The process of obtaining of porous permeable materials by electric current sintering of metal powders, fibers and nets

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Abstract. The paper presents the results of a study of the production of porous materials based on metal powders, fibers and nets by the method of electric sintering. The method of production porous materials based on tin-phosphor bronze powders of grade BrO10F1, fibers and grids from corrosion-resistant steel is given. The images of appearance and structure of the specimens and the study results of their properties are presented: porosity, permeability coefficient, pore sizes. It has been established that the materials manufactured by electric current sintering have a satisfactory complex of filtering properties and may be used for purification of liquids and gases.

Keywords: porous permeable materials, electric current sintering, metal powders, fibers and nets, properties.

1. Introduction
The development of machine-building industry and other industries requires the development of materials with a specific complex of physico-chemical, mechanical and functional properties. The manufacture of products by powder metallurgy methods opens up possibilities for regulating the structure and studying their properties. Electric current sintering is based on the combined action of electrical energy and mechanical pressure. It makes it possible to carry out simultaneous sintering and pressing of powder materials, in contrast to traditional technological processes of powder metallurgy with separate performance of these operations [1]. The methods of electric current sintering attract with their efficiency, low energy consumption, the possibility of automation, and high performance [1]. As compared with traditional methods of powder metallurgy, they make it possible to refuse the costly tooling and protective atmosphere providing significant energy savings [1]. Moreover, it is possible to adjust the technological modes at the stage of manufacturing each product in the batch, when using electric current sintering methods.

The heating of metals to the melting temperature using electric current was applied by a Russian researcher N.G. Slavianov in 1888 [2]. Sintering of metal powders by passing an electric current through them was patented by Taylor [3] in 1933. In 1944, Kremer published a paper [4], which describes the method of electrocontact sintering of powders under pressure using a machine for contact welding. Since then, various methods of electric current sintering have appeared, which differ significantly in the nature of physical processes [5]. Electric current sintering methods are grouped according to the nature of the main realized electrophysical phenomena, taking into account some fundamental features that distinguish them from traditional technological methods of powder metallurgy [1]. These include various process methods based on the use of electrical energy or specific physical phenomena generated by this energy [9]. The nature of the process and results of direct heating are influenced by many factors, for example, the electrical parameters of the voltage and current pulses applied to the electrodes (shape, frequency, power, etc.), as well as the design and technological features of the electrodes.

The analysis of the known sintering methods of porous powder materials by electric current has
shown that electro-pulse sintering (EPS) and electro-discharge sintering (EDS) [10] are promising for the production of porous materials from metal powders. However, sintering by electric current in known sources is used as a preliminary or intermediate treatment of powder materials [10]. The issues of manufacturing permeable materials during one stage of sintering by electric current were not considered therein.

The purpose of this paper is to study the process of obtaining porous materials based on metal powders from tin-phosphor bronze powder BrO10F1, fibers and nets from corrosion-resistant steel 12X18H10T by electric current sintering.

2. Experimental
Investigation of the production process of porous materials by electric current sintering was carried out using the spot welding machine MT 2201 UHL4 (Figure 1). Tooling set consisting of special copper conductive electrodes, punches and a graphite matrix have been developed for the production of specimens [10]. This made it possible to obtain specimens in the form of a disk with a diameter of 12 and a thickness of up to 20 mm. Appearance and diagram of the tooling set are presented in Figure 2.

![Figure 1. Spot welding machine MT-2201 UHL4](image)

The pressure at which the process of particle sintering was carried out could be regulated in the range from 1 to 25 MPa, ensuring a tight contact of the particles throughout the entire volume of the workpiece and, therefore, evenly distributing the electric current passing through the section of the workpiece.
Figure 2. Tooling set for sample production
a) diagram of the tooling set: 1 – matrix; 2 – punches; 3 – current-conductive electrodes; 4 – sintered material; b) appearance of the tooling set; c) tooling for electric current sintering in the spot welding machine

Tin-phosphor bronze powder BrO10F1 (own-produced), fibers and a net of corrosion-resistant steel 12X18H10T have been used as initial materials. The powder had particle sizes (minus 1.0 + 0.63) mm. The fibers (cut from the wire) had a diameter of 0.2 and a length of 2 to 7 mm. The surface morphology of the powder and fibers is shown in Figure 3. The net had a wire diameter of 1.2 mm and a mesh size of 2.5 mm. The surface morphology of the experimental specimens was examined on a high-resolution scanning electron microscope "Mira" of Tescan company (Czech Republic). The research equipment is shown in Figure 4.

Figure 3. Surface morphology
a) of the particles in the tin-phosphorous bronze powder fractions (minus 1.0 + 0.63) mm obtained by atomization of the melt with a gas flow
b) of fiber surface of corrosion-resistant steel 12X18H10T, × 100;
c) of fiber surface of corrosion-resistant steel 12X18H10T, × 500
The manufacturing technology for producing the specimens was as follows. The lower punch was inserted into the graphite matrix. Portions of powder or fibers were poured into the die cavity and the upper punch was mounted. Accessories were mounted between the conductive electrodes of the spot welding machine (Figure 2c). A pressure of 5-20 MPa was applied to the punches through the electrodes. Sintering was performed by passing electric current. To prepare the specimens from the nets, the billets with a size of 27×27 mm were cut out and laid in layers directly between the current-conducting electrodes. Then electric current was passed.

3. Results and Discussion
Sintering of the bronze powder specimens was performed under the following conditions: current of 7.5-12.3 kA and passage of current duration was from 0.4 to 3.6 seconds. The effective current was 8.9 kA, current density 7.87 kA/cm$^2$; the number of welding current pulses was 120, and the heating time was 2.4 s.
Sintering of fiber samples was performed at the current of 7.5 - 11.6 kA and passage of current duration was from 0.4 to 3.6 s. The effective current was 8.9 kA, the current density was 7.87 kA/cm$^2$; the number of welding current pulses was 60, and the heating time was 1.2 s.
Sintering of net specimens was performed at the current of 6-12 kA and passage of current duration was from 0.4 to 3.6 s. The effective current was 8.9 kA, the current density was 7.87 kA/cm$^2$; the number of welding current pulses was 120, and the heating time was 2.4 s.
Metallographic study of the structures was performed using the light microscope MeF-3 of Reichert company (Austria) (Figure 5). As can be seen on the images, the sintering process of all materials is characterized by a good contact formation. The appearance of the obtained samples is shown in Figure 6; their structures are shown in Figure 7.
Figure 6. The specimens of porous materials sintered by electric current:
   a, b) a specimen based on bronze powder;
   c) a specimen of fiber-based corrosion-resistant steel 12X18H10T;
   d) a specimen of net-based corrosion-resistant steel 12X18H10T

Figure 7. Structures of specimens obtained by electric current sintering, × 50:
   a) tin-phosphor bronze powder; b) fiber-based corrosion-resistant steel 12X18H10T;
   c) net-based corrosion-resistant steel 12X18H10T

Porosity (according to GOST 18898-89), permeability coefficient (in accordance with GOST 25283-82) and pore sizes (according to GOST 26849-93) have been determined on the obtained samples. The research results have shown that porosity for the specimens of tin-phosphor bronze BrO10F1 powders is 28-36 %; permeability coefficient is (250–1850)⋅10^{-13} m²; pore size is 150-250 µm; shear strength is 32 MPa. Porosity for the specimens of corrosion-resistant steel 12X18H10T fibers is 30-39 %; permeability coefficient is (40–51)⋅10^{-13} m²; pore size is 80-164 µm; shear strength is 35 MPa. Porosity for the specimens of corrosion-resistant steel 12X18H10T nets is 27-36 %; permeability coefficient is (920–1000)⋅10^{-13} m²; pore size is 350-1000 µm; shear strength is 39 MPa.

The analysis of the results leads to the conclusion that the samples of permeable materials produced with the help of electric current assisted sintering have a satisfactory set of filtering properties and can be used for clarification of liquids and gases.

The analysis of the obtained results makes it possible to draw a conclusion that samples of permeable materials obtained by the electric current sintering have a satisfactory complex of filtering properties and can be used for liquid and gas purification.
The results of the studies were used to produce a mesh filter in the form of a disk. The base of the mesh filter was made of a compact material of corrosion-resistant 12X18H10T steel with a thickness of 1.5 mm with nine holes 2.7 mm in diameter and lining from a mesh of 12X18H10T corrosion-resistant steel (Figure 8a). The sintering of the mesh filter was performed at an effective current value of 8.9 kA, a current density of 7.87 kA/cm², a current passage time of 2.4 s, a number of the welding current pulse was 120, a modulation time of the leading edge of the current pulse was 0.2 s, heating time 2.4 s. Images of metallographic research showed that the fusion of the lining from the mesh to a compact base has been observed along the entire perimeter of the product (Figure 8b, c), which indicates good contact formation.

Figure 8. Net filter after sintering the compact base and filtering net lining from corrosion-resistant steel 12X18H10T:
   a) from the side of the sintered lining from the mesh to the compact base;
   b) metallographic investigation of the filter, from the compact base side;
   c) metallographic investigation of the filter at the interface of a compact base-hole

As a result, it can be concluded that the method of sintering with electric current makes it possible to obtain products with specified properties that can be used as filters for liquid purification.

4. Summary
The process of manufacturing permeable materials based on metal powders through the example of tin-phosphor bronze BrO10F1 powder, corrosion-resistant steel 12X18H10T fibers and nets by single-step electric current sintering has been tried out. The structure and properties of the specimens made of spherical dispersed bronze BrO10F1 powder and corrosion-resistant steel 12X18H10T fibers and nets have been studied. It has been found out that the obtained specimens have a satisfactory complex of filtering properties. The specimens made of tin-phosphor bronze powders have porosity of 28-36 %, permeability coefficient is \((250–1850)\cdot10^{-13}\text{m}^2\), pore size is 150-250 µm and shear strength is 32 MPa. Porosity for the specimens of corrosion-resistant steel 12X18H10T fibers is 30-39 %; permeability coefficient is \((40–51)\cdot10^{-13}\text{m}^2\); pore size is 80-164 µm; shear strength is 35 MPa. Porosity for the specimens of corrosion-resistant steel 12X18H10T nets is 27-36 %; permeability coefficient is \((920–1000)\cdot10^{-13}\text{m}^2\); pore size is 350-1000 µm; shear strength is 39 MPa. The possibility of electric current sintering of permeable materials based on bronze powders and fibers from corrosion-resistant steel for one sintering has been confirmed.
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