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Investigation of the Influence of High Hydrostatic Pressure on the Abrasive Wear of Hard-Alloy Materials

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Abstract—This paper outlines the results of an experimental study of the influence of high hydrostatic pressure on the abrasive wear of hard-alloy materials based on tungsten carbide (~90% WC ± 10% Co), as well as alloys based on iron with high contents of chromium. A specially developed setup has been described in the paper that makes it possible to test materials under the hydrostatic pressure of up to 250 MPa at different friction speeds. An investigation of the surfaces of samples using the Scanning Electron Microscopy method has revealed that the main damage of alloy surface occurs due to the delamination and spalling of hard particles. It has been revealed that the hydrostatic pressure significantly influences the wear rate of the investigated materials. When the pressure increases to 200 MPa, the wear of materials with high contents of chromium increases seven times, while for the material based on tungsten carbide, it increases twice.

Keywords: abrasive wear, hyperbaric pressure, hard alloys, deep-sea mining

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INTRODUCTION

The intensification of production processes for high abmient pressures leads to the need to investigate the influence of high hydrostatic pressure (hyperbaric pressure) on the process of wear of machinery components. There is the field in the engineering oceanology associated with the devices and mechanisms that perform different kinds of works under the conditions of high hydrostatic pressure. This field includes projects related to the development of mineral resources on the ocean floor using underwater vehicles and robots of different kind, including ones for wrecking and ecological works. In this case, the reliability and uptime of equipment are the key factors in determining the economic feasibility of the whole process, which significantly depends on the degree of continuity of the operation of a whole system.

There are numerous publications dedicated dealing with the wear related failures during the friction process of materials, as well as the influence of high hydrostatic pressure on their mechanical properties [1–9]. P.W. Bridgman has pioneered the first fundamental research on the friction of metallic materials under the conditions of high and ultrahigh uniaxial pressure [2]. These investigations underlay the hypothesis on the binominal dependence of specific frictional force, which Kragel'skii proposed and developed [3]. In a number of papers dealing with the high hydrostatic pressure, the method of uniaxial compression (V.V. Lavrent'ev) [4] and the method of thin films (B.V. Deryagin) [5] were applied. The investigations were conducted for polymeric materials and basically confirmed the binominal dependence of the specific friction force. However, these methods have disadvantages; it is difficult to conduct research when applying lubricants; there is no the possibility to separately vary the amount of compression pressure and the contact pressure; the distribution of stresses in the material of friction does not fully and not always correspond to the conditions of high hydrostatic pressure [1].

The publicly available knowledge on the influence of high hydrostatic pressure on wear of alloys is still poor and incomplete as it is difficult to use them to design a machinery and to predict the service life of existing units. The wear of metallic alloys is usually characterized by two processes, i.e., delamination and spalling [6]. The prevalence of one of these processes depends on the conditions of loading, as well as on the structural state of material. In addition, the environment in which the wear directly takes place can have a significant influence on the process of wear due to side effects like corrosion. The cyclic component of the load leads to fatigue. The rate of accumulation of microdamages, such as micropores and microcracks in the contact areas, depends on the cyclic component of the stress tensor, the amount of which is determined

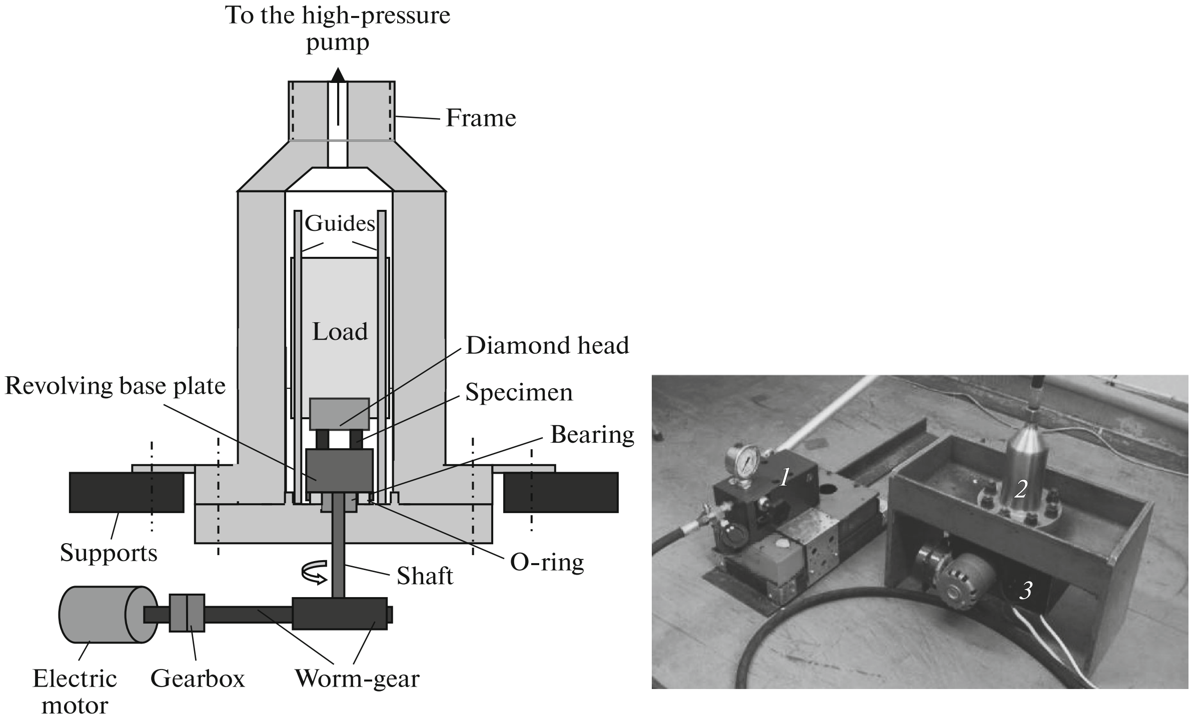

Fig. 1. Test setup: (*1*) high-pressure pump, (*2*) high-pressure vessel, (*3*) electric drive.

by the value of hydrostatic pressure in the liquid medium.

It should be noted that the dependence of wear rates on the value of hydrostatic pressure at which the wear process takes place has a nonlinear behavior. This is primarily due to the influence of hydrostatic pressure on the strength and plastic properties of metals. For some materials, there is a threshold pressure for which a hardness and plasticity of metal change significantly [1]. For example, for steel with 46% concentration of Co, depending on the regimes of heat-treatment, the pressure threshold is approximately 130–190 MPa.

In general, as it was mentioned above, the direct influence of hydrostatic pressure on the process of the abrasive wear of materials was yet poorly studied (at least to date, only a few results are publically available).

WORK OBJECTIVE

The main objective of this experimental study was to determine the degree of influence of hydrostatic pressure on the abrasive wear of structural materials remaining in contact with a harder material. Four different materials widely used in oil and gas, as well as the mining industry for the elements of a cutting tools, used for hard rock were selected as specimens subjected to friction. To minimize the influence of the second element in a friction pair on the process of wear as a whole, such a material was chosen, the wear of which could be neglected with respect to the wear of all four selected alloy materials. For this reason, synthetic diamond was used as an abrasive material.

MATERIALS AND METHODS

For this experimental study, the specimens of hard-alloy material were used: alloy no. 1 based on tungsten carbide (~90% WC ± 10% Co), and three alloys with a high content of chromium, i.e., alloy no. 2 (0–3% Mo, 2.5% Ni, 25% Cr, 20–36.3% C, and the rest is Fe), alloy no. 3 (16–18% Cr, 0–3% Mo, 2.8–3.2% C, and the rest is Fe), and alloy no. 4 (5% C, 1.25% Si, 20% Cr, 6% Mo, 6% Nb, 0.8% V, and the rest is Fe).

Figure 1 shows the test setup, which authors developed specially for this work making it possible to investigate the abrasive wear of materials under high hydrostatic pressure.

The test setup consists of (*1*) a high-pressure pump, (*2*) a high-pressure vessel, and (*3*) an electric drive. The test setup makes it possible to carry out tests at water pressures of 1–250 MPa that corresponds to an immersion depth of up to ~2.5 km. The tests were conducted at the room temperature. All specimens under investigation had a cylindrical shape (3 mm in diameter and 12 mm in length) and were fastened vertically. Figure 2 shows a view of the specimens under investigation.

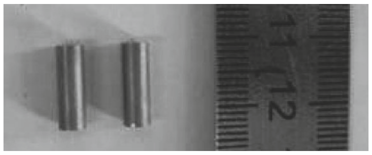

Fig. 2. Appearance of the studied specimens.

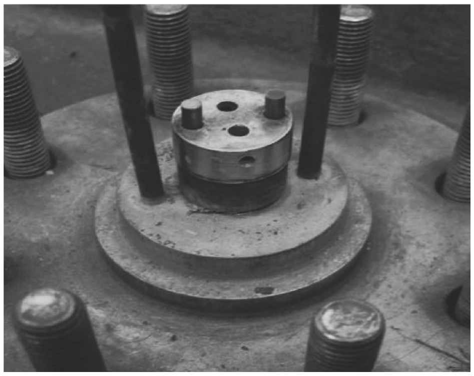

Fig. 3. Revolving base plate with specimens.

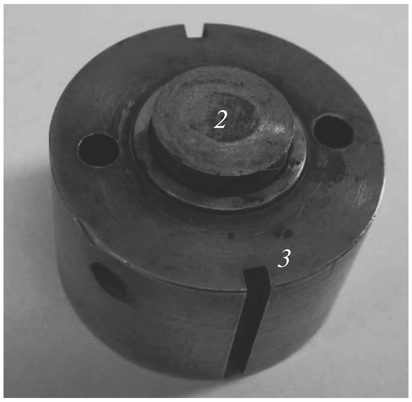

Fig. 4. Weight (*3*) with fastened diamond head (*2*).

The specimens were fastened to the revolving base plate (*1*) (Fig. 3).

The specimens under investigation were in contact with a cylindrical diamond head (*2*) fastened at the center of weight (*3*) (Fig. 4). The rotation frequency of the revolving base plate was 0.8 Hz.

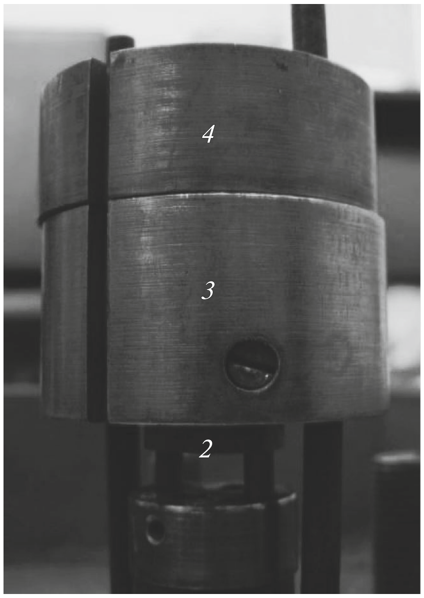

Fig. 5. (*1*) Revolving base plate with specimens (*3*, *4*) placed under loads (*2*) with diamond head.

The diamond head of AW 20*20*80*8 AC4 80/63 M2-01 type was used. The designations are as follows: 20*20*80*8 are the dimensions of the head (diameter, height, and bore diameter), the diamond powder is grade AC4 (synthetic diamonds of higher brittleness, the grains of which are presented by aggregates with an extended surface), the grain range is 80/63 (narrow grain range, 60–80 μm are the smallest and largest grain sizes of the main fraction), and M2-01 is the binding material (0% copper, 20% tin). Figure 5 shows the location of the diamond head with regard to the specimens under test. The total weight of weight (*3*) with the diamond head and additional weight (*4*) was 432 g. The area of the contact of the specimen–diamond head friction pair is shown in Fig. 6. The times of loading of specimens under pressures of 1, 100, 150, and 200 atm were identical and amounted to 3 h. The weight loss during the process of wear was determined by the laboratory scales of AV60-01 type, the maximum allowable error of which amounted to ±0.5 mg. Three identical experiments were conducted in order to estimate the repeatability of tests.

RESULTS AND DISCUSSION

Figure 7 shows the dependencies of the wear of the studied specimens on the value of the hydrostatic pressure. An analysis of the surfaces of specimens by scanning electron microscopy reveals that the basic wear mechanism of materials based on tungsten carbide and cobalt is the spalling of tungsten carbide particles (Fig. 8). In the friction area, unlike the rest of the material under consideration, there is no puttying of the microcracks, which indicates the insufficient quantity of the binding material (Co).

The initial surface of specimen no. 2 (Fig. 9) contains many pores and cracks, and has a very lacy appearance among the investigated specimens. The friction area is characterized by lamellar cold harden-

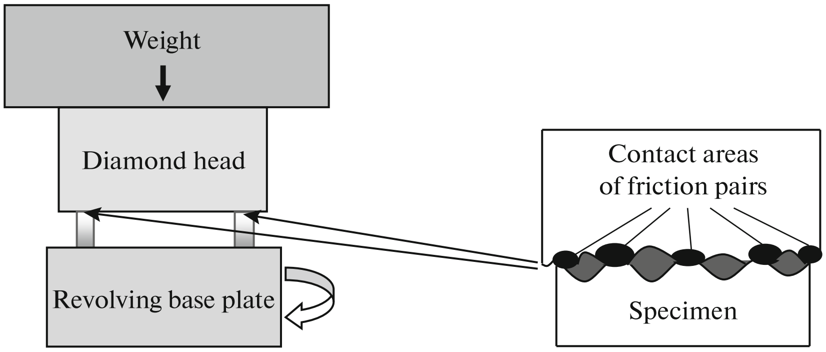

Fig. 6. Contact area of specimen–diamond head friction pair.

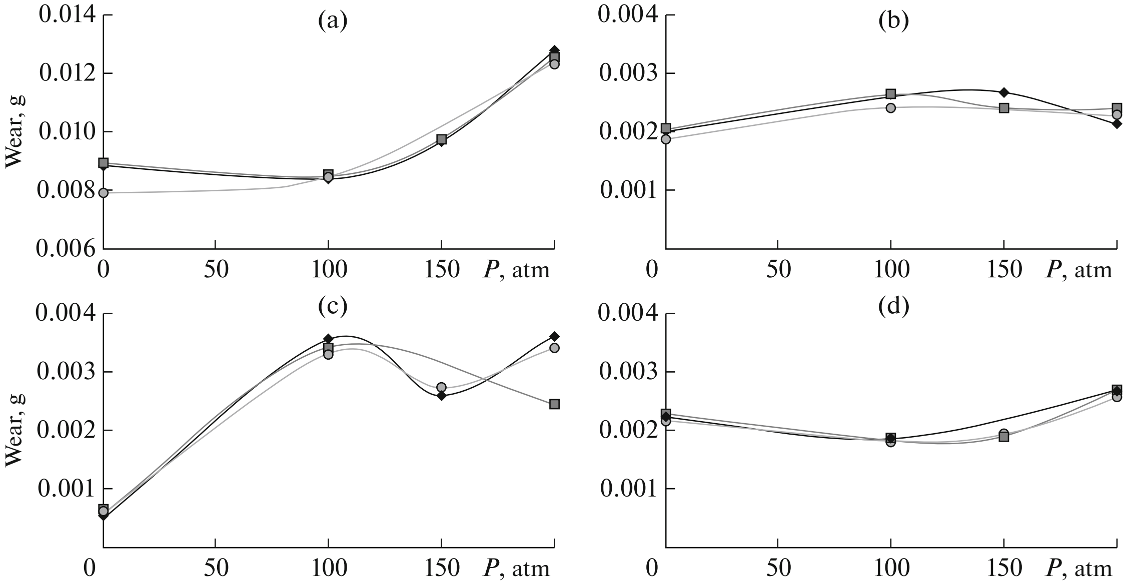

Fig. 7. Dependencies of wear of studied specimens on the value of hydrostatic pressure ((a)–(d) are specimen nos. 1–4, respectively).

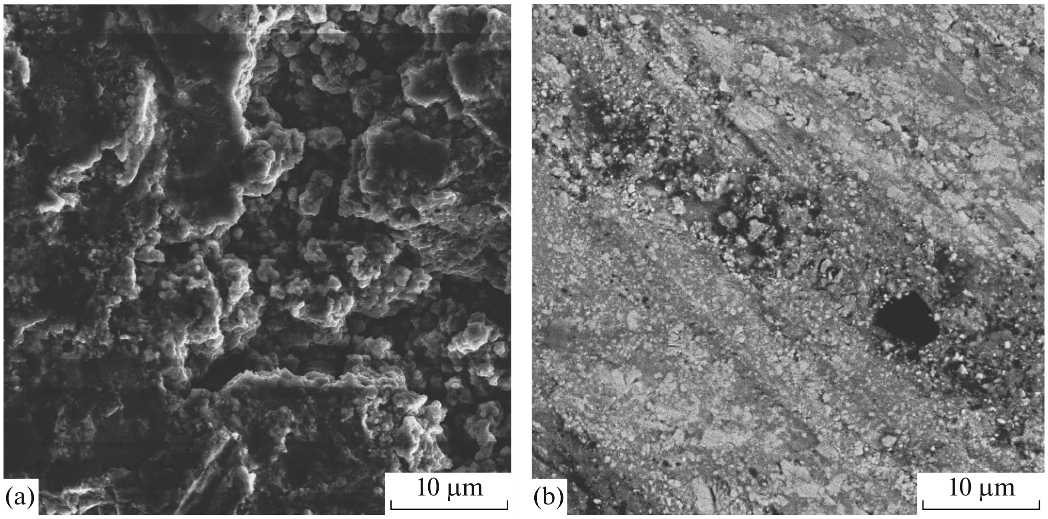

Fig. 8. Surface of specimen no. 1: (a) initial; (b) surface after tests.

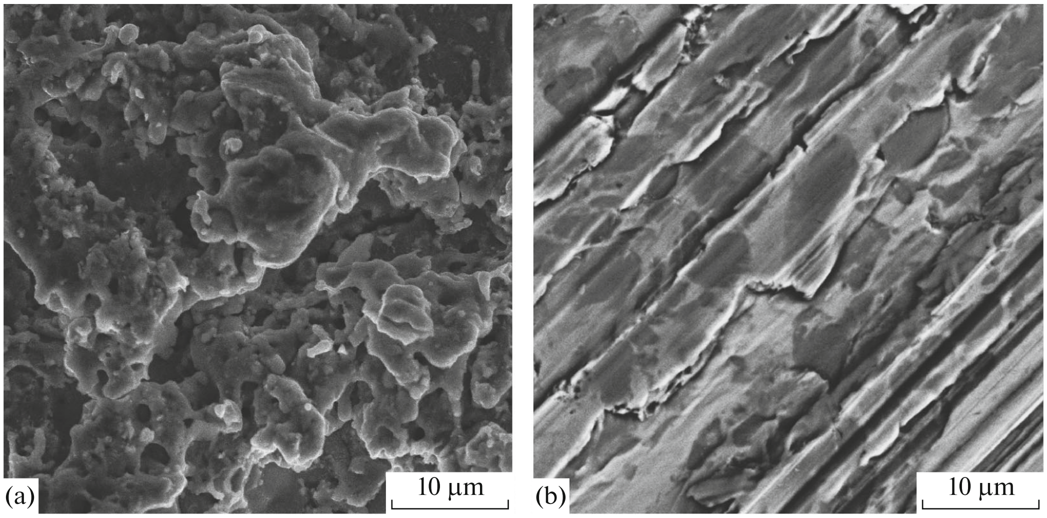

Fig. 9. Surface of specimen no. 2: (a) initial; (b) surface after tests.

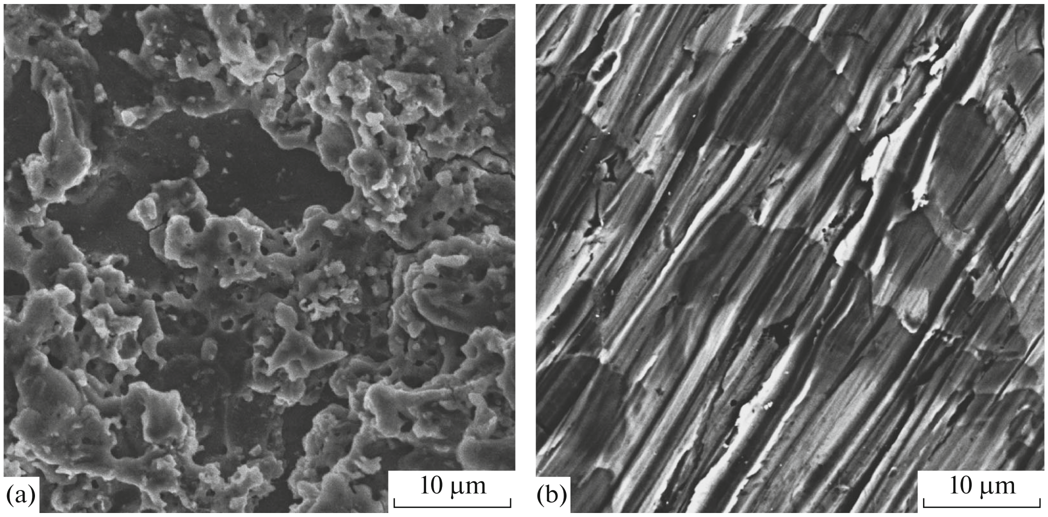

Fig. 10. Surface of specimen no. 3: (a) initial; (b) surface after tests.

ing and the partial delamination of a knurled film, which is easily visible in microphotography (Fig. 9b). The surface is noticeably puttied. In the initial state of the material of specimen no. 3 (Fig. 10a), there are extended cracks and many pores. There are hardly any cracks in the friction area (see Fig. 10b); i.e., they are puttied by cold hardening. One can draw the conclusion that the balance of elements that compose the alloy is such that, in the friction area, the viscous properties of alloy come into power and, as a result, the initial microcracks are puttied. There are the groups of dark spots in the friction area. The X-ray microanalysis in the regime of mapping by line revealed that these areas are enriched with Cr and C; thus, for the alloy composition, some heterogeneity is characterized and appears in the presence of domains of the inclusion of chromium carbide phase.

The material of specimen no. 4 has a large percentage of binding material (in this case, iron). There are long strips (see Fig. 11b) obtained as a result of the sliding of the diamond particles over the specimen surface. Part of the material is extruded by the edges of the strips. The spalling of solid particles is observed. The material is characterized by the absence in Ni alloy, which is an element that provides viscosity and higher contents of 5% C, 20% Cr, 6% Mo, and 6% Nb, which in turn impart hardness and brittleness. The spalling is less intensive than in material based on tungsten carbide.

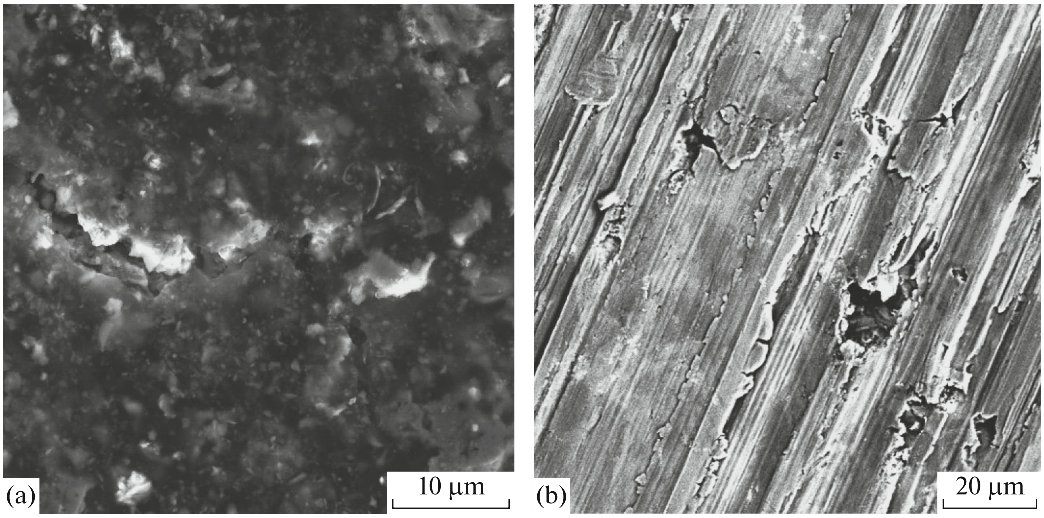

Fig. 11. Surface of specimen no. 4: (a) initial; (b) surface after tests.

CONCLUSIONS

It has been revealed that high hydrostatic pressure leads to the increased wear of materials used in this study. An analysis of the surface state of the investigated specimens of high-alloyed materials revealed that the basic mechanisms of wear are the delamination and spalling of hard particles. It is obvious that the hydrostatic pressure basically exerts a significant influence on the wear rates of studied alloys. For specimen no. 3 (16–18% Cr, 0–3% Mo, 2.8–3.2% C, and the rest is Fe), when pressure increases up to 200 MPa, the wear increases seven times, while for material based on tungsten carbide, the wear increases twice. The pressure exerted the least influence on the wear of material of specimen no. 4 (5% C, 1.25% Si, 20% Cr, 6% Mo, 6% Nb, 0.8% V, the rest is Fe).

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