Theoretical and Experimental Studies of the Properties of Porous Permeable Materials from Industrial Waste for Use in Various Fields of Mechanical Engineering

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Abstract. This article theoretically and experimentally investigates the scientific and technical problem of using multilayer porous permeable materials from industrial waste with controlled functional and technological characteristics by predicting the composition, structure, properties using computer information technology. These porous permeable materials (PPM) from industrial waste are suitable for the purification of technical liquids and gases, which has increased the efficiency of use of products in various fields of mechanical engineering. The results of this scientific work are used in the development of porous permeable products - filters - for the purification of technical, industrial water, lubricants and fuels from mechanical impurities, contaminants.

Keywords: Porosity, Forecasting, Properties, Permeable, Filtering

1 Introduction

Modern industry needs new structural and functional materials, including composite and nanostructured. The technological equipment introduced to meet these demands, automated and robotic, which is equipped with nonlinear drives, allows to develop fundamentally new technologies for the production of materials with high performance properties. The instrument base of diagnostics and scientific researches provides research of structure of new materials in any dimensional scale from nano- to macro-.
The rapid development of high-performance computer systems and software allows for computer modeling of new materials and advanced technologies [1-4].
The study of porous materials in various industries is a current global trend and is realized using the methods of computational materials science with the use of computer metallographic analysis.
The formation and structuring of information about PPM for parallel computer modeling of technologies and loaded structures is a topical issue that can and can be successfully solved by scientists.

An important area of research and research is to study the relationship between the structure and properties of porous permeable materials. Metal porous materials are the predominant class of structural materials in mechanical engineering, the main purpose of which is the ability to carry a force load. The internal structure significantly affects the mechanical properties of metallic materials [5].
Therefore, the study, forecasting and targeted formation of the characteristics of strength, durability, wear resistance and other performance properties is necessarily associated with the search for the physical nature of changes in the structure of materials under the influence of technological and operational loads.

2 Literature Review

The problem of studying the properties of porous permeable materials is important both for scientific purposes and in their practical use. The creation of new materials with predetermined properties makes new demands on the study and solution of problems that require immediate and effective solutions [6].
The results of field experiments to study the properties of PPM are taken into account in the development of separate technological instructions, but the widespread introduction is constrained by the high cost of physical experiment and conservative attitude of practicing technologists to this initial operation [7].
In research practice, the process of studying a discrete environment is of constant interest and recently it has been successfully solved by methods of mathematical and computer modeling [8].
Analysis of the current state of theoretical and experimental research in powder metallurgy indicates a clear trend in the descriptive properties of materials and physical processes in them [9].
In the direction of computer modeling of PPM properties, the works of Kadushnikov R.M. are widely known. on modeling the evolution of the microstructure of polydisperse materials during sintering [10].
Possibilities of application of geometrical modeling of microstructure at research of polydisperse materials as one of methods of the description of their real structure are resulted in article [11].
Adaptation of the properties of the PPM structure to the intended application is a serious problem for materials scientists, as long as there are no methods of accurate morphological processing [12].
Quantitative and qualitative relationships between the morphology of porous material, its local and global filtering properties are important in many applications [13].
The porosity and its distribution throughout the sample is a feature with a certain effect on the filtering properties of the flow and mass of PPM.
The direct dependence of permeability on the structural features of the PPM (porosity, pore size distribution, pore shape and curvature coefficient) will be valid only for certain types of filter materials.
In a number of works [14, 15] correlations are offered for the estimation of permeability of ППМ depending on the size of particles of powder, that determine reduction of

coefficient to penetrating with the increase of surface of particles (reduction to the fac tor of form).
Analyzing the current trends in the creation of PPM today there is a need for comprehensive research and development of scientific and practical principles of forecasting, modeling, development of the structure and properties of PPM from industrial waste, development of new, based on existing, technology for powder products with high mechanical and functional properties with adjustable porosity for cleaning liquids and gases based on computer information technologies.

3 Researches Methodology

The study of capabilities and evaluation of modern software for computer tools for the study of metallographic images in order to determine the qualitative and quantitative characteristics of metals or alloys is dictated by scientific and industrial problems that have arisen in modern materials science.
The main requirement for qualitative analysis of images can be formulated and set as follows: on a photograph obtained under a microscope, it is necessary to identify structural components, and then classify them by brightness, size and shape.
The practical implementation of this includes such tasks that have become classic, such as segmentation, filtering defects and selection of objects from the background, defining the boundaries of objects, pattern recognition [16].
The morphology of PPM determines their filtering characteristics and, consequently, their effectiveness in many areas of application. Adaptation of the properties of PPM structure to the intended application is a serious problem for materials scientists, as long as there are no methods of accurate morphological processing [17].
Quantitative and qualitative relationships between the morphology of the porous material, its local and global filtering properties are important in many applications [18].
The studied PPM sample consists of a solid metal structure (monolithic skeleton; opaque) with a porosity of ~ 69% (intermediate voids, shaded) (**Fig. 1**).

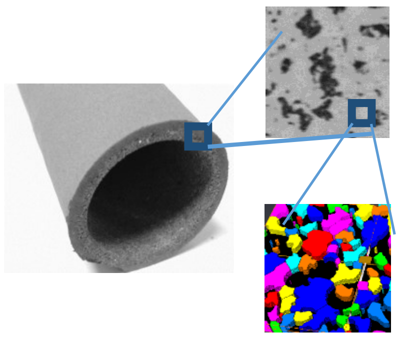


Fig.1. 3D-image of the reconstructed volume of the cylindrical sample PPM

The direct dependence of permeability on the structural features of PPM (porosity, pore size distribution, pore shape and curvature coefficient) will be valid only for certain types of filter materials [19].

In a number of works [20] correlations are offered for the estimation of permeability of PPM depending on the size of particles of powder, that determine reduction of c oefficient to penetrating with the increase of surface of particles (reduction to the factor of form).

4 Results

4.1. Determination of the dependence of permeability on the structural features of PPM.

To ensure minimal pressure drop losses in the filtered medium, the highest permeability of the PPM should be as high as possible at a given filtration fineness. The permeability increases with increasing porosity, pore size, pressure drop and decreases with increasing thickness of the filter element and viscidityof the filtrate. This is quite clear from **table 1.**

Table 1. Correspondence of permeability to porosity

Curvature coefficient, %	Porosity, %	Permeability, Darcy
5,6	46,2	375
10,5	40,8	317
15,0	35,2	243
19,0	32,7	200
22,7	27,4	134

4.2. Study of PPM permeability experimentally.

Determination of permeability through the permeability coefficient was made by [2]. Based on previous studies, the particle size of SHX15 steel powder was chosen to be 0.1-0.16 mm, as this fraction makes it possible to produce PPM with an average pore size of 20 μm [2].

The influence of the amount of pore former on the pore size and porosity is shown in **Fig.2, 3**. As shown in the graphs of experimental studies, the addition of pore generator $CO(NH_2)_2$ leads to an increase in pore size and porosity, these characteristics can be increased several times.

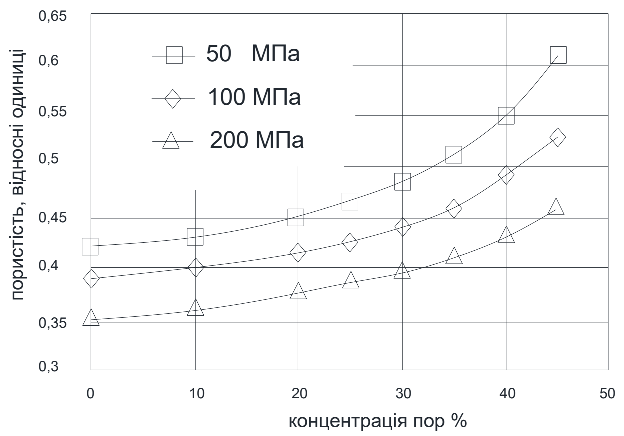


Fig.2. The effect of compression pressure and concentration of the pore former on the porosity of the PPM powder powder steel BBS15 with a particle size of 0.1-0.16 mm

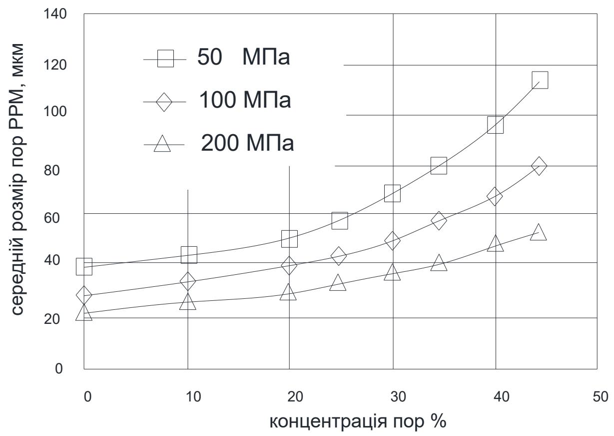


Fig.3. Influence of pressure of compression and pore-forming concentration on the pore size of PPM steel powder BBS15 with a particle size of 0.1-0.16 mm

From the point of view of optimal filtration characteristics, PPM with an asymmetric porous structure used for cleaning liquids or gases characterized by the presence of low-concentration polydisperse solid contaminants should have lower porosity and smaller pore sizes in the flow direction.

At the same time, filtration effectively occurs when the first layer, placed on the original surface of the PPM, with zero concentration of pore-forming agent (with minimal porosity and pore size) provides the required filtration fineness; the second layer, placed on the entrance surface of the PPM, with the maximum pore concentration (with maximum porosity and pore size) catch the largest parts of the pollutant.

The porosity and pore size of the intermediate layers of PPM are easily adjusted by changing the concentration of the pore former.

These results of experimental studies allowed to develop the technology of PPM production by the method of layer formation [2] and became a prerequisite for further filtering studies.
For samples with different porosity, the completeness and fineness of filtration were determined. The results of this study are presented in **table 2.**

Table 2. The dependence of the completeness and fineness of the liquid filtration on the properties of the source powders

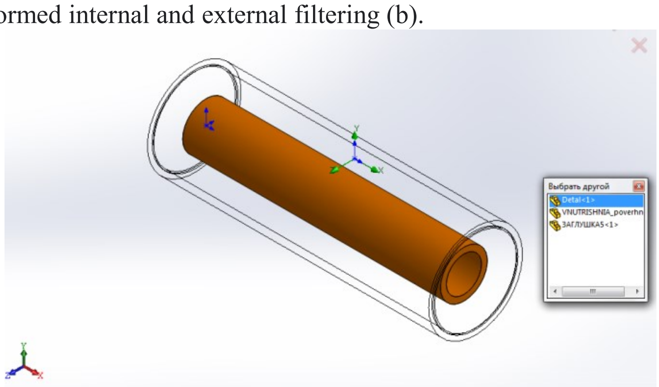
The average particle size, microns	Porosity material, %	Diameter of pore, μm	Fineness filtrations, microns
0,050-0,100	28	25	7-9
0,100-0,150	30	30	15-18
0,150-0,200	35,5	55	20-25
0,200-0,250	36,5	75	35-45
0,250-0,300	38,5	130	50-65
0,300-0,500	40	160	75-85

4.3. Investigation of PPM permeability by modeling methods.
To model the permeability of PPM, we use the following realistic data **table 3.**

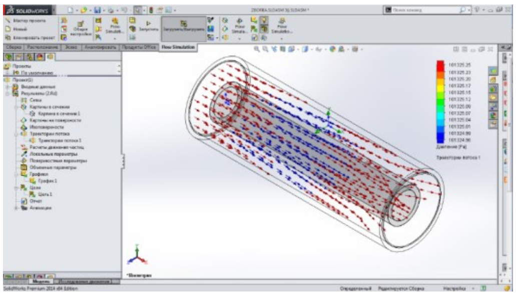
Table 3. Chemical composition of steel powder BBS15

Chemical element	Percentage composition, %
Si	0,17-0,37
Cu	0,25
Mn	0,20-0,40
Ni	0,30
P)	0,027
Cr	1,30-1,65

Fig. 4 shows a 3D model of PPM made of steel powder SHX15 with a given real data (a) and performed internal and external filtering (b).



a)



b)

Fig.4. 3D model of PPM made of SHX15 steel powder with given real data (a) and internal and external filtering (b)

Figure 5 shows the cross section of the flask in which the PPM is fixed. Inside the flask, the liquid inside the filter moves into the flask. The speed at which the liquid acts on the PPM is determined. Blue areas indicate the areas of the flow in which the speed is minimal, and red is the maximum.

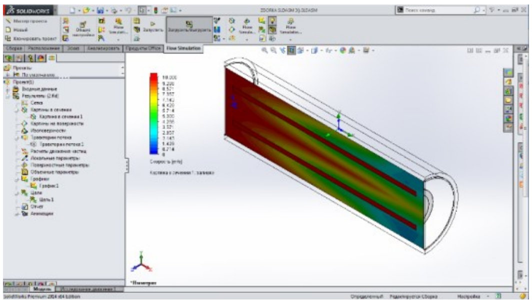


Fig.5. Display of cross section of PPM by the parameter of internal filtration rate

4.4. Systematic determination of PPM permeability.

The environment of the water is represented by moving arrows, which in different parts of the PPM are marked with different colors, according to the maximum and minimum values that they receive in the process of movement.

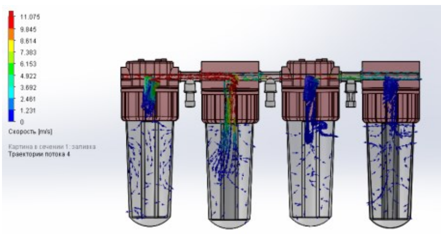


Fig.6. Directions of water flow in a system of four PPM when determining the speed

5 Conclusions

On the basis of these results it is possible to do such conclusions **(table 3)**:
1. Porous permeable materials have a high degree of purification of the liquid medium from solid microparticles and fine impurities;
2. PPM can be used as filters to filter the variety technical means;
3. Porous permeable materials can be used in the same way for water purification as drinking water.

Table 4. Characteristics of PPM

Indexes	Value of indexes
Porosity, %	25-55
Operating temperature	… 100
The filtration efficiency of dispersed micro-impurities with a particle size greater than 0.01 μm,%	… 99,99
Productivity of ultrafiltration of water at a pressure drop in the filter of 0,1 MPas, l / cm^2 × h	… 10
Productivity of ultrafiltration of gases at pressure drop on the filter of 2 kPa, l / cm^2 × h	… 40
Bending strength, MPa	≥ 0,5
Geometric dimensions of samples, mm:	
cylinders, pipes, glasses, diameter;	up to 40
length	up to 100

In addition, the results allow us to draw conclusions about the effectiveness of cleaning liquids:

1. The resistance of a porous filter element depends on the pore size and total pore volume, filtration rate, wall thickness and grittiness of initial powder;
2. The fineness of filtration and resistance have a direct dependence on the size of the porosity of the filter element. The higher the porosity - the higher the fineness of filtration and resistance;
3. As the particle size of the powder increases, the resistance of the filter material decreases, but the filter properties decrease.
4.The pore diameter has a direct dependence on the particle size of the original impurities.

6 Acknowledgement

On the production base of Ningbo FUTEC Co., Ltd (Ningbo, PRC), an experimental batch of multilayer porous permeable materials made of ShH15 steel powder by radial isostatic pressing was manufactured. The efficiency of the new filter PPM compared to similar traditional PPM was 82%.

Based on the results of a study at the Guangdong Juhang Institute for New Materials Institute for Advancer Material Co., LTD (Guangdong Province, PRC), a batch of three-layer PPM was introduced to clean up technical fluids from a mechanical contaminant. PPM data have a coefficient of permeability of 3, and the resource and dirt capacity are 1.5 times higher than the known single-layer filter PPM, with the filter mass by 20% less.

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