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Methodology development of the materials erosion tests

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Abstract. The research paper describes a centrifugal stand and a methodology of materials testing for erosive wear in a simulative medium, which contains water, abrasive particles, and corrosive-active elements, which are analogous to the formation fluid of oil wells. There are test results in water with abrasive of four types powder materials based on iron and copper, alloyed with Ni, Cr, Mo. The experiment parameters: the fluid jet speed is 11...16 m·s⁻¹, the impact angle is 45°...90°, silica sand and corundum particles of different dispersion F100, F40, F24. A linear dependence of the relative wear rate on the experiment time at various impact was revealed. The wear of powder materials in liquid with corundum F100 is approximately 5 times more than with similar fraction silica. The material PK90N4MG2KD15 has the greatest erosion wear resistance under the influence of F100 fine particles.

1. Introduction

Erosion-corrosive damage of details is often found in oil production equipment, pulp pipe, mine pumps, hydraulic turbines, and other types of machine-building installations, which leads to great economic losses in case of their failure and repair. In submersible multistage centrifugal pumps for oil producing, erosion is manifested in the form of “washouts” of the flow-through part of the pump stages and components of gas separators (figure 1). Powder materials are widely used in the pump stage manufacturing. However, their erosion resistance is not regulated by the design and technological documentation, and there are no methodologies of the corresponding tests.

The research papers of many authors have been devoted to the erosion processes study. A fundamental review of the methods and design models is given in the article [1]. Erosive wear models of plastic and brittle materials were described in the research papers [2-4]. In research paper [5], mechanistic models were considered for predicting the erosive wear of pipelines and it is based on computational fluid dynamics. On the basis of physical models, stands have been created to determine the wear resistance of materials, to experimentally estimate the rate of erosion, and to study the influence of various factors on it.





Figure 1. Erosion-corrosion of multistage centrifugal pumps component.



Figure 2. Erosion-corrosion of gas separator component.

Stands differ in the method of abrasive particles acceleration to the specimen surface: due to the pressure of the working medium (gas jet) [6] or a centrifugal accelerator [7]. As a working medium, both gaseous and liquids or suspensions mediums are used. Stands with the use of a gas jet, as a rule, are single-positioned (one specimen); stands with the use of a liquid are mainly multi-positioned. In various types of stands it is necessary to solve a number of technical problems. For example, in research paper [8], a developed centrifugal accelerator with eight specimens, simultaneously installed at different angles, was presented. However, the circulation of the same mixture in a closed loop during the experiment leads to the loss of cutting properties by the abrasive particles, the wear of the service pump and the decrease in the accuracy of the experiment. Similar problems may arise in the test procedure under a sliding drop of a jet of liquid with abrasive particles on specimens [9]. Most of the known devices are intended for erosion wear testing mainly in an abrasive-containing environment.

The purpose of this work is to develop a stand for erosion wear, test methodologies, as well as conducting of experiments with powdered materials in an abrasive-containing medium.

2. Experimental details

2.1. Experimental setup

Based on the study of international experience in the Mechanical Engineering Research Institute of the Russian Academy of Sciences a rotating test machine for erosion-corrosion measurement has developed [10], which has several advantages. A special feature of the rotating test machine is the single use of abrasive. This is achieved by separating the abrasive from the liquid in a sand feeder. Thus, the service pump that is pumping the liquid is not subject to wear. The materials used in the rotating test machine and the equipment allow experiments with a corrosive liquid at temperatures up to 80°C .

The installation is based on the principle of a rotating nozzles with a back-to-back arrangement of fluid motion and consists of a plate with a test chamber, an adjustable-speed electric motor, feeder sand, a mixer, a rotor, an auxiliary pump, a gravity separator, flow meter, measurement and control systems. Prior to each test, the separator tank is filled with working liquid. With the help of an auxiliary pump for chemical liquid, the liquid is delivered into the mixer, where it mixes with the abrasive. The fluid jet speed in the specimen is determined indirectly through flow rate measurement using flow meter. In test chamber 1 there is a rotating shaft 2 on which rotor 3 is installed with two (or four) channels and hard alloy nozzles 4, figure 2. Specimens 5 are installed in specimen holder made of fluorine plastic on the rotor opposite the nozzles under different angles to the fluid jet. The chamber is closed with a transparent cover 6. Seals 7 prevent liquid from flowing at the points of contact with the rotating rotor. When the rotor rotates, the liquid that is coming from the mixer, under the action of centrifugal forces, is accelerated in the rotor channels and through the nozzles at a certain angle on the specimens, producing

erosive destruction of their surface. Then the liquid flows from the chamber through the pipe into the gravity separator, where the abrasive particles are deposited.

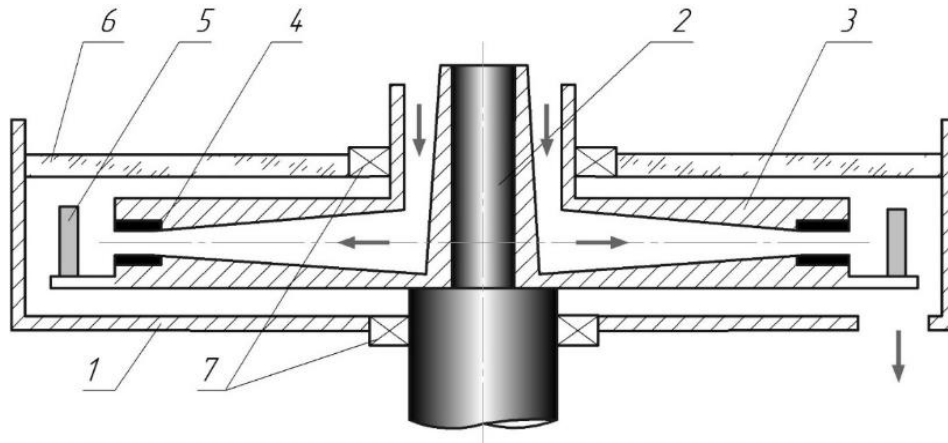


Figure 3. Test chamber scheme: 1 – test chamber; 2 – shaft; 3 – rotor; 4 – nozzle; 5 – specimen; 6 – cover; 7 – seals

The distance from the specimen to the nozzle can vary; the specimens installation angle relative to the flow (the angle between the specimen surface and the nozzle axis) is adjustable from 30° to 90° . At the same time, two (or four) specimens are installed at a certain angle and at a certain distance from the nozzle. The abrasive dispenser allows you to adjust the flow of solid particles into the mixer, thereby achieving a change in the concentration of particles in the model liquid. During the experiment, the rotational speed of the rotor and the fluid jet speed in each specimen remain constant.

After the experiment, the specimens are weighed and determine the weight-loss. As a criterion of materials wear resistance during erosion, the relative wear rate I_r was adopted [4]:

$$I_r = \frac{\Delta m}{M_a}$$

where Δm – the specimen weight-loss, g; M_a - abrasive mass in the experiment, g.

The test machine allows you to analyze the influence of various factors on the erosion: abrasive concentration, particle shape, velocity and temperature of the liquid, fluid properties, impact angle, material properties of the specimen, etc.

2.2. Experiment parameters

Water with an abrasive was used as a model liquid. The concentration of solid particles varied from 0.6 to $1.1 \text{ g}\cdot\text{l}^{-1}$, the rotational speed of the rotor was changed from 950 to 1500 rpm, the flow rate of the liquid was from 1 to $1.5 \text{ m}^3\cdot\text{h}^{-1}$. The experiments were carried out at two values of the impact angle, $\alpha = 45^\circ$ and $\alpha = 90^\circ$, fluid jet speed in the specimen was 11 and $16 \text{ m}\cdot\text{s}^{-1}$, and at room temperature. The repeat number of experiments under the same conditions is not less than three.

One of the research paper objectives is the timing of experiment in testing powder materials. With a long duration of the experiment, the material costs of abrasive materials and electricity increase. With a short experiment time, significant wear values can be obtained by increasing the abrasive concentration. However, at the same time, the results can be distorted due to collisions of particles with each other and a large amount of equipment wear. Also the invariance condition of the specimen wear mechanism is important during conducting the experiment. For example, if in the process of experiment, microcutting at some stage passes into fatigue failure, then when materials with different properties are tested, the ratio of their relative wear rates may change. For this reason, a comparison of the wear resistance of these materials will be incorrect.

2.3. Material and specimen preparation

Testing specimens for wear were made by “Keramet” Company in the form of rectangular plates of $25 \times 15 \times 3$ mm made of four types iron-based powder materials, table 1. The materials were obtained by method of powder metallurgy: pressing a mixture of powders and burning in dissociated ammonia atmosphere with simultaneous infiltration with copper. The roughness of the specimens is $R_a = 0.14$ μm . Table 1 presents the results of measuring the microhardness of materials.

The microhardness was determined using a PMT-3 microhardness tester at a load of 0.98 N. The specimens were pressed into a conductive epoxy resin at 180°C using a specialized *CitoPress* hot press. The preparation of thin sections was carried out using *Struers Rotapol 21* machine. During polishing, paper-based circles of silicon carbide were used, the surface was polished using diamond paste and *OP-8* oxide suspension based on SiO_2 .

The microstructure of the specimen surface was studied using a scanning electron microscope *Hitachi S-3400N* at accelerating voltage of 15 kV. The microscope is equipped with an X-Ray energy dispersive spectrometer *NORAN* for conducting local X-ray spectral analysis. The weight of the specimens was measured on the “Ohaus” weighting system with a measurement accuracy of 0.0001 g. The profile of the wear area was determined using a *Model 202* profile meter (Caliber, Russia).

The powder steels under study have either a ferritic-pearlitic structure (see figures 4,6,7) or pearlite (figure 5) with copper inclusions and alloying depending on the composition Ni, Cr, Mo and other elements.

Table 1 Chemical composition and microhardness of powder steels

	Material brand	Composition, % (by weight)							Microhardness (HV)
		C	Cu	Cr	Ni	Mo	S	Mn	
1	PK70D15	0.61...0.9	13...17	—	—	—	—	—	346.3 $\pm$ 3.1
2	PK90H4MG2KD15	0.81...1.2	13...17	—	3...5	0.3...0.7	0.15...0.45	1...3	504.9 $\pm$ 4.8
3	PK10H16N9D20	< 0.3	18...22	15...17	8...10	—	—	—	269.6 $\pm$ 2.4
4	PK10H7N4D20	< 0.3	18...22	6...8	3...5	—	—	—	410.2 $\pm$ 2.8

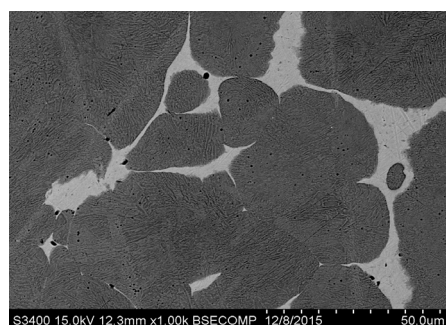


Figure 4. Structure of PK70D15 powder steel.

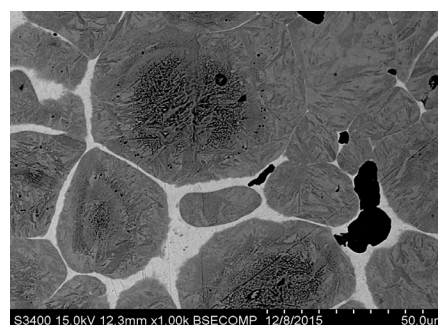


Figure 5. Structure of PK90N4MG2KD15 powder steel.

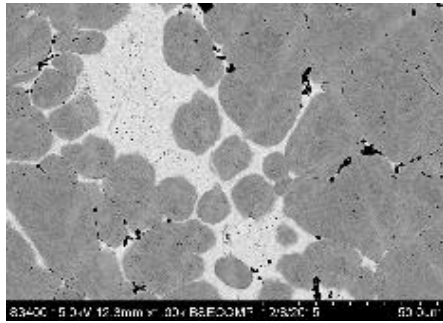


Figure 6. Structure of PK10H16N9D20 powder steel.

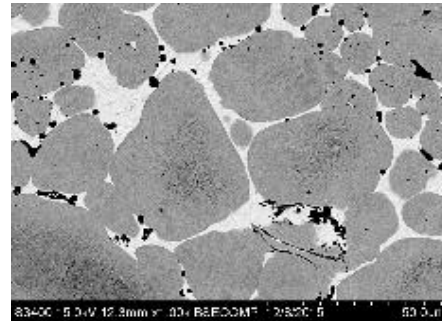


Figure 7. Structure of PK10H7N4D20 powder steels.

2.4. Abrasive particles size and shape

The grain-size composition and the average particle size of the abrasive were measured using *Analysette 22 MicroTec Plus FRITSCH* Company's microanalyzer for laser beam diffraction, scanning a suspension of the analyzed powder in water.

An abrasive represents silica sand or corundum particles of different dispersion. The shape of silica particles is round (see figure 8), corundum is acute-angled (see figures 9, 10, 11). Silica sand of this shape and size is found in the formation water of oil wells. Corundum is used by many researchers and has good wear properties.

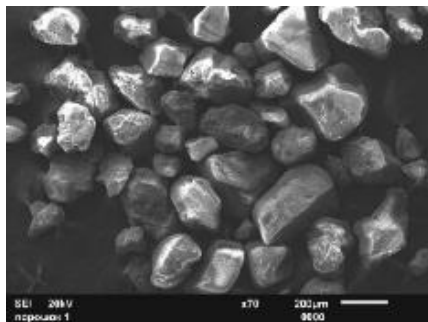


Figure 8. Silica sand form.

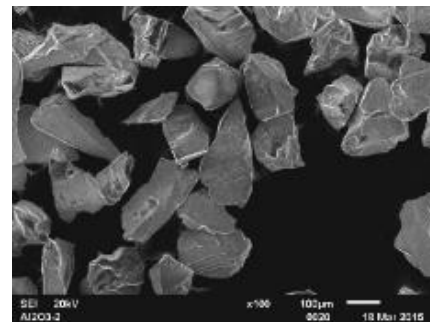


Figure 9. Corundum F100 form.

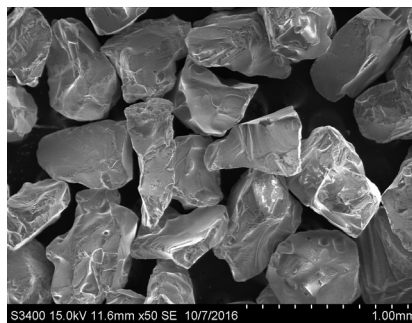


Figure 10. Corundum F40 form.

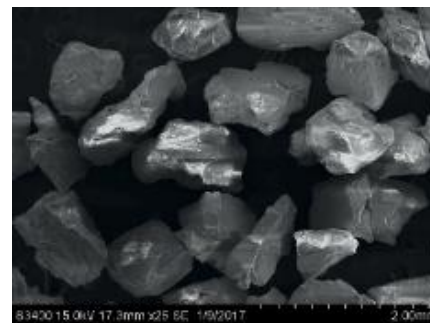


Figure 11. Corundum F24 form.

The grain-size composition of the silica sand powder includes 10% of the fine fraction with a particle size up to 100 μm , about 80% of the particles are from 100 to 280 μm , and the remaining 10% are represented by a larger fraction – up to 420 μm . The same trend is observed in powders of fine F100

corundum. The main fraction of the powder (83%) has a size from 100 to 280 μm . The average particle size of silica sand and corundum F100 is $D_m = 180 \mu\text{m}$. F40 corundum powder consists of two fractions of 320...580 μm and 580...880 μm , the amount of which differs slightly. The average particle size is $D_m = 530 \mu\text{m}$. The particle size of F24 corundum is in the range from 600 μm to 1.1 mm.

3. Results

For methodology development, we analyzed the kinetics of erosion, on the basis of which the experiment time was chosen. The specimen made of PK70D15 material was tested in abrasive liquid at a jet speed of 16 $\text{m}\cdot\text{s}^{-1}$ and an impact angle of 45° and 90°. After each experiment with the duration of 160 min, the specimen was weighed, the profile diagram of the erosion area was recorded, and the relative wear rate was determined and set again in the same way, table 2. The recorder profiles are presented in the figures 12 and 13. The numbers 1, 2, 3, 4 at figures 12 and 13 correspond to test number in table 2.

The results of experiments showed that the kinetic of erosion is linear, i.e. with an increase in the duration of the experiment, the value of relative wear rate I_r practically does not change. With such duration of experiment, it is possible to obtain significant wear values for both the least wear resistant and more wear resistant ones with acceptable measured values.

Table 2 Results of wear kinetics tests

Test number	Test duration T, min	$I_r \cdot 10^6, \text{g}\cdot\text{g}^{-1}$	
		$a=45^\circ$	$a=90^\circ$
1	160	2.13	2.27
2	160	1.93	1.93
3	160	2.13	2.00
4	160	2.26	2.26

The average value of the relative wear rate under the specified conditions is $2.11 \cdot 10^{-6} \text{g}\cdot\text{g}^{-1}$, the variation of results is within 7%.

The profile measuring of the worn surface showed that the wear profile depends on the impact angle of the specimen. In both cases, at $a=90^\circ$ and $a=45^\circ$, the wear is unequal. The maximum depth of the worn surface at $a=90^\circ$, figure 12, is 1.5 times greater than at $a=45^\circ$, figure 13. A similar relationship is observed when using corundum of the same fraction (figure 9). It should be noted that the intensity of wear in these cases is approximately the same.

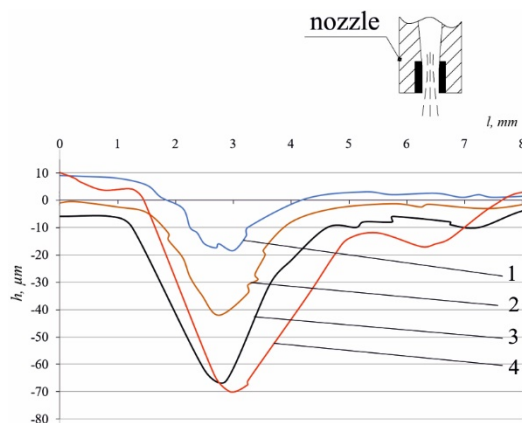


Figure 12. Wear track of surface in moving direction (test with silica sand, impact angle $a=90^\circ$), h – wear, l – length

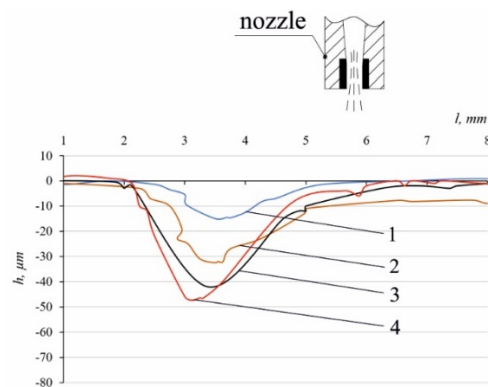


Figure 13. Wear track of surface in moving direction (test with silica sand, impact angle $\alpha=45^\circ$)

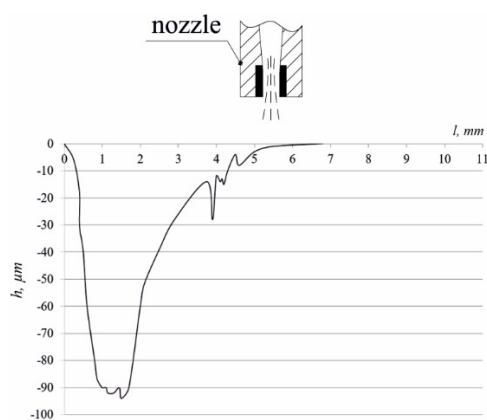


Figure 14. Wear track of surface in moving direction (test with corundum F100, impact angle $\alpha=90^\circ$)

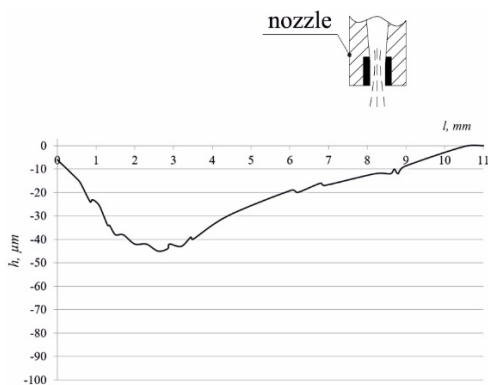


Figure 15. Wear track of surface in moving direction (test with corundum F100, impact angle $\alpha=45^\circ$)

The region of maximum specimen wear is displaced relative to the center of the nozzle due to flow divergence in the centrifugal accelerator as the rotor rotates. Figures 12-15 show schematically the location of the nozzle relative to the wear area of the specimen surface.

Figures 16 and 17 presents the testing results of four types powder materials according to the developed methodology. It is revealed that the type of abrasive influences strongly the wear resistance of materials. The relative wear rate of specimens when tested in water with F100 corundum is about 5 times greater (depending on impact angle) than in water with silica sand of a similar fraction. The relative wear rate of powder materials increases with size increasing of the abrasive. The greatest wear is observed when tests with F24 corundum is conducted, the average particle size of which is $D_m = 900 \mu m$. For example, for material No. 1 (PK70D15), the relative wear rate when tested with F24 abrasive is 1.4 times higher than when tested with F40 abrasive ($D_m = 530 \mu m$), and 1.8 times higher than the results with tests with F100 abrasive ($D_m = 180 \mu m$).

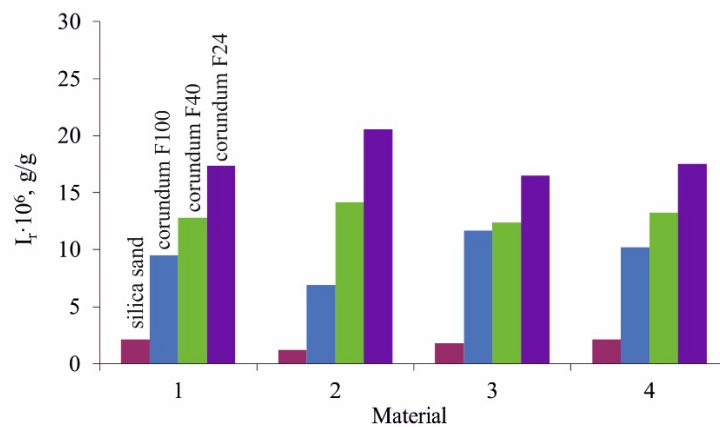


Figure 16. The relative wear rate of the study materials (see table 1) at the jet speed $16 \text{ m} \cdot \text{s}^{-1}$ and impact angle $\alpha = 90^\circ$

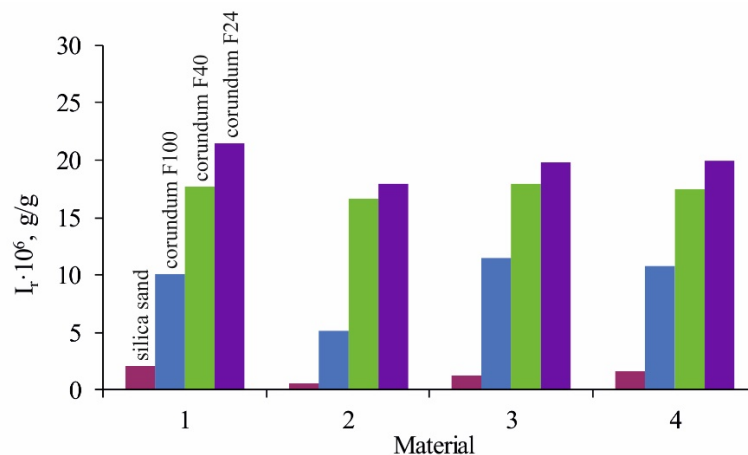


Figure 17. The relative wear rate of the study materials (see table 1) at the jet speed $16 \text{ m} \cdot \text{s}^{-1}$ and impact angle $\alpha = 45^\circ$

As shown by the test results, the difference in the wear resistance of specimen No. 2 (PK90N4MG2KD15), which has the greatest hardness among the tested materials (see table 1), is noticeable only when exposed to small abrasive particles of *F100* dimension. When large particles of *F40* and *F24* size are applied, the difference decreases and is within the range of the measured values. However, there is a noticeable difference in the intensity of wear associated with the installation angle of the specimens. When exposed to large particles, *F40* and *F24*, the relative wear rate is somewhat lower at an impact angle of 90° .

4. Conclusion

Based on the results obtained, the following main conclusions can be drawn.

The most significant parameter affecting the erosion wear resistance of powder materials at a given jet speed is the abrasive type. The wear of powder materials in water with *F100* corundum is ~ 5 times greater than with silica sand of a similar fraction.

The size of the abrasive also affects the relative wear rate of powder materials. With an increase in the size of corundum from *F100* to *F24*, the wear rate of material PK70D15 increased 1.8 times.

The hardness of the powder materials under the research has little effect on their erosion wear resistance to wear under given conditions. The material PK90N4MG2KD15 has the greatest wear resistance under the conditions of exposure to abrasive particles of *F100* dimension.

When testing for erosion wear, it is necessary to take into account the unevenness of specimen surface wear.

5. Summary

Erosion-corrosion damage to the multistage centrifugal submersible pumps installations leads to large economic losses in the repair of equipment, and the mechanism of such damage is not well known. A methodology of erosion testing on the centrifugal type stand basis has been developed, which makes it possible to analyze the features of wear and rank materials for durability. The test results of powder materials with different content of nickel, chromium and molybdenum can be used in the design and manufacture of pumping stages, providing the necessary resource and cost savings. The further direction of test method improvement is the development of a test procedure in a corrosive, abrasive-containing medium.

References

- [1] Meng H C and Ludema K C 1995 *Wear* **181–183** 443
- [2] Finnie I 1972 *Wear* **19** 81
- [3] Hutchings I M 1981 *Wear* **70** 269
- [4] Kragelskiy I V, Dobychin M N and Kombalov V S 1977 *Basics of calculations for friction and wear* (Moscow: Mashinostroenie) p 526
- [5] Kozyrev S P 1971 *Hydroabrasive metal wear at cavitation* (Moscow: Mashinostroenie) p 240
- [6] Yang K, Rong J, Liu C et al. 2016 *Tribology International* **93** 29
- [7] Söderberg S, Hogmark S, Engman U and Swahn H 1981 *Tribology International* **14(b)** 333
- [8] Azimian M and Bart H J 2015 *Wear* **328–329** 249
- [9] Santa J F, Baena J C and Toro A 2007 *Wear* **263** 258
- [10] Patent 2444719 Russian Federation 2012