Tribological tests of wear-resistant coatings used in the production of drill bits of horizontal and inclined drilling

A L Maslov, I Yu Markova, E S Zakharova, N I Polushin and A I Laptev
National University of Science and Technology «MISiS», Moscow, Russia

E-mail: anatmaslov@mail.ru

Abstract. It is known that modern drilling bit body undergoes significant abrasive wear in the contact area with the solid and the retracted cuttings. For protection of the body rationally use wear-resistant coating, which is welded directly to the body of bit. Before mass use of the developed coverings they need to be investigated by various methods that it was possible to characterize coatings and on the basis of the obtained data to perform optimization of both composition of coatings and technology. Such methods include microstructural studies tribological tests, crack resistance and others. This work is devoted to the tribological tests of imported brand of coating WokaDur NiA and and domestic brand of coating HR-6750 (both brands manufactured by Ltd “Oerlikon Metco Rus”), used to protect the bit body from abrasive wear.

1. Introduction
One of the important moments in the development of modern drill bits with PDC-elements is to protect the body from abrasive wear in the contact area with drillings cuttings and sludge. Thus reducing the abrasive wear at the place of fixing PDC-element to the body, it is possible to significantly increase the service life of the bit [1].

Protection of the bit body may be achieved by various methods. For example, it is possible to apply wear resistant coatings which contain nano- or microparticles. Due to the first coating can significantly reduce the friction coefficient between contacting cuttings and sludge from zone of drilling and body of the bit. As such particles the most rationally using nanodiamonds or aluminum oxide nanoparticles. Electroplated deposited coatings have high hardness and wear resistance [2, 3] and it is promising avenue for increased bit life. Coatings which contain microparticles (usually from several tens to 1000 μm), provide protection of the bit body due to presence of very hard particles in the matrix (for example, tungsten carbide). During the work the coating with high-hardness particles doesn't wear. In this case, as with other coatings which contain the nanoparticles, there is a wear of the matrix with the subsequent departure of particles from it. Therefore, the development of various wear-resistant coatings which will work with abrasive slurry, it is advisable to carry out complex study of the matrix [4].

Method of gas-flame surfacing was got widely spreading on deposition of wear-resistant coatings on body of the bit. This is due to the fact that the resulting coating has a high hardness, corrosion resistance, speed of deposition, while the heating of the bit occurs locally, which does not reduce the characteristics of the bit body [5].
2. Materials, equipment and method of processing results

The samples were made of steel St3 and used as substrates, and as wear-resistant layers were selected as follow coatings:

– HR-6750, thickness: 2.6 mm;
– WokaDur NiA, thickness: 2.6 mm.

Tribological tests of samples were performed on automated machine friction (tribometer) CSM Instruments’s TRIBOMETER (Switzerland) [6], № 44739-10 in GRSI using a rotary motion in "rod-drive" in accordance with the "Methodology for performance measurements of the friction coefficient \( f \) and \( l \) wear on tribometer CSM Instruments’s "TRIBOMETER" (Switzerland). MVI KTI/10 (FR.1.28.2010.07504). The parameters were used in tribological tests are shown in table 1. Testing scheme of samples is shown in figure 1.

| Parameter                     | Value                                      |
|-------------------------------|--------------------------------------------|
| Track radius \( R \)          | 5, 6.5 mm                                  |
| Applicable load \( F \)        | 1 N                                        |
| Linear speed \( V \)           | 10 cm/s                                    |
| Counterbody                   | Ball, 3 mm diameter                        |
| Material of counterbody       | SiC \((R = 5 \text{ mm})/\text{Al}_2\text{O}_3 (R = 6.5 \text{ mm})\) |
| Mileage \( L \)               | 22 700 cycles                              |
| Environment                   | Air                                        |

Tests consistent with international standards (ASTM G99-05 and DIN50324). Experimental dependences of the friction coefficient on the path smoothed by 7 points.

Tribological tests were carried out on samples of the device, located in SHS Center in NUST «MISiS».

The complex study of the microstructure of wear-resistant coatings was carried out on a scanning microscope JSM-6480LV, located at the Center for Collective Using in NUST «MISiS».

3. Results of the tribological tests

Results of tribological tests of samples are shown in table 2. The test results show that the friction coefficient of WokaDur NiA coating smaller than HR-6750 coating.

In both cases established no wear of samples (less than \( 10^7 \text{ mm}^3/\text{N/m}) \)), which speaks of their high abrasion resistance to abrasion (example path is shown in figure 2). Less wear of counterbody from aluminum oxide due to the fact that there is "salting" the track on which moves counterbody.

Results of tests were shown that friction coefficients of HR-6750 coating were 0.57 and 0.68 for counterbodies made from silicon carbide and aluminum oxide, and WokaDur NiA coating were 0.57 and 0.66 respectively.
Table 2. The tribological characteristics of the studied sample.

| Sample | Counterbody | Wear, mm$^2$/N/m | Coefficient of friction |
|--------|-------------|------------------|------------------------|
|        |             | Sample           | Counterbody            | Initial | Maximal | Average | Final   |
| HR-6750| SiC         | 1.8·10$^{-6}$    | 0.29                  | 0.73    | 0.68    | 0.64    |
|        | Al$_2$O$_3$ | No               | 0.3·10$^{-6}$         | 0.21    | 0.79    | 0.71    | 0.69    |
|        | SiC         | (<10$^{-7}$)     | 3.7·10$^{-6}$         | 0.42    | 0.64    | 0.57    | 0.54    |
| WokaDur| Al$_2$O$_3$ |                  | 0.7·10$^{-6}$         | 0.23    | 0.85    | 0.66    | 0.60    |

Figure 2. The wear path of counterbody from silicon carbide by coating on brand of HR-6750.

The time dependences are of similar character. At the stage of the running is observed increase the coefficient of friction, which is associated with the peculiarities of formation of the contact surface in the presence of solid particles in the coating. At a later stage, the friction coefficient is stabilized, coupling work is quite stable character (figure 3).

Figure 3. The time dependences of the friction coefficient for samples with coatings of HR 6750 and WokaDur NiA with counterbodies from silicon carbide (a) and aluminum oxide (b).
Increasing wear of counterbodies in the case with WokaDur NiA coating can be explained by the fact that the ligament and the particles have microhardness greater than ligament and particles of HR-6750 coating (table 3), and as well as different structures.

**Table 3.** Average values of microhardness HV matrix, particles and substrates.

|                  | St3–HR-6750 | St3–WokaDur NiA |
|------------------|-------------|-----------------|
| Coating          | 599         | 590             |
| Strengthening particles | 2145      | 2452            |
| Steel hull       | 206         | 213             |

In WokaDur NiA coating is dominated by large particles of tungsten carbide size of 200–500 μm and the particles are much closer than in HR-6750 coating with tungsten carbide particles of size preferably less than 200 μm (figure 4). Closer arrangement of the particles to each other, as well as their larger size leads to a higher load at which the chipping particles from the matrix, and accordingly a lower coefficient of friction with increased wear.

![Figure 4](image1.png)

**Figure 4.** The microstructure of coatings HR-6750 (a) and WokaDur NiA (b).

### 4. Conclusions
In the course of tribological tests of two brands of wear-resistant coating used to protect shells diamond blade PDS-bits of abrasive wear during the drilling process, it was found that the best values of the friction coefficient is observed to cover brand of WokaDur NiA, contain large particles of tungsten carbide.

### Acknowledgment
This work was carried out within the framework of the federal target project of the program “Research and development in priority areas of development of the scientific and technological complex of Russia for 2014-2020” on the topic “Development of technology for manufacturing high-performance horizontal and tilt drilling drill bits for the oil and gas industry” agreement No. 14.581.21.0012 (unique identifier of the agreement RFMEFI58115X0012) with financial support of applied scientific research by the Ministry of Education and Science of the Russian Federation.

### References
[1] Nekrasov I N, Bogomolov R M, Ischuk A G, Gavrilenko M V, Morozov L V, Muhametshin M M and Krilov S M 2008 *Patent of Russian Federation № 2389857 10.11.2009* 31
[2] Polushin N I, Ovchinnikova M S and Maslov A L 2014 *Advanced material research* 1040 199–1
[3] Polushin N I, Ovchinnikova M S, Maslov A L and Kuchina I Yu 2015 *Izv Vyzov. Series “Chemistry and chemical technology”* 58 55–7
[4] Polushin N I, Bogatirev A V, Laptev A I and Sorokin M N 2016 Izv Vyzov "Powder metallurgy and functional coatings" 1 60–6
[5] Langford J V and Delvice R Patent of Russian Federation № 2167262 10.01.2001
[6] Petrijik M I and Levashov E A 2007 Crystallography 52 1002–10