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A Porous Material Based on Cobalt and Nickel Powders

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Abstract

Porous materials from a mixture of cobalt and nickel with a pore volume fraction of more than 68 % were obtained by powder metallurgy methods. We found the impact of the ratio of nickel and cobalt powders used in the synthesis of a porous material (including for cases when only nickel or cobalt is used) and the conditions for pressing powders on structural parameters such as open and closed porosity, pore size.

Keywords

Cobalt; bimodal distribution; micro-X-ray spectral analysis; nickel; porosity; porous material; pressing; sintering.

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Introduction

Currently, the question of the regularities of forming a porous structure in various materials including nanostructured ones is a fundamental problem, which is being solved by many scientists. The determination and study of the physical and chemical mechanisms of the formation of a porous structure in synthesized metallic powder materials is of great scientific interest. At the same time, the possibility of practical application of such materials in various industries and biomedicine makes the studies interesting from practical perspective.

The porosity distributed over the volume of compacted powder materials is inherently a defect that is undesirable for structural materials, but for functional materials, it can be a source of various unique properties [1–4]. Investigation of sintering mechanisms and regulation of porosity will make it possible to obtain a material with predetermined values of porosity, pore size and a given phase composition. Accordingly, search for methods to control the parameters of porous structures and development of strategies to manipulate them is a promising and interesting direction of research.

This work is aimed at obtaining volumetric high-porous metallic materials on the basis of mixtures of nickel and cobalt powders by powder metallurgy methods and revealing the dependencies between the formed porous structure and their physical and mechanical properties.

Experimental

In the production of porous materials, commercial nickel powders obtained by electric wire explosion (Fig. 1) and cobalt of PK-1U grade were used. To obtain a porous material, two methods of pressing mixtures of cobalt and nickel powders with different ratios and pore-forming substances were used in the research: the one-side pressing on a hydraulic press in a cylindrical mold and the all-round compaction in CIP 62330 hydrostat (Avure Technologies). Ammonium bicarbonate powder with a particle size of less than 40 μm was used as the blowing agent. The following ratios of nickel and cobalt powders were used, respectively: 1:1, 1:3, 3:1, and also only nickel and only cobalt. The range of pressures during pressing was from 50 to 400 MPa. The resulting compacts were heat-treated in a reducing medium: the sintering was carried out in a hydrogen stream at a temperature of 700°C for two hours, which was 0.48 of the melting

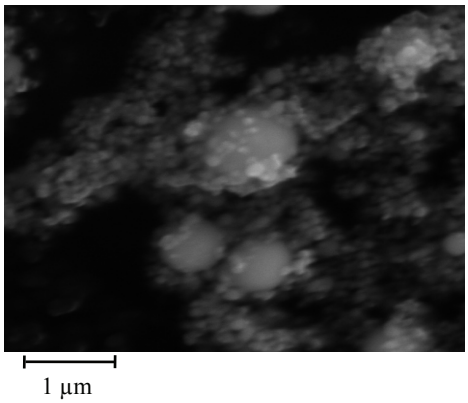


Fig. 1. A photo of nickel powder

point of nickel and 0.46 of the melting point of cobalt. Prior to this, the blowing agent was subject to burning off from the samples for an hour in the flow of argon at a temperature of 120°C.

An important functional characteristic of the structure of porous materials is the pore size, the determination of which was carried out according to GOST 26849–86 "Powder materials. A method for determining the size of pores". The pore volume was determined according to GOST 18898-89 "Methods for determining density, oil content and porosity". A porous structure of sintered samples was studied using the electronic scanning microscope with Zeiss Ultra plus X-ray microanalyzer and Tescan Vega II SBU electronic microscope.

Results and discussion

The resulting nickel powder images revealed that the particles have a different shape, preferably of the order of 100 nm size. However, large spherical particles larger than 500 nm in diameter were also present.

The influence of the ratio of nickel and cobalt on the values of the pore size and porosity was investigated (Table 1). The pressing pressure was 400 MPa. As can be seen from the presented results, the relative value of the open pore volume slightly depends on the ratio of nickel and cobalt powders in the compact. We observed a decrease in the open porosity from 73.8 to 71.3 % with an increase in the content of nickel powder from 0 to 75 wt% and a sharp decrease to 66.4 % in a sample obtained from nickel powder without the addition of cobalt powder. The value of the volume of closed pores within the errors of the determined values did not change with the variation of the ratio of nickel and cobalt powders in the compacts and did not exceed 0.7 %, and only in the sample without cobalt powder was 2 %.

With an increase in the content of nickel powder in the compacts, a reduction in the pore size was observed (Table 1). This can be explained by the fact that nickel powder particles have a bimodal size distribution (Fig. 1) with a predominance of particles with a size of about 100 nm, and hence an increase in the number of such particles in the powder mixture, as one would expect, results in a decrease in the space between densely packed particles, i.e. to a decrease in the pore size.

Also, to determine the influence of pressing conditions on the final properties of the samples, such as the porosity and pore values, a number of experiments were performed with varying the load when pressing a powder mixture with a ratio of 50 wt% of nickel and 50 wt% of cobalt. The results are shown in Table 2. It should be noted that pressing at a pressure of 50 MPa did not make it possible to obtain a strong sample under this sintering conditions.

According to the results of the study, we can note a decrease in the values of open porosity with an increase in the value of the pressing load, which is quite natural. At the same time, a change in the pressing pressure in the range from 100 to 400 MPa did not significantly affect the values of the closed porosity within the errors of the determined values, which did not exceed 0.8 %. With an increase in the pressing pressure, a slight decrease in the pore size was observed, which was also natural.

Table 1

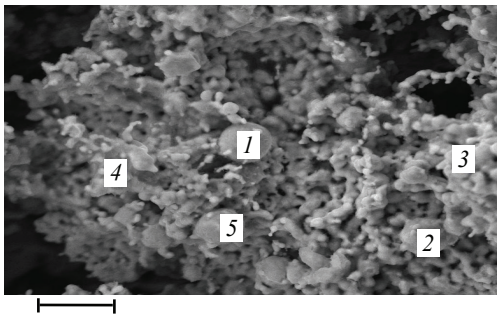
Effect of composition on porous material properties

Mass fraction of nickel powder, %	Mass fraction of cobalt powder, %	Pore size, μm	Open porosity, %	Closed porosity, %
0	100	12	73.8	0.7
25	75	10	73.7	0.1
50	50	10	72.8	0.2
75	25	7	71.3	0.3
100	0	8	66.4	2.0

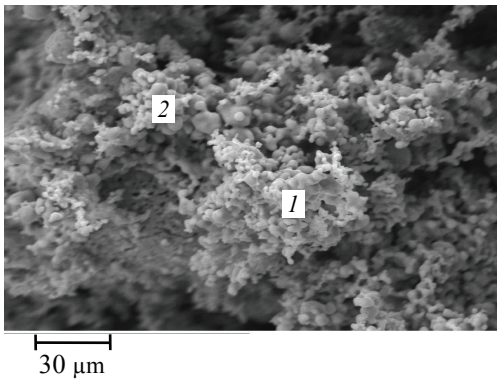
Table 2

Effect of pressure and pressing conditions on properties of porous material

Pressing pressure, MPa	Pore size, μm	Open porosity, %	Closed porosity, %
100	10	77.6	0.7
200	8	74.9	0.8
400	8	73.0	0.3
200, hydrostat	7	70.1	0.3



a)



b)

Fig. 2. SEM images of a sample pressed at a pressure of 400 MPa (*a*) and of 100 MPa (*b*):
Range (Content, wt %) *1*: O – 4.85; Co – 6.28; Ni – 88.87; *2*: O – 4.26; Co – 7.48; Ni – 88.26; *3*: O – 3.56; Co – 66.24; Ni – 30.20; *4*: O – 10.35; Co – 63.99; Ni – 25.66; *5*: O – 6.27; Co – 8.40; Ni – 85.33 (*a*); *1*: O – 7.75; Co – 17.78; Ni – 74.47; *2*: O – 3.18; Co – 72.27; Ni – 24.55 (*b*)

The total porosity of the material obtained with the use of pressing in a hydrostat at 200 MPa turned out to be 5.3 % lower compared to the material pressed under the same pressure on a hydraulic press, which might result from all-round compression applied in the hydrostatic press, as opposed to a one-sided compression in a metal cylindrical matrix on a hydraulic press.

Scanning electron microscopy of the obtained materials was carried out. Fig. 2 show microscope photos of the chips of samples containing nickel and cobalt powders in a ratio of 1:1 obtained by pressing under different pressures. The porous structure of both materials has similar external features and has a bimodal character: in addition to large pores with a size of more than 10 μm formed by the burning of the blowing agent, there are small pores with a size of 1 μm or smaller obtained in the initial mixtures of nanopowders.

The homogeneity of the distribution of elements in the resulting materials was also evaluated by the method of micro-X-ray spectral analysis (Fig. 2). Since the materials obtained in the study were sintered from the powders of individual elements at relatively low temperatures, it is to be expected that the diffusion processes will not go to the end and the final structure will inherit the chemical features of the initial mixture of powders, as evidenced by the results of micro-X-ray spectral analysis.

Conclusions

Porous materials from a mixture of cobalt and nickel with a pore volume fraction of more than 68% were obtained by powder metallurgy methods. The porous structure of the resulting materials has a bimodal character, consisting in the pronounced predominance of large (more than 10 μm) and small (less than 1 μm) pores, most of which are open. It is established that the porosity of the material depends weakly on the ratio of the nickel and cobalt powders in the initial mixture. The chemical composition of the materials produced by the pressure treatment and heat treatment retains its heterogeneity.

Acknowledgement

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