IOP Conf. Series: Journal of Physics: Conf. Series **857** (2017) 012028 doi:10.1088/1742-6596/857/1/012028

The study of microstructure of wear-resistant coatings applied for protection from abrasive wear of horizontal and tilt drilling drill bits

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Abstract. Drill bits of the cutting type over the period of their existence have undergone significant changes – from the use of carbide cutters to diamond composite PDC elements, in which the diamond layer is applied to a hardmetal substrate. Using such elements, it was possible to significantly increase the service life of the drill bits, however, during work, there is a significant abrasive deterioration of the bit body, which does not fully realize the advantages of PDC elements. Therefore, to protect the body from wear use special wear-resistant coatings. This work is devoted to research of microstructural coatings, namely coatings brands WokaDur NiA, HR-6750, HR-6750 with sublayer Rock Dur 47 on various steel substrates which applied by the gas-thermal spraying in Ltd "Oerlikon Metko Rus". They were examined with the use of scanning electron microscopy, X-ray phase analysis and a Vickers micro-hardness tester. It was established that the microhardness of the coating matrix is 590–660 HV, and the microhardness of tungsten carbide particles reinforcing the coating, is 2145–2455 HV.

1. Introduction

During operation, the drill bit body experiences considerable abrasive wear in its contact zone with the cuttings of the drilled rock, which leads to a weakening of the fastening and premature removal of the PCD-elements from the bit body. Due to the incomplete development of the PCD-elements is significantly reduced resource of drill bit [1].

There are various methods for applying wear-resistant coatings, such methods include various variations of low-temperature CVD and PVD deposition or electrochemical and gas-thermal spraying that meet the following requirements for the application of a wear-resistant coating on the bit body [2–6].

Firstly, the coating must have a high hardness (higher than the hardness of the drill bit body, preferably above the hardness of the drilled rock) and corrosion resistance.

Secondly, there should be a close value of the thermal linear expansion coefficient (TLEC) of both applied coating and the drill bit body materials. If the condition is not met, then at high temperatures the coating will peel off.

Thirdly, the application temperature should not exceed the melting point of the drill bit body. The most commonly used wear-resistant coatings are applied by gas-plasma method such as hand-gas-plasma welding. Therefore, the purpose of this work is a microstructural study of wear-resistant coatings containing tungsten carbide particles obtained by manual gas flame deposition in order to increase the resistance of the PDC-bit body to abrasive wear [7, 8].

2. Materials and equipment

As substrates used samples were made from steels of marks St3, St45 and KHVG, which can be used as a drill bit body, and the coatings have been chosen as the following wear-resistant layer:

– HR-6750 with 2.6 mm thickness, directly on the surface of steels;

– HR-6750 with 2.6 mm thickness on a pre-applied Rock Dur 47 sub-layer with 0.2 mm thickness;

– WokaDur NiA with 2.6 mm thickness directly on the surface of the used steels.

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

X-ray diffraction (XRD) measurements were performed at NUST "MISiS" using DRON-3M (Co K_α radiation). The micro-hardness of matrix and carbide particles was determined by Knoop/Vickers Hardness Tester the Tukon 1102, the load on the indenter was 200 g, the exposure time under load – 5 s.

3. Results and discussion

Figure 1 shows the typical microstructure of the obtained coatings deposited on different substrates.

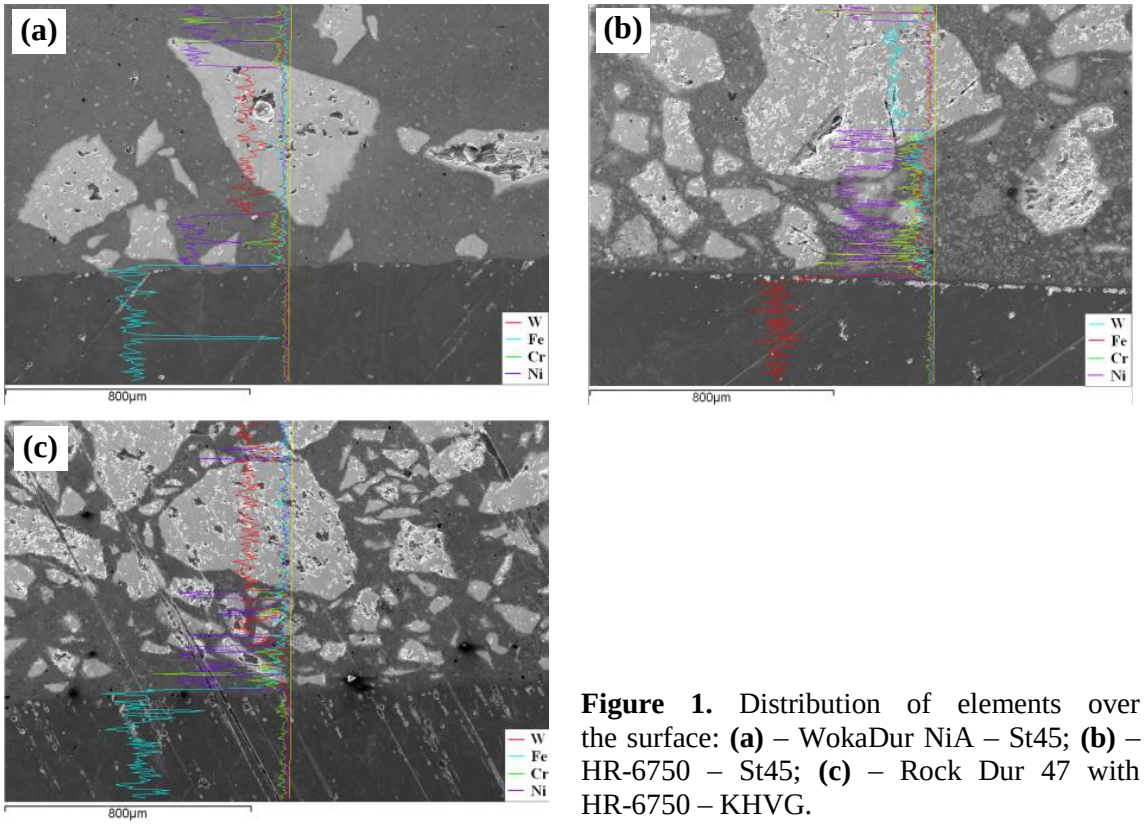

Figure 1. Distribution of elements over the surface: **(a)** – WokaDur NiA – St45; **(b)** – HR-6750 – St45; **(c)** – Rock Dur 47 with HR-6750 – KHVG.

A microscopic examination of the structure of the coatings is showed differences in all samples. Primarily due to the size of the carbide particles. Coating brand HR-6750 consists of particles with highly developed structure (figure 1(b)). The basis of all coatings is a nickel matrix with additive elements (Cr, B, Si, C) and carbide particles. Elemental analysis of the matrices revealed the presence of the following elements and their quantitative ratio, which are summarized in table 1.

The study of samples with a sublayer of Rock Dur 47 is showed partial dissolution in the process of applying HR-6750. As an example, figure 2 shows the distribution of elements on the surface of the thin section of the transition zone (coating-substrate) of the sample St45.

As a result of measurements of samples with different substrates and coatings, it was found that the microhardness of the matrix was 590–660 HV, and tungsten carbide particles 2145–2455 HV (table 2). The microhardness of the KHVG steel substrate is twice or more than the microhardness of the

substrates of St3 and St45 steels, which is associated with partial hardening of the substrates from this steel when the samples are cooled after the application of wear-resistant coatings.

Table 1. Elemental analysis of the matrix coatings

Coating	Weight, % wt.	
	Ni	Cr
HR-6750	81.09	18.91
HR-6750 with sublayer Rock Dur 47	85.56	14.44
WokaDur NiA	91.03	8.97

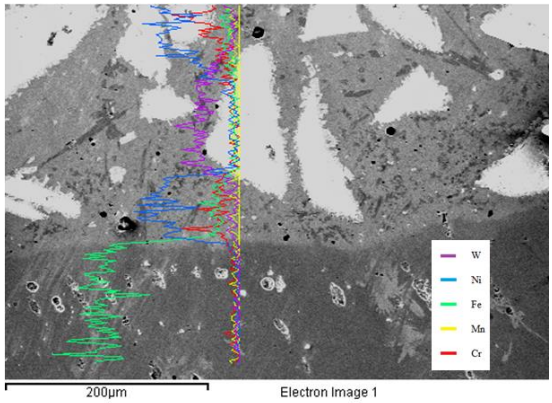

Figure 2. Distribution of elements over the surface.

Table 2. Average values of microhardness of HV matrices, particles and substrates.

	Microhardness, HV		
	St3 – WokaDur NiA	St45 – WokaDur NiA	KHVG – WokaDur NiA
Coating	590	588	620
Strengthening particles	2452	2351	2442
Steel housing	213	275	580
	St3 – HR-6750	St45 – HR-6750	KHVG – HR-6750
Coating	599	759	653
Strengthening particles	2145	2165	2282
Steel housing	206	242	1011
	St3 – HR-6750 with sublayer Rock Dur 47	St45 – HR-6750 with sublayer Rock Dur 47	KHVG – HR-6750 with sublayer Rock Dur 47
Coating	595	614	662
Strengthening particles	2303	2233	2185
Steel housing	210	241	591

According to the results of the XRD (figure 3) it was found that in samples with coating HR 6750 and sublayer Rock Dur 47 there are phases of WC, W_2C, Cr, Cr_7Ni_3. The ratio of the phases WC and W_2C in these samples is different, the sample HR 6750 dominated by the phase of the WC compared to

W_2C, the sample underlayer Rock Dur 47 inverse relationship. In samples coated WokaDur NiA discovered the phases of WC, W_2C, CrNi.

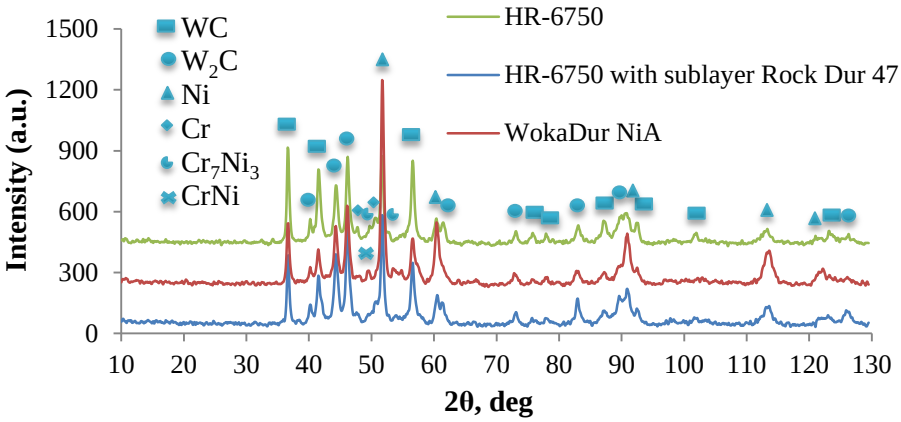

Figure 3. X-ray pattern of samples with coating deposited on a substrate St45.

4. Conclusions

In the process of conducting microscopic studies of wear-resistant coatings used to protect the cases of diamond blade PDC-bits from abrasive wear during drilling, it has been established:

– the microhardness of the matrices of the coatings obtained is 590-660 HV, and the microhardness of the tungsten carbide particles is 2145-2455 HV;

– a micro-X-ray spectral study of the Rock Dur 47 sublayer revealed its partial dissolution in the process of surfacing a wear-resistant coating HR-6750.

Based on the conducted studies, we can recommend the use of WokaDur NiA as a wear-resistant coating, which is explained by the highest hardness of carbide inclusions in comparison with other coatings. As a substitute for WokaDur NiA coating, it may be recommended to coat the HR-6750 with a sublayer of the Rock Dur 47. Among the substrates, we can recommend structural carbon steel grade St45. Its mechanical properties satisfy the requirements imposed on the drill bit housing, and its quenching does not take place under the conditions of obtaining a wear-resistant coating.

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.

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