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DEVELOPMENT OF TECHNOLOGY OF MANUFACTURE OF DRILL BITS WITH PROTECTIVE COATING OF WORKING BODIES

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The peculiarities of manufacturing drill bits and cutters are considered and studied. The carried out analysis of operation of working bodies of drill bit frames showed that during drilling most often a wear of cutters, a protective coating of sitters and a calibrating surface of frames of drilling bits occur. It was investigated that in arc surfacing using TIG method, low rates of heating and cooling of metal during preheating of working bodies of a bit allow reducing residual stresses and avoiding the formation of cracks in coatings and base material. It was established that the optimal thickness of surfacing the protective coating should be within 2.0–3.0 mm, where a uniform distribution of tungsten carbides throughout the volume of the deposited layer is observed, which effectively resists wear of the working bodies of blades and frames of bits in the conditions of alternating and shock loads, hydroabrasive wear, corrosion, erosion, etc. It was established that bits with a protective coating, having a high wear and corrosion resistance, increase the mechanical speed of drilling and solve the most important task of reducing the number of lowering and lifting operations when drilling gas and oil wells. As a result of carried out production tests of manufactured drill bits, it was found that protective coating of working bodies allows extending the service life. 18 Ref., 1 Table, 8 Figures.

Keywords: bits, cutters, drilling, wear, working body, polycrystalline diamond cutter (PDC), hard-alloy coating, surfacing, tungsten carbides, microstructure, wear resistance, tests

For effective drilling of subsoils for extraction of hydrocarbons requires a proper choice of a bit under certain operating conditions. The main drilling tool is a bit for rotational drilling (which, broadly speaking, is classified as a bit with fixed cutters or as a cone bit) is intended for different rocks and a wide range of conditions. Today at the Ukrainian market drill bits are represented by bits of domestic and foreign production.

In the world there are more than three dozen companies engaged in development and production of a drilling tool. The leading place is occupied by «Varel International», «Hughes Christensen», «Hallburton», «Smith Bits», «Reed Hycalod», «National Oilwell Varco», «Schlumberger», «Reed Tools Company», «Baker Hughes» and «Gemdrill», etc. These companies deliver tools to more than 86 countries. The share of imported drill bits in the Ukrainian market for oil and gas industry amounts to about 12 %, and for mining it is 14 %.

The main characteristics of wearing out PDC bits (of both own as well as foreign production) in deposits of Ukraine are: wear of teeth — 17 %, breakage of teeth — 30 %, chipping of teeth — 31 %, loss of teeth — 3 and 19 % — absence of wear [1].

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In Ukraine, PDC and cone bits are produced by the V.M. Bakul Institute for Superhard Materials [2] and the Drohobych Drill Bits Plant «LLC «Universal drilling equipment» [3]. The disadvantage of PDC bits produced by the V.M. Bakul Institute for Superhard Materials is insufficient protection of working bodies, namely blades and calibrating surface of the frame without a protective coating, which significantly affects their wear resistance and service life.

At the Drohobych Drill Bits Plant «LLC «Universal drilling equipment», tricone drill bits are mostly produced, in which cutters are equipped with insert hard-alloy teeth. The disadvantage of cone bits is an insufficient protection of working bodies, namely the loss of fragments of a cutter (splitting of cutter body, breakage of leg axle), rolling bodies (jamming of supports and stop of cutters rotation) or an entire section (splitting, wear, loss of insert rock-destruction mountings of cutters).

The use of PDC bits with a protective coating of working bodies provides an increase in sinking by an order and more as compared to cone bits and bits without a protective coating and reducing the cost of lowering-lifting operations. This indicates the need in further investigations in the direction of analysis and selection of data on drilling, since drilling with the use of PDC bits allows facilitating drilling works, shortening terms of wells construction, especially in the process of drilling deep wells, and the absence of moving elements in the design of bits excludes the emergency situations. The design of PDC bits provides a long-term service life and high drilling speeds due to a high wear resistance of the protective coating of working bodies and cutting elements of PDC-cutters, the absence of a bearing support, which improves sinking of drilling tool. Insignificant effect of a bit operation dynamics on the bottom-hole and a drill rod (as compared to cone bits) and a high wear resistance of the protective coating and cutters of a calibrating surface exclude the need in reaming and calibrating wellbore before lowering of a frame column.

For drilling tool, the main indices of mechanical properties of wear-resistant coatings are hydroabrasive wear resistance, hardness and corrosion resistance, which provides an effective resistance to a number of problems of wearing working bodies of bits in the conditions of alternating and shock loads, hydroabrasive wear, corrosion, erosion, etc. The strength of the protective coating depends on temperature, pressure, mechanical load, aggressiveness of the medium and strength of rocks. Having a high wear and corrosion resistance, bits with a protective coating increase the speed of mechanical drilling and solve the most important task of reducing the cost of a meter of sinking.

Taken into account the abovementioned, the aim of the work consisted in development of a technology for manufacture of drill bits with a protective coating of the working bodies, which provides an extension of the service life.

Figure 1. Scheme of arrangement of working bodies of a bit: *1* — cutter; *2* — hard-alloy insert of calibration surface; *3* — interblade space for sludge removal; *4* — protective coating of watercourse; *5* — hard-alloy nozzle of watercourse; *6* — protective coating of working bodies of blades

Materials and methods. The object of investigations are the areas of working bodies of frames of steel drill bits. Examinations of microstructures were carried out according to the standard procedure in the Tescan Mira 3 LMU electron microscope and the Neophot 32 optical microscope. Welding devices: Koral-300 and PRS-3M. Composite material: Tero Cote 7888T.

Results of investigations. To protect working bodies of drilling tool from different types of wear, composite materials based on Ni, Fe, NiCr, NiCrBSi, copper, etc. alloys reinforced with tungsten carbides are widely used [4, 5]. This is primarily associated with the unique properties of the reinforcing phase of such alloys — tungsten carbides. Tungsten carbide is one of the hardest and most shock-resistant carbides, and surfacing of a hard-alloy coating (HAC) is a fast method to deposit a tungsten carbide coating on the areas of working bodies exposed to the action of intense abrasive loads and it help to maintain mechanical properties over a wide temperature range, resistant to frictional corrosion and is able to form a strong bond with metals [6, 7].

The carried out studies of wear resistance of composite materials in the conditions of hydroabrasive wear showed that wear resistance of the protective coating TeroCote 7888T based on Ni-Cr-B-Si system with chipped tungsten carbide particles exceeds the wear resistance of relite «L3-11-7» and Diamax M [8]. According to the results of investigations on wear resistance, the alloy TeroCote7888T was selected, on the basis of which studies of this material on corrosion resistance were carried out. The results of studies of corrosion resistance showed [9] that the use of a protective coating deposited using a composite material TeroCote 7888T provides a significant reduction in the corrosion rate of steel working bodies of drill bits without a protective coating. Based on the results of studies of hydroabrasive and corrosion wear of composite materials, the main attention was paid to this alloy, which belongs to the category of corrosion-resistant protective materials.

The stability and performance of drilling with the use of steel bits having a protective coating directly depends on the ability of cutting structure elements in the form of polycrystalline diamond cutters and hard-alloy inserts to resist abrasive wear of the blades around these elements, which strive to destroy the system for fixation of these rock-destroying elements (Figure 1). In particular, abrasive wear of steel areas of the blades located around the cutting and calibrating elements, as well as the brazing alloy that keeps them from pulling, promotes an uncovering, increase in the size of the protrusion and a gradual loss of individual elements.

To determine the thickness of the protective coating of working bodies of bits, research works on surfacing of the composite TeroCote 7888T alloy were carried out. Surfacing was performed by TIG method on the specimens of 30Kh steel of 14 mm thickness. During surfacing of a wear-resistant layer of up to 1.5 mm (Figure 2, *a*) on the specimens, a chaotic arrangement of tungsten carbide particles, and at 2.0–3.0 mm (Figure 2, *b*) — a uniform arrangement of tungsten carbides thorughout the entire volume of the deposited layer is observed. With an increase in the coating thickness of 3.5 mm (Figure 2, *c*), a bulk of the tungsten carbide particles is located in the lower and middle zones, and it is practically absent in the upper zones. All this can be explained by physical properties of the composite material, because the matrix material contains 65 % of tungsten carbides. A high content of tungsten carbides does not allow the matrix material to get wet and spread on the surface of the base metal.

Based on the results of the carried out works, it can be stated that the optimal thickness of surfacing should be within 2.0–3.0 mm, where a uniform distribution of tungsten carbides throughout the volume of the deposited layer is observed, whereas at a smaller thickness, tungsten carbide particles are located in the upper zone, and at a larger one, tungsten carbide particles are mainly located in the middle and lower zones of surfacing. The thickness of the deposited wear-resistant layer in the range of 2.0–3.0 mm provides an effective protection of the surface of the working body of a steel drill bit from corrosion, erosion and abrasive wear during drilling of gas and oil wells.

The technology of manufacturing drill bits with a protective coating of working bodies requires a number of technological operations. From its own developments on the base of the E.O. Paton Electric Welding Institute of the NAS of Ukraine such a technological scheme was created:

- designing of a bit taking into account well conditions;
- manufacture of bit parts at the five-coordinate processing center (CNC);
- surfacing of wear-resistant hard-alloy material on working bodies;
- mounting and brazing of cutters and hard-alloy inserts;
- treatment of surfaces of a bit to the size;
- tests.

The choice of drill bit types at the designing stage was made in two ways: according to mechanical and abrasive properties of rocks and on the basis of industrial data. The design of a drill bit was based on six factors of influence, namely: characteristics of drilled out rocks according to [10], drill bit diameter, load, number of rotations, volume of flushing fluid, bottom-hole pressure. Of course, the mentioned parameters do not fully describe all possible factors of influence, but they were chosen by us because namely these parameters are recorded in drilling logs. An additional parameter for bits of domestic production was drilling type (1 — rotary; 2 — turbine).

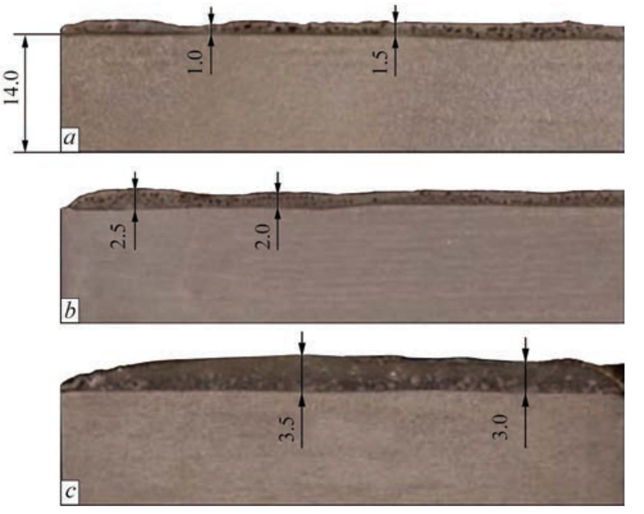

Figure 2. Deposition of wear-resistant coating on specimens: *a* — 1.0–1.5; *b* — 2.0–2.5; *c* — 3.0–3.5 mm

At the stage of designing drill bits, information on operation performance was used. Such information was obtained from the data of wear-out time of similar structures in real drilling conditions. Modeling of drill bits with a diameter of 165.1 mm (Figure 3) was carried out based on the results of our previously carried out works on underground and surface drilling of soft-medium, medium and hard rocks for extraction of dispersed methane and natural gas [11]. According

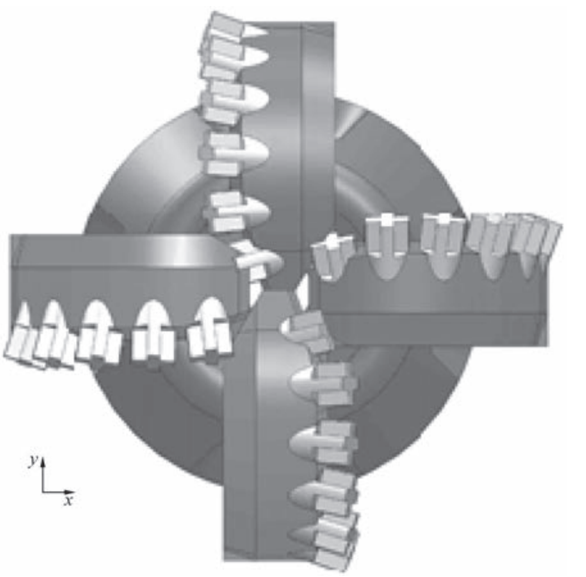

Figure 3. Modeling of cutters of blades of bit frame

Figure 4. Frame of an integrally-milled bit

to the results of the works carried out at the PWI, designs of drill bits and calibrators were developed and patents for their invention were obtained [12, 13].

The manufacture of a drill bit included turning and milling of the frame, drilling of the central channel of the frame and boring of channels for flushing fluid supply to cool the blades and cutting edges of diamond-hard alloy cutters. The works were performed at a five-coordinate processing center (CNC). The billets of frame for integrally-milled bits (Figure 4) and billets of frame and blades for combined (Figure 5) drill bits were made. Combined bits differ from integrally-milled ones in the fact that the frame of a bit is joined to the blades by welding, which allows reducing the cost of manufacturing bits.

Welding of the blades with the frame of a drill bit was performed by argon arc welding in a pure argon of grade A using nonconsumable electrode in the apparatus «Koral-300». The root of the weld was produced with filler wire of grade VNS-17 (03Kh11N-10M2T) of 2 mm diameter. The welding current is I = 140–150 A, voltage is U = 11–12 V. Reinforcement of the leg of the weld was performed using a filler wire of grade 18Kh4GMA of 3 mm diameter (I = 160–170 A, U = 12–13 V). To relieve welding stresses in the welds, the bit was tempered in a furnace at a heating temperature of 640 °C for 2 h. The bit was cooled in air. The hardness after tempering was *HB* 179.

According to the results of the carried out works [14, 15] on deposition of a protective coating of the working bodies of frames of drill bits, a composite material TeroCote 7888 T was chosen, which wets the base metal well and has no defects during surfacing of a layer on the leading and running-off areas of mounting sockets for diamond hard-alloy cutters (DHAC). During the development of the technology of surfacing corrosion-resistant layer to the areas of the working bodies of the bits, a preference was given to arc surfacing. The essence of the surfacing process consists in using heat for melting filler material and its joining with the base metal of a bit frame. The need in using local heating of the working bodies of a bit frame is predetermined by low values of flowability and spreading of the composite material, which contains about 65 wt.% of particles of tungsten carbides as compared to its base – high-temperature alloy of the metal system Ni–Cr–B–Si. Using the possibilities of arc surfacing, on the surface of the blades it is possible to produce a deposited layer of the required thickness and chemical composition with the desired properties.

Before deposition of the protective coating on the areas of the working bodies, graphite plugs should be tightly mounted into the sockets of the blade holes, which make it possible to protect these holes from leakage of the deposited wear-resistant alloy during surfacing and a preheating of the working bodies of the frame to the temperature of 400–500 °C should be carried out. During surfacing of the areas of the working bodies (Figure 6, *a*), two sources of thermal

Figure 5. Combined bit: *a* — frame; *b* — blades

Arc surfacing modes

Voltage, V	Current type	Current, A	Argon flow rate, dm^3/min	Surfacing rate, m/h	Power source
10–12	Direct, straight polarity	80–100	2.5–3.0	2–4	PRS-3M

Figure 6. Deposition of coating on working bodies of a bit: *a* — blade; *b* — bit after brazing of diamond-hard-alloy cutters and inserts

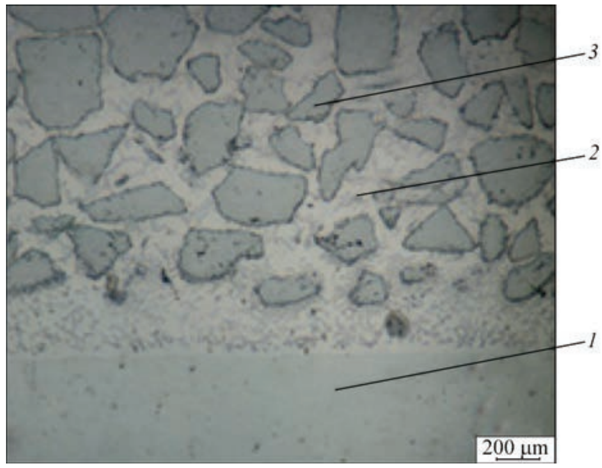

Figure 7. Microstructure of coating of a steel bit: *1* — 30Kh steel; *2* — matrix based on NiCrBSi alloy; *3* — tungsten carbides

power were used: electromagnetic field of high-frequency alternating current (induction) for preheating of the frame, and a heat released by the TIG method of surfacing — deposition of the filler TeroCote 7888T alloy at a temperature of 1200–1250 °C (Table).

The average thickness of the deposited layer of the working bodies of the blades was 2–3 mm.

Brazing of diamond-hard-alloy cutters in the sockets of the holes of the working bodies of the blades of the bit frame was carried out at a temperature of 650–680 °C (Figure 6, *b*) because a higher temperature of heating begins to affect the strength properties of polycrystalline diamond cutters [16, 17]. All this can lead to graphitization of polycrystalline synthetic diamonds, formation of cracks caused by the difference in the coefficients of thermal expansion of diamond and cobalt, and, as a consequence, to the destruction of the diamond layer.

To determine microstructure of the protective coating, microsections of 30Kh steel with a deposited layer were made (Figure 7). Metallographic examinations showed that in TIG surfacing during the formation of the deposited layer, a uniform distribution of tungsten carbide particles throughout the volume of the composite material TeroCote 7888T occurs, which causes a uniform distribution of hardness along the depth of the coating.

The microstructure of the deposited layer of the steel bit contains a solid nickel-chromium solution reinforced with tungsten carbides and a content of silicon and boron depressants. The presence of boron and silicon in the composition of filler wires provides them with self-fluxing properties during surfacing on steel. Tungsten carbides of irregular shape (of different sizes) are distributed throughout the whole field of the microsection. It is known from the literature that a high-quality wear-resistant coating should have a uniform distribution of solid phases with a distance between these phases smaller than the size of abrasive particles [18].

The produced structure of the deposited coating layer provides an effective protection of the surface of the working bodies of drill bits from erosion and abrasive wear caused by the influence of such materials as sand, gravel, earth, minerals, etc. A tough matrix of the deposited alloy absorbs shock loads and improves the corrosion resistance, whereas the special shape of tungsten carbides makes it impossible to pull them out from the matrix. The examinations showed that during TIG surfacing, low rates of heating and cooling of the metal during preheating of the working bodies of the bit allow reducing residual stresses and avoiding the formation of cracks in the coatings and the base material.

After each use, the bits are subjected to maintainance and repair. Repairs are carried out at the area of repair of the working bodies of bits applying the same

Figure 8. Drill bits with a protective coating: *1* — combined bit; *2* — integrally-milled bit; *3* — calibrator

technology as in the production of new drill bits. A batch of drill bits and calibrators with a protective coating of working bodies of 165.1 mm diameter, manufactured at the PWI, successfully passed tests during drilling wells in oil and gas condensate fields of Kharkiv region (Figure 8).

Conclusions

1. It was established that optimal thickness of surfacing of the protective coating should be within 2.0–3.0 mm, where a uniform distribution of tungsten carbides throughout the whole volume of the deposited layer is observed.

2. According to the results of production tests of steel drill bits, it was established that using of these bits with a protective coating of the working bodies allows increasing the service life during drilling of gas and oil wells.

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