PECULIARITIES OF INDUCTION BRAZING OF DIAMOND-HARD ALLOY CUTTERS TO BLADE OF BODY OF COMPLEX DRILL BIT

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It is determined that application of existing technology for brazing of diamond-hard alloy plates (DHP) and hard alloy holder to bit blade does not provide necessary quality of parts due to overheating of brazed-in cutter in brazing of the next one that results in overheating of following diamond-hard alloy cutter (DHC) and degradation of diamond layer owing to graphitization. Different heat sources of bit blades for brazing were analyzed. Technology of induction brazing of DHC to drill bit blade providing necessary characteristics of diamond layer of DHC as a cutting tool was developed. Manufacturing process of induction brazing of DHC to drill bit blade allowing brazing of DHC to blade without overheating of its diamond layer and preserving its high level service characteristics was designed. It is shown that proposed technology of induction brazing of DHC to bit blade allows using brazing filler materials with brazing temperature not more that 680–700 °C without loose of this layer serviceability. Brazing filler materials of standard origin and developed at the E.O. Paton Electric Welding Institute of the NAS of Ukraine were tested in process of investigations. A conclusion that brazing filler materials of Ag–Cu–Zn–Ni–Mn and Ag–Cu–Zn–Sn–Ni–Mn systems are the most perspective for induction brazing of DHC to blade was made based on results of generalization of test complex. Technology of welding of blades to body of drill bit was developed which allows reducing spattering of electrode metal on diamond layer of DHC and improving weld formation. This technology of brazing of DHC to blades of body of complex drill bit was applied in full-size products and tested under real service conditions during on-land drilling of gas wells. 6 Ref., 1 Table, 5 Figures.

Keywords: *induction brazing, superhard materials, diamond-hard alloy cutter, diamond-hard alloy plate, hard alloy holder, bit, heat resistance, brazing filler material*

Technology of manufacture of drilling tool with diamond-hard alloy plates (DHP) in Ukraine was developed at the V.N. Bakul Institute for Superhard Materials of the NAS of Ukraine. However, domestic technology of manufacture of diamond drill bits, developed many years ago, does not fulfill current requirements. Brazing of DHP and hard alloy holders to blade was combined in known technology that did not allow controlling temperature of diamond layer. The situation was aggravated by application of induction heating with loop inductor which was used for subsequent brazing-in of hard alloy holder and DHP to the blade. In this case, non-uniform temperature field was created in brazing of the next DHC as well as reheating of brazed-in DHC during brazing of the following one took place. Moreover, induction heating was combined sometimes with flame heating that creates the danger of direct contact of diamond layer with torch flame. Development of new technology requires investigation of various aspects of this process.

Aim of the present study lies in development of technology for brazing of DHC to blade and welding of blade to body of complex bit for providing minimum effect of heating on diamond layer properties, i.e. preservation of service characteristics of diamond layer of DHC as a cutting tool, increase of wear-resistance and value of headway of drill bit up to the level of foreign analogues.

The aim put by is achieved through development of new designs of drill tool [1, 2], i.e. setting of additional diamond-hard alloy cutters (DHC) on bit gage surface is used for drill bit and increase of dimensions of dovetail grooves for washing and lifting of cuttings and new brazing technology are applied for calibrator.

Present study provides the results of investigations on DHC joining to blade with the help of brazing. Different sources of heating of bit blades for brazing are analyzed. Selection of method and equipment providing necessary efficiency of the process, convenience and safety of equipment operation as well as control of brazing parameters has significant importance. Correct selection of equipment and method of brazing

Classification of methods for brazing of hard alloy tool

Brazing method	Tool	Type of production
Brazing in continuous furnace with shielding atmosphere	All, except for large-size cutters of cutoff saws	Mass, large-scale, small-scale of different types of tool at large output
Brazing in chamber furnaces with atmosphere shielding	Same	Small-scale, piece
Induction brazing with operating frequency 2–66 kHz	Large-size and cutoff saws, drilling tool, road harrow	Any
Induction brazing with operating frequency 66–440 kHz	Cutoff cutters, drilling tool, cutoff saws with body thickness not more than 4 mm	»
Resistance soldering	Disc saws and cutters for treatment	Special
Flame brazing	Outsize drilling bit	Small-scale, piece production, repair

provides optimum conditions for formation of strong weld, elimination of high level of residual stresses, and, respectively, increase of service life and safety of tool in process of its operation.

Finished brazing filler materials are used for tool brazing, therefore, brazing is classified as a rule on method of heating. In turn, these methods are divided on methods of shielding of brazed joints from oxidation during brazing. Besides, their selection depends on scale of planned production, i.e. whether it will be small-scale production with large variety of products or large-scale production of single-type tool (Table).

Induction brazing is the most widespread method of manufacture of drilling tool, regardless large quantity of variants of performance of brazing process and variety of equipment. Further, the most attention is given to this method of brazing of drilling tool and the main principles of preparation to brazing, location of DHC, hard alloy inserts, brazing filler material, flux and positioning of tool in the inductor are considered.

Induction brazing is the most highly applied method of manufacture of hard alloy tool as in small-scale production and piece brazing as well as in large-scale production.

Efficiency of induction heating depends on electric parameters caused by characteristics of generator and inductor (current frequency, field intensity, proximity effect and etc.) and physical-chemical properties of tool and structural materials. Increase of frequency of generator current rapidly decreases depth of current penetration in material being brazed, i.e. gradient of temperatures on its surface and in depth is increased.

Heat conduction of hard alloy of tungsten group (VK) is 1.5 times higher than heat conductance of structural steel and 3 times than that of hard alloys of titanium-tungsten group (TK). It rises several times with increase of cobalt content. Specific electric resistance of hard alloys of TK group is 2 times higher of that in hard alloys of VK group and temperature conductivity of hard alloy of TK group is 3.5 times lower than in hard alloy of VK group. This explains low heat resistance of hard alloy of TK group in comparison with VK group. On practice, this results in appearance of cracks in tool using hard alloys of TK group. These materials require keeping of conditions of uniform smooth heating and cooling of tool in process of brazing.

The most important in the process of brazing is not to allow band heating of hard alloy, in particular, of VK group, that can result in formation of cracks in the tool. TVCh generators of 10–66 kHz frequency are the most universal at the present time. Higher values of frequency can be used for small parts, however, there are some manufacturing difficulties with uniform heating control, that results in loss of process efficiency and appearance of critical residual stresses. Modern TVCh units can be equipped by programmer with controller providing high uniform heating of parts based on set program at speed corresponding to that of rejection of heat in the internal material layers. Heating speed of 40–100 °C/s is considered the optimum one that, except for mentioned above, can be achieved through corresponding selection of gap between the part and inductor (8–15 mm). Reduction of gap results in non-uniform heating.

Configuration of the inductor was chosen based on minimum temperature difference at heating of operating elements of blades for brazing. Uniformity of heating was determined in experimental way. The blind holes were drilled in blade housing for this. Distribution of temperature in the blind holes of the blade is determined with the help of thermal couples of TKhA type and several TRM202 devices at set specific heat power (Figure 1). Surface heating could not provide uniform distribution of temperatures in the surface layer. Temperature of body surface is always higher than set for internal boundary of the layer. It can be seen from Figure that the lower time of heating, the higher is surface temperature and the lower is temperature in the deeper layers.

Double-loop inductor of special structure (Figure 2) providing uniform temperature field in area of cutter brazing was developed for brazing of DHC into blade working zone. Procedure of selection of size and shape of inductive drive (inductor) was determined in experimental way. In our case, the values of current in each wind depend on gap between part and inductive drive as well as geometry dimensions of winds. This effect is used in some cases for achievement of required temperature of heating of parts of different section and sizes.

As can be seen from Figure 2 showing also the curves of temperature distribution in body (housings) of blade being heated, the first loop of inductor heats working zone up to 680–700 °C and the second loop plays a role of preheating up to 580–600 °C. At induction heating the electromagnetic energy from outside comes inside the body through its surface and then transforms into the heat energy inside the body. Heat energy due to heat conduction effect moves from the places with high temperature to the places with low one. Temperature of separate points of the body is constantly changes. Dependence of temperature on geometry coordinates is determined by distribution of heat sources in the blade being heated, properties of material and time during which heating takes place.

Surface and deep heating are used in our case allowing obtaining uniform heating of the part in required zone without preheating of the separate areas. It is necessary to increase time of heating and reduce specific power supplied to the part for this. The effect of heat conduction is observed in our case as well providing transfer of heat to the less heated areas. In this situation a character of temperature distribution is different than in heat transfer from outside when using only effect of heat transfer. Since heat evolution mainly takes place in a layer of Δ thickness (where Δ is the depth of current penetration), then temperature in this layer has the highest increase. In deeper layers the temperature achieves smaller values during the same time. However, difference in temperatures is small [3] in scope of layer of Δ thickness.

Performance of simultaneous brazing of all cutters to the blade became possible only with the help of high-frequency heating. When using this technology, the diamond layer of the cutter stays minimum time at high temperature and pre-

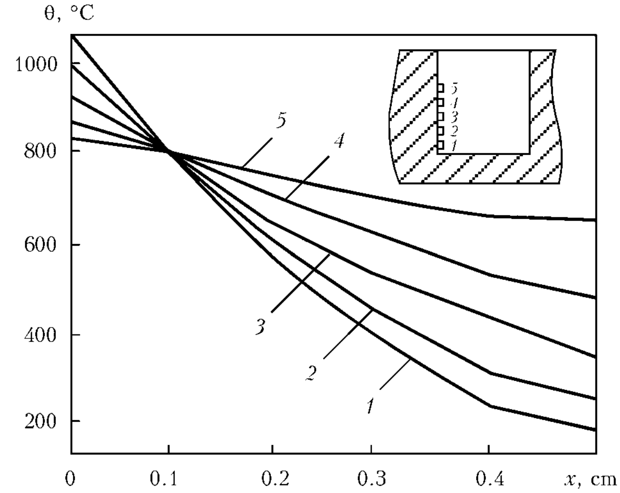

Figure 1. Distribution of temperature in steel body of the blade at set specific heat power under condition of obtaining of specified temperature of surface θ = 800 ± 20 °C at 0.1 cm depth: *1* — t = 1.5 s; *2* — 2.8; *3* — 3.2; *4* — 4.5; *5* — 10

serves required technological properties in operation. At that, temperature field in zone of the cutter brazing became smooth along the whole operating element of the blade, brazing temperature makes approximately 680–700 °C. It should be noted that developed compositions of brazing filler materials of Ag–Cu–Zn–Ni–Mn and Ag–Cu–Ni–Mn–Pd [4, 6] systems which were used in brazing of complex DHC, give good wetting of low-alloy steel of the blade and material of the cutters' substrate as well as provide safe join-

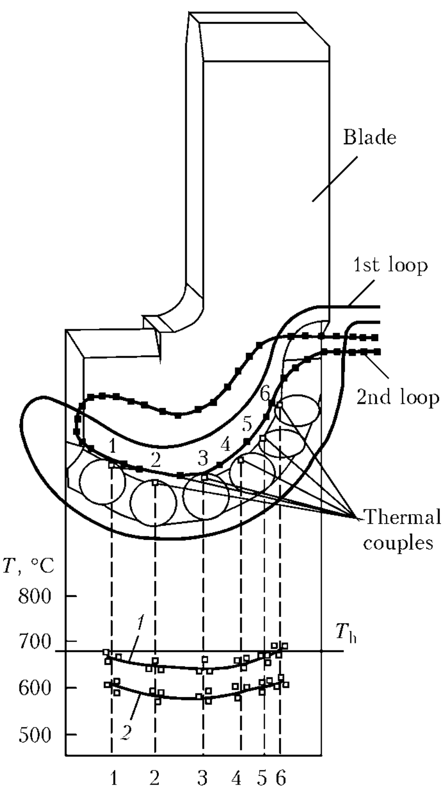

Figure 2. Scheme of location of double-loop inductor and distribution of temperatures in zone of brazing in connection of two loops (*1*) and one (*2*) loop

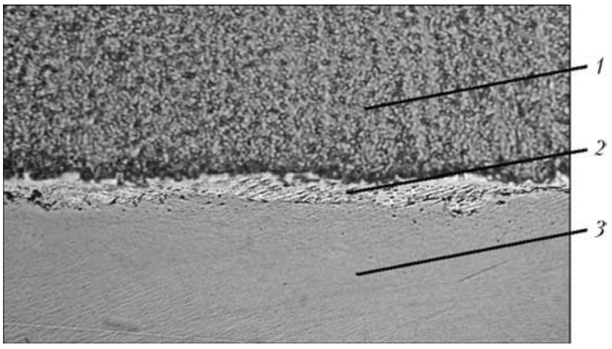

Figure 3. Microstructure (×300) of brazed DHC + steel joint before drill bit testing: *1* — hard alloy VK8; *2* — brazed seam; *3* — steel 30Kh

ing of the latter to blade. Analysis of microstructure of brazed joint shows that brazing filler material of Ag–Cu–Zn–Ni–Mn system gives good wetting of hard alloy as well as steel, moreover fusion zone from both sides is smooth without formation of wide diffusion zones. Figure 3 shows microstructure of brazed DHC steel joint.

Results of mechanical tests showed that the brazing filler materials of copper–silver– zinc–tin system, alloyed by other elements (manganese, nickel, palladium etc.) provide sufficient shear strength (around 300 MPa) and good spreading of the brazing filler material over steel blade as well as hard alloy.

It should be noted that brazing filler materials of Ag–Cu–Zn–Ni–Mn and Ag–Cu–Ni–Mn–Pd systems are suitable on their technological properties for brazing of DHC to bodies of drill bits. The experiments were carried out using generator VChI4-10U4 of 10 kW power. The following devices were developed and manufactured for DHC to blade brazing:

Figure 4. Appearance of bit blade with brazed-in DHC

- single loop inductor for front end part of the operating blade where brazing of diamond-hard alloy inserts takes place;
- double loop inductor for front part of the operating blade where DHC brazing takes place;
- regulating device which holds the blade in set position relatively to the inductor.

Surfaces of the blade parts being joined are cleaned from dirt, grease and corrosion products before DHC to blade brazing. Checking of accuracy of value of gaps on diameter of hole in 0.05–0.1 mm range relatively to DHC was made. Then flux of PV-209 grade was spread in zone of brazing in a form of paste, manufactured by means of flux and water mixing in a form of pastry mixture at water to flux proportion 100:60 (wt.%) as well as inserts of brazing filler material and DHC were introduced in the blade holes. High-frequency heating of working zone of mating parts, i. e. DHC and brazing zone of operating elements of the blade was carried out up to complete melting of the brazing filler material and formation of outer fillet areas on whole section of DHC to blade holes. If incomplete braze penetration of DHC to blade holes is found, the brazing filler material in form of wire of 1.2–2.0 mm diameter was additionally introduced in the braze zone. The following parameters of heat source were used in DHC to blade brazing, i.e. I_{main} = 0.7 A; I_{anode} = 1.5–2.0 A. Figure 4 shows appearance of blade with brazed-in DHC of drill bit.

Technology of joining of blades to body of drill bit, developed at the V.N. Bakul Institute for Superhard Materials of the NAS of Ukraine, was performed by manual arc welding. At that electrodes of ANO-4 grade of 4 and 5 mm diameters were used. Weld leg was reinforced with the help of manual arc welding by UONI-13/55 grade electrodes of 3 mm diameter. The main disadvantage of this technology is reheating of DHC in blade to body welding, at which degradation of diamond layer of DHC takes place, that, in turn, influences on chemical-physical properties of DHC. Significant spattering of electrode metal in zone of DHC being brazed is observed in process of welding. Technology of steel welding in shielding media [5] was used for elimination of these disadvantages in joining of blades to bit body. As a result reduction of electrode metal spattering on diamond layer of DHC and improvement of weld formation were achieved. Maintaining of optimum welding conditions helps to eliminate overheating of the operating elements of diamond-hard alloy plates at which secondary melting of the brazing filler material can take place.

According to proposed technology, joining of blades to body of drill bit was performed using semi-automatic welding in mixture of shielding gases (82 % Ar + 18 % CO_2) by copped-coated wire Sv-08G2S of 1.2 mm diameter on Fronius device at welding current I_w = 180–200 A and voltage U = 18–20 V. No reinforcement of the weld legs was carried out, since metal filled in the gap between blade and bit body met strength characteristics of welded joint of bits, tested under real service conditions. Optimum welding conditions, quantity and sequence of weld deposition, time pauses for weld cooling and etc, were worked out. Particular attention was paid to welding of upper part of bit blade where welding arc is close to diamond layer of DHC.

Figure 5 shows new design of diamond drill bit with calibrator of 132 mm diameter for on-land drilling of gas and oil wells after brazing and welding. Industrial tests were successfully carried out using new designs and new brazing technology at Zasyadko Coal Mine.

Pilot-industrial batch of drill bits for underground and on-land drilling of wells for recovery of dispersed methane was manufactured using pilot batches of brazing filler materials of Ag–Cu–Zn–Ni–Mn and Ag–Cu–Zn–Ni–Mn–Pd [6] systems that allowed extending their service resource as well as several times increase value of well headway.

Figure 5. Drill bit with calibrator for on-land drilling of wells

Conclusions

1. New technology was developed for brazing of diamond-hard alloy cutters to blades, according to which all the cutters in contrast to known solutions are brazed in the blades simultaneously that eliminates secondary heating of the cutter and reduces danger of diamond layer degradation.

2. Technology of production of drill bits and calibrator developed at the E.O. Paton Electric Welding Institute was implemented at Zasyadko Coal Mine (Donetsk) for underground and on-land drilling of gas wells.

3. It is determined based on results of performed commercial investigations of diamond drill bits equipped with diamond-hard alloy cutters that application of indicated bits for on-land drilling of gas wells increases wear-resistance of drilling tool and speed of drill in comparison with serial bits of Russia and Ukraine.

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