DEVELOPMENT OF THE TECHNOLOGY OF BRAZING DIAMOND–HARD ALLOY CUTTERS

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Brazing temperature influence on performance of diamond–hard alloy plates (DHAP) and diamond–hard alloy cutters (DHAC) was studied. It is established that application of copper-zinc and copper-manganese filler metals for brazing the composite cutter is not optimum because of the high heating temperature that leads to marked degradation of physico-mechanical properties of DHAP diamond layer because of graphitization. Technology of brazing DHAP with hard alloy mandrel (HAM) was developed that ensures the required properties of the diamond layer as a cutting tool. Technology of DHAC brazing (DHAP + HAM) was developed allowing performance of DHAC brazing with HAM and preserving its service properties on a high level. A lot of attention was given to assessment of performance of DHAC diamond layer after heating for brazing by gauging of a certain rock. It is shown that the proposed technology of DHAC brazing with diamond layer cooling allows application of filler metals with more than 700 °C brazing temperature without loss of this layer performance. During investigations standard filler metals and those developed at the E.O. Paton Electric Welding Institute were tested. Generalization of a set of tests led to the conclusion that Ag–Cu–Zn–Ni–Sn–Mn and Ag–Cu–Zn–Ni–Mn–Pd system filler metal are the most promising. Developed technology has been applied for items and tested under the actual service conditions. 9 Ref., 2 Tables, 4 Figures.

Keywords: *brazing, brazing filler metal, superhard materials, diamond layer, diamond–hard alloy cutter, diamond–hard alloy plate, hard alloy mandrel, graphitization, drill bit, thermal stability*

Drilling of oil and gas wells in soft, medium-hard and hard rocks is performed with application of drill bits, cutters, inserts and other types of tools fitted with cutting elements in the form of two-layer diamond–hard alloy plates (DHAP) and diamond–hard alloy cutters (DHAC). In Ukraine DHAP are manufactured at V.N. Bakul Institute for Superhard Materials (ISM) of the NAS of Ukraine. They are two-layer plates [1] of 13.5 mm diameter and 3.5 mm height, in which one layer of 0.5–0.8 mm height is a diamond polycrystal, and the other layer is a hard alloy substrate. Therefore, making DHAC of the necessary size requires joining DHAP with hard alloy mandrel (HAM).

It should be noted that foreign companies, for instance Element Six, Smith, Hugnes, Reed, Security, Ulterra and De Beers manufacture DHAC of the required dimensions by cutter height and the operation of DHAP brazing to hard alloy substrate during their manufacturing is not required.

The objective of the work was development of the technology of brazing DHAP with HAM, providing minimum influence of heating on diamond layer properties, i.e. preserving the physico-technological characteristics of the diamond layer as the cutting tool. They, in their turn, influence the mechanical speed and feed range of the drill bit. This paper gives the results of studies on DHAP fastening to HAM by brazing. Studied were DHAC manufactured by leading foreign companies and local manufacturer.

DHAC of Syndrill grade of Element Six Company (Great Britain) and DHAP of ISM were studied to determine their thermal stability and wear resistance. The term thermal stability of DHAP and DHAC determines the limits of temperature and time of heating, at which the diamond-containing layer preserves its physico-mechanical properties, particularly, wear resistance values. This concerns both the process of plate sintering and their service. The higher the value of DHAP thermal stability the better are the prospects for their application for drilling oil and gas wells by diamond drill bits.

DHAP and DHAC heating was performed in a muffle furnace in the temperature range of 500–1000 °C for 1 to 20 min. Analysis of the obtained results shows that temperature and time of soaking have a great influence on DHAP and DHAC thermal stability (Figure 1). For locally manufactured DHAP heating at temperature above 650 °C and soaking for 3 min leads to diamond layer degradation. Much better results on thermal stability, compared to DHAP, were obtained

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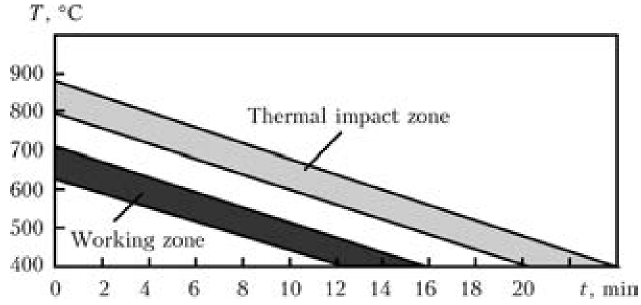
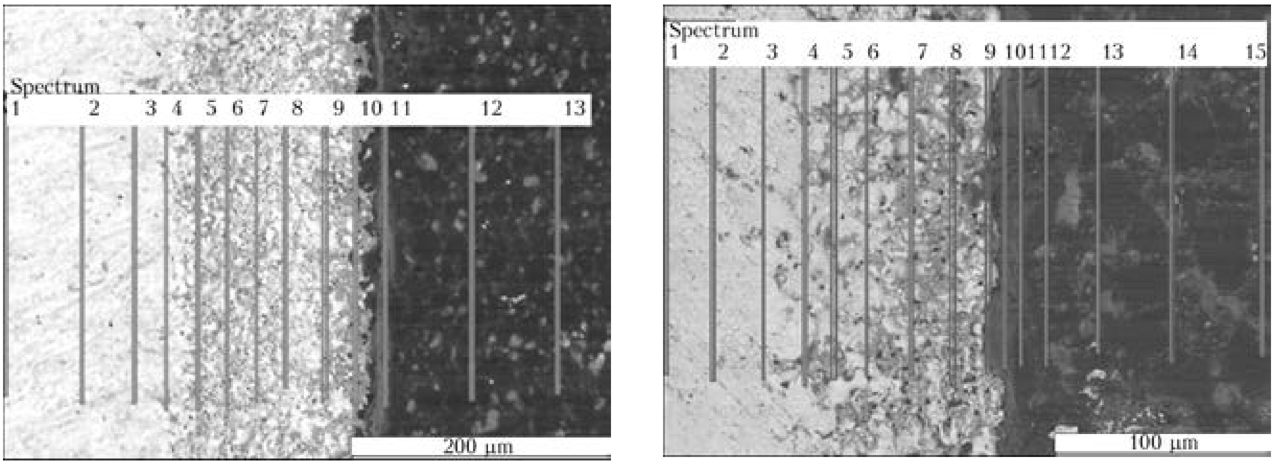


Figure 1. Areas of DHAP and DHAC thermal stability: *1* — series-production technology of ISM; *2* — technology of Element Six Company (Syndrill grade)

for Syndrill DHAC of Element Six. Their thermal stability is equal to 850 °C at heating for 3 min.

To determine the differences in thermal stability of DHAP of ISM and Syndrill DHAC of Element Six microstructural examination of diamond-containing layer was conducted (Figure 2). Investigation results revealed that the cause for low thermal stability of DHAP samples (ISM) is the high cobalt content in the diamond layer. Conducted examination in electron microscope Zeiss EVO 50 XVP showed that samples of Syndrill DHAC have a uniform distribution of cobalt in diamond-containing layer and its



Spectrum number	C	Co	W
1	28.72	4.24	67.04
2	30.70	4.04	65.26
3	31.00	3.19	65.81
4	35.78	2.73	61.49
5	44.06	3.61	52.33
6	48.21	3.36	48.43
7	46.95	3.23	49.82
8	38.77	2.74	58.49
9	34.18	3.73	62.09
10	40.71	6.97	52.32
11	93.01	2.34	4.65
12	95.95	1.70	2.35
13	95.11	2.53	2.36
Average value	51.01	3.42	45.57
Root-mean-square deviation	25.63	1.28	24.96
Maximum value	95.95	6.97	67.04
Minimum value	28.72	1.70	2.35

a

Spectrum number	C	Co	W
1	13.28	12.72	73.99
2	8.25	11.66	80.10
3	10.50	11.30	78.19
4	21.96	9.62	68.42
5	19.36	9.82	70.83
6	15.23	8.16	76.61
7	14.22	6.60	79.18
8	12.60	8.33	79.07
9	6.69	11.95	81.36
10	10.07	26.01	63.92
11	71.73	9.62	18.64
12	89.85	4.06	6.09
13	87.66	3.84	8.50
14	88.58	4.97	6.45
15	93.54	3.60	2.87
Average value	37.57	9.48	52.95
Root-mean-square deviation	36.13	5.51	33.01
Maximum value	93.54	26.01	81.36
Minimum value	6.69	3.60	2.87

b

Figure 2. Microstructure and element content of spectra (wt.%) of Syndrill DHAC (*a*) and of DHAP ISM (*b*)

amount is equal to 7 wt.% unlike local DHAP, in which cobalt content is 26 wt.%. Increase of cobalt and lowering of carbon content have a negative influence on thermal stability and wear resistance (lowering their values). It should be taken into account when joining DHAP (ISM) to HAM.

At DHAP heating up to a critical temperature (670–700 °C) [2] physico-mechanical properties of the diamond layer abruptly degrade, because of diffusion interaction between the diamond particles and cobalt. Graphitization of polycrystalline synthetic diamonds and cracking, caused by the difference in thermal expansion coefficients of diamond and cobalt, take place, resulting in fracture of the diamond layer.

Earlier studies of the processes of DHAC brazing were conducted at V.B. Bakul ISM [3]. Experimental retrofitting of DHAC brazing technology was performed using copper-zinc filler metals of grades L63, LNKoMts 49-9-0.2-0.2, LNMts 60-9-5, MNMts 68-4-2, LMtsZh 51-1.5-0.75 with the temperature range of melting from 880 up to 1000 °C. However, melting temperature of these filler metals is by 150–250 °C higher than that of destruction of synthetic diamonds that required application of special measures on diamond layer cooling in brazing. The greatest difficulties at optimization of DHAC brazing technology consisted in heating of DHAP substrate surface up to a temperature ensuring filler metal spreading, at intensive simultaneous cooling of the diamond layer.

As in the opinion of the authors of this work, temperature of DHAP diamond layer should not be higher than 700–720 °C, and temperature of brazing DHAP substrate surface should be not less that 930–950 °C, temperature gradient by DHAP height should be of the order of 80–90 °C/mm. Analysis of the process of brazed seam formation and its condition after shear testing showed that the best and most stable results were obtained with application of LNKoMts filler metal. However, the authors do not give any data on wear resistance of brazed joints that is the main characteristic in drill bit operation.

At DHAP joining with HAM actually brazing of two hard alloys is performed, as the diamond coating is located on DHAP outer surface. Graphitization temperature of each grade of synthetic polycrystalline diamonds depends on many factors, including degree of purity (quantity of impurities of metals-catalysts), heating environment and time of soaking at elevated temperature [4]. Such features of synthetic diamonds should be taken into account at selection of filler metal composition, and its temperature interval of melting. PWI conducted extensive investigations in this direction [5–7].

Investigation of DHAC and DHAP thermal stability (see Figure 1) showed that the diamond layer in local DHAP degrades at the temperature of about 650–680 °C. As the currently available filler metals have liquidus temperature above 700 °C, the method of brazing with forced cooling was developed for joining DHAP with HAM. This requirement was realized in a specially designed unit of ingenious design (Figure 3), which allows performing simultaneous or separate heating of DHAP and HAM, measuring temperature on the surface of DHAP diamond layer, as well as changing the temperature of DHAP and HAM heating and cooling.

Calculation of the inductor for brazing presents considerable difficulties. As a result of the skin effect, current density is non-uniformly distributed across the section of inducing current wire. Actually, most of the inductors for brazing, particularly those at radio frequencies (UHF) are made proceeding from experimental data with subsequent retrofitting after testing them in operation. When designing the inductor, we tried to apply an enclosing structure, when the inductor is located outside the item being brazed, and follows the component configuration in the brazing zone. Enclosing inductors are characterized by the highest efficiency and provide more uniform heating [8].

At design of parts to be brazed, we envisaged the possibility of mounting an inductor of such a configuration that would ensure heating of the required zone. Inductor position was selected allowing for the mass and thermophysical proper-

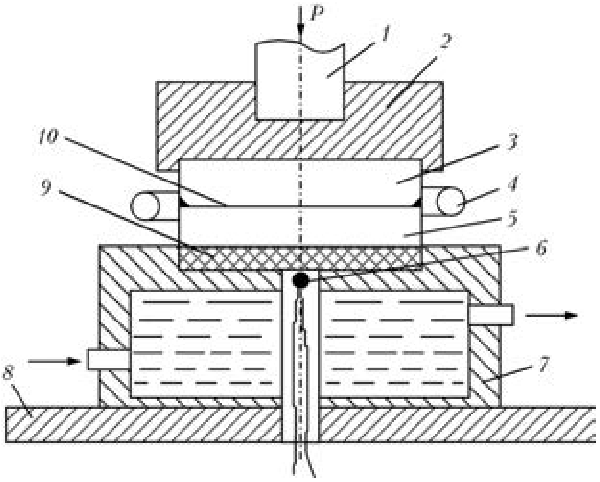


Figure 3. Schematic of device for induction brazing of DHAC: *1* — support; *2* — ceramic insert; *3* — HAM; *4* — inductor; *5* — DHAP; *6* — thermocouple; *7* — cooler; *8* — base; *9* — diamond layer; *10* — seam

Table 1. Shear strength of joints of hard alloy plates VK8 + VK8

Sample number	Filler metal grade or system	T_b, °C	Compression force P, kg	Shear strength τ_{sh}, MPa
1	Ag–Cu–Zn–Ni–Mn	700	3217	225
2	Ag–Cu–Zn–Ni–Mn–2Pd	730	3575	250
3	PM-50	850	4032	282
4	PM-72	950	3675	257
5	PSr-40	620	3500	245
6	Ag–Cu–Zn–Ni–Mn–5Pd	750	4500	315
7	Ag–Cu–Zn–Sn–Mn–Ni	750	5634	394

ties of materials so that the parts being joined reached the brazing temperature simultaneously.

DHAP + HAM heating temperature was determined using thermocouples of chromel-alumel type of two-channel meter-regulator of TRM 202 type. As a result of conducted experiments inductor location relative to mated composite parts of DHAC was selected. Heating was conducted from a more massive part, considering that the less massive part can be heated both by induction currents, and due to heat transfer from the massive part (Figure 4). To improve heating efficiency the gap between the inductor and heated surface of the parts was selected to be minimum in the range of 5–7 mm.

Heating duration in brazing essentially influences the quality of brazed joints. Short time of heating (less than 5–10 s) is insufficient for completion of the process of cleaning by the flux of the surfaces to be brazed and achievement of the same temperature by all the elements participating in brazing. At longer time of heating oxidation of filler metal and brazed metal takes place, leading to deterioration of the results (defects) of brazed joints.

As a result of conducted experiments on optimization of technologies and modes of heating, a graph of temperature distribution in the body of parts being brazed, was plotted. Figure 4 shows the curves of temperature distribution at induction heating of hard alloy substrate under the condition that at 0.1 cm depth the temperature is equal to 700 °C. It follows from the given data that the smaller the depth of current penetration, the higher is the surface temperature and the lower the temperature in deeper-lying layers. In our case, an inductor was selected, which provides uniform temperature field of the brazed parts at heating.

Selection of optimum composition of filler metal in DHAC manufacture, requires determination of shear strength and wear resistance of brazed joints. At the first stage at brazing of samples for shear testing filler metals given in Table 1 were applied. The Table also gives the results of testing performed using a special device in R-05 rupture machine at ISM.

At the second stage — at determination of wear resistance — DHAP + HAM were joined. For this purpose DHAC was made using the above filler metals, and wear resistance testing of DHAC diamond layer was performed in a special facility, which simulates the actual service conditions. The essence of this method [9] consists in that friction of tested sample against an abrasive surface is performed and then its wear intensity is determined. In other words, gauging

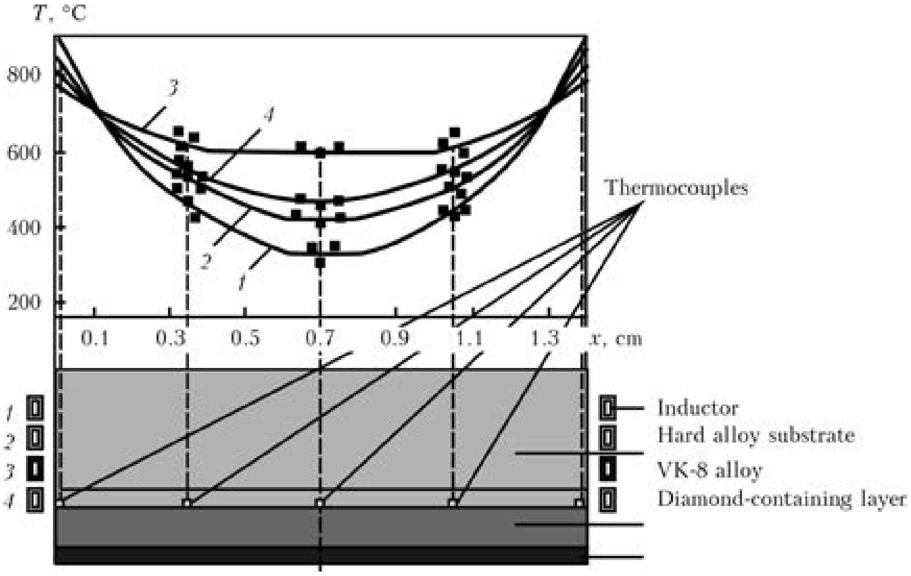


Figure 4. Influence of inductor position (*1–4*) relative to the blank on temperature distribution across the section of hard alloy substrate

Table 2. Wear resistance testing of DHAC hard alloy plates

DHAC sample number (DHAP + HAM)	Filler metal alloying system	DHAP cooling	Feed range, m (rock is sandstone)	Extent of wear on back edge *h*, mm
1	Ag–Cu–Zn–Cd (PSr-40)	Yes	50	0.15–0.20
2	Ag–Cu–Zn–Ni–Mn	Same	50	0.18–0.20
3	Ag–Cu–Zn–Ni–Mn–5Pd	No	30	Complete wear
4	Ag–Cu–Zn–Ni–Mn–5Pd	Yes	50	0.15–0.22
5	Cu–Zn–Mn–Ni–Sn–Cr (PM-50)	No	20	Complete wear
6	Cu–Zn–Mn–Ni–Sn–Cr (PM-50)	Yes	50	1.5–2.0
7	Cu–Mn–Ni–Si–Fe (PM-72)	Same	15	Complete wear
8	Ag–Cu–Zn–Sn–Mn–Ni	»	50	0.15–0.22

of that rock for which the sample is intended is performed.

DHAC brazing without cooling by various filler metals leads to complete wear of the diamond layer. Results of wear resistance testing showed that at brazing with filler metals of PM-50 and PM-72 grades DHAC are characterized by the lowest wear resistance even with cooling, and they cannot be applied in manufacture of drill bits, even though at studying of hard alloy material wetting these filler metals showed one of the best results and satisfactory shear strength.

DHAC wear resistance in the presence of cooling system could be increased up to the required level at application of filler metals of Ag–Cu–Zn–Cd, Ag–Cu–Zn–Ni–Mn, Ag–Cu–Zn–Ni–Mn–5Pd and Ag–Cu–Zn–Sn–Mn–Ni systems, having a lower melting temperature (610, 700, 740 and 720 °C, respectively). They ensure the required extent of wear not greater than 0.3 mm that allows them to be used in manufacture of drill bits, designed for well drilling on soft, medium-hard and hard abrasive rocks. Investigation data are given in Table 2.

Conclusions

1. Influence of temperature-time cycle of brazing on DHAC diamond layer and its performance (thermal stability and wear resistance) was established.

2. Developed technology of brazing DAHP + HAM provides lowering of heat impact on the diamond layer and allows preservation of its service properties at a high level

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