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EFFECT OF STRUCTURE OF JOINT ZONE OF DIAMOND LAYER WITH HARD-ALLOY SUBSTRATE OF BRAZED CUTTERS ON THEIR SERVICE LIFE

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Service life of the drilling bits with diamond-hard-alloy cutters (DHC) is determined by value of drifting under conditions of abrasive, erosion and corrosion wear in drilling of degassing holes. Evaluation of wear and microstructure of a joint of diamond layer with hard-alloy substrate of «Syndrill» integral cutter of «Element Six» Company (Ireland) and complex cutter (ISM of NASU) of drilling bits after completion of their life was carried out in the work. It is shown that cobalt in the integral cutters is uniformly distributed in the diamond layer and its amount makes up to 2.06 wt.% in contrast to complex ones, where amount of cobalt is 4.35 wt.%. Increase of cobalt content and decrease of volume content of the diamond grains in diamond layer of the complex cutters reduce their heat and wear resistance. Porosity of complex diamond-hard-alloy cutters is 2 times more in comparison with integral «Syndrill» cutters that promote penetration of larger amount of brazing alloy elements (cooper and zinc) in a transition zone of joint of hard-alloy substrate and diamond layer. 7 Ref., 2 Tables, 6 Figures.

Keywords: *drilling bit, diamond layer, diamond-hard-alloy cutter, diamond-hard-alloy plate, hard-alloy substrate, sintered material, brazing, brazing alloy, microstructure, porosity, wear*

Life of working parts of the drilling bits, equipped with integral and complex diamond-hard-alloy cutters, depends, mainly on physical-chemical properties of diamond layer and its adhesion to hard-alloy substrate after effect on it of thermal brazing cycle as well as strength and corrosion properties of brazed joint «DHC–blade of drilling bit operating element» [1–4].

High rate of wear is caused by differences in heat expansion rate between diamond particles and cobalt as well as high temperature, which effects the kinetics of chemical reactions between cobalt and diamond particles and process of diamond layer graphitizing. Considerable difference in the coefficients of heat expansion of diamond particles $1.1 \cdot 10^{-6}$ °C^{-1} and cobalt $12.0 \cdot 10^{-6}$ °C^{-1} promotes high levels of thermomechanical stresses in a transition zone of DHC joint.

Graphitizing of diamond layer of «Syndrill» cutters of «Element-Six» Company (Ireland) is significantly accelerated at more than 800 °C temperature and for cutter of diamond-hard-alloy plate (DHP) of ISM of NASU it is more than 680 °C [2]. This results in degradation of cutting edge and rise of cutters' wear, deterioration of effectiveness of drill through tool and decrease of drifting value (Figure 1).

Aim of the work is to investigate the effect of microstructure of a joint of diamond layer with hard-alloy substrate of drilling bit DHCs on their service life.

The drilling bits tests were carried out in drilling of degassing holes at 12th western airway of L_1 bed in Donbass. Drilling was performed using electrohydraulic machine for deep hole drilling of GBH 1/89/12 type from «Deilmann-Haniel» Company (Germany) at angles of drilling to horizon from 8 to 60°. A drilling mode was the following: nominal frequency of machine spindle rotation 70–100 min^{-1}; drilling thrust 50–100 kN. Drilling of the degassing holes of up to 150 m length was carried out on a matrix rock, represented by siltstone and abrasive sand rock at uniaxial compression strength limit up to 120 MPa. Consumption of technical water for borehole cleanout and drilling tool cooling made up to 50 l/min.

The integral and complex DHCs were brazed into seats of drill bit blade with the help of silver brazing alloy BAg-1a in a temperature range 650–680 °C. After the working parts of the steel drilling bits (Figure 1) have run the specific service life, the cutters were brazed out of the blade seats. Total time of holding τ at DHC brazing temperature made τ = 90–120 s.

Investigation of the microstructure of hard-alloy substrate to diamond layer joint was carried out on metallographic sections (cross section, wear of cutting edge made around 2 mm) using scanning electron microscope LEO EVO 50 XV.P (Karl Zeiss, Germany) equipped with energy-dispersive analyzer INCA-energy 450 (Oxford Instruments, England).

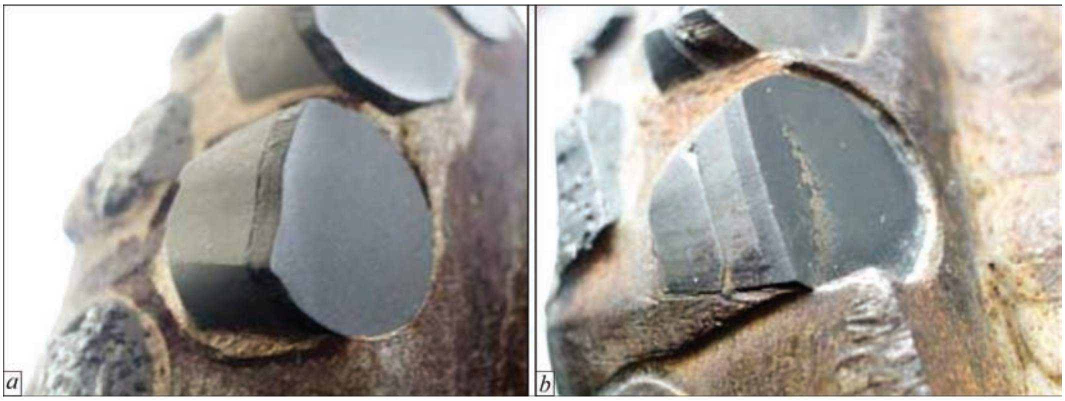

Figure 1. Appearance of worn cutters of steel drilling bit blade (×3): *a* — «Syndrill» DHC after 1000 m drifting; *b* — complex cutter of DHP of ISM of NASU after 250 m drifting

Distribution of the main elements (Figure 2) in a characteristic radiation of tungsten, cobalt, carbon indicates the presence of carbon in a diamond-containing layer (on the right) and in the segment adjacent to hard-alloy substrate (on the left) of integral «Syndrill» DHC of «Element Six» Company (Ireland). Tungsten and cobalt are located in the hard-alloy substrate and transition zone with diamond layer.

A joint of integral cutter (DHC) conventionally consists of three typical sections, namely hard-alloy substrate A, transition zone B, C, D, diamond layer E, which differ by inhomogeneous microstructure (Figure 3) and various chemical composition (Table 1).

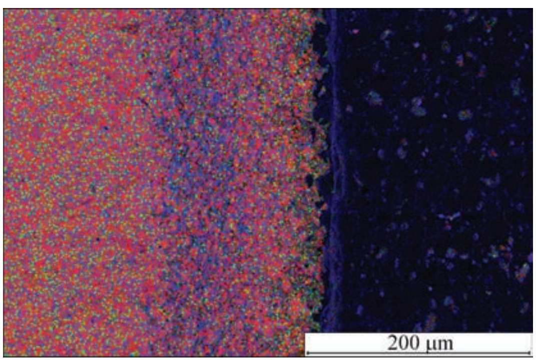

Figure 2. Distribution of elements of «Syndrill» DHC in characteristic radiation: carbon — blue, tungsten — red; cobalt — green

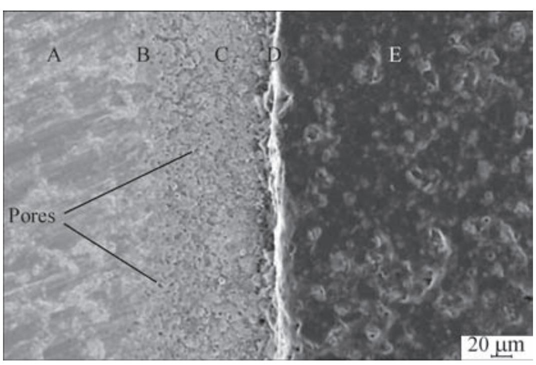

Figure 3. Microstructure of «Syndrill» DHC: A — hard-alloy substrate, (B, C, D) — transition zone, E — diamond-containing layer

A hard-alloy substrate A consists of fine-dispersed particles of tungsten carbide (light grey) bound by cobalt-based alloy (grey) containing up to 1.63 wt.% of nickel. It has a microstructure typical for hard-alloy sintered material of WC–Co system. Nickel is used as a catalytic agent [5] in sintering of the fine dispersed powders.

Hard sintered material of WC–Co system (segment B, around 10 μm width) with lower amount of cobalt (2.82 wt.%) additionally contains a separate phase of copper with zinc alloy with relationship of these elements 1.7/1. Segment C of around 120 μm width (Figure 6, *a*) has more refined microstructure of tungsten carbides, matrix of which consists of sintered material of WC–Co system and additionally contains, wt.%: 1.45 Ni and 5.59 Cu. A transition zone (segment D of around 10 μm width) has a nonuniform structure of sintered material of WC–Co (light) and C–Co (dark) systems, which contains inclusions of copper with zinc alloy at relationship of these elements 0.73/1. A diamond layer (segment E) consists of grains of polycrystalline diamonds bound by cobalt-based alloy and contains wt.%: 94.96 C; 2.06 Co (dark); 2.31 W and 0.67 Ni.

Distribution of the main elements (Figure 4) in the characteristic radiation of tungsten, cobalt, carbon of DHP complex cutter (ISM of NASU) indicates the presence of carbon in the diamond layer (on the right) and lower intensity of spectrum in a segment adjacent to the hard-alloy substrate (on the left). Tungsten and cobalt are distributed in the hard-alloy substrate. Local distribution of cobalt

Table 1. Content of elements (wt.%) in examined segments of «Syndrill» DHC

Segments	C	Co	W	Ni	Cu	Zn
A	29.42	3.92	65.03	1.63	–	–
B	42.27	2.82	41.02	1.20	3.63	2.18
C	41.15	2.83	48.98	1.45	5.59	
D	89.2	1.55	4.07	–	2.18	3.00
E	94.96	2.06	2.31	0.67	–	–

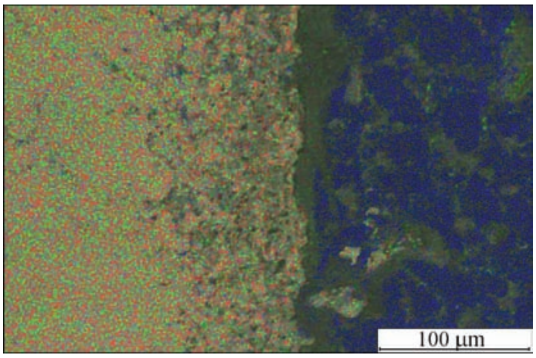

Figure 4. Distribution of elements of DHP (ISM of NASU) in characteristic radiation: carbon — blue, tungsten — red; cobalt — green

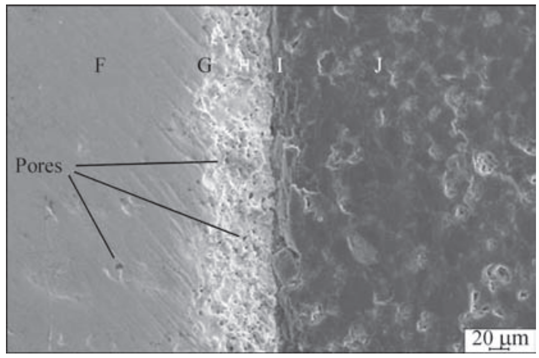

Figure 5. Microstructure of complex DHP (ISM of NASU): F — hard-alloy substrate, (G, H, I) — transition zone, J — diamond layer

(green spectrum) was determined in the segment of transition zone with diamond layer.

The joint of complex cutter, by analogy with previous DHC, consists of three typical segments different by inhomogeneous microstructure (Figure 5) and various chemical composition (Table 2).

Hard-alloy substrate F includes coarser particles of tungsten carbide (light grey) in a cobalt matrix (grey). It is similar by structure to commercial sintered material and on chemical composition it is close to VK12 alloy. Cobalt matrix G of the sintered material of WC–Co system of around 10 μm width with relatively lower amount of cobalt 9.16 wt.% additionally contains a separate phase in form of copper with zinc alloy. Segment H of around 90 μm width (Figure 6, *b*) in the transition zone is characterized by coarse grains of carbides of WC–Co system sintered material and additionally contains copper and zinc phase in relation of these elements 2.3/1. Segment I of around 10 μm width has a non-uniform microstructure typical for sintered material of tungsten carbide and diamond powders of WC–Co systems (light) and C (diamond) — Co (dark) as well as contains the inclusions of phase of copper with zinc alloy in 1.6/1 relationship. Diamond layer J contains wt.%: 89.92 C; 4.32 Co; 5.73 W.

The results of investigations showed that content of carbon naturally changes at transfer from the hard-alloy substrate to diamond layer in the separate segments, wt.%: 29.42 (A), 42.27 (B) and 41.15 (C) and rapidly rises from 89.2 (D) to 94.96 (E). Amount of cobalt (see Table 1) of DHC in the segments makes, wt.%: 3.92 (A) and 2.83 (C) and that in diamond layer 2.06 (E). Content of tungsten, on the contrary, reduces from segment A to segment E, and that in the diamond layer makes only several percent. Regularity of change of carbon and cobalt content proves complex structure of composite material of DHC consisting of sintered fine dispersed powders of the next system, namely WC–Co (hard-alloy substrate), WC–C–Co (transition zone), C–Co diamond layer.

Table 2. Content of elements (wt.%) in examined segments of DHP (ISM of NASU)

Segments	C	Co	W	Cu	Zn
F	10.48	12.22	77.30	–	–
G	19.07	9.16	65.22	4.11	2.44
H	10.46	5.36	52.99	21.8	9.39
I	67.48	7.96	13.75	6.76	4.05
J	89.92	4.35	5.73	–	–

Composition of complex DHC is also naturally varies in the separate segments, wt.%: carbon — 10.48 (F), then rises up to 19.07 (G) and reduces to 10.46 (H), and in moving across the boundary increases to 67.48 (I) and rises in the diamond layer to 89.92 (J). Amount of cobalt (see Table 2) in the segments of joint of complex DHC makes, respectively, wt.%: substrate — 12.22 (F), transition zone — 9.16 (G), — 5.36 (H), — 7.96 (I) and that in the diamond layer — 4.35 (E).

Examined segments of the transition zone of hard-alloy substrate and diamond layer of integral and complex DHC include elements from the brazing alloy, i.e. copper and zinc. A width of transition zone of hard-alloy substrate to diamond layer of integral DHC (Figure 6, *a*) is approximately 1.55 time more than of complex DHC (Figure 6, *b*).

It is known [6] that porosity of the complex domestic cutter of DHP makes 2–5 %. It can be assumed that in the processes of manufacture of complex DHP

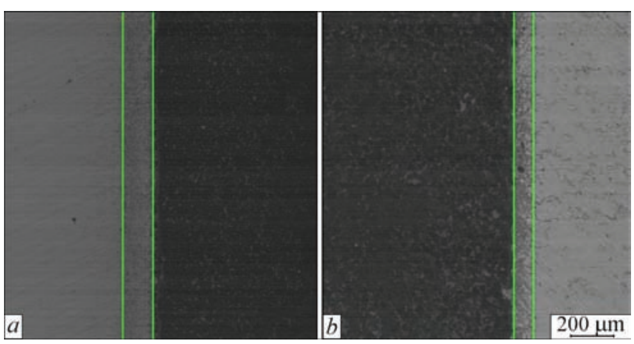

Figure 6. Microstructure of DHC with marker of width of transition zone, μm: *a* — «Syndrill», 140.6; *b* — DHP (ISM of NASU) 90.82

[2] and its fixing [3] in the holes of blades there are diffusion processes taking place in brazing, when elements of the brazing alloy, in this case copper and zinc, penetrate through the pores in the transition zone. Work [1] determined that the transition layer of hard solution based on copper with zinc is mainly formed in the near-boundary segments with hard-alloy substrate when using silver brazing alloys in the technological processes of brazing of sintered materials of WC–Co system. Porosity of domestic DHP is approximately 2 times more in comparison with DHC of «Element Six» Company (Ireland), that promotes increase of amount of copper and zinc, which forms solid solutions based on copper with zinc of alternating composition at near-boundary transition zone with hard-alloy substrate and diamond layer.

Small size WC grains and small amount of cobalt are present in the transition zone of «Syndrill» DHC in the examined segments B, C, D. They increase hardness and wear resistance due to strength. In the complex DHC G, H, I segments of the transition zones contain WC coarse grains and high content of cobalt reduces hardness and wear resistance, but rises impact toughness of the sintered alloy. Work [7] shows that coarser grains of tungsten carbides (WC) promote increase of hard alloy porosity.

Following the results of investigation of the joint of diamond layer and substrate in the specimens, produced by «Element Six» Company (Ireland) and DHP (ISM of NASU), it can be stated that the diamond layer of «Syndrill» DHC is less susceptible to effect of thermal brazing cycle and has significantly larger resource, and, respectively, value of drifting of drilling bit. High volume content of diamond grains and rigidly limited amount of cobalt binding powder in the polycrystalline DHC layer rise its strength properties, heat and wear resistance. The transition zone of «Syndrill» DHC has a relatively large dimensions, fine-grain structure of tungsten carbides (WC) and low content of cobalt as well as lower porosity in comparison with DHP (ISM of NASU). This promotes increase of hardness and relaxation of residual stresses under conditions of alternating loading.

Today, less porous sintered materials of WC–Co system are produced by means of introduction of the fine particles of tungsten carbide in a cobalt matrix and using a method of high-temperature synthesis in vacuum or in hydrogen atmosphere. Change of cobalt content and size of fine-dispersed particles allows receiving tens of standard classes of solid sintered alloys. These complex materials combine hardness at limited deformation with strength and resistance to crack formation.

Conclusions

1. Drilling bits, equipped with the integral cutters, have larger (4 times) service life in comparison with complex cutters, due to high volume content of diamond grains and limited amount of binding cobalt in the polycrystalline layer.

2. Copper and zinc components of the brazing alloy are present in the segments of transition zone adjacent to hard-alloy substrate and diamond layer. Higher porosity of complex DHC promotes increase of amount of Cu–Zn system alloy.

1. Khorunov, V.F., Stefaniv, B.V., Sabadash, O.M. et al. (2012) Peculiarities of restoration technologies of drill bits with diamond-hard-alloy cutters. In: *Problems of life and safety of service of structures, constructions and machines*: Transact. of 2010–2012 results. Kyiv, PWI, 488–493 [in Russian].
2. Stefaniv, B.V. (2013) Development of the technology of brazing of diamond-hard-alloy cutters. *The Paton Welding J*., **2**, 37–41.
3. Stefaniv, B.V. (2013) Peculiarities of induction brazing of diamond-hard- alloy cutters to blade of body of complex drill. *Ibid*., **8**, 49–53.
4. Stefaniv, B.V., Khorunov, V.F., Sabadash, O.M. et al. (2015) Peculiarities of restoration technology for worn working parts of steel and matrix bodies of drilling bits. In: *Problems of life and safety of service of structures, constructions and machines*: Transact. of 2013–2015 results. Kyiv, PWI, 688–696 [in Russian].
5. Chintamaneni, V., Bellin, F. (2013) *High-temperature treatment at high heating rate of pdc cutters*. Pat. 2628593, RU, Int. Cl. C21D 9/22, E21B 10/567 [in Russian].
6. Goncharenko, I.M. Physical basics of development and manufacture of hard alloys. http://portal.tru.ru
7. Besson, A., Burr, B., Dillard, S. et al. (2000) On the cutting edge. *Oilfield Review*, 12(**3**), 36–57.

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