Simulation of compaction of porous permeable materials of complex shape during radial-isostatic compression

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Abstract. Recent years have been characterized by a significant increase in the use of compaction processes for porous permeable materials. It is at this moment that the traditional schemes and technologies for producing products are constantly being improved, and progressive methods of pressing, in particular, radial-isostatic pressing, are being used. Therefore, along with traditional research methods, the method of preliminary computer modeling and prediction of the behavior of powder materials in the process of compaction, and the creation of appropriate mathematical models, is increasingly used.

In this article, the process of compaction of porous permeable materials of complex shape made of BBS15 steel powder by radial-isostatic pressing is studied using computer simulation.

The regularities of compaction of products-filters of complex shape in the form of a flask are considered. It was found that when compressing porous permeable materials of complex shape, the distribution of the porosity value is uneven. As the radius increases, the porosity increases.

It is shown that in the manufacture of filters of complex shape in the form of a flask, the porosity distribution depends on the sealing scheme: the wall material is compacted more intensively during radial pressing, and the filter bottom material is compacted more intensively during axial pressing.

The simulation is based on a continuum approach. The ratio of the porous body's plasticity theory was used as the determining relations. The determination of the workpiece shape, compaction, and density, stress, and strain fields is based on the finite element method.

Keywords: Modeling, Forecasting, Compaction, Porosity distribution, Deforation, Stress

1 Introduction

Powder metallurgy with each new developed technological process demonstrates the advantages that allow you to obtain materials with the best or with all new properties,

to produce products in the most cost-effective way. These products include porous permeable materials (PPM).
The choice of optimal parameters for the process of creating porous permeable materials is a complex and important task of modern efficient production. The success of solving the problems that arise in this process is measured by the quality and degree of forecasting the processes and phenomena that accompany these technologies, namely, the compaction of powder material. It is possible to increase the efficiency of traditional technologies, as well as to introduce waste-free production of products for a wide range of purposes, save energy, reduce labor costs, and control the parameters of the structure of powder permeable materials in the process of their production by means of forecasting using modern modeling tools.
PPMs are widely used in various branches of modern industry [1-3]. In particular, they are used as filters for cleaning liquids and gases.
A promising method for producing filter elements is radial isostatic pressing of powders [4-7]. The method allows you to produce long products of simple and complex shapes with a uniform distribution of porosity. Compaction of the powder occurs under the influence of an elastic element, which makes it possible to effectively mechanize and automate the process, increase production culture, reduce energy consumption, and so on. Small volumes of intermediate media can reduce the metal content, size and cost of equipment compared to other types of pressing.

2 Literature Review

At the moment, there are a number of publications that have conducted experimental [8-10] and theoretical studies [11, 12] to determine the porosity distribution in films whose shape is a hollow cylinder. At the same time, the regularity of compaction of powder filter elements of complex shape is not observed.
Analysis of the literature data [13, 14] shows that promising methods for obtaining PM are methods that are aimed at creating a PM with an anisotropic structure, in which the size and number of pores change in the direction of filtration. In such PPMS, a layer with a minimum pore size will determine the filtration fineness, the permeability is an integral value that is determined by the porous structure of the entire material and the contaminant in the filtration process is distributed over the entire volume of the filter element, which allows increasing the filter life.
Filter PPMs in the form of rotation bodies (pipes, disks, flasks, etc.) are becoming more common in various branches of technology, as they have a high technological design. The main requirements for the geometric of such products are to ensure the accuracy of external and internal dimensions.
The *purpose of this work* is to study the influence of the radial-isostatic compression scheme on the regularities of compaction and form change of the filter element, which has a complex shape in the form of a flask, using computer modeling.

3 Researches Methodology

Technological parameters of the PPM pressing process determine the size, shape, and distribution of properties by volume of products, which, in turn, affects the performance properties of filters.

Choosing the optimal parameters for the pressing process is a difficult task. That is, along with traditional research methods, the method of preliminary computer modeling is now being used more and more widely. This was made possible due to significant progress in understanding the main features of the behaviour of powder materials in the process of compaction, and the creation of appropriate mathematical models.

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Widely used such PPMs are characterized by a high production efficiency. The dimensions of the devices they are part of determine the size and shape of such products. Increasing the performance of these devices while maintaining their size allows you to significantly increase the efficiency of their use.

The simulation is based on a continuum approach. The relations of the theory of plasticity of a porous body were used as determining relations [15]. The determination of the workpiece shape, compaction, and density, stress, and strain fields is based on the finite element method [16].

The most suitable for pressing elastic shells made of polyurethane, which can withstand multiple deformations at pressures up to 600 MPa. These shells retain their elastic properties well, are technologically efficient when manufactured, and have good adhesion properties to metals and ceramics [17].

The accuracy of the compression obtained by radial-isostatic compression depends on the accuracy of manufacturing the inner surface of the elastic tool (**Fig.1**).

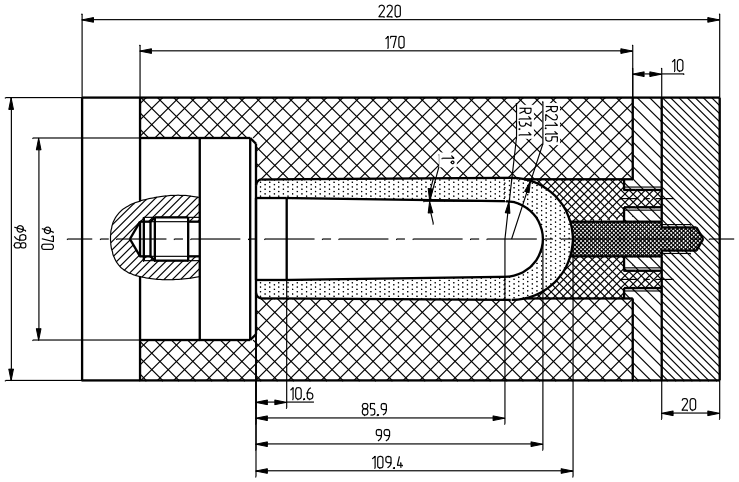


Fig.1. Form for pressing filters with spherical bottom.

For comparison and analysis of the finished product, two sealing schemes were considered: radial (**Fig.2, a**) and axial (**Fig.2, b**). The powder material, which is compacted – powder of steel BBS15. The initial porosity of the filter element was 0.7. The compaction occurred on the mandrel under the influence of elastic envitonment, the material of which is polyurethane.

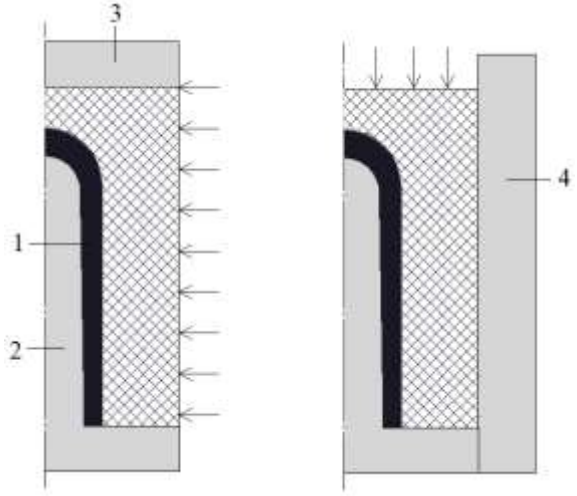


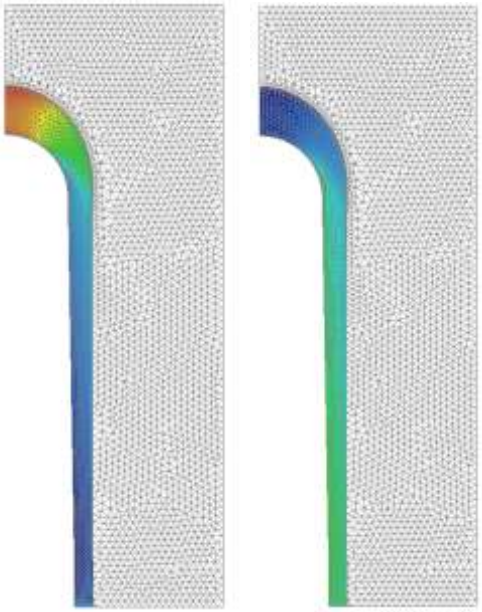
Fig.2. Schemes of radial (a) and axial (b) sealing: 1-powder compacted, 2-mandrel, 3-cover, 4-wall.

Due to the symmetry, half of the axial section was considered in the simulation. It was believed that the mandrel was stationary. It was also considered that the radial seal has a fixed cover (3 in **Fig.2**), and for axial compression, the fixed wall (4 in **Fig.2**). The surface of the polyurethane, on which the force load was applied, moved at a constant speed in the radial (radial seal), or in the axial (axial seal) direction.

4 Results

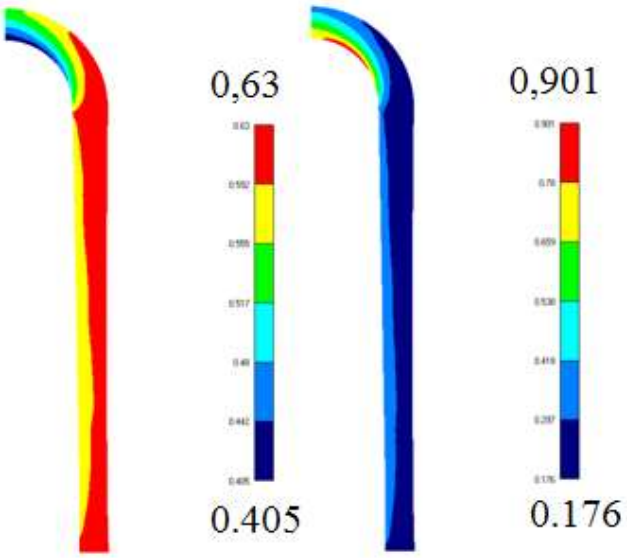
At the initial moment, the wall of the filter element is sealed. The distribution of porosity along the radius of the filter wall is uneven. As the radius increases, the porosity increases. The distribution of the amount of accumulated plastic deformation is also uneven. The maximum value of accumulated deformation is in the inner surface of the filter wall, and the minimum value is in the outer surface.

Fig. 5, 6 shows the distribution of porosity and accumulated plastic deformation under axial compression. The powder is most intensively compacted in the area of the bottom of the filter. The distribution of porosity along the bottom radius is uneven (**Fig.5, a**). As the radius increases, the porosity increases.



a b

Fig.5. Schematic representation of the porosity distribution (a) and the amount of accumulated plastic deformation (b) under axial compression.



a b

Fig.6. Results of porosity distribution (a) and accumulated plastic deformation (b) under axial compression.

During further pressing, the relative density of the wall increases and the process spreads, compacting to the bottom of the filter element. However, as can be seen in **Fig.5**, at the end of the pressing process, the porosity in the filter bottom region is significantly higher than in the wall region. The nature of the change in porosity along the wall radius remains the same as at the beginning of pressing. The distribution of porosity along the wall height is uneven: in the lower and upper parts (**Fig.5, a**) the porosity is higher.

The amount of accumulated plastic deformation is distributed over the filter volume in the same way as the relative density distribution. In the bottom area of the filter element, it is lower.

Compaction of the powder in the wall area occurs to a lesser extent. The porosity is lower in the inner surface of the wall and higher in the outer surface. The amount of accumulated plastic deformation is higher in the area of the inner wall surface.

In this regard, a radial compaction scheme was considered, in which the powder was compacted in the radial direction (**Fig.7**). The simulation results are shown in **Fig.8-10.**

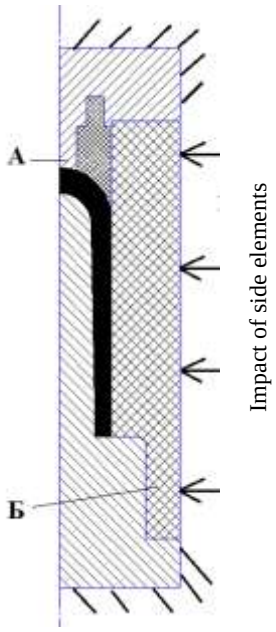
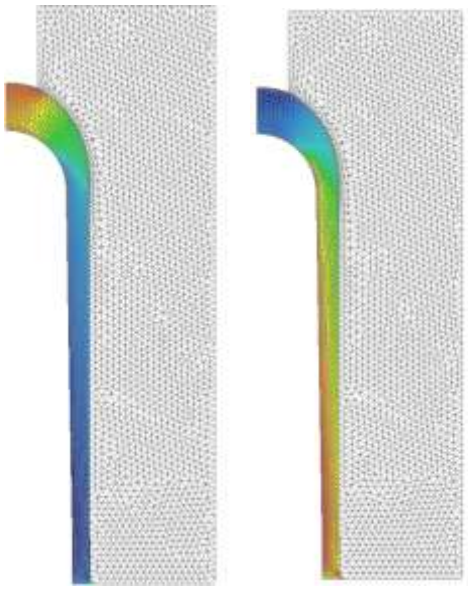


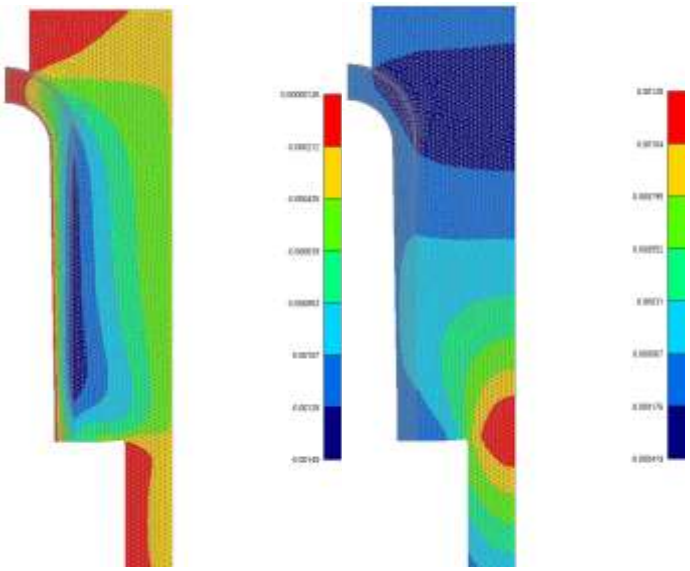
Fig.7. Scheme of radial-isostatic pressing for obtaining PPM in the form of a flask.

At the first stage, the wall is compacted more intensively, and at the second stage - the bottom of the filter element. As a result, the porosity and accumulated plastic deformation are distributed more evenly.



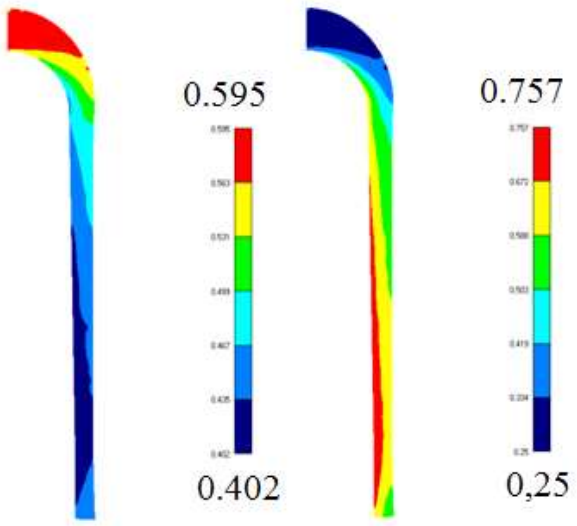
a b

Fig.8. Schematic representation of the porosity distribution (a) and the amount of accumulated plastic deformation (b) during radial compaction



a b

Fig.9. Movement of the powder in the PPM in horizontal (a) and vertical (b) with radial compaction.



a b

Fig.10. Results of porosity distribution (a) and accumulated plastic deformation (b) in radial compaction.

When radially-izostatic pressing of a powder filter element in the form of a flask, the distribution of porosity values and accumulated plastic deformation over the volume of the product is uneven and depends on the sealing scheme.
When the load is applied radially, the material is compacted more intensively in the area of the filter wall. The bottom of the filter is less compacted (**Fig.11**).



Fig.11. Filter PPM in the form of flasks, which is obtained from a powder BBS15.

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5 Conclusions

When radially isostatic pressing of a cylindrical powder filter element, the porosity distribution is uneven. As the radius increases, the porosity increases.
When pressing a powder filter in the form of a flask, the distribution of the values of porosity and accumulated plastic deformation over the volume of the product is uneven and depends on the sealing scheme.
When the load is applied radially, the material is compacted more intensively in the area of the filter wall. The bottom of the filter is less compacted.
In the case of using the axial load scheme, there is a more intensive increase in the sealing of the filter bottom. The filter wall is also compacted, but less intensively.
The use of a scheme in which the powder is first compacted in the radial and then in the axial direction makes it possible to obtain a more uniform distribution of the cost and accumulated plastic deformation.
As the radius increases, the porosity of the filter wall and bottom increases, and the amount of accumulated plastic deformation decreases.

6 Acknowledgement

The main results of this work are implemented in production at the Lutsk place of activity of state-owned enterprise "Ukrspyrt" (Lutsk) and LLC "WOG TRADE" (Kyiv) for cleaning technical liquids and fuel from mechanical contamination [18]. The use of developed single-layer filter PPMs made of BBS15 steel powder, obtained by means of radially static compression, increases the uniformity of porosity separation of filter materials by 20-30% and increases the penetration by 15-20% in comparison with similar traditional filter materials.

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