$= \frac{R_{K1} + R_{K2}}{2}$ is the average value of radius of circular membrane fold.

CONCLUSIONS

1. In the studied range of geometrical parameters of double-wall TSS the optimum structure is the one, in which the rectilinear and circumferential joints with different requirements to strength and ductility of welds are made by microplasma and laser welding processes.

2. Studied technology of producing permanent joints of austenitic stainless steel sheets allows ensuring the leak-tightness of deformable shells, both during forming, and at reverse transformation using excess pressure.

3. Complete transformation of double-wall TSS of a conical type up to design dimensions by creating excess pressure in the inner cavity, is possible with following of certain regularities of geometrical parameters on their inner and outer shells. Required ratios of working volumes of air in the structure interwall space are determined by relative values of radii of its bases, and are independent on the angle of conicity of the side surfaces at fulfillment of the condition of their isometricity.

4. The structure obtained by tight joining of double-wall conical TSS to each other preserves the functional properties of transformable elements included into it. The change of configuration of interwall gaps of each double-wall shell, associated with the need to unite the structure inner space into one volume, should be accompanied by fulfillment of the established dependencies of geometrical parameters in the connections.

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PECULIARITIES OF WEAR AND CRITERIA OF REPAIRABILITY OF DRILL BITS WITH DIAMOND–HARD-ALLOY CUTTERS

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The degree of wear and criteria of repairability of drill bits with diamond–hard-alloy cutters were studied. Statistical data on service life of different types of diamond drill bits were analysed.

Keywords: *headway, mechanical speed, superhard materials, diamond layer, diamond–hard-alloy cutter (DHAC), wear resistance, drill well, polycrystalline diamond cutter (PCDC)*

The rocks making up the well bore hole differ in composition and have different properties, depending on which the rocks can be destructed by cutting, spalling, abrasion or crushing. The character of fracture depends on the hardness and ductility of rock. Hence, drilling of wells is performed by using the certain type of tools. The main tool for mechanical destruction of rock to drill a well is a bit. Different types and kinds of bits are applied currently in practice.

The purpose of this study was to investigate peculiarities of wear and criteria of repairability of drill bits with DHACs.

The objects of the study are rotary drilling tools, such as bits, bores, various crowns and drill heads fitted with diamonds, hard alloys or diamond–hard-alloy materials in the form of cylindrical inserts. The drill bits and heads are made from strong and wear-resistant materials, as during the drilling process a bit is affected by axial loads, including impact ones, torque moment, as well as pressure and reactivity of a drilling mud.

In drilling, the initial shape of working surfaces of inserts changes due to wear, this leading to decrease in technical and economic indicators of the drilling tools. Abnormal wear and formation of circular grooves on the working surfaces of the bits make the tools unserviceable.

Wear of the working surfaces of drilling tools is a complex process caused by many factors,

Table 1. Classification for defining of wear of drill bits

Cutting structure				B	G	Notes	
Inside rows (I)	Outside rows (O)	Character of wear (D)	Location (L)	Compaction of support (B)	Wear on diameter B 1/16 (G)	Other types of wear (O)	Cause of pulling out from well (R)
1	2	3	4	5	6	7	8

including properties of the tool materials and rock at the well bottom, quality of design of the tools, efficiency of cleaning of rock destruction elements and flushing-out of the well.

Much factual data have been accumulated up to now concerning the service life of drills with DHACs and their repairability. To drill oil and gas wells, Ukraine applies mostly the drill bits made in the USA, China and Russia, and to a lesser degree the domestic drill bits. A weak point in drilling hard and superhard rocks of the drill wells is considerable wear of the domestic bits, and to a certain degree of the imported ones. To extend their service life, it is necessary to repair these expensive items. However, no repair and reconditioning of the domestic and imported bits are performed in Ukraine. Bits of the leading companies, such as «Reed Tools», «Smith Tools», «Hughes Christensen» and «Volgaburmash», the extent of wear of which is not in excess of 30 %, are taken out from Ukraine for repair to the USA, Canada and other countries.

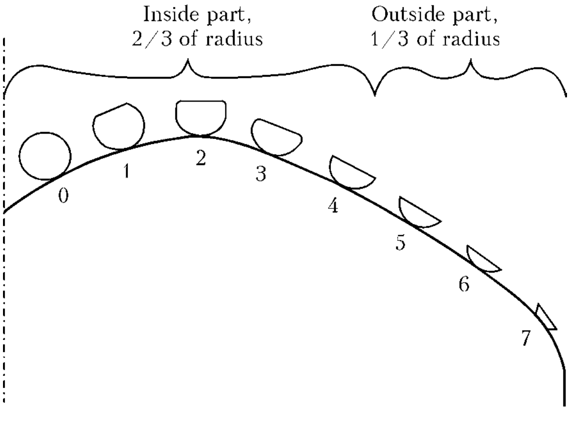

Figure 1. Schematic of wear of cutting structure

Therefore, investigation of the peculiarities of wear and criteria of repairability of domestic and imported bits is a pressing problem, the solution of which will allow extension of service life of the bits and provide much savings.

The E.O. Paton Electric Welding Institute analysed the peculiarities of wear of DHACs of steel and die drill bits, which had been used for drilling of wells in rock. The work was performed by using the method for description of wear of the bits based on the classification system accepted by the International Association of Drilling Contractors (IADC) [1, 2], according to which eight parameters are used to define wear (Table 1). In our case, to define wear it is enough to use six parameters, except columns 5 and 8 of the Table.

Consider in detail the classification for defining wear of bits given in Table 1.

Wear of inside and outside rows. Columns 1 and 2 are used to define wear of the cutting structure. Column 1 (I — inside row) gives the code of wear of that part of the cutting structure which does not touch the well walls in operation of the bit at the well bottom. As a rule, inside rows make up 2/3 of the entire cutting structure (Figure 1). Characterisation of wear of the cutting structure located at the inside rows allows reducing the quantity of variants of wear and determining its cause in more detail.

Column 2 (O — outside row) gives the code of wear of the cutting structure of a bit, which during the drilling process is in direct contact with the well walls. The outside rows make up 1/3 of the entire cutting structure (see Figure 1). Characterisation of wear of this part of the structure helps to evaluate correctness of op-

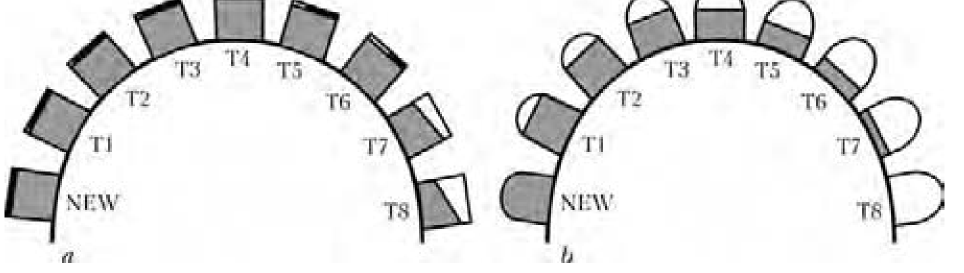

Figure 2. Schematic of wear of DHACs (*a*) and hard-alloy inserts (*b*): *a*: 0 — bit cutter is not worn out; 1–7 — cutter is worn out to 10, 15, 25, 30, 50, 70 and 100 %, respectively; 8 — complete loss of cutting structure; *b*: 0 — bit insert is not worn out; 2, 4, 6 — insert is worn out to 25, 50 and 75 %, respectively

eration of the gauge part of the cutting structure of a bit in the well.

The linear scale in a range of 0 to 8 is used to describe wear of DHACs or hard-alloy inserts. The number of the degree of wear increases with wear of the PCDC (Figure 2, *a*) and hard-alloy inserts (Figure 2, *b*).

Characterisation of wear of a bit. Column 3 (D — character of wear) gives the code indicated in Table 2 to define the main (dominant) character of wear.

Column 4 (L — location) uses the letter or digital code to indicate the location on the bit surface where wear of the cutting structure oc-

Figure 3. Location of the type of wear on drill bit

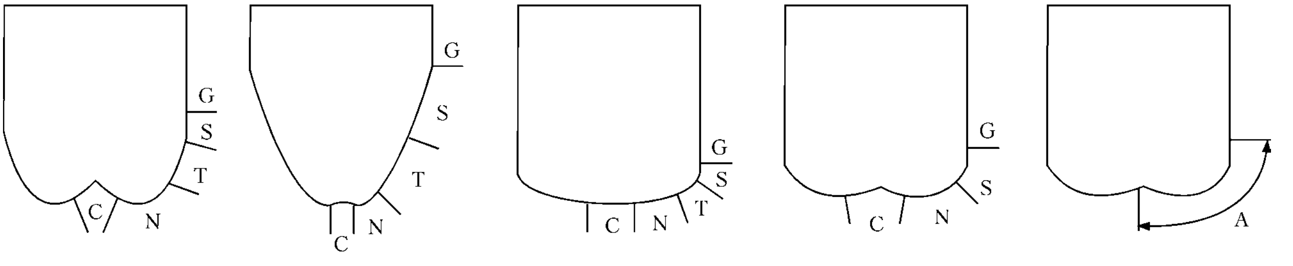

Figure 4. Schematics and codes of wear of cutting structure of bits: N — cutting structure that is closest to the bit top (middle row of bit cutters M is located between rows N and G); G — gauge row, cutting structure located on the gauge surface of bit; A — all rows (entire cutting structure of bit); C — inside cone surface; T — outside cone surface; S — shoulder

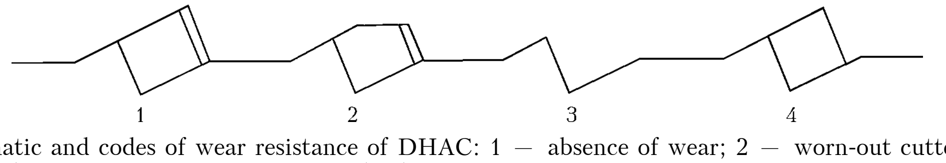

Figure 5. Schematic and codes of wear resistance of DHAC: 1 — absence of wear; 2 — worn-out cutters (WT); 3 — loss of cutter (LT); 4 — break of diamond plate (BF)

Table 2. Character of wear of bits

BC	Break of part of bit	LT	Loss of cutters
BT	Cutters are broken	NO	Absence of wear
BU	Sludging-up of bit	NR	Unfit for repeated trip-in
CC	Formation of cracks on bit	OC	Eccentric wear
CD	Bit stall	PB	Mechanical damage of bit in round-trip operations
CI	Bit bite	PN	Clogging of nozzle bushing in channel flushing
CR	Punching (wear of bit top)	RG	Wear of gauge part of cutting structure
CT	Spalling of cutter	RO	Circular wear on bit
ER	Erosion wear	RR	Bit is fit for repeated trip-in
FC	Flat wear	SD	Damage of cutter nose
HC	Thermal heating of cutters	SS	Effect of self-sharpening of cutters
JD	Operation of bit on metal	TR	Formation of ridges on bit
LC	Loss of bit	WO	Wash-out of bit body
LN	Loss of nozzle bushing of bit	WT	Wear of cutters

Table 3. Tolerances on outside diameters of drill bits

Nominal outside diameter of bit, mm	Inches	Millimetres
From 85.76 to 349.3 inclusive	From −0 to +0.313 (1/32)	From −0 to +0.794
From 355.6 to 444.5 inclusive	From −0 to +0.625 (1/16)	From −0 to +1.588
From 447.68 and more	From −0 to +0.938 (3/32)	From −0 to +2.381

curred (Figure 3). The codes used to describe the location of wear on diamond drill bits are shown in Figure 4.

The codes of wear resistance of cylindrical DHACs are shown in Figure 5.

Wear of a bit on its diameter. Column 6 (G — outside diameter) defines wear of a bit by its size. For this the diameter of the bit is measured before it is lowered into the well and when it is pulled out by using a special sizing ring. Tolerances on the outside diameter of the diamond bits according to API are given in Table 3.

Column 7 (O — other types of wear) uses the same two-letter codes as in Table 2 to describe the secondary characteristic of wear of a bit, in addition to the characteristics of wear of the cutting structure listed in column 3.

Application of a new generation of oil and gas production bits fitted with PCDCs, made by the world leading companies (DDI, «Reed Hycalog», DPI, «Baker Hughes», «Smith International», «King Dream», «Security»), provides substantial advantages over the roller bits [3]: 4–5 times increase in a headway per bit and mechanical speed of drilling, decrease in the quantity of round-trip operations, substantial reduction of the cost of 1 meter headway and cost of 1 hour operation of a drilling unit, high wear resistance of cutters, possibility of the efficient reuse of repaired bits without deterioration of performance due to the absence of movable elements, high lifespan, etc.

The base for restoration of performance of the diamond drill bits is replacement of PCDCs and reconditioning of the surface layer of a die. Unbrazing of the worn-out cutters and brazing of

Table 4. Characteristics of wear of a die bit made in the USA (rock — gray sandstone, dark-gray siltstone, and dark-gray argillite)

Type of wear	Classification of wear according to IADC	Example of wear
Wear of cutting edges of PCDC	SS — wear of cutting edges WT — general wear	
General wear/fracture of PCDC	WT — general wear CT — spalled cutters BT — broken cutters	
Local wear of coating and core of bit body with fracture of PCDC seats	RO — wear of cutting structure on circumference FC — flat wear WO — washout of bit	
General wear of bit body	WO — washout of bit FC — flat wear of bit	

the new ones by using silver filler metals are the key technological processes for replacement of DHACs.

The weight of milled, welded and die bits, which differs but slightly for different types of bits, ranges from 5 to 200 kg, depending on the outside diameter (93–495 mm). Design of the blades, their quantity and schemes of location of cutters in different types of the bits differ greatly, which also requires an individual approach to selection of a source and power of heating, and of a method for transfer of the thermal energy to ensure the quality repair of each drill bit.

It is a known fact that the PCDCs of a bit wear out differently — the most worn-out cutters are the central ones, and the least worn-out cutters are the peripheral ones, i.e. the load on cutters is distributed in a statistically indeterminate way. Therefore, in visual examination of a bit it is necessary to compile a list of defects for a given type of the bit and determine the quantity and quality of the PCDCs for their complete or partial replacement.

In selection of a heating source for unbrazing of the PCDCs from the bit blade seat, it is necessary to take into account the temperature resistance of a polycrystalline diamond layer, weight and quantity of the bit blades, as well as the scheme of location of the cutters in a bit.

Analysis of the thermal energy sources [4–10] for different design types (welded, all-milled, die) of the diamond drill bits and extent of their wear (not more than 50 %) showed that the volumetric heating methods (in furnace, salt melt) do not meet requirements of monitoring of temperature-time conditions of the technological process used for replacement of DHACs. The most rational methods for brazing-in of the PCDCs in terms of maintenance of physical-chemical properties of their diamond layer are flame and induction heating.

The temperature-time conditions for unbrazing of the PCDCs from the diamond drill bits (welded steel, with die body and all-milled steel body) were determined as a result of the investigations:

• for the mass one (with the whole blade) the most suitable heating method is induction heating with a maximal capacity of up to 30 kW;

• for the selective one (one or several) — heating with one or two gas torches No.4 at a maximal capacity of the gas mixture (oxygen–propane/butane) amounting to 10 kW.

The peculiarities of repair of bits depend on the density and physical-chemical properties of the corrosion-resistant surface layer of the bits, as well as the effect on the temperature-time heating conditions, strength of the polycrystalline diamond layer and quality of the brazed joints between the PCDCs and the bit die.

The extents of wear of the diamond drill bits (welded steel, with die body and all-milled steel body) supplied to the E.O. Paton Electric Welding Institute of the NAS of Ukraine for repair were determined according to this classification. Tables of wear of the drill bits depending on the physical-chemical characteristics of rock were plotted on the basis of the investigation results. Characteristics of wear of the «Baker Hughes» (USA) die drill bit with DHAC are given as an example in Table 4. The final estimate of wear of the given bit according to IADC is as follows: 3 7 RO T 0 I (CT, BT, WT, FC) PR — subject to repair.

CONCLUSIONS

1. Tables of the peculiarities of wear of bits and defects in DHACs and hard-alloy inserts were complied according to the IADC classification.

2. Criteria of repairability were determined for the three types of worn-out bits: steel welded bit (Ukraine), bit with an all-milled steel body (Russia), and bit with a die hard-alloy body (USA).

3. The main types of wear of PCDC bits in fields are as follows: wear of cutters (17 %), break of cutters (30 %), spalling of cutters (31 %), fallout of cutters (3 %), and absence of wear (19 %).

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