MANUFACTURE OF DRILL BITS FOR PRODUCTION OF DISPERSED METHANE IN MINE WORKING

V.F. KHORUNOV, S.V. MAKSYMOVA and **B.V. STEFANIV**
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

The effect of the brazing temperature on performance of diamond-hard alloy cutters was investigated. It was shown that a combination of the developed brazing filler metals and technology provided a substantial increase in length and rate of well drilling, which was proved by the industrial test results.

Keywords: *superhard materials, diamond layer, diamond-hard alloy cutter, rock destruction tool, bit, methane, brazing, brazing filler metal*

The main tool for efficient drilling of the earth's interior in production of hydrocarbons is a bit for rotary drilling, which is classified as a bit with fixed cutters, or roller bit, intended for different rock types and a wide range of conditions [1]. The bits with fixed cutters have blades, which are a single whole with the body and are rotated together with it. The roller bits have metal roller cones, which are independently rotated with rotation of a bit in a working face.

The cost of drill bits is only 1–5 % of the total cost of a well, but they directly determine the cost of drilling a unit length of the well, as the time required to drill it depends upon the drilling rate and service life of a bit till wear. The bits with fixed cutters are more expensive. But they drill quicker and their lifetime is longer, compared to the roller ones, in some hard and abrasive rock. They can be fitted with cutters with natural or synthetic diamonds. Cutters with synthetic polycrystalline diamonds are more resistant to impact loads than with the natural ones, and are very efficient in hard, moderately abrasive rock. The efficiency of using these diamonds is limited by thickness of a diamond plate, which is determined by diffusion of cobalt from the hard-alloy substrate into the diamond layer, as well as by stresses induced by thermal expansion of tungsten carbide and its shrinkage. High residual stresses and dry diamond grains may cause delamination, exfoilation and cracking in the diamond plates as a result of incomplete penetration of cobalt in synthesis of polycrystalline diamonds. In turn, this reduces the service life of a cutter and a bit as a whole [1].

In the CIS countries, the key materials to manufacture tools are cermet hard alloys of the type of VK-6, VK-8, VK-15, VK-20 etc., and superhard materials, such as natural and synthetic diamonds. Theoretical and technological principles of producing such materials were worked out by the V.N. Bakul Institute for Superhard Materials of the NAS of Ukraine [2, 3].

The purpose of this study was to select brazing filler metals, develop technology for brazing diamond-hard alloy cutters (DHAC) and technology for manufacturing drill bits. The DHACs (Figure 1) are manufactured by brazing diamond-hard alloy plates (DHAP) to hard alloy holders (HAH), i.e. tungsten carbide base alloys, where cobalt (2 to 25 wt.%, depending on the alloy grade) is used as a binder. The DHACs employed in the experiments were hard alloy cylinders with a diameter of 13.5 mm and height of 3.5 mm, coated with a 0.7–0.8 mm thick layer of synthetic polycrystalline diamonds. The diamonds used in the form of crystals with a maximal size of 20–60 μm are characterised by shape stability, high hardness, wear resistance, and low thermal expansion coefficient.

Diamond is a meta-stable modification of carbon, and physical-mechanical properties of the diamond layer dramatically degrade in heating of DHAP to a critical temperature (670–700 °C) [3, 4] because of diffusion interaction between the diamond particles and cobalt (Figure 2). Catalytic graphitisation of polycrystalline synthetic diamonds, formation of cracks due to different thermal expansion coefficients of diamond and cobalt, and, as a result, fracture of the diamond layer take place.

The temperature of graphitisation of each grade of synthetic polycrystalline diamonds depends upon many factors, including the degree of purity (content of metal catalyst impurities), heating environment and time of holding at an increased temperature. Therefore, to manufacture DHAC by brazing traditional DHAP (with polycrystalline synthetic diamonds) to hard alloys, it is necessary to allow for the above peculiarities of the synthetic diamonds. Melting point

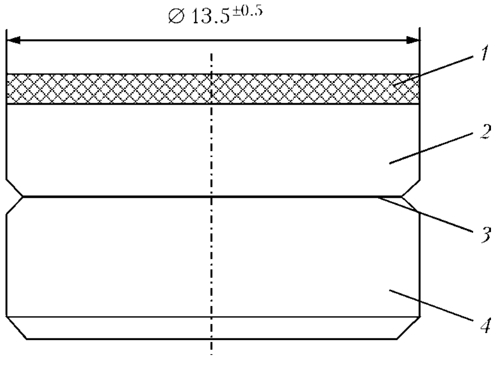

Figure 1. Schematic of DHAC: *1* — diamond layer; *2* — hard alloy substrate; *3* — brazed seam; *4* — HAH

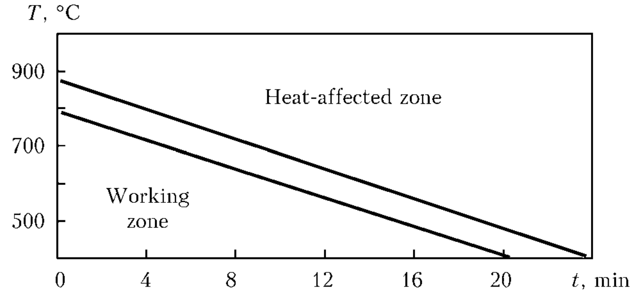

Figure 2. Dependence of ultimate heating temperature of DHAP on heating time

of a brazing filler metal should not exceed 650–700 °C, and it should be characterised by good fluidity and wettability with respect to the base materials. As the base material and brazing filler metals have substantially different thermal expansion coefficients, the filler metals should be characterised by a high ductility for relaxation of stresses induced at the interface between the phases. Moreover, considering loads that affect DHAC during operation, shear strength of the brazed seam should be not lower than 300 MPa, and wear of DHAC under the test conditions given below should be no more than 0.2 mm.

Such contradictory requirements are hard to meet with the DHAC manufacturing technology that exists since the Soviet time and with the available brazing filler metals. For example, copper-zinc filler metals alloyed with different elements, which improve their physical-mechanical and technological characteristics, have received wide acceptance for joining hard alloys. These filler metals spread well over hard alloys and are extensively applied to produce joints of these materials. However, using them for brazing DHAP leads to degradation of synthetic diamonds because of a high temperature of the process.

Copper-silver filler metals characterised by a low melting temperature, sufficient ductility and good fluidity hold more promise for brazing DHAP to hard alloys. The base in this case is eutectic alloy of the Cu–Ag system with a melting point of 779 °C [5]. Adding such materials as zinc, cadmium and tin allows the melting point of filler metals to be decreased, this having a positive effect on their technological properties. The area of spreading of filler metals greatly depends upon their composition (Table).

It should be noted that joining DHAP to HAH is, in fact, brazing of two hard alloys, as the diamond coating is located on the outer surface of DHAP. Therefore, at the first stage, to determine shear strength of the brazed joints, two plates of hard alloy VK-8 simulating DHAC were brazed to each other. That made the investigations much simpler and less expensive.

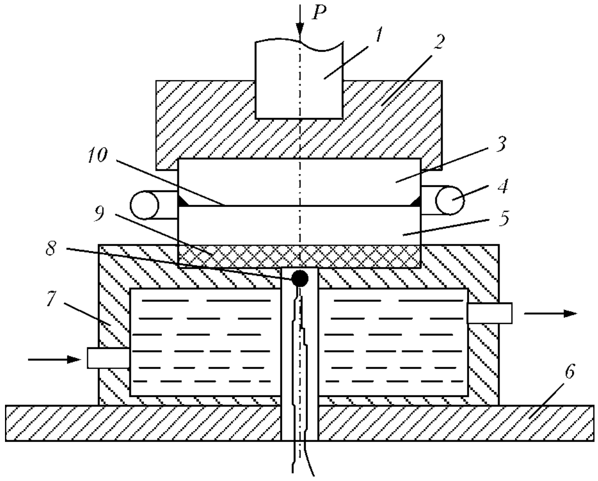

Figure 3. Schematic of fixture for brazing DHAC: *1* — hold-down; *2* — support; *3* — HAH; *4* — inductor; *5* — DHAP; *6* — substrate; *7* — cooler; *8* — thermocouple; *9* — diamond layer; *10* — brazed seam

As shown by the results of mechanical tests, filler metals of the copper-silver system alloyed with other elements (zinc, manganese, nickel etc.) provide a sufficient shear strength (about 300 MPa). However, the shear strength is a mandatory, but insufficient parameter for choosing optimal composition of a filler metal to be used to manufacture DHAC.

To generate the reliable information, it is necessary to subject the brazed joints to the comprehensive tests, which make it possible to evaluate strength and wear resistance. Wear resistance is a key parameter that most realistically reflects service conditions of drill bits fitted with diamond cutters. The level of wear resistance depends upon the temperature of heating of the diamond layer and time of holding at this temperature. Therefore, brazing of DHAC to investigate wear resistance was carried out in a special fixture (Figure 3), where the diamond layer contacted the surface being cooled (to compare, some cutters were brazed without cooling). The heating parameters provided by generator VChI4-10U4 were as follows: I_{grid} = 0.1 A, I_{anode} = 0.6–0.7 A. The resulting cutters (Figure 4) were tested on a rig that simulated real

Area of spreading of brazing filler metals over hard alloy substrate

Basic system (filler metal grade)	Heating time, s	Filler metal melting temperature range, °C	Filler metal spreading area, mm^2
Ag–Cu–Zn–Cd (PSr-40)	24	590–610	89.87
Ag–Cu–Zn (PSr-45)	27	665–730	67.63
Ag–Cu–Zn–Sn (BAg-7)	26	618–651	46.33
Ag–Cu–Zn–Ni–Mn (BAg-22)	23	680–699	121.40
Cu–Zn–Mn–Sn–Ni (PM-50)	25	780–870	119.18
Cu–Mn–Fe–Ni (PM-72)	40	810–890	50.19

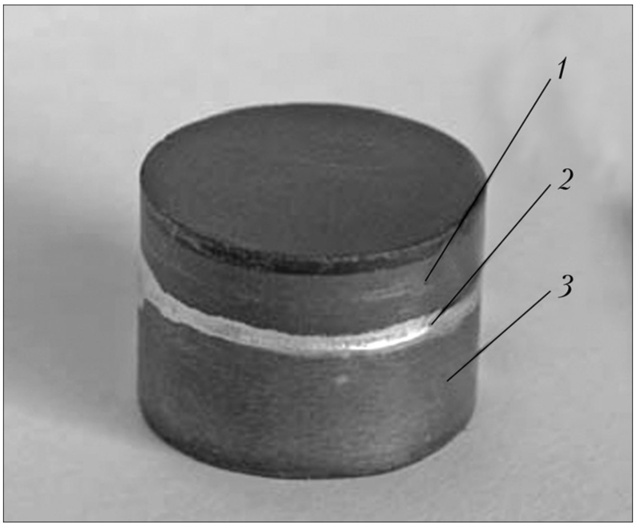

Figure 4. Brazed DHAC for drill tools: *1* — DHAP; *2* — brazed seam; *3* — HAH

service conditions. In other words, it was gouging of the rock (e.g. quartz sandstone) for which a given cutter was meant.

The test parameters were as follows: longitudinal feed speed — 0.55 m/s, cut depth — 0.5 mm, transverse feed — 28 mm/pass, no cooling, and rock destruction products were not removed from the gouging zone (no water was used). The value of wear after gouging was measured on the rear edge of DHAC by using optical microscope. The tests conducted allowed choosing the filler metals that provided the required level of wear resistance, which was not in excess of 0.2 mm. The results obtained were used to develop the technology for brazing DHAC to a blade. This is the most critical operation in terms of maintaining properties of the diamond layer. With the traditional technology, brazing of the cutters is performed in series, i.e. the previous cutter is subjected to repeated heating when brazing the next cutter. Moreover, induction heating is sometimes combined with flame (surface) one, this being dangerous in terms of the probability of the direct contact of the diamond layer with the torch flame.

The special design of an inductor providing a uniform temperature field within the zone of brazing of cutters was developed in the course of this study. That made it possible to perform simultaneous brazing of all cutters by using only high-frequency heating. With this technology, the diamond layer is held at a high temperature for a minimal time and preserves its properties required for operation. It should be noted that the optimal compositions of filler metals provide good wetting of low-alloy steel of a blade and substrate material of the cutters, as well as reliable fixation of the latter in the blade (Figure 5).

Joining of blades to the body was carried out by semi-automatic MIG welding in argon atmosphere. Welding conditions, quantity and sequence of deposition of welds, time pauses for cooling of the welds etc. were selected. The special attention was given to welding of the upper part of a bit, where the welding arc went closely to the diamond layer.

Figure 5. Blades of drill bits with DHAC brazed into them

Figure 6. Drill bit fitted with DHAC

The developed technology and filler metals were applied to manufacture a batch of the bits intended for drilling the medium-hardness rock (Figure 6). The bits successfully passed industrial tests and were used in the process of production of dispersed methane at the A.F. Zasyadko Mine.

The industrial tests showed that application of the optimal compositions of filler metals and the developed technology by using the domestic DHAPs allowed increasing the drilling length from 100–120 to 400–450 m. When using foreign DHACs with no change in design of the bit and stabiliser, the drilling length was increased to some extent, but capabilities of these cutters were underutilised. And only the combination of the improved design of the bit and stabiliser, developed brazing filler metals and technology made it possible to achieve a drilling length of over 1000 m (without repair). After removal of accidental damages caused, e.g. by harder rock inclusions, the drilling length increased to 1500–1700 m or more.

1. (2000) Besson, A., Burr, B., Dillard, S. et al. (2000) On the cutting edge. *Oilfield Rev.*, Autumn, 36–57.
2. Novikov, I.V. (2008) Development of synthesis of superhard materials. In: *Actual problems of current materials science*. Vol. 2. Kiev: Akademperiodika.
3. (2005) *Tools from superhard materials*. Ed. by N.V. Novikov. Moscow: Mashinostroenie.
4. Artyukhov, V.P., Pruss, O.P. (1997) Analysis of the processes of brazing of diamond-hard alloy cutters. *Sverkhtv. Materialy*, **2**, 38–43.
5. (1996) *Constitutional diagrams of binary metallic systems*: Refer. Book. Ed. by N.P. Lyakishev. Vol. 1. Moscow: Mashinostroenie.