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Work Capacity and Durability of Rolling Cutter Drill Bits (Analysis of Criteria and Research Results).

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ABSTRACT

Main aspects of drilling process efficiency depend largely on the durability of the rolling bit cutting structure, directly destructing the rock, and their support nodes. Therefore, considerable number of researches is devoted to the study of the criteria of rolling cutter bits work capacity. The review of literature about work capacity criteria of carbide cutting structure of rolling cutters is given. The results of own researches of bits, worked off in field conditions, are described. A significant unevenness of wear-out and destruction of carbide bit cutting structures, both on crowns and rolling cutters as well as of the support nodes in sections is discovered. Specific causes of working capacity loss by carbide teeth of tested drill bits are their destructions as result of partial chipping of the working surface and breakdowns. The greatest number of teeth of the tested bits was destroyed on the middle and peripheral crowns. In general, the largest proportion of teeth destruction on the rolling cutter occurs in the first one. Support nodes of the first rolling cutter also go out of order most often too. These research results correlate well with ones of workload for bit supports and cutting structures.

Keywords: drilling, bit, rolling cutter, cutting structure, support, destruction, wear-out

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INTRODUCTION

Main aspects of drilling process efficiency depend largely on the durability of rolling cutting structure, directly destructing the rock, and their support nodes. Therefore considerable number of researches is devoted to the study of criteria of rolling cutter bits work capacity. Issues of durability of drill bits with milled cutting structure [1, 2, 3, 4] are studied most thoroughly. Rolling cutter bits with carbide cutting structure have substantial differences in the nature of teeth destruction and damage, which material is highly resistant to abrasive wear-out, but it has a tendency to fragile destruction [5, 6] due to relatively low impact resistance and low impact resistance to tension stress.

Bit rolling cutters roll along the downhole during drilling operations and teeth successively interact with the rock, exposed to a complex force impact. When interacting of teeth with the downhole, forces acting on the tooth by the destroyed rock are constantly changing, changing the stress state of tooth material. Teeth interaction with the rock has a smash nature [2, 7, 8, 9, 10] due to bit longitudinal vibrations, caused by several reasons. In addition, the teeth of rolling cutters cutting structure do not only roll, but also slide along the downhole, which results to their wear-out. State analysis of the carbide cutting structure for bits of various design, worked off in stand and field conditions, conducted by different researches [5, 11, 12], showed that there is a variety of wear-out and destruction types in operation. In the paper [5] the following classification was specified for the damage and destruction types of carbide drill bits cutting structure:

- smash and fatigue wear-out, causing teeth breakage and chipping;
- abrasive wear-out;
- smash-abrasive wear-out;
- hydroabrasive wear-out;
- teeth crushing;
- teet loss.

Moreover, the limiting teeth wear-out and destruction type for rolling cutter bits is a smash and fatigue wear-out. Most researchers also point out that the change in the shape and size of working surfaces of carbide teeth in the abrasive, hydroabrasive and smash-abrasive wear-out is insignificant and practically has no impact on their working capacity. Having a place in the drilling practice, teeth loss of the rolling cutter body and their impact on the working capacity of carbide cutting structure reduce as improving the design and teeth fastening technology.

The review of literature leads to the conclusion, that working capacity loss of carbide cutting structure of rolling cutter bits occurs mainly due to teeth destruction. These destructions have very diverse nature and can be classified into three groups:

- breakdown;
- chipping;
- crushing.

It is assumed that a bending moment impact is the cause of breakdown and chipping, and teeth crushing occur under high compressive loads impact. In paper [5] it is suggested that the teeth working surface breaking-off, occuring in the initial period of the bit working at the downhole precedes chippings and breakdowns. In the paper [13] it is proposed to classify destruction types of carbide teeth, depending on the nature of the external force impact:

- teeth destruction under compressive stress;
- teeth destruction under impact of tangential stresses;
- teeth breaking-off under impact of single and multiple overloads.

However, this classification is rather conventional, as teeth are in a complex stress state in real conditions of bit interaction with the downhole, and a complex set of normal and tangential stresses simultaneously acts on them, causing their destruction. Exploring the shape of destruction surface of carbide teeth, the authors of the paper [5] point out, that "two typical destruction zones: the zone of failure origin on the teeth surface and the zone of cracks rapid development" can be identified on the destruction surface. It allows the author to conclude that the teeth destruction has mainly fatigue nature.

METHODS

Shape and size of the rock destruction tool affect significantly the durability of rolling bits cutting structure and rock destruction efficiency. Mechanisms of rock destruction under static and dynamic impression of indenters of various shapes in the rock block [4, 8, 14, 15] were studied most thoroughly. The research results for the rocks destruction during drilling are given in papers [16, 17, 18]. Paper [6] deals with the study of rock destruction and strength characteristics of carbide teeth of various shapes. It attempts to choose a comprehensive evaluation criterion of working capacity for carbide teeth of different shapes. Based on this criterion, the author offers carbide teeth with a new, more optimal shape of the rock destruction surface, in his opinion. Such main characteristics of the cutting structure, as the teeth diameter and their spacing, inter-crown gaps, teeth exposure over the rolling cutter body, teeth layout on crowns and crowns layout on the rolling cutter have the most significant impact on the rock destruction efficiency and strength of the carbide cutting structure of rolling cutter bits. Researches for the optimization of the mentioned above main characteristics of the carbide cutting structure have been conducted since invention of rolling cutter bits with carbide cutting structure and so far. Stand and field tests of several series of specially designed bits, differ from each other by only one characteristic when the immutability of the others [3] were conducted in order to determine the impact of main characteristics of the cutting structure on the drilling process efficiency. This allowed us to exclude the possibility of mutual impact of characteristics and to receive general advice for their optimal values selection. There are also other papers devoted to the study of the characteristics impact of carbide cutting structure on the bits working efficiency. Most of these papers deal with study of such characteristics as teeth diameter and their spacing, teeth layout on crowns and the choice of optimal values of these characteristics in accordance with physical and mechanical properties of drilled rocks. In our view, the issue about the impact of crowns layout on the rolling cutters radial the downhole on drilling efficiency and durability of the bits cutting structure is not enough studied. Currently, crowns layout on the rolling cutters is conducted based on the requirement of necessary downhole overlap, taking into account the necessity of more or less even distribution of cutting structures on the rolling cutters. The surfaces quality of carbide teeth affects significantly on their strength characteristics. The defects presence on the surface layer, which is stress concentrator, leads to process intensification of teeth destruction. Carbide teeth resistance depends also on other technological factors, such as the method of teeth press-in [13]. In paper [5] it is also found, that the connection rigidity "tooth – rolling cutter" affects the durability of carbide teeth. The reduction of this rigidity allows improve the carbide cutting structure durability. Thus, the durability of carbide cutting structure, limited by teeth destruction, depends on a large number of structural and technological factors. In the known researches, the general nature of the carbide teeth destruction of rolling cutter bits was studied in sufficient detail. However, most researchers did not set itself the task of quantity analysis of destroyed teeth on each crown of each rolling cutter of the tested bit. In addition, researches were conducted in different years on the bits of various types and sizes, with significant differences in the design of cutting structure and support nodes, so that even the published data were difficult to use.

Many researchers also found the uneven wear-out and destruction of cutting structure elements and rolling cutter support nodes. Uneven wear-out is observed both at worked off bits with milled cutting structure [3, 4, 5, 8], and at worked off bits with pin carbide cutting structure [5, 13]. When production working off, there was an uneven wear-out in the construction of rolling cutter bits with carbide cutting structure of the first ones. Bits broke down mainly because of the wear-out of the first rolling cutter top, teeth chipping on peripheral crowns and rolling cutter supports jamming. In the following bits structures they managed to reduce unevenness of wear-out and destruction of carbide cutting structure and improve the bits working efficiency by changing the geometric shape of rolling cutters, increasing the teeth diameter and tops making on all three rolling cutters. However, it fails to eliminate the uneven wear-out and destruction of carbide cutting structure completely. In paper [16] it is pointed out that the teeth, most susceptible to destruction, are arranged on the peripheral crown. Unfortunately, there are no quantitative data about the teeth destruction on crowns and bit rolling cutters in the paper.

As shown in papers [3, 5], the wear-out intensity of the support nodes elements and the jamming possibility of rolling cutter supports essentially depend on the initial values of the radial and axial gaps in the bearings. These gap values can vary quite significantly, even within manufacturing tolerance. Therefore, in our opinion, the unevenness of support wear-out in sections can not be explained clearly only by technological errors of manufacturing. Thus, the wear-out and destruction unevenness of cutting structure elements and rolling cutter support nodes can be explained by impact of structural and technological factors, that lead to an uneven forces distribution on the bit sections and cutting structure elements as well as rolling cutters supports [19, 20]. The uneven wear-out of bits cutting structure can be explained also by different slide values of the rolling cutter crowns [4, 16]. The wear-out intensity of cutting structure increases with the slide value increase. However, sliding significantly modifies also the process force characteristics of cutting structure and downhole interaction. With increasing of teeth penetration depth in the rock, the proportion of the tangential force component, acting on the tooth when sliding along the downhole, increases. Since the largest sliding has been observed in peripheral crowns due to the imperfect shape of rolling cutters, the tangential force components on the peripheral crowns teeth will be larger than on the middle crown teeth. Based on the assumption, that different load and in some cases also overload values, acting on working elements of support and cutting structure, correspond also the various degrees of wear-out and destruction of them, it is very important to study the nature and degree of load uneven distribution on elements of bit cutting structure and the reasons, causing it. Knowledge of load characteristics of the elements of rolling bit cutting structure when interaction it with the downhole would allow scientifically-based approach to the issues of cutting structure and supporting node bearings improvement of the rolling cutters in the field of their rational layout, which would exclude the overload of partial working items.

RESULTS

In the known researches, the general destruction nature of carbide teeth of the rolling cutter bits was studied in sufficient detail. However, most researchers did not set itself the task of quantity analysis of destroyed teeth on each crown of each rolling cutter of the tested bit. In addition, researches were conducted in different years on the bits of various types and sizes, with significant differences in the design of cutting structure and support nodes, so that even the published data were difficult to use. In this regard, for a comprehensive qualitative and quantitative picture of wear-out and destruction of carbide cutting structure of rolling cutter bits we have tested 250 bits of the type Ш215, 9ТКЗ-ЦВ-3 and 100 bits of the type Ш215, 9К-ПВ, worked off in field conditions. The degree of wear-out and destruction of rolling bit cutting structure has been established by height measuring and determining the number of destructed teeth separately on each crown of each rolling cutter. Cutting structure setup of tested bits and agreed notation of crowns are shown in fig.1 and fig.2.

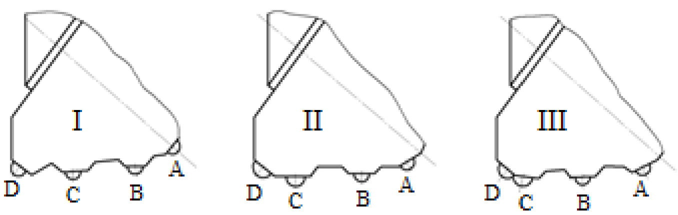

Fig. 1 Setup of rolling bit cutting structure Ш 215, 9К- ПВ
(I, II, III – rolling cutter numbers; A, B, C, D – notation of rolling cutter crowns)

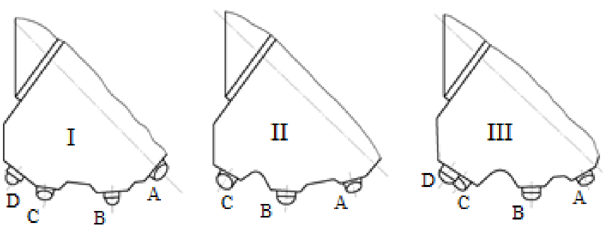

Fig. 2 Setup of rolling bit cutting structure Ш215, 9ТКЗ-ЦВ (b)
(I, II, III – rolling cutter numbers; A, B, C, D – notation of rolling cutter crowns)

Studies have shown that although in most cases the bits working capacity is determined by support resistance, bits cutting structure durability is also insufficient. Thus, out of 250 tested bits III215 and 9ТКЗ-ЦВ 105 bits have fully worked-off at support and cutting structure. Destructions of carbide teeth of tested bits are specific causes of working capacity loss as result of partial chipping of the working surface and the teeth breakdown. Based on the complicated relief of fracture surfaces it can be assumed, that in many cases, teeth breakdown occurs as result of several partial chippings. Abrasive wear-out develops slowly, causing a slight change in their size and shape. Intensive abrasive wear-out of cutting structure is observed only in jamming cases of rolling cutters supports. Carbide teeth loss of the rolling cutter body has been rarely observed. Therefore, teeth chipping and breakdown are the main cause of failure of carbide cutting structure.

Table 1 shows the average data about number of destroyed teeth in percentage of the total teeth number on the rolling cutter crowns of tested bits.

Table 1: Cutting structure state of worked-off bits

bit type	Number of rolling cutter	Number of destroyed teeth, %				
		Crown A	Crown B	Crown C	Crown D	On average for rolling cutter
Ш215, 9К-ПВ	I	16,0	42,3	39,5	23,3	30,3
	II	16,7	32,5	38,1	21,5	27,2
	III	25,2	23,9	39,4	15,7	26,1
Ш215, 9ТКЗ-ЦВ-3	I	20,0	32,6	33,0	38,5	31,0
	II	17,6	34,3	39,6	-	30,5
	III	16,0	17,9	42,0	37,2	28,0

The number of destroyed teeth is different in various crowns. For bits III215, 9К-ПВ the largest share of destroyed teeth falls on middle crowns. Thus, 42.3% and 39.5% of teeth are destroyed on the first bit rolling cutter on B and C crowns respectively, while there are only 16.0% and 23.3% on A and D crowns. Figure 3 shows typical cases of the cutting structure destruction for the worked off bits of this type.

Figure 3. Typical destruction cases of cutting structure for the worked off bits of the type Ш215, 9К-ПВ

For bits of type ТКЗ the largest share of teeth destruction falls on the peripheral and middle crowns, and the number of destroyed teeth on the top crowns is small. Breakdowns are predominant destruction type for the bits of type TK3. Figure 4 shows the typical destruction cases of cutting structure for the worked off bits of this type.

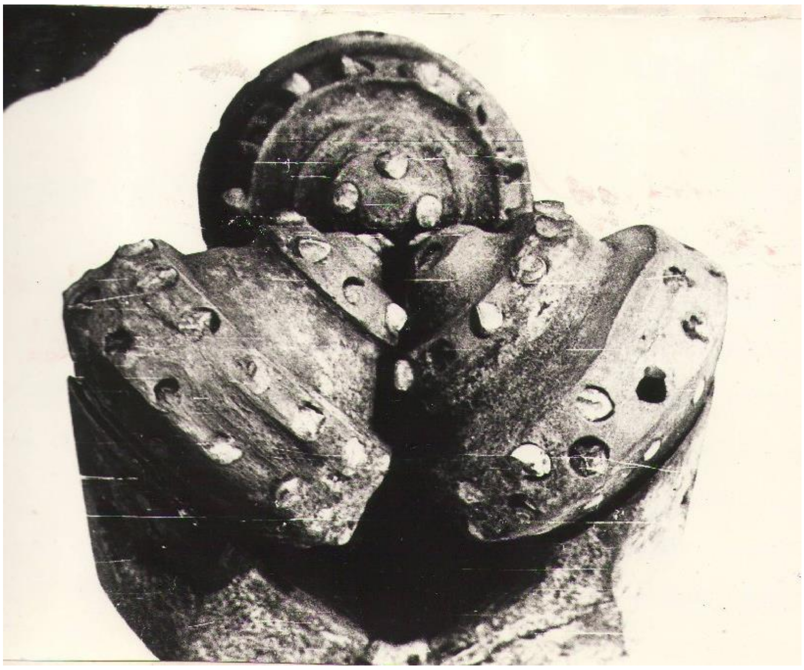

Figure 4. Typical destruction cases of cutting structure for worked off bits Ш215, 9ТКЗ-ЦВ-3

The share of destroyed teeth is also different on average for each rolling cutter. The greatest number of destroyed teeth on bits of both types falls on the first cutter.

In addition to wear-out and destruction of carbide teeth in tested bits there is a significant wear-out of the pin, rolling bodies and support surfaces on the rolling cutter. This in turn leads to occurring in bits support of excessive radial and axial gaps, at which rolling bodies loss as well as rollers turning and rolling cutter jamming often occur. In such cases, the bit becomes unfit for further operation. Furthermore, increase in axial play when the excessive wear-out of the ball (lock) bearing can lead to crowns meshing of the adjacent cutters, causing the teeth chipping. It was made an evaluation of the support state for the values of axial and radial play, where the rolling bodies loss occur, as well as for the number of jammed rolling cutters. These data were summarized in Table 2.

Table 2: Supports state of worked off bits

Bit type	Bits number	Sections number	Rolling cutter number	Number of rolling cutters in % to the total number of studied ones		
				axial play >5 мм	loss of the rolling bodies	rolling cutters jamming
Ш215, 9К-ПВ	100	300	I	8	10	36
			II	10	14	24
			III	4	4	30
Ш215, 9ТКЗ-ЦВ-3	250	750	I	2,8	7,2	43,6
			II	3,2	3,2	42,4
			III	3,2	4,4	38,8

As follows from the table, jamming is the most common cause of the supports failure of the tested bits. Assuming that rolling cutters with jammed support and lost rolling bodies are not fit for further operation, so this is most often cause for breakdown of the first rolling cutter of both types of bits, making up 46% and 50.8% respectively for bits of the type Ш215, 9К-ПВ and ones of the type Ш215, 9ТКЗ- ЦВ-3. The study found that the supports wear-out of rolling cutters occurs very unevenly. For example, if the total number of bits of the type K, unfit for further operation, due to excessive wear-out of rolling cutter supports, is taken as 100%, so 38% of bits will have finally only one failed support on a single rolling cutter, 28% - two failed rolling cutter supports, and only 34% of bits will have all three rolling cutter supports out of order.

DISCUSSION

Thus, as a result of conducted researches it is found the significant unevenness of wear-out and destruction of rolling bits carbide cutting structure, both on crowns, and on the rolling cutters and on the support nodes in sections. For bits of the type Ш215, 9К-ПВ the largest number of teeth destruction occurs on middle crowns of all cutters. For bits of the type Ш2І5, 9ТКЗ-ЦВ-3 the largest number of teeth destruction occurs on middle and peripheral crowns. In general, for all rolling cutters, the largest share of teeth destruction for both type bits falls to the first rolling cutter. Support nodes of the first rolling cutters go out of order most often too. Obtained results do not coincide with the known results of other researches. Most researchers believe that the greatest amount of teeth destruction of pin bits and the most abrasive wear-out occur on the peripheral bit crowns. In some cases, top crowns are most susceptible to destruction and wear-out. The following circumstance is the reason for such conflicts, in our view. In most cases, bits designed for drilling of soft rock and rocks of medium hardness were studied. Such bits have a significant teeth extension from the rolling cutter body and the greater axes displacement of the rolling cutters. These bits have a significant teeth sliding on peripheral and top crowns on the downhole, causing the large tangential forces acting on teeth, which leads to breakdown and intense abrasive wear-out.

CONCLUSION

Uneven wear-out and destruction of cutting structure elements on rolling cutter crowns and supports in sections can be explained by different load. The tested bits are designed for hard rock drilling and have a small teeth exposure from the rolling cutter body. Therefore, axial loads act mostly on teeth and cause compressive stresses therein. As the largest share of the destroyed teeth falls on the middle crowns, it can be assumed that these crowns take up a larger share of the axial load. These same reasons may explain the more often failure of the supporting nodes of the first rolling cutters of the tested bits. The obtained results correlate well with the results of our conducted analytical and experimental researches of cutting structure load and rolling cutter bit supports. Reducing of the load uneven distribution on the cutting structure elements and support node bearings of the rolling cutters can significantly improve the bits work capacity. According to our research, the load unevenness of cutting structure and supports can be reduced due to more rational cutting structure distribution on the rolling cutters surface [21].

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