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ПРОМЫШЛЕННОСТЬ ПОРОШКОВОЙ МЕТАЛЛУРГИИ, ЭКОНОМИКА И ОРГАНИЗАЦИЯ ПРОИЗВОДСТВА

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DEVELOPING NEW DESIGN AND INVESTIGATING POROUS NOZZLES FOR ABRASIVE JET MACHINE

Запропоновано новий підхід щодо підвищення зносостійкості сопел абразивоструменевих машин. Виготовлено пористий елемент — частина сопла нової конструкції абразивоструменевої машини. Проведено перетворення отриманих 2D відсканованих зображень в 3D модель з метою комп'ютерного моделювання симуляції потоку повітря через пористу циліндричну вставку.

Ключові слова: *абразивоструменева машина, сопло, комп'ютерне моделювання, карбіди, повітряний прошарок, СВС процес.*

Introduction

An abrasive jet machining of large and difficult-to-access surfaces is and important process of cleaning engineered products from dirt, rust, different chemical coatings, and surface preparation before prime coating, painting, decorative treatment, etc. An equipment for abrasive jet machining consists of the following basic parts: air and abrasive particles supply unit with an adjusted rate and concentration under necessary pressure and a guide part or a nozzle, where the above-mentioned mixture is supplied to create the required flow parameters, such as initial speed, direction, and force of the flow, contact area of abrasive particles on the surface processed. Such nozzle operates in very aggressive conditions and, therefore, experiences a great wear. Thus, working properties of this part of the abrasive jet machine worsen that badly affects initial parameters of the mixture flow. For example, this article describes how to model and to investigate the possibility to avoid or to minimize the wear of the nozzle.

Analysis of the last researches and publications. The wear resistance of the internal surface of the nozzle is a complex problem. A large attention was paid to the solution hereof, especially, to produce this part from wear resistant hard materials whose properties testified by various patents. The materials used are hard-alloys, ceramics, carbides (boron (B_4C), titanium (TiC), tungsten (WC), tantalum–hafnium (Ta_4HfC_5)), artificial diamonds. Boron carbide proved to be the most popular material for such application.

Boron carbide (B_4C) was first synthesized by Henri Moissan in 1894. This heat-resistant compound possesses unique properties, such as high radiation

shielding properties and chemical resistance, and is very attractive for its electrophysical properties etc. Due to the complex lattice type and high hardness chemical compound, the boron carbide approaches the corresponding values for diamond and comes number 3 in the top hardest known materials (after diamond and boron cubic nitride). Thus, large polycrystals of any form can be produced from the boron carbide only. Hard materials based on boron carbide are widely used for the manufacture of products, which resist mechanical, chemical, hydro- and air- abrasion, and also other types of wear. This material is suitable for producing nozzles, various friction elements, butt-end sealings, and other parts, which are widely employed in today's industry. Compact products made of boron carbide can be produced by two methods: either fusion or powder metallurgy. The first method has not become universal. Powder metallurgy is the main way of making products from boron carbide and B_4C-based materials in our days [1].

Constraining factors. Producing nozzles for abrasive jet machines encounters some constrains, such as intricacy in manufacturing, necessity to use complex technological equipment and expensive materials that makes the finished product expensive.

The purpose of this study is to explore fundamentally new terms to increase the wear resistance of the nozzle for the abrasive jet machine and increase its durability.

Experimental Procedure

The wear and tear of nozzle for the abrasive jet machine is caused by the change of geometrical dimensions of the internal working surface. Because of the friction of abrasive particles on the internal profile of the nozzle, the latter loses original form that results in the change of initial parameters of the flow of the mixture of air and abrasive particles, such as rate (this rate usually equals to 800 m/sec for Venturi industrial nozzles).

The design of Venturi industrial nozzle UDC32–450 served as a prototype.

Figure 1 shows basic internal dimensions of the Venturi-shaped nozzle UDC32–450. This configuration (internal shape) provides converting entry parameters of the flow into required operating parameters. The flow of mixture of the air with abrasive particles is supplied into the wide inlet with specified pa-

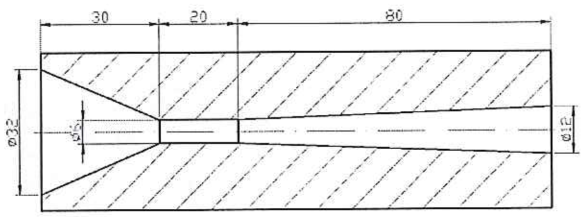


Fig. 1. Configuration of the Venturi-shaped nozzle UDC32–450: basic internal dimensions

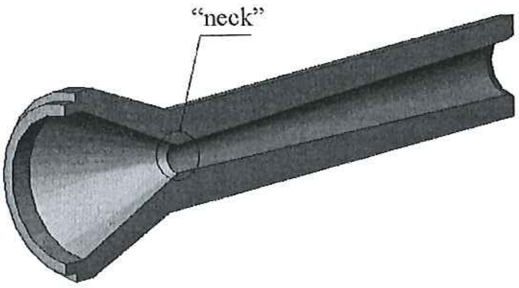
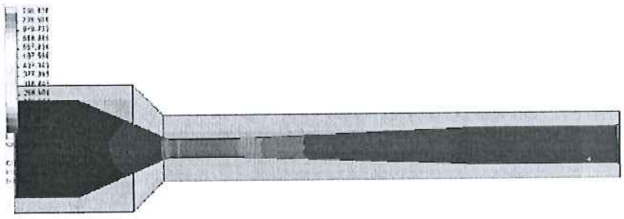
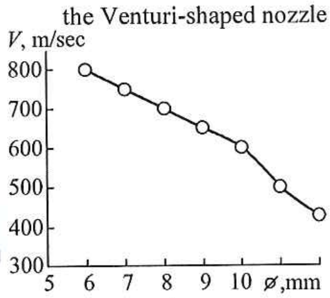


Fig. 2. Location of the maximum wear of the Venturi-shaped nozzle



a



b

Fig. 3. Evaluation of nozzle wear off: *a*) simulation of the air flow motion using SWFS; *b*) variation of outlet flow rate with a nozzle diameter

rameters: pressure 6 bar, rate 30 m/sec. Due to the internal shape, the flow reaches the rate of 800 m/sec at the narrow outlet, which is the required operating rate.

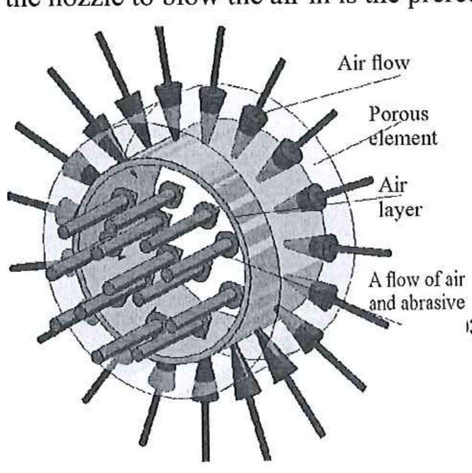
The examination of worn out Venturi nozzles revealed that the maximum wear has occurred in the narrow cylindrical channel having dia. 6 mm (Fig. 2).

Carried out with SolidWorks Flow Simulation software (SWFS), seven computer simulations of the flow motion in a nozzle of different diameters, i.e. the simulation of the neck wear of the nozzle from Ø6 mm to Ø12 mm (Fig. 3*a*) demonstrated a rate decrease of the outlet flow from 800 to 426 m/sec (Fig. 3*b*) that impacted the abrasive jet machining.

So, we can make a conclusion that nozzles for abrasive-jet machining lose their working properties because of increasing of internal diameter of so called "neck".

An idea to eliminate or to decrease the negative effect of the above-mentioned abrasives on internal walls of the nozzle came on. This can be achieved by implementing an additional air layer to cut off the contact of abrasive particles with the internal surface of the nozzle. Figure 4 demonstrates the basic principle of how it works.

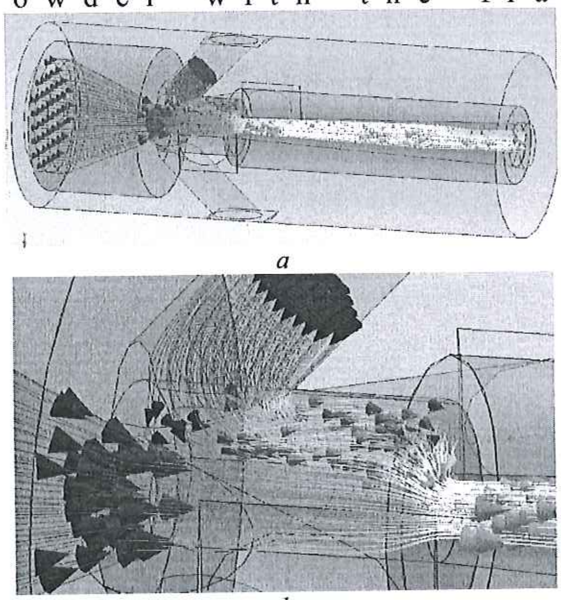
An additional air flow will be supplied in radial direction, i.e. perpendicular to the main flow of the mixture of air with abrasive particles. A porous wall of the nozzle to blow the air in is the prerequisite to create this additional air layer.



To minimize the wear, the design of the nozzle neck was changed from solid to combined one. The new design was virtually tested with SWFS CAD. Trial data were entered as per real operation of the abrasive jet machine. Figure 5 shows test results.

Insert. Based on the tests, a three-part assembling nozzle was designed. These parts are: wide inlet, porous cylindrical insert through which an additional air flow will be supplied perpendicularly to the basic flow, and narrow outlet. Figure 6 demonstrates a drawing for manufacturing such insert.

The presented porous element was made from a mixture of Ti-based metallic powder with the fraction size of



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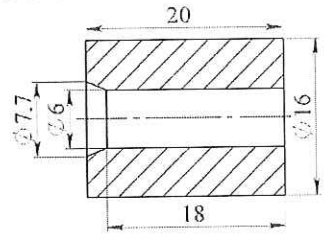
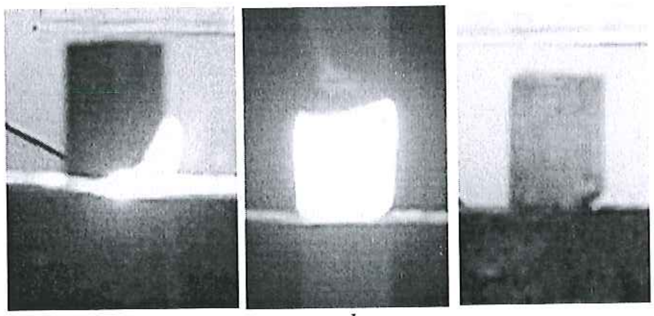


Fig. 6. Basic geometrical dimensions of porous insert

◀ *Fig. 5.* Simulation of air flows inside the nozzle when the abrasive jet machine is running: a) general construction; b) megascopic type of flow mixing in a porous insert area



a *b* *c*

Fig. 7. Sintering of a sample by self-conducting high-temperature synthesis: *a*) initiation of self-conducting high-temperature synthesis; *b*) self-conducting high-temperature synthesis; *c*) final stage of self-conducting high-temperature synthesis

+0.63–1.6 mm and a carbon soot in 10 : 1 ratio. Pressing was conducted in a vertical screw press with 40 MPa force during 5 minutes.

Sintering was carried out by self-conducting high-temperature synthesis (Fig. 7) during 1 minute, because, best of all, the mixture (the porous element is

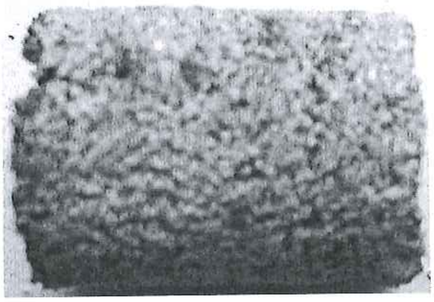


Fig. 8. Sintered porous insert

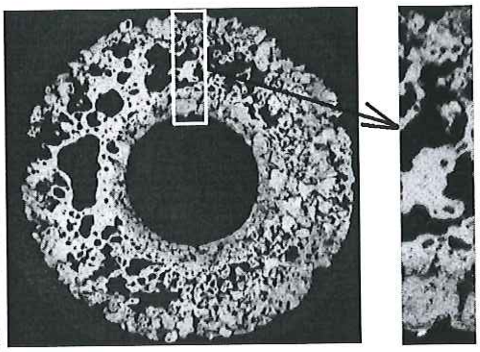
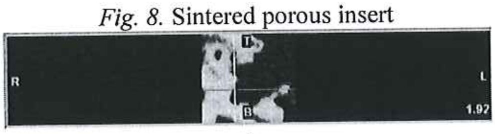


Fig. 9. Simplification of image



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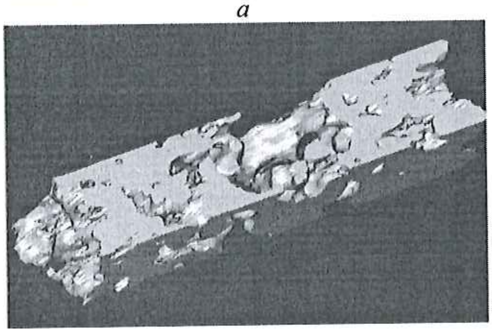

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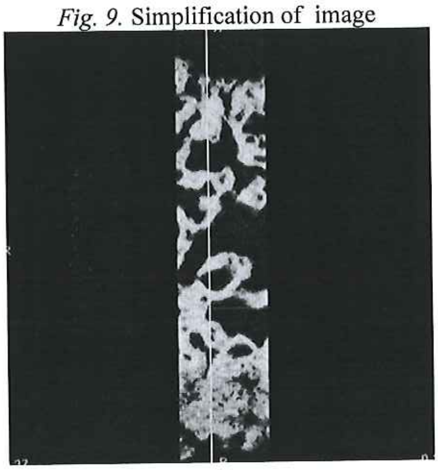

c

Fig. 10. Conversion of 2D images into 3D images with Mimics 8.1: *a*) front view, *b*) 3D model, and *c*) top view

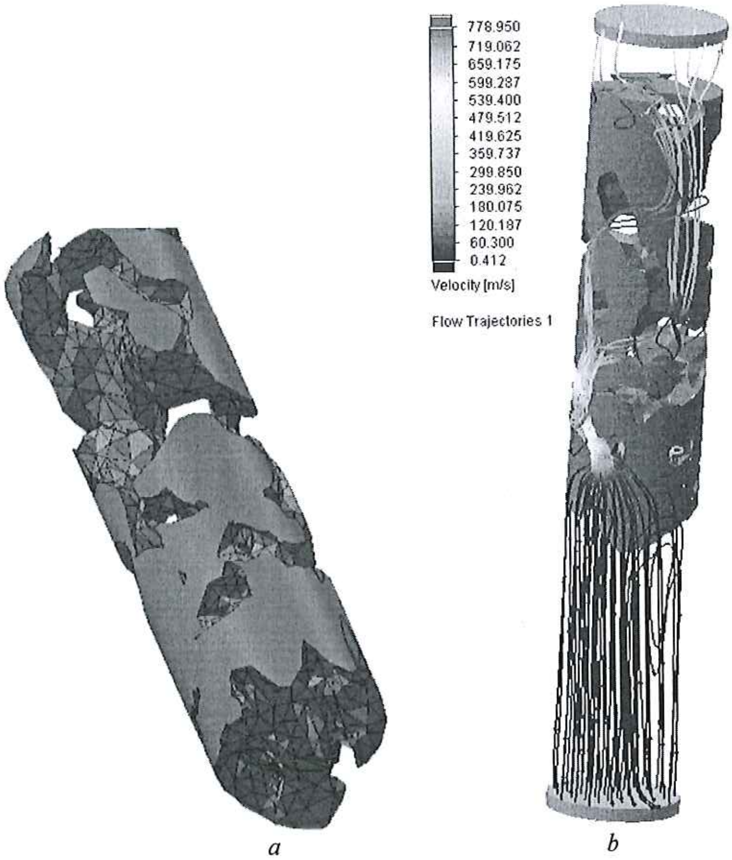

Fig. 11. 3D modelling: *a*) conversion of a 3D image into a solid object with SWFS; *b*) result of the air flow simulation with SWFS

made of) is handled by this type of sintering. Figure 8 shows a sintered porous insert produced.

The underlying structure of the porous sample produced was analysed with electronic-scanning microscope X-TEK 225/320 kV CT SPECIAL. This research

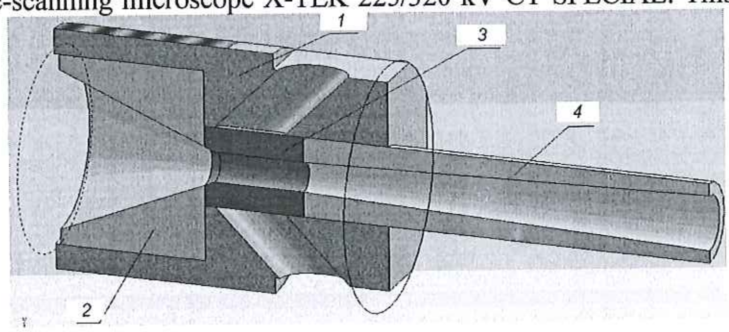

Fig. 12. CAD model of basic parts of a newly designed nozzle for the abrasive jet machine: *1*) body; *2*) wide conical inlet; *3*) porous cylindrical tubular insert; *4*) narrow and long conical outlet

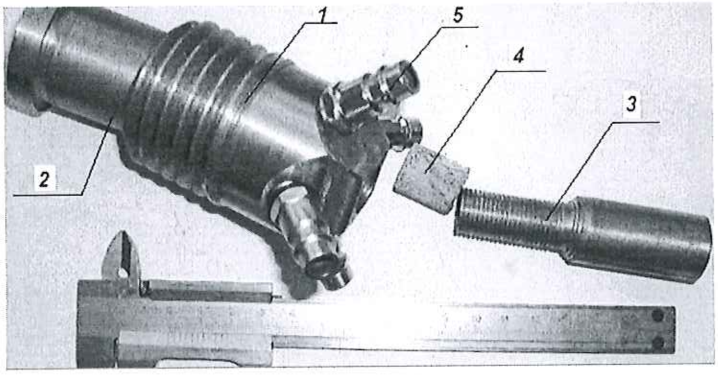

Fig. 13. Basic parts of a newly designed nozzle for the abrasive jet machine: *1*) body; *2*) wide conical inlet; *3*) narrow and long conical outlet; *4*) porous cylindrical tubular insert; *5*) air supply fittings

was conducted at the Manchester X-ray Imaging Facility (MXIF) in the University of Manchester. Scanning with 0.01 mm slice thickness across the height of porous insert resulted in 2000 images of the underlying porous structure.

To perform computer simulation of the flow through produced porous insert of the nozzle, it is necessary to "convert" the real made object into its digital 3D copy. To carry out this work, a number of operations were conducted on the image simplification (Fig. 9), converting of 2D images into 3D images with Mimics 8.1 software (Fig. 10), converting it in a solid object with SWFS (Fig. 11*a*), approximation of necessary numerical and vector parameters of air flows with SWFS, i.e. creation of real-like virtual experiments. The porosity of porous element was 0.566; the rate of inlet air was 30 m/sec; the air supply pressure was 6 bar; air leak pressure was 1 bar.

The simulation (Fig. 11*b*) showed that an average flow rate of the air leak from porous medium is equal to 500 m/sec. It means that during the air supply in radial direction through porous element, it resisted the basic flow. As a result, an air layer (which prevents the contact of abrasive particles with the nozzle surface) forms on the internal working surface of porous insert.

The above investigation and tests resulted in a new nozzle design (Fig. 12) for the abrasive jet machine and production of its basic parts.

Figure 13 demonstrates a fully completed product manufactured according to the new design.

Conclusions

A fundamentally new method of increasing the wear resistance of nozzle for the abrasive jet machine was created due to the formation of an air layer on the internal working surface of the nozzle insert, which prevents the friction of abrasive particles against the instrument walls.

A new assembly construction of a nozzle for the abrasive jet machine (which is based on the use of a porous cylindrical insert) and researches on produced porous insert were described.

Modeling and simplification of the "digital copy" of really made porous insert were carried out. A simulation of the air flow through porous element that enables a new method to increase the wear resistance was performed.

All necessary parts of the new nozzle construction for the abrasive jet machine were produced.

Предложен новый подход в повышении износостойкости сопел абразивоструйных машин. Изготовлен пористый элемент — часть сопла новой конструкции абразивоструйной машины. Проведено преобразование полученных 2D отсканированных изображений в 3D модель с целью компьютерного моделирования симуляции потока воздуха через пористую цилиндрическую вставку.

Ключевые слова: *абразивоструйная машина, сопло, компьютерное моделирование, карбид, воздушная прослойка, СВС процес.*

The paper presents a new principle of improving the durability of a nozzle for abrasive jet machine. Results of the study on the manufactured porous element (a part of the new design of abrasive jet nozzle) were presented. Conversion of obtained 2D scan results into 3D with the purpose of computer modelling to simulate the air flow through a porous cylindrical insert was carried out.

Keywords: *abrasive jet machine, nozzle, computer simulation, carbides, air layer, self-conducting high-temperature synthesis.*

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