HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

UDC 539.67:678.668

DETERMINATION OF OPTIMAL SINTERING REGIMES IN THE PRODUCTION OF CYLINDRICAL FILTERS WITH AN ANISOTROPIC STRUCTURE AND HIGH OPERATIONAL PROPERTIES FROM BrOF-10-1 BRONZE POWDERS UNDER THE INFLUENCE OF CENTRIFUGAL FORCE

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Doi: https://doi.org/10.5281/zenodo.21473167

Abstract: This article investigates the technology of producing cylindrical filters with an anisotropic structure and high operational properties from BrOF-10-1 bronze powders under the influence of centrifugal force. Technological problems in the simultaneous sintering of powder fractions of various sizes are analyzed, and a method is proposed for adding phosphorus to the chemical composition in a specific mass fraction corresponding to the powder size. This ensures the optimal value of the interparticle contact (sintering neck) (F = 0.15–0.20) at a temperature of 800–810 °C. The optimal process regimes were determined using mathematical planning, and the properties of the filters obtained by the new method were compared with those produced by traditional methods.

Keywords: bronze powder, BrOF-10-1, sintering, temperature, sintering neck, contact neck, anisotropic structure, operational property, centrifugal force, mathematical planning, porosity, permeability.

Introduction. Porous materials and filters produced using powder metallurgy are widely used in many industrial sectors to clean liquids and gases from mechanical particles. The main properties of filters are recognized as their pore size and permeability coefficient. However, during operation, filters are subjected to significant external pressure and mechanical forces. Therefore, it is required that filters possess not only high permeability but also sufficiently high mechanical strength for long-term use. These indicators directly depend on the quality of the raw material sintering process. In particular, forming cylindrical filters with an anisotropic structure composed of multi-fraction powders under centrifugal force and sintering them under a single temperature regime creates technological difficulties. The main goal of this article is to determine and investigate the optimal sintering regimes in the production of anisotropic filters with high operational properties from BrOF-10-1 bronze powders.

Main part. During our experimental stages, we observed that in the 3-stage experiment, 4 hours were spent solely on the raw material sintering process. This is because it is impossible to simultaneously sinter powder fractions of different sizes at the same temperature. At a uniform temperature, small-sized powders would melt, while large-sized powders would develop an insufficient sintering neck. This negatively affects the operational properties of the filter, particularly its mechanical strength. To solve this problem, scientists have conducted several studies and proposed various methods [1, 2]. Among these, the most convenient and effective method for BrOF-10-1 bronze is temperature control through altering the chemical composition [3]. We will attempt to change the chemical composition by adding phosphorus. According to scientific experience, the purpose of adding phosphorus is to prevent small particles from melting during sintering and to ensure that the

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sintering neck of large powders remains within the range of 0.15–0.20 of the powder diameter. Figure 1 illustrates the optimal sintering necks of the powders during the sintering of BrOF-10-1 bronze raw materials [4].

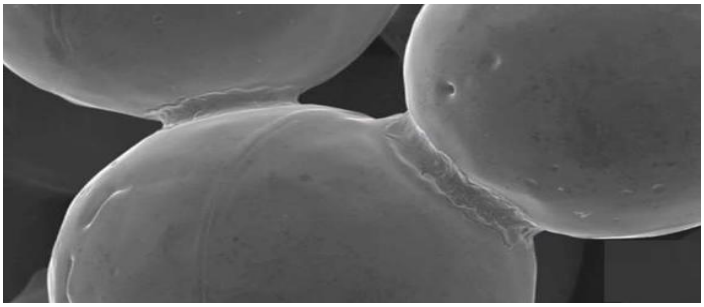


Figure 1. Optimal sintering neck of particles (equal to 0.15–0.20 of the particle diameter)

In order to find the optimal sintering temperature for BrOF-10-1 bronze powders, we utilize the method of mathematical planning in our experiment. The relative size of the interparticle contact, defined as the ratio of the interparticle contact diameter to the particle diameter, was chosen as the decisive optimization parameter (F). The phosphorus content (X1), the average size of the powder particles (X2), and the sintering temperature (X3) were taken as the associated variables (optimization factors). A plan consisting of 24 experiments was selected; in this plan, one factor is varied at three levels, and the remaining two factors are varied at four levels. The selected optimization factors and the specified levels of variation are presented in Table 1.

Table 1

Values of optimization factors and their variation ranges.

Levels of variation of optimization factors	**OPTIMIZATION FACTORS**		
	Phosphorus content, (X_1) mass %	Average powder size, (X_2) mkm	Sintering temperature, (X_3) °C
-1	0,11	44	780
0	0,36	-	-
-0,33	-	88	800
0,33	-	139	820
1	0,58	176	840

The experimental plan is presented in Table 2. Based on the experimental data, the following regression equation was developed:

$$F = 0.2053 = 0.1165X_1 - 0.0363X_2 - 0.0221X_1\ X_3 - 0.1406X_3 - 0.0784X_1^2\ X_3$$

The adequacy of this equation is confirmed using the Fisher criterion; the calculated value was 1.46, which is lower than the tabular value. This indicates that the equation fits the experimental data.

To graphically represent the obtained equation, lines corresponding to constant parameter values were drawn. Analysis of the indicated relationships showed that at a specific sintering temperature, it is possible to achieve the same value of interparticle contact (sintering neck) for different fractions.

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Using the established relationships between the powder sintering temperature, particle size distribution, and phosphorus content, it is easy to select powder compositions that share the same optimal sintering temperature.

Table 2

Planning matrix, experimental and calculated values of the optimization parameters.

Experiment numbers	CODED OPTIMIZATION VALUES			Optimization parameter values	
	X_1	X_2	X_3	Exp.	Calc.
1	-1	-1	-1	0,089	0,088
2	-1	-1	-0,33	0,111	0,118
3	-1	-0,33	-0,33	0,096	0,119
4	-1	-0,33	1	0,125	0,144
5	-1	0,33	-1	0,026	0,037
6	-1	0,33	-0,33	0,055	0,068
7	-1	1	0,33	0,069	0,068
8	-1	1	1	0,118	0,099
9	0	-1	-1	0,125	0,104
10	0	-1	-0,33	0,214	0,196
11	0	-0,33	0,33	0,285	0,269
12	0	-0,33	1	0,360	0,369
13	0	0,33	-1	0,034	0,058
14	0	0,33	-0,33	0,176	0,145
15	0	1	1	0,255	0,225
16	0	1	1	0,340	0,318
17	1	-1	-1	0,250	0,279
18	1	-1	-0,33	0,377	0,332
19	1	-0,33	0,33	0,322	0,368
20	1	-0,33	1	0,460	0,414
21	1	0,33	-1	0,210	0,228
22	1	0,33	-0,33	0,320	0,284
23	1	1	0,33	0,320	0315
24	1	1	1	0,352	0,272

As an example, Table 3 presents the values of powder particle sizes and phosphorus content that ensure a specific relative size of the interparticle contact at the sintering temperature. Here, the interparticle contact (sintering neck) constitutes F = 0.15–0.20 at a temperature of 800–810 °C.

In obtaining cylindrical filters with an anisotropic structure and high operational properties under the influence of centrifugal force, powders with a phosphorus content corresponding to the values presented in Table 3 were used. The sintering process was carried out in a hydrogen atmosphere for 1 hour at 800–810 °C.

Table 3

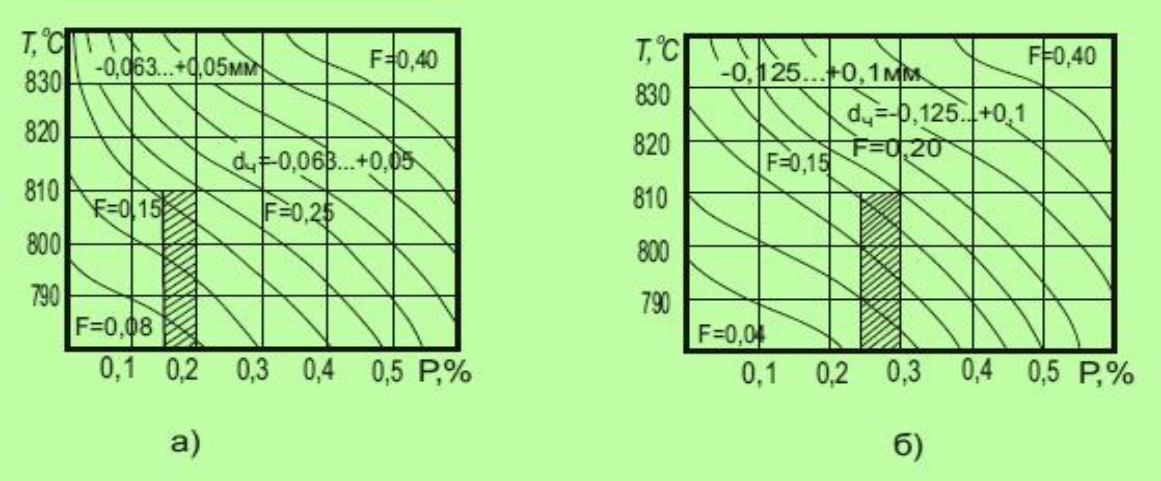
Values of powder particle sizes and phosphorus content ensuring a specific relative size of the interparticle contact at the sintering temperature.

Powder particle size, mm	Phosphorus content, mass %
-0,050...+0,040	0,19...0,21

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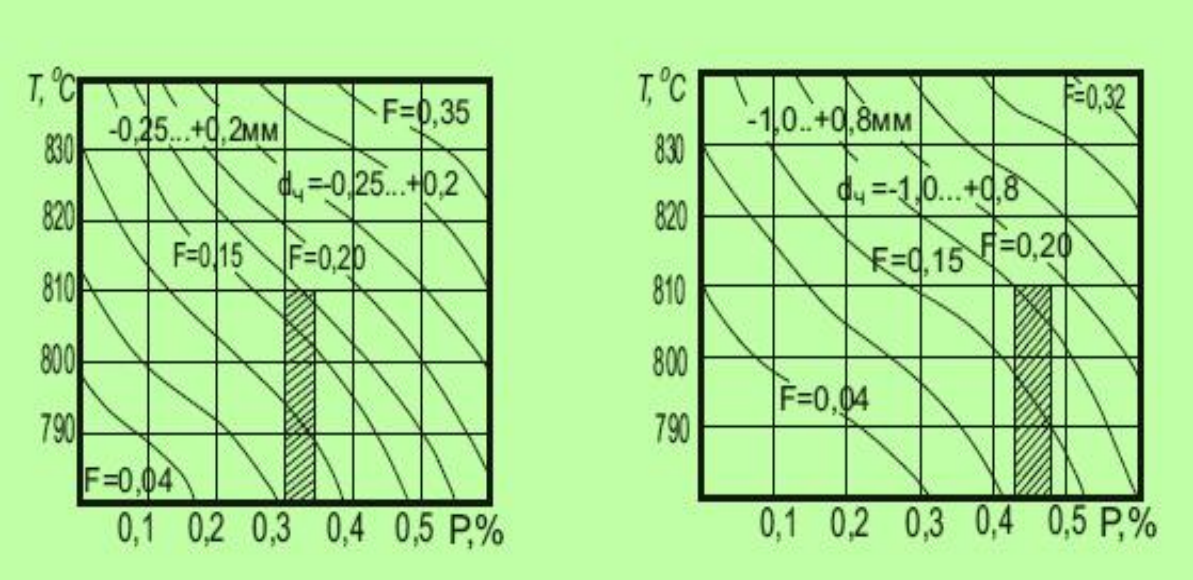
-0,063...+0,050	0,22...0,23
-0,080...+0,063	0,23...0,25
-0,100...+0,080	0,25...0,27
-0,125...+0,100	0,27...0,29
-0,160...+0,125	0,29...0,31
-0,200...+0,160	0,31...0,33
-0,315...+0,200	0,34...0,36
-0,400...+0,315	0,36...0,38
-0,500...+0,400	0,38...0,40
-0,680...+0,500	0,40...0,42
-0,800...+0,680	0,42...0,45
-1,000...+0,800	0,44...0,46
-1,250...1,000	0,45...0,48

Figure 2. Dependence of the sintering temperature on the phosphorus content for specific values of the ratio of the contact neck diameter to the particle diameter: a) 0.05...0.063 mm; b) 0.1...0.125 mm; c) 0.2...0.25 mm; d) 0.8...1.0 mm.



a) particle size 0.05...0.063 mm;
b) particle size 0.1...0.125 mm;

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c) **d)**

c) particle size 0.2...0.25 mm;
d) particle size 0.8...1.0 mm;

Figure 2. Dependence of the sintering temperature on the phosphorus content for specific values of the ratio of the contact neck diameter to the particle diameter.

Table 4 presents the comparative values of the methods for obtaining cylindrical filters with an anisotropic structure and high operational properties from BrOF-10-1 bronze powders using the traditional method and under the influence of centrifugal force.

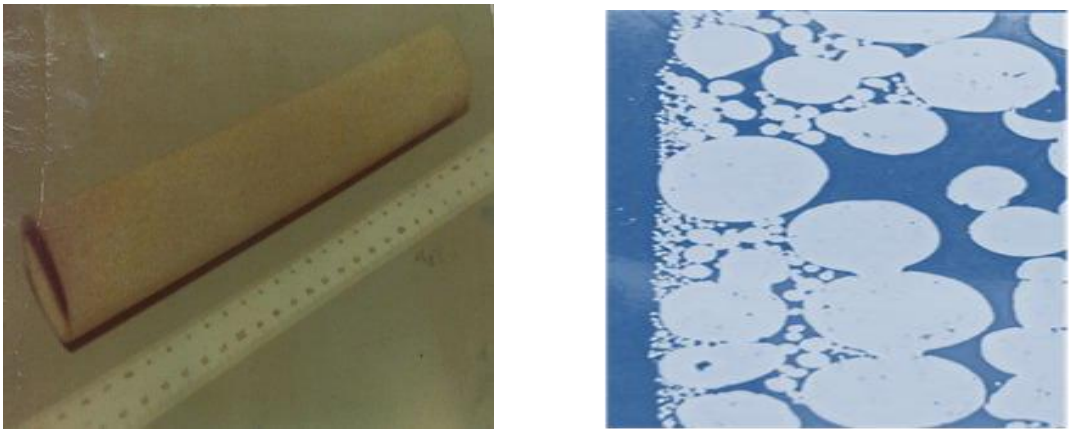
Table 4

Comparison of the operational properties of cylindrical filters obtained by traditional and centrifugal force methods.

Main properties	**Traditional method TP No. 231.13001263.00024**	**New method TP No. 0116501510**
Average porosity, µm	20	**20**
Permeability coefficient, m²	$70x10^{-13}$	**$170x10^{-13}$**
Efficiency parameter E_1	0,09	**0,14**
Cleaning indicator (forward direction), %	3	**12**
Cleaning indicator (reverse direction)	3	**1**
Cleaning indicator, µm	8-12	**1-3**
Mechanical strength - $\sigma_{ИЗГ}$, *МПа*	42	**78**

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Figure 3 depicts the general appearance (a) and the microsection structure (b) of a cylindrical filter with an anisotropic structure and high operational properties, obtained from BrOF-10-1 bronze powders under the influence of centrifugal force.



a) b) x100

Figure 3. General appearance (a) and microsection structure (b) of a cylindrical filter with an anisotropic structure and high operational properties obtained from BrOF-10-1 bronze powders under the influence of centrifugal force.

Conclusion. Based on the conducted research and mathematical analyses, the following scientific and practical conclusions were drawn:

1. An optimal regime for obtaining cylindrical filters with an anisotropic structure and high operational properties from BrOF-10-1 bronze powders under the influence of centrifugal force has been developed. According to this regime, a temperature of 800–810 °C was established for the simultaneous sintering of various fractions, and a technology of adding phosphorus corresponding to the powder size was introduced.

2. Compared to the indicators of the filter obtained by the traditional method, it was found that the permeability coefficient, mechanical strength, and efficiency parameter of the filter obtained by the new method increased approximately twofold.

3. The cleaning indicator (fineness) of filtration improved to 1–3 μm, and the cleaning quality increased 3 times.

4. The ability to collect solid particles from the air increased by 3 times, successfully extending the filter's service life to 8–10 years. Furthermore, the total time required for the technological process was reduced by 3 hours, which significantly increases the economic efficiency of production.

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