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CORROSION RESISTANCE OF COMPOSITE MATERIAL DEPOSITED BY TIG METHOD USING FLEXIBLE CORD TeroCote 7888T

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Increasing the corrosion resistance of drill bits with protective coatings is an urgent problem in Ukraine. For drilling tool, the main indices of physical and mechanical properties of wear-resistant coatings are abrasive wear, corrosion resistance and hardness (microhardness). It allows effectively resisting wear of working bodies of blades and a body of drill bits under the conditions of alternating and shock loads, hydroabrasive wear, corrosion, erosion, etc. It was investigated that a uniform distribution of tungsten carbide particles throughout the whole volume of deposited layer causes the same hardness over the coating depth and significantly increases the resistance of coating to corrosion wear. It is shown that microhardness of the matrix of a composite material TeroCote 7888T based on NiCrBSi exceeds the microhardness of steel 30Kh by 2.2 times. According to the results of corrosion tests, it was established that the protection of steel 30Kh by a deposited layer on the basis of a composite material TeroCote 7888T under the conditions simulating operating ones allows reducing the corrosion rate of working bodies of steel drill bit by almost 53 times. 10 Ref., 1 Table, 4 Figures.

K e y w o r d s : surfacing, tungsten carbides, microstructure, microhardness, wear resistance, corrosion rate, corrosion spot

Drill bits are operated in different climatic zones, under aggressive conditions and are subjected to different loads. The classic types of wear of a drilling tool in industry are: abrasion, erosion, shock, friction, heating, corrosion and cavitation one. The losses as a result of wear are manifested not only in the loss of funds for the purchase of new equipment, but also in the idle period during repair. For more than a century history, it was shown that the application of protective coatings to the working parts of drill bits can significantly increase the life of a drilling tool.

To protect the drilling tool from different types of wear, composite materials based on Ni, Fe, NiCr, NiCrBSi, brass, etc., strengthened with tungsten carbides [1] are widely used. First of all, this is associated with the unique properties of the reinforcing phase of such alloys as tungsten carbides. The most widespread use in the industry belongs to tungsten monocarbide WC with a stoichiometry of 6.13 % C. It is characterized by a high hardness *HV* 2200, compressive strength of 5−7 GPa and elasticity modulus of 700 GPa, preserves mechanical properties over a wide range of temperatures, resistant to friction corrosion and capable of forming a strong bond with metals [2, 3].

The problem of corrosion, along with an intensive wear, is very important for working bodies of a drill bit during drilling of oil and gas wells. The stability and performance of drilling using steel bits with a protective coating, including bits with rock destruction elements in the form of polycrystalline diamond cutters, directly depends on the ability of the elements of «cutting structure» of bits to resist abrasive wear of the brazing alloy and the areas of blades around these elements that seek to destroy the system of fastening these rock destruction elements. Therefore, the protective coating of steel areas of the working bodies of the blades located around the cutting and calibrating elements keeps them from tearing, causes baring, increasing the size of the projection and a gradual fallout of separate elements.

The carried out investigations of wear resistance of composite materials under the conditions of hydro-abrasive wear [4] showed that the wear resistance of a protective coating applied with TeroCote 7888T with chipped tungsten carbide particles exceeds the wear resistance of coatings applied with the use of relite «LZ-11-7» (spherical granules of tungsten carbide) and Diamax M (grinded tungsten carbide particles) by 1.7 and 2.9 times, respectively. Based on the results of investigations of hydroabrasive wear of composite materials, the main attention was paid to the composite alloy TeroCote 7888T, which belongs

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to the category of corrosion-resistant protective materials.

Taking into account the abovementioned, the aim of the work was to investigate the corrosion resistance of the metal deposited using TeroCote 7888T composite material under the laboratory conditions simulating the operation of a drill bit during drilling wells (temperature, chemical composition, wear, etc.).

Materials and methods. As the object of the investigations a composite material flexible cord TeroCote 7888T was selected. The examination of microstructure was performed using the standard procedure in the optical metallographic microscope MMT-1600B. The digital image of the microstructure was obtained with the use of the Carl Zeiss ICc5 camera. The microhardness was measured in keeping with the standard procedure according to GOST 2999 [5] in the PMT-3 microhardness meter. The corrosion tests were performed using the method of massometry according to GOST 9.908 [6].

Results of investigations. To deposit protective coating on the specimens, the composite material (self-fluxing brazing alloy TeroCote 7888T in the form of a flexible cord with a diameter of 5 mm according to DIN 8555: G21−350−GR) was used. The cord had a core of nickel wire of 1.2 mm diameter and a sheath of a matrix alloy of the NiCrBSi system with a high content of tungsten carbide. The working temperature of surfacing was 1170 °C (±50 °C). The size of particles of a chipped tungsten carbide was 0.10−0.70 mm. The content of tungsten carbide in the matrix alloy does not exceed 65 wt.%.

The arc surfacing of test specimens was performed with the help of the PRS-3M welding machine. The application of deposited layer was performed in an arc method by a non-consumable tungsten electrode in a shielding gas — technical argon. The optimal conditions with the lowest heat input were as follows: U = 10−12 V; I = 50−60 A, deposition rate was 2−4 m/h. The surfacing was carried out in a horizontal position on all the sides of the rectangular specimen. The average thickness of the deposited layer was 8−10 mm. After surfacing, the specimens were grinded, the thickness of the deposited layer on each side was approximately 1.5−1.8 mm.

To determine the microstructure, a microsection was made from the specimen with the deposited layer. Metallographic examinations showed that the deposited layer and the base metal are combined by a thin transition layer of a diffusion origin (Figure 1), which indicates that the base metal did not melt and the filler metal did not dissolve in it. The microstructure of the deposited alloy contains a solid solution based on nickel-chromium strengthened with tungsten carbides and the content of silicon and boron depressants. The presence of boron and silicon in the composition of filler wires provides self-fluxing properties to them during surfacing on steel. The tungsten carbides of irregular shape (of different sizes) are distributed throughout the whole microsection field.

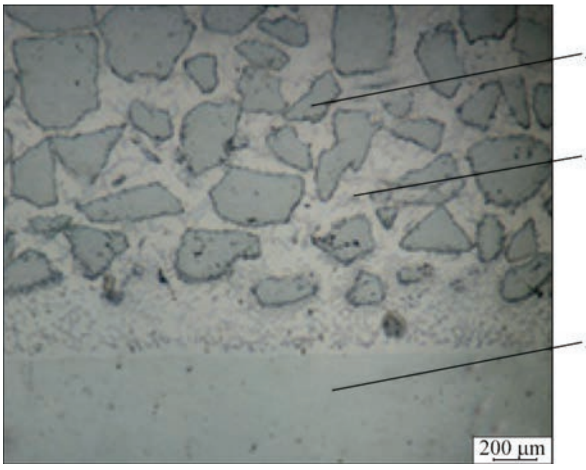

Figure 1. Microstructure of deposited layer (30Kh steel): *1* — base metal; *2* — matrix based on alloy NiCrBSi; *3* — tungsten carbides

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 being smaller than the size of abrasive particles [7]. Such a uniform distribution of tungsten carbide particles throughout the volume of the deposited layer provides the same hardness throughout the depth and considerably improves the resistance of coating to corrosion wear.

The measurements of microhardness on the surface of the deposited layer and the base metal were performed in the PMT-3 microhardness meter at a magnification of ×130 at a ratio of the load to the indentation area. The loads of 50 g weight (for the base metal) and 200 g (for the deposited layer) were used. The specimen was divided into three areas for measurements: the base metal, the matrix in the middle of the deposited layer, the tungsten carbide particles (Figure 1). At each area

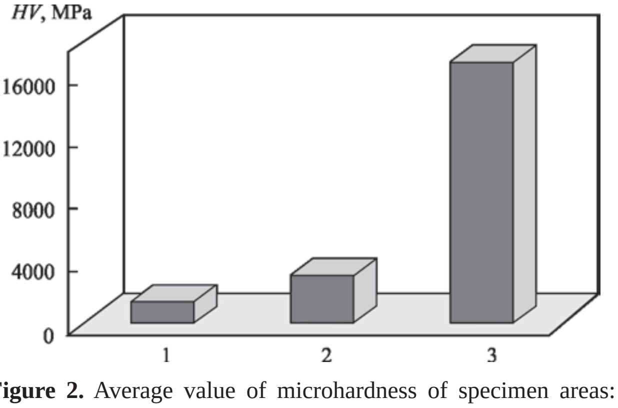

Figure 2. Average value of microhardness of specimen areas: 1 — steel 30Kh; 2 — matrix based on alloy NiCrBSi; 3 — tungsten carbides

Rate and penetration depth of corrosion of steel 30Kh and deposited layer

Characteristics of specimen	Corrosion rate, g/(m^2·h)	Corrosion penetration depth, mm/year
Specimen with deposited layer	0.257–0.261	0.18
Steel 30Kh	8.42	9.5

ten measurements were performed at a holding time of 15 s. According to the obtained data, the average values for each area were determined (Figure 2): 1 — base metal (steel 30Kh) — 1400.8 MPa; 2 — matrix based on NiCrBSi alloy — 3123.5 MPa; 3 — tungsten carbides — 16850 MPa (16.8 GPa).

The corrosion resistance of the deposited metal based on the alloy TeroCote 7888T was evaluated on two specimens (Figures 3, 4). For comparison, the corrosion resistance of steel 30Kh was evaluated.

The resistance of the deposited metal layer to the action of the moving medium was evaluated by the appearance of the specimens and the corrosion rate. To simulate the effect of the corrosive medium and solid particles present in the drilling cuttings during drilling wells, the study was performed in a moving medium based on 3 % NaCl solution of the following composition: 400 ml of H_2O + 12 g of NaCl + 200 g of quartz sand in the mlw MR25 installation at a room temperature. The time of holding specimens in the moving medium was 95 h, the fluid flow rate was 60–90 rpm and the total duration of tests (with and without stirring) was 172 h. After the tests were finished, the corrosion products were removed from the specimen surface according to GOST 9.907 [8]. Inspection of the surface of the specimens before and after the examinations was performed visually. The area of corrosion damages of the base metal was evaluated according to GOST 9.311 [9], item 5. The rate of corrosion of the specimens was determined by the method of massometry in compliance with the indices according to GOST 9.908 [6] in g/(m^2·h):

$$V_p = \frac{\Delta m}{Sl}, \qquad (1)$$

where Δm is the weight loss of the specimen, g; S is the surface area of the specimen, m^2; t is the duration of investigations, h.

The depth of corrosion penetration in mm/year was calculated by the formula:

$$V_h = 8.76\frac{V_p}{\rho}, \qquad (2)$$

where V_p is the corrosion rate, g/(m^2·h); ρ is the density of the metal, g/cm^3.

For steel 30Kh — ρ = 7.8 g/cm^3, for composite alloy TeroCote 7888T — ρ = 12.4 g/cm^3.

The results of the investigation are shown in Table and in Figures 3, 4.

Specimens with deposited layer. The surface of the specimen before testing is uniform and has a metallic color (Figure 3, *a*). After testing on the entire surface, on both sides, darkening spots of the deposited layer and pits with a diameter not more than 1 mm are visible. Corrosion damages have the appearance of corrosion spots of different sizes: from (10×1) mm to (5×3) mm and tiny pits (Figure 3, *b*). The total area of corrosion damages is close to 0.00004 m^2 (at the total surface area of the specimen being 0.0045 m^2).

The area of corrosion damages of the base metal is about 2 % (Figure 3, *c*) and is estimated by the point

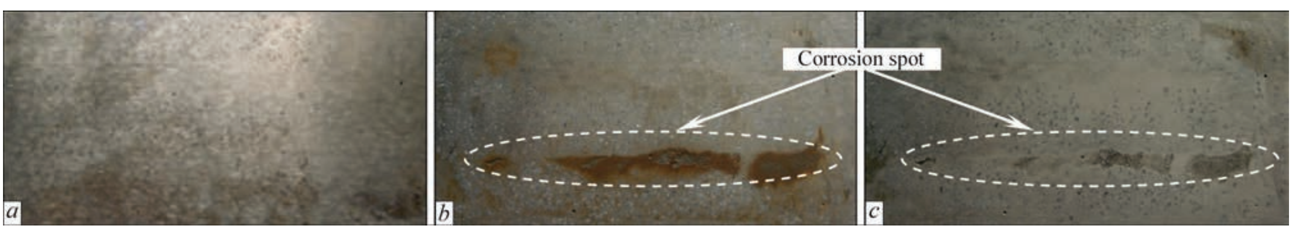

Figure 3. Outer appearance of specimen surface of deposited layer on the basis of NiCrBSi: *a* — in the initial state; *b* — with corrosion products; *c* — after removal of corrosion products

Figure 4. Outer appearance of specimen surface of deposited layer on the basis of steel 30Kh: *a* — in the initial state; *b* — with corrosion products; *c* — after removal of corrosion products

6 (the area of damages of the base metal is from 1 to 2.5 %) according to Table 2 GOST 9.311 [9] by a ten-point scale. The corrosion rate of the specimen was 0.257 g/(m^2·h), the corrosion penetration depth was 0.18 mm/year (Table).

Specimen of steel 30Kh. Before the tests the surface of the 30Kh steel specimen (Figure 4, *a*) has a metallic color. After tests, the entire surface is covered with brown corrosion products (Figure 4, *b*), after removal of which corrosion spots are present occupying more than 70 % of the total area (at a total surface area of the specimen being 0.0035 m^2), Figure 4, *c*. According to GOST 9.908 [6], the type of corrosion is identified as a continuous uniform. The corrosion rate was 8.42 g/(m^2·h), the depth of corrosion penetration was 9.5 mm/year (see Table).

According to GOST 9.502 [10], if the corrosion rate of iron and ferrous metals is from 0.1 to 0.5 mm/year, which is estimated by a point 6, the resistance of the metal to uniform corrosion is considered to be lowered. If the corrosion rate is from 5.0 to 10.0 mm/year (point 9), the metal is considered to be weak resistant.

Conclusions

1. According to the results of investigations, it was found that during TIG surfacing using a flexible cord TeroCote 7888T, during the formation of the deposited layer the tungsten carbide particles are uniformly distributed over the entire deposited layer volume, which determines the uniform distribution of hardness over the depth of the coating.

2. The results of carried out investigations showed that the use of protective coating deposited with flexible cord TeroCote 7888T allows reducing the corrosion rate of working bodies of drilling tool of 30Kh steel by approximately 53 times, which will promote extending its service life.

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