CURRENT STATE OF METHODS FOR LOW-DENSE CONSTRUCTIONAL COMPOSITE MATERIALS PRODUCING (OVERVIEW)

E.P. Shcherbakova[1], A.D. Prokhorova[1], A.V. Karpenko[2], T.B. Yanko[3]
[1]Karaganda State Technical University, Karaganda, Kazakhstan;
[2]Zaporizhzhya National University, Zaporizhzhya, Ukraine;
[3]State Research and Design Titanium Institute (PJSC Titanium Institute),
Zaporizhzhya, Ukraine

The analysis of existing methods for imparting a porous structure to structural composite materials is carried out. In particular, the introduction and subsequent removal of the filler, the addition of foaming agents or separately prepared foam to the suspension, as well as gas formation. Discloses a method of introducing into the material of the hollow microspheres, which finds use in the development of thermal barrier composites. The introduction and subsequent carbonization of additives is considered. A method for producing highly porous carbon-graphite materials with a uniformly distributed pore structure using isostatic pressing with pyrocarbon in the form of a binder is considered. Describes the receipt as highly porous carbon materials of foam coke based on carbon microspheres, carbon materials based on fibers, pressed carbon black, porous pyrocarbon and related materials, as well as porous glassy carbon.

Low-density structural composite materials are of particular importance in modern technology, since they are characterized by a sufficiently high level of operational parameters.

When you create composite materials with controlled porosity in the matrix of the tight-meltable materials are introduced hollow microspheres. Therefore, powder metallurgy methods are most applicable, since the process of obtaining such materials is characterized by the stages of mixing, pressing and sintering. In the preparation of these materials have problems associated with large differences in the physico-mechanical characteristics, the nature of the starting components and the complexity of their interactions during sintering.

There are several methods for imparting a porous structure to materials [1], in particular:
– introduction and subsequent removal of the filler;
– adding foaming agents or separately prepared foam to the suspension;
– chemical reaction gas formation.

The first method consists in adding solids, suspensions or a melt of organic and inorganic materials to the composition of the metal powder, which are removed after the workpiece is formed by evaporation, sublimation or burning, with the subsequent formation in the metal matrix of numerous pores uniformly distributed over its volume.

According to the second method, a suspension of metal powder is mixed with a foaming agent or with separately prepared foam obtained by machining aqueous solutions of certain surfactants.

The third method is based on the foaming of a melt or metal powder dispersed in an organic medium by gas released during chemical reactions of interaction or decomposition of existing system components, as well as specially introduced additives. The formation of a porous structure during chemical pore formation represents several successive processes, the main of which can be considered the chemical interaction of system components with the formation of gas bubbles, their expansion, migration in volume and fixation of the cellular structure of the material.

According to the first method, porous materials are obtained from molybdenum, tungsten, and tungsten carbide [2]. In accordance with the first method, beryllium foam is obtained [3]. Beryllium powder and zinc powder are mixed and sintered at a temperature of 1373 K. In the process of heating, zinc evaporates, and beryllium foam with a density $0.5 \cdot 10^3$ kg/m^3 is obtained.

The second method produces foams of iron and copper [4]. Salts and other organic compounds are used as a foaming agent. They are mixed with an aqueous suspension of powders of metals and their oxides. Then the foam mass is poured into molds and dried. The dried preforms are sintered in an atmosphere of hydrogen at a temperature of 1173…1473 K. The porosity is regulated by the use of powders of different grain sizes, as well as by changing the composition of the foam mass.

To obtain porous metal products, gaseous blowing agents (oxygen and nitrogen) are used [5]. The molten metal is transferred into a heated crucible, a gas or alloy containing titanium and zirconium hydrides is introduced. A small vacuum is created in the crucible, which promotes foaming.

To obtain foamed metals by gas formation using chemical reactions, organic compounds and gas-forming reagents with metal powders are used [6]. The mixture is heated and foamed due to the gases obtained by decomposition of the gas-forming reagent. In [7], a method for producing porous materials by the reduction of metal with soot was described. The preparation of complex carbides with high porosity is presented in [8].

The above methods for creating highly porous materials have several disadvantages. The method of introducing and removing the filler is time-consuming, the products obtained have a higher relative density and lower strength than the products obtained by the foam method. The foam method equires a long period of

drying workpieces, besides obtaining a foam metal density above $5.7 \cdot 10^3$ kg/m^3 is very difficult.

Recently, the method of introducing hollow microspheres into the material has become the most promising method of pore formation. Such thin-walled microspheres find application in the development of heat-shielding composite materials. Microspheres are characterized by low density, high specific compressive strength, resistance to deformation, good heat-insulating ability.

Composite materials based on aluminum oxide are known, their main field of application is high temperature insulation. For these purposes a composite material obtained by mixing hollow spheres aluminum-magnesian with a binder and then forming the resultant mass and firing at temperatures of 1673…2073 K [9].

Composite materials obtained by vapor-phase densification of porous graphite, powdered and fibrous fillers by pyrolytic carbon possess great potential [10, 11]. Of great interest are syntactic foams filled with carbon microspheres. For high-temperature insulation, materials based on carbon microspheres of phenolic or epoxy resin (binder) with a density of 1900…2300 kg/m^3, carbonized at a temperature of 1273 K are used [12, 13].

The hollow microspheres introduced to obtain high porosity should not be destroyed during the manufacturing process of the material, which can be ensured by the use of solid phase sintering, i.e. sintering at temperatures below the melting point or softening of the components.

One of the common methods for manufacturing highly porous materials is the introduction and subsequent carbonization of additives [14]. In the resulting materials, the porosity is 55…60%. As carbonizing additives, mainly low-ash polyfraction organic substances, hydrocarbons, as well as petroleum coke and granular polystyrene balls are used. During carbonization, additives form a carbon residue.

The formation of the structure of highly porous carbon-graphite materials are mainly influenced by the content and particle size distribution of the blowing agent and partially its chemical nature, as well as the type of binder, the method of forming the workpiece and the process parameters [15].

Among the main factors that influence the formation of porous structure in the carbon materials include:
– ratio between filler and binder in the press powder;
– the nature of the filler and binder;
– distribution of a binder between particles during mixing and pressing;
– particle size distribution of the filler;
– pressing pressure;
– type and amount of pore-forming additives;
– firing temperature and duration;
– additional impregnation with subsequent firing.

To obtain artificial graphite, fillers and binders of various nature are used. Petroleum pyrolysis coke (non-calcined and calcined), pitch coke, natural flake graphite and crushed pyrographite are used as filler. As a binder for all types of carbon materials, resins or pitches with different softening temperatures are used [16].

To obtain highly porous carbon-graphite materials with a uniformly distributed pore structure, the isostatic pressing method is used, and pyrocarbon is used as a binder [17]. According to the described technological schemes receive materials with a porosity of 25…35%.

By the methods of increasing the porosity include:
– changing the quantity or quality of the binder;
– introduction of pore-forming substances;
– filler application with narrow fractions of particle size distribution.

The possibilities of the first method, which consists in increasing the binder content in the press mass or reducing the yield of coke residue from the pitch by diluting it with resins or oils, are limited. It is impossible to obtain highly porous carbon-graphite materials with a given character of the porous structure, and a decrease in the yield of coke residue causes a decrease in the strength characteristics of the materials.

The essence of the second method consists in introducing into the mass (mixture, press powder) pore-forming agents, which are used as organic or mineral substances, which decompose during the heat treatment of the workpieces, which leads to the formation of additional open porosity in the materials. The porosity is controlled by introducing a predetermined amount of a pore-forming agent, and particles of a certain granulometric composition influence the size of the pores prevailing in the material.

The third method is based on the use of a filler of narrow fractions of particle size distribution and is the main one in the production of highly porous carbon-graphite materials by foreign companies [18, 19].

Materials obtained using microspheres are characterized not only by low density, but also by a number of other valuable properties: high specific compressive strength, resistance to deformation, good heat-insulating ability [20].

Among the materials obtained on the basis of the microspheres can be divided into two main groups:
– materials in which microspheres are used as a filler uniformly distributed in a matrix of a binder component [21];
– materials obtained by sintering (or gluing) microspheres [22].

For the manufacture of these materials, microspheres of polyfraction composition are used. Changing the geometric parameters of the microspheres, as well as the number of bundles forming the bridges, expands the ability to control the strength and thermophysical properties of materials.

The first group includes composite heat-shielding materials with organized porosity obtained by powder metallurgy [23, 24]. Powdered borides and carbides of transition metals are used as a matrix, and hollow microspheres of carbon and aluminum oxide are used as pore-forming agents. The introduction of hollow microspheres allows to obtain composite materials with porosity from 25 to 50% and strength of 40…50 MPa.

The second group includes the material described in [22], for the manufacture of which microballoons from glass were used, chromaluminophosphate binder was used as the binder forming the bridges between the particles (9.08% Al_2O_3, 4.64% Cr_2O_3, 37.04% P_2O_5).

The choice of such a bundle made it possible to control the average size of the bridge, and, consequently, the mechanical properties of the material, if the shape of the microballoon is constant. Depending on the amount of binder, the density of the material varies from 250 to 400 kg/m^3, while the strength increases from 2.5 to 5.5 MPa.

Highly porous carbon materials should also include foam cokes from carbon microsphere (syntactic foams), fiber based carbon materials, pressed soots, porous pyrocarbon and materials binded by them, and porous glassy carbon.

To obtain carbon microsphere-based foam cokes, hollow carbon microspheres from pitch, phenolic, alkyd and epoxy resins, polyesters and polyamides are introduced into thermosetting resins.

Upon receipt of highly porous materials based on carbon microspheres, the latter are dispersed in a liquid resin or mixed with a solid binder. Phenolic, polyurethane, epoxy, furfuryl, alkyd, silicone, polyester unsaturated resins, as well as polyvinyl alcohol and polyacrylonitrile are used as binders. Due to the low crush and abrasion resistance of carbon microspheres to preserve them and improve the formation of products, the binder is usually dissolved. A mixture of microspheres with a binder is loaded into a mold and pressed at low pressure. The mold is heated to a temperature of 413…493 K for 15…120 min, while the solvent is removed, and the binder is polymerized. Heat treatment is performed in an inert medium at temperatures above 1073 K.

Materials based on carbon microspheres are characterized by low thermal conductivity (especially at low temperatures) in combination with a low apparent density and high compressive strength.

Highly porous glassy carbon is of undoubted interest as a material for filtering highly aggressive media, electrodes, heaters, catalyst supports, etc. Products from this material are obtained by pouring a polymerizable mixture into a container of the appropriate shape and size, filled with particles of water-soluble salt (KCl) of a given granulometric composition as a pore former. For this purpose resin obtained by poly-condensation of furfural with phenol in the presence of an acid catalyst. After partial polycondensation at a temperature of 323…353 K and washing the salt (pore-forming agent), the preform is dried. For final curing, the preform is kept for a week at a temperature of 453…473 K and subjected to carbonization in an inert environment at 1473 K. The resulting material has a density of 340 kg/m^3, pore size 250 μm. By adjusting the molding pressure, these parameters can be varied over a wide range. So, with an increase in pressure from 9.8 to 39.2 and 78.5 MPa, the density increases from 520 to 800 and 1000 kg/m^3, porosity decreases from 73 to 56 and 45%, and the maximum pore size from 10 to 4.5 and 2.8 μm, respectively. For the production of highly porous carbon materials based on foamed polymers (foam cokes), foam plastics (gas-filled cellular materials with insulated pore-bubbles) and porous plastics (foamed materials with open pore-cavities) are used. Foam and porous plastics are obtained from synthetic resins using blowing agents.

Phenol-formaldehyde, phenol-furfural-formaldehyde, urea-formaldehyde, organosilicon (silicone), epoxy, polyurethane resins, polystyrene, polyethylene and other polymeric materials are used as the basis [20, 21]. The pore-forming agents are various substances of organic and inorganic origin, for example ammonium carbonate.

For the foam coke production uses FF brand foams plastics based on phenol-formaldehyde resin and FK brand based on products of combining phenol-formaldehyde resin with SKN-40 nitrile rubber to produce materials with a density of 0.19…0.23 g/cm^3. To obtain denser foam materials, the proportion of pore-forming agent in the original composition is reduced. To obtain lighter materials with a more uniform porous structure, plasticizers (high-boiling esters) are introduced into the initial composition.

By the carbonization of foams in industrial furnaces produces foam cokes VK-900 and VK-20-900. The process is carried out in a protective environment (carbon backfill). If necessary, foam coke is processed at higher temperatures (up to 2873 K), but this treatment affects the mechanical properties of the material. The results of [21, 22] showed that polymers from chains of macromolecules without cross-linking or with a small number of them during pyrolysis are almost completely degraded, giving a small coke residue. And polymers with a spatial structure of macromolecules (network structure), characterized by a rigid structure with a large number of cross-links, give a fairly high yield of coke residue – 55% (mass.), turning into foam coke.

It was shown in that the introduction of carbon fillers (soots, coke powders, graphite) into the feedstock somewhat reduces shrinkage, which is uniform in all directions under uniform heating during pyrolysis. In this case, the main mass loss occurs up to coke formation temperatures (973 K).

Introducing of highly dispersed artificial graphite into the composition does not have a significant effect on the formation of the crystalline structure of foam materials during their heat treatment, and the added substance practically does not change the degree of graphitization. Natural graphite introduced into polyfurfuryl alcohol or phenolic resin has a catalytic effect on the process of ordering the crystal structure of a monolithic material (glassy carbon). A similar effect was exerted by metal impurities of cobalt, nickel, and iron introduced into the initial polyurethane foam.

Due to their low strength, foam cokes cannot be used as thermal insulation in devices with relatively large internal and external mechanical stresses, as well as subjected to shock loads and friction. To give foam coke more wear resistance and increase their strength, the deposition of pyrocarbon from the gas phase is used, which increases the chemical resistance of the material. For this purpose, thermoplastic or thermosetting resins or mixtures thereof with finely ground carbon materials (soot, coke, graphite) are applied to the outer surface of the products, followed by drying and carbonization of the resulting crust. Such an operation is sometimes combined with thermal treatment in the atmosphere of hydrocarbon gases.

To increase the strength of foam cokes, powders of graphite, metals, oxides, and carbides are introduced

into the initial polymer compositions. However, the introduction of increasing amounts of these substances (fillers) leads to an increase in the size of the predominant pores and the appearance of individual large pore-shells with a diameter of up to 5…8 mm.

At the same time, the introduction of various fillers into the initial resin does not allow to get foam materials of increased strength at high temperatures. To obtain such foam materials, it was proposed to impregnate the foam coke in a vacuum furnace at a temperature of 2073…2273 K with a mixture of silicon and boron. To preserve the initial structure of the foam coke in the boron – silicon – carbon system, the fraction of the first two elements should be less than 30% of the carbon mass. The density of the composition is controlled by both the density of the foam coke and the degree of impregnation, with which the concentration of boron and silicon increases, and the concentration of carbon decreases.

Thus, impregnation of the foam coke with the silicon – boron system allows one to obtain material with low density values, sufficiently high strength, and chemical resistance in oxidizing media at normal and elevated temperatures. The material can be used as thermal insulation and for filtering aggressive media at high temperatures [23].

The category of highly porous carbon materials should also include materials based on soot (with its high content) using various polymer resins as a binder. These materials are characterized by a narrow pore distribution spectrum and sufficient strength for industrial use.

The most widely used methods for producing low-density materials, in which pores are created by gases arising from chemical reactions of charge components. For the expansion of the ceramic suspension, various chemical reactions are used, accompanied by the release of gaseous products: thermal decomposition of carbonates, the interaction between carbonates and acids with the release of carbon dioxide, between metals and acids or bases with the release of hydrogen, as well as between organic compounds.

In the reactions between carbonates and acids, calcium, magnesium, strontium, barium, lithium, iron and ammonium carbonates are used as gas-forming agents. When carbonate reacts with acid, carbon dioxide is released:

$$Me_2CO_3 + 2H^+ \rightarrow CO_2 + 2Me^+ + H_2O. \qquad (1)$$
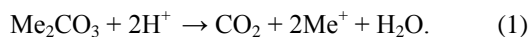
Using the reaction of thermal decomposition of carbonates allows one to obtain ceramic foamed products with porosities up to 60%. From a mixture of finely ground powders Al_2O_3, SiO_2 and carbonate (for example, Li_2CO_3 or Na_2CO_3), an aqueous slurry is obtained, and products are cast from it upon preliminary firing to a temperature of 1273 K, the carbonates are completely decomposed with the formation of CO_2, which creates uniformly distributed small cells. After machining, the product is subjected to final firing at 1573…1773 K.

There are a variety of methods associated with the formation of foams in reactions with the evolution of hydrogen when using hydrogen peroxide as a gas generator. Methods are also used based on the interaction of metals with acids or alkalis with the evolution of hydrogen by reaction:

$$2Me + 2H^+ \rightarrow H_2 + 2Me^+. \qquad (2)$$
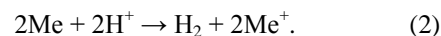
The method of pore formation as a result of hydrogen evolution during the interaction of aluminum with acids and alkalis is widely used. For example, for the manufacture of Al_2O_3, ZrO_2, MgO foam oxides, reactions between aluminum powder and NH_4OH are used.

Along with the bases, mixtures of aluminum powder with acids (hydrochloric, sulfuric, nitric and phosphoric) are also used in the interactions in all cases, hydrogen is released, which forms bubbles.

For the manufacture of phosphate foams, a mixture containing an oxide filler, a phosphate binder and a foaming agent is used.

Thermoset resins or aqueous solutions of organic substances are introduced as ligaments in the preparation of foam materials using organic compounds.

Due to the peculiar structure, porous materials have specific structurally dependent properties, which sharply differ (in some cases by an order of magnitude or more) from properties corresponding to the chemical composition of compact materials. Usually, open porosity predominates in porous materials; only ceramics obtained by gas methods have closed porosity, or rather voidness (gas cells isolated by completely sintered shells).

In works [23, 24] on the study and selection of pore formers for the production of highly porous carbon-graphite materials, wood sawdust, lignin, and ammonium chloride were studied. The best results were obtained using NH_4Cl as a foaming agent. It has been established that with increasing pore-forming content, porosity, average pore diameter and water permeability increase, and the coefficient of pore tortuosity and their average number per unit surface of the material decrease.

The research results on the search for the optimal technology for producing highly porous materials using pore-formers are partially summarized in [23], where the method of introducing a pore-former into the charge is most fully considered.

In the general case, when the pore-former is completely removed during heat treatment, the porosity of the material does not depend on its chemical nature and its choice is due to manufacturability and economic indicators. By processability is understood the possibility of obtaining particles of a given particle size distribution without subsequent aggregation, the exclusion of additional operations, such as drying, as well as non-toxicity and inertness with respect to the equipment material.

The mismatch of the temperature ranges of the maximum gas evolution of the binder and the pore-former agent is also essential when choosing a pore former. Good results can be obtained by using a mixture of substances with different decomposition temperatures as a pore-former. This improves the conditions for the release of volatiles, allowing you to enter a larger amount of pore-forming agent into the original

composition and perform heat treatment of workpieces according to the industry production firing regimes of serial production.

It was believed that the use of NaCl as a pore-forming agent that does not change its state of aggregation at the softening temperatures of the preforms (373…473 K), maximum gas evolution (673…753 K) and the formation of coke from the binder (873…973 K), provides a porous carbon material with preset pore size. However, it was later shown [24–26] that there is no direct relationship between the particle size of NaCl and pore size. The introduction of a small amount (20%) of NaCl increases the open porosity of the material, but practically does not affect the nature of its distribution in pore size and its maximum radius. This situation is explained by the fact that during the heat treatment of materials with NaCl as a pore former, a peculiar porous structure is formed in them [26]. In the place of the sample where the NaCl particle was located, after its removal as a result of thermal decomposition, a pore remains whose shape and size approximately correspond to the pore-forming particle. Since the porous structure of the calcined material is already formed during baking due to carbonization of the binder, the decomposition products of the pore former at higher temperatures are removed through a system of pores that were previously formed as a result of coking of the binder and representing capillaries and pores – channels of small cross section (2…5 μm) [27]. This ready network of branched capillaries connects the pores formed by NaCl particles between themselves and the surface of the sample.

With an increase of the NaCl content in the press powder over 20%, the open porosity and the size of the maximum pore diameter increase, while the character of the pore size distribution changes.

The need to manufacture porous products from non-plastic materials has led to the development of a method of casting from aqueous suspensions into gypsum molds [21]. When casting into porous molds, the suspension is maintained until a product is formed, which is molded due to capillary suction forces, which determine the flow of the liquid phase to the walls of the mold. Together with the liquid and moving the solid particles of the suspension. The liquid is absorbed into the pores of the form, and solid particles are packed on its walls.

High-quality molding of workpieces can only be achieved with good suspension fluidity, its high sedimentation and aggregative stability with a high solids content and good mold fillability.

The dispersion of the particles distributed in the suspension determines its stability, viscosity and affects the density of the resulting workpieces. With an increase in the dispersion of particles in accordance with an increase in their specific surface, the ability to bind water rises, and therefore suspensions containing dispersed (up to 5…10 μm, mainly 1…2 μm) particles, in most cases, have a higher viscosity than suspensions with a coarse powder. Spherical powders with minimum particle porosity provide a higher density. The liquid phase for the preparation of the suspension is selected individually with low viscosity and chemical inertness to the solid phases of the suspension.

The most frequently water and paraffin are used as the liquid phase of the suspension. Water provides the suspension with the necessary fluidity, provides a good filling of the porous form and the smooth transfer of the suspension along the drainage tracks.

As a material for porous forms, gypsum is used. The blanks from most materials after molding are well separated from the gypsum molds. In some cases (molding carbide powders), an adhesive film of graphite, talc, bentonite clay, sodium or ammonium alginates has to be applied to the inner surface of the gypsum mold.

The suspension is prepared by single-stage or two-stage methods, as well as the method of maximum saturation with the addition of a granular filler. According to a one-stage method, previously crushed material is wet milled. In the two-stage method, dry grinding is first carried out and then wet in order to obtain a suspension. In this case, a solid phase with a lower dispersion is formed. The acceleration of the dry grinding operation in the two-stage method is carried out by the addition of surfactants. High-density preforms are obtained by adding coarse powders to the dross at the mixing stage. This method is most effective when forming large-sized and thick-walled products, as it provides a high rate of mass gain of the workpiece and their small shrinkage during drying.

When casting, the suspension is poured into the mold until it is completely filled. The molding mechanism consists in the directional deposition of suspension particles on the walls of the mold under the action of fluid flows. As a result of liquid absorption into the pores of the mold material, forces arise that move and stack particles on the mold surface with a layer of uniform thickness.

Products are air-dried in ovens or dryers on wooden stands. To prevent cracking, the drying temperature should rise slowly and evenly. The optimum drying temperature is 383…433 K. Firing or sintering of billets is carried out in furnaces according to the regimes depending on the material of the workpiece.

The use of slip molding to create materials reinforced with discrete fibers allows you to distribute the fibers and powder evenly throughout the body. Removal of the dispersion medium from the slip is carried out without resorting to its absorption by the mold material. In this case, perform:

– slip molding under vacuum in metal molds with perforated walls;

– pressure slip molding of the order of several megapascals in split molds with walls of porous material.

Fibrous insulation materials represent a separate class of heterogeneous systems of artificial origin and therefore they can be considered composite materials. In structural materials, fibers play the role of a power cage providing high strength properties and the possibility of deformations in the required direction.

The whole variety of fibrous materials by the nature of the structure can be divided into three main groups: materials with random distribution of fibers in the volume; materials with an ordered flat distribution of fibers and materials representing various combinations

of a chaotic and ordered arrangement of layers of fibrous material.

CONCLUSIONS

An analysis is made of existing technologies for the production of low-density structural composite materials based on refractory metals, using gaseous foaming agents, and also by impregnating porous carbon frames with liquid and gaseous impregnates.

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СОВРЕМЕННОЕ СОСТОЯНИЕ МЕТОДОВ ПОЛУЧЕНИЯ НИЗКОПЛОТНЫХ КОНСТРУКЦИОННЫХ КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ (ОБЗОР)

Е.П. Щербакова, А.Д. Прохорова, А.В. Карпенко, Т.Б. Янко

Выполнен анализ существующих методов придания конструкционным композиционным материалам пористой структуры, в частности, введение и последующее удаление наполнителя, добавление к суспензии пенообразователей или отдельно приготовленной пены, а также газообразование. Описан метод введения в материал полых микросфер, который находит применение при разработке теплозащитных композиционных материалов. Рассмотрены введение и последующая карбонизация добавок, а также метод получения высокопористых углеграфитовых материалов с равномерно распределенной структурой пор и использованием изостатического прессования с пироуглеродом в виде связующего. Описано получение в качестве высокопористых углеродных материалов пенококсов на основе углеродных микросфер, углеродных материалов на основе волокон, прессованной сажи, пористого пироуглерода и связанных им материалов, а также пористого стеклоуглерода.

СУЧАСНИЙ СТАН МЕТОДІВ ОТРИМАННЯ НИЗЬКОЩІЛЬНИХ КОНСТРУКЦІЙНИХ КОМПОЗИЦІЙНИХ МАТЕРІАЛІВ (ОГЛЯД)

Є.П. Щербакова, А.Д. Прохорова, Г.В. Карпенко, Т.Б. Янко

Виконано аналіз існуючих методів надання конструкційним композиційним матеріалам пористої структури, зокрема, введення і подальше видалення наповнювача, додавання до суспензії піноутворювачів або окремо приготовленої піни, а також газоутворення. Описано метод введення в матеріал порожнистих мікросфер, який знаходить застосування при розробці теплозахисних композиційних матеріалів. Розглянуто введення і подальша карбонізація добавок. Розглянуто метод отримання високопористих вуглеграфітових матеріалів з рівномірно розподіленою структурою пор з використанням ізостатичного пресування з піровуглецем у вигляді сполучного. Описано одержання в якості високопористих вуглецевих матеріалів пінококсів на основі вуглецевих мікросфер, вуглецеві матеріали на основі волокон, пресованої сажі, пористого піровуглецю і пов'язаних ним матеріалів, а також пористого скловуглецю.