollution occurs as a result of the activities of metallurgical industries. Thus, in the production of ferrosilicon and crystalline silicon in the metal smelting process gaseous substances and dust-like waste are formed in large quantities.

At the Bratsk ferroalloy plant (BFP) in the production of crystalline silicon, microsilica (MS) is deposited from the gases leaving the smelting furnace in a special gas cleaning system. Disposal of waste is possible in several ways: destruction of waste with their conversion into safe products; conservation of waste in a safe condition; the use of waste in the production process; the use of waste in enterprises of other industries. In order to identify the problems associated with the use of silica-containing dust waste, it is necessary to assess their composition and properties.

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2

2 Materials and Methods

Despite the differences in chemical composition, color and carbon content, the smallest dust particles, which are silicon and ferrosilicon waste products, have common properties: they are condensates of silicon vapor (silicon monoxide); they mainly consist of globules, the average diameter of which is 0.1...0.2 μm (see Figure 2); they are amorphous and characterized by high SiO2 content (84...98%); cause storage and transportation problems. X-ray phase analysis shows that microsilica mainly consists of the x-ray amorphous phase, as evidenced by the blurred peak in the region of 18θ...30θ. The crystal phase in the sample of microsilica is practically absent and is represented by β-quartz (d=0.425; d=0.335; d=0.245; d=0.154), carborundum (d=0.251; d=0.154) and graphite (d=0.335) - (Fig.1).

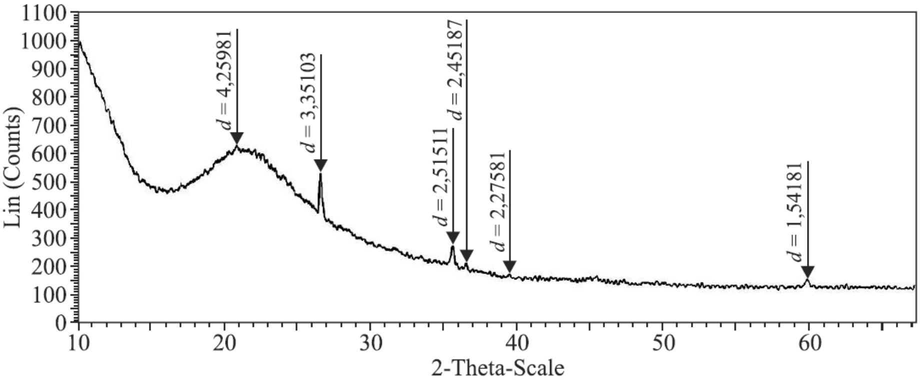

Fig. Error! No sequence specified**.** The diffraction pattern of microsilica.

Derivatographic studies of microsilica have shown a total loss of sample weight when heated to 1,000°C equal to 11.84%, up to 220°C – 8.5%, from 220°C to 1,000°C – 3.1%. The loss of mass in the first stage is due to the removal of adsorbed water from the sample from the air. At the second stage there is a gradual decrease in the mass of samples without visible physical and chemical transformations. The curves of thermogravimetric analysis indicate the presence of water (t=20 – 220°C). The thermogram is shown in Figure 3.

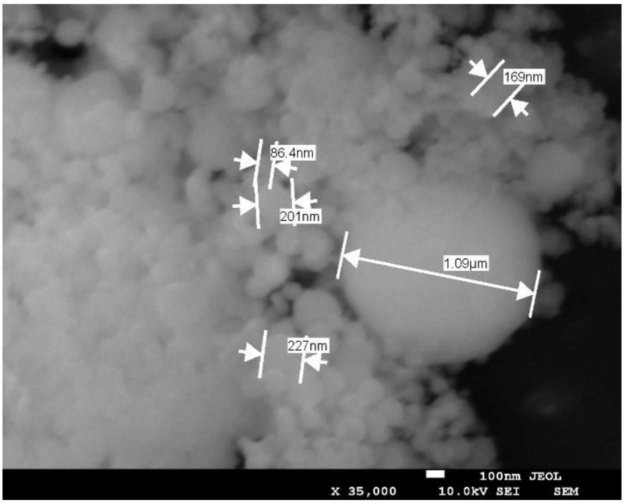

Fig. 2. Microsilica particles x 35 000.

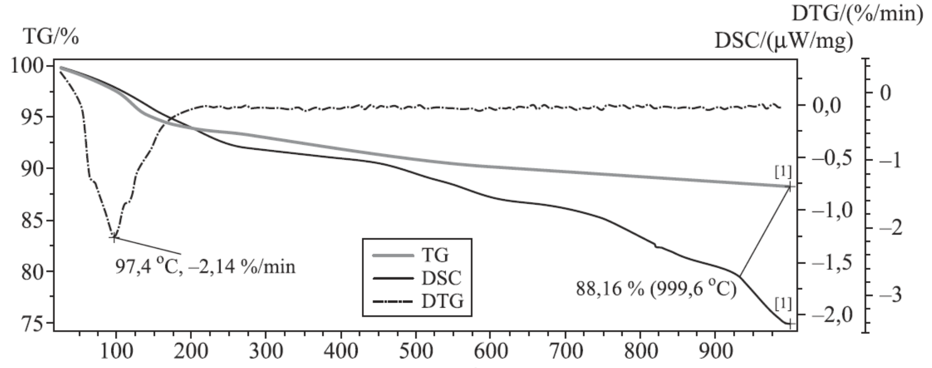

Fig. 3. Thermogram of microsilica.

The exceptionally high dispersion of the MS and its structure explain the reduced bulk density - from 150 to 250 kg / m3. Despite the large amounts of capture of silica waste, their mass use is restrained, due to the fact that the gas cleaning products are lightweight material, not convenient for transportation. In particular, by a specific example it can be shown that cement carriers with a capacity of 35 tons of cement can accept 7...9 tons of

4
MS, which correspondingly increases the cost of its transportation. The above significantly increases the cost of the material delivered to the consumer over long distances, and reduces the economic efficiency of enterprises interested in the use of dust-like waste.

The sludge and dust of MS do not have an irritating and toxic effect on the skin, as well as the ability to accumulate in the body [2, 3] with repeated contact with the stomach. Table 1 shows the main physical and technical properties of the MS "BFP" [4].

Table Error! No sequence specified.. MS physical and technical properties.

Material	**Density kg/m^3**	**Specific surface, m^2/g**	**Humidity**	**Hydrogen Indicator, (pH)**
Microsilica	280	34	3	6

The granulometric composition of the MS according to the BFP waste technical passport is presented in Table 2.

Table 2. Granulometric composition of microsilica.

Weight content, %	**Particles size, mkm less**							
	0.1	0.1...0.2	0.2...0.4	0.4...1.0	1.0...10	10...50	50...100	more 100
Microsilica	8.5	34.5	30.0	8.0	2.5	1.0	5.0	11.0

Table 3 shows the chemical analysis of MS (according to BFP) [5].

Table 3. Chemical analysis of microsilica.

Content of oxides, wt. %							
Compound	SiO_2	Fe_2O_3	CaO	MgO	Na_2O+ K_2O	Al_2O_3	SO_2
Microsilica	90.0–94.0	1–3	0.7–1.4	0.2–0.4	0.1–0.5	0.7–1.5	Up to 0.09

The MS composition and properties are prerequisites for its use in various industries. Despite the undeniable effectiveness of MS in solutions and concretes, waste disposal is possible in the production of thermal insulation materials, where MS can act not only as an additive, but also as the main filler.

The nearest prospects in increase of thermal protection of buildings and decrease in heat losses through the protecting designs are connected with development and use of the vacuumed heat-insulating materials of new generation which coefficient of thermal conductivity is much lower, than for traditionally used heat-insulating materials [6-7].

Obtaining the plate material from granular and powder materials by vacuum technology is a promising technology for producing plate insulation. Vacuuming helps to ensure low thermal conductivity and durability, including by reducing the negative impact caused by the effect of condensation of water vapor [8]. The main components of the filler of vacuum insulation panels are highly porous materials-polydisperse granular powders, the physical basis of the thermal conductivity of which is discussed in detail in [9-10]. The thermal conductivity of dispersed systems is determined by the following factors: the thermal conductivity of the solid frame material, the type and convection of gas in the pore space, its pressure, radiation, porosity of the frame and its individual particles, as well as the thermal conductivity of the contact between these particles [11-14].

The principles of creating a vacuum insulation panel is based on the fundamental laws of physics, claiming that the absence or decrease of pressure inside the porous material reduces its thermal conductivity.

The investigated low-vacuum insulation panel is made on the basis of the porous structure filler enclosed in a gas-tight shell; it has three main components: a "filler", giving the panel mechanical strength in the vacuumed state and high thermal insulation properties, by reducing the transfer of heat through the convective component of the thermal conductivity of the air. The ideal filler material should have an open porous structure with a very small pore size and high resistance to infrared radiation; a “gas-tight barrier", which serves as an insulating shell for air and vapors. The thermal protection properties of the vacuum panel and its durability largely depend on the characteristics of this material; an "infrared silencer", introduced into the filler to reduce the radiant component of the thermal conductivity.

3 Results

To study the possibility of using microsilica in a vacuum insulation panel, prototypes were made based on it. The dosed amount of the filler powder was dried, after which the mixture was poured into molds and pressed. The finished plates were put in an airtight shell and sent to a vacuum packaging machine of "DZQ-410 2E" type. After vacuuming, the shell of the product was sealed at the ends. Test results of samples and properties of other traditionally used thermal insulation materials are given in Table 4.

Table 4. Properties of thermal insulation materials

Material	Thermal conductivity, W/(m· K)	Heat transfer resistance, W/(m °C)	Material thickness, m	Combustibility class
Low-vacuum insulation panel	0.025	10	0.25	incombustible
Foam polyurethane	0.028	10	0.28	highly flammable
Foam polystyrene	0.030	10	0.30	highly flammable
Mineral wool	0.046	10	0.46	incombustible

4 Discussion

6

In relatively shallow vacuum (of 0.085 MPa) thermal conductivity of the LVIP samples amounted to 0.025 W/(m·K). Due to the fact that the outer LVIP layer is covered with non-combustible fiberglass, and the filler of silicon dioxide is not combustible, panels are referred to non-combustible materials [15]. No odor and toxic release, water absorption, the ability to reuse and lower coefficient of thermal conductivity make the vacuum insulation panels on the basis of microsilica a promising insulating material. The use of crystalline silicon waste in the production of vacuum thermal insulation panels will provide not only an effective thermal insulation material, but will also help to reduce the environmental burden on the environment.

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