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Research Status of Influencing Factors on Rock Breaking of PDC Cutter

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Abstract

Rock breaking with PDC cutter is to use its cutting force to break rocks by shearing. It is increasingly widely used in drilling rock breaking such as oil and gas exploitation etc. Understanding the mechanism of influencing factors of rock breaking with PDC cutter is conducive to optimizing bit design, improving rock breaking efficiency and prolonging service life. According to the interaction process between PDC cutter and rock, the influencing factors of PDC cutter rock-breaking efficiency are analyzed, and the action mechanism of PDC cutter cutting parameters, cutter shape, rock properties and working environment is sorted and summarized. The analysis results show that different influencing factors have different action mechanisms on PDC cutter rock-breaking. Quantifying the action mechanism of PDC cutter rock-breaking factors and analyzing and coordinating the main influencing factors are important prerequisites for improving the efficiency of PDC cutter rock-breaking.

Keywords

PDC Cutter; Rock Breaking; Influencing Factors; Action Mechanism.

1. Introduction

PDC drill bit has excellent features such as high rock breaking efficiency, good stability and long life, which are favored in the fields of oil and gas exploration and mining excavation, and can adapt to a variety of formations from soft to hard. PDC cutter breaking technology directly affects the rock breaking efficiency and drilling speed of PDC drill bit [1]. In the process of PDC cutter breaking, PDC cutter first use its axial force to press into the rock, and then use its tangential force to shear the rock, and finally achieve the purpose of breaking the rock. the key of PDC cutter breaking is to control the interaction process between PDC cutter and rock to reduce the specific work of breaking and tangential force, in order to improve the efficiency of rock breaking [2]. The rock breaking efficiency of PDC cutter is mainly interrelated with the cutting parameters, cutter shape and the working environment of the interaction between PDC cutter and rocks. To improve the rock-breaking efficiency of PDC cutter, many scholars have conducted theoretical analysis and experimental research on rock-breaking of PDC cutter to analyze the interaction mechanism between PDC cutter and rocks. In this paper, according to the current research status of PDC cutter breaking efficiency at home and abroad, the mechanism of the effect factors of PDC cutter breaking technology is reviewed in terms of cutting parameters, cutter shape, rock nature and working environment of PDC cutter to provide a theoretical reference for the development of PDC cutter breaking technology.

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2. PDC cutter breaking mechanism and evaluation index

2.1 Rock breaking mechanism

Before studying the PDC cutter breaking mechanism, we should first understand the nature of the rock, research shows that: among the strength properties of rocks, compressive strength is the highest, shear strength is the second, tensile strength is the lowest, compressive strength is often several times to more than ten times higher than shear strength. The PDC cutter is first pressed into the rock under the action of axial force F_n to produce a small crater, and then scrapes the rock by tangential force F_r to break the rock, as shown in Fig. 1. The experimental results show that the shear breaking of PDC cutter is significantly better than the impact breaking of dental wheel cutter, and the PDC cutter adopt an efficient shearing method to improve the efficiency of rock crushing.

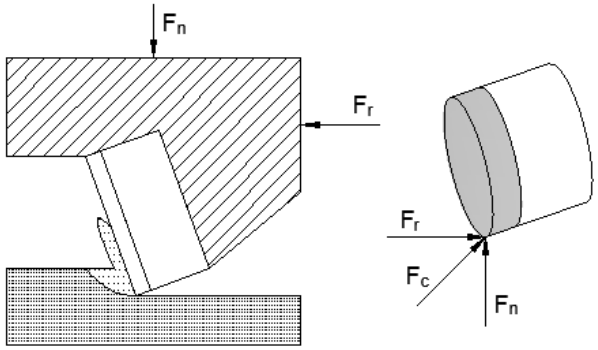

Fig. 1 Schematic diagram of PDC cutter breaking mechanism

2.2 Evaluation indicators

In the process of PDC cutter breaking, speed and efficiency are the eternal theme of rock breaking. The smaller the crushing ratio work, the higher the efficiency of PDC cutter, which is expressed as the energy required to crush a unit volume of rock, and the expression is [3]:

$$MSE = \frac{W}{V} \tag{1}$$

In the formula (1), MSE indicates the specific work of breaking rock, J/m^3; W indicates the work consumed by breaking rock, J; V indicates the volume of rock broken, m^3. In the case of the same cutting depth, the magnitude of the axial force indicates the ability of the PDC cutter to eat into the ground, the smaller the required axial force, the stronger the ability to eat into the ground; the magnitude of the tangential force indicates the difficulty of the PDC cutter to break the rock, the smaller the required tangential force, the easier it is to break the rock; because the cutting cutter of the existing PDC drill almost no longer sets the side rotation angle, so the radial force of the PDC cutter is almost zero, so it is not as Therefore, it is not a research content. Since the tangential force is a dynamic load, the magnitude of the tangential force is measured by the average tangential force.

$$W=F_r \square S \tag{2}$$

In equation (2), W indicates the work consumed by crushing the rock, J; F_r indicates the average tangential force, N; S indicates the cutting stroke, m.

$$V=A \square S \tag{3}$$

In equation (3), V denotes the volume of rock, m3; A denotes the projected area of the cutting surface, m2; S denotes the cutting stroke, m.From equation (2) and equation (3), equation (4) can be deduced as follows.

$$MSE = \frac{W}{V} = \frac{F_r \square S}{A \square S} = \frac{F_r}{A} \tag{4}$$

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The MSE in Eq. (4) represents the specific work of rock breaking, Pa. From Eq. (4), it can be seen that the smaller the average cut depth, the smaller the specific work of rock breaking, the higher the efficiency of rock breaking.

3. Mechanism of action of influencing factors

Both the crushing ratio work and the average tangential force depend on the characteristic parameters of the PDC cutter and the rock. According to the interaction between PDC cutter and rocks, the four influencing factors of cutting parameters, cutter shape, rock properties and working environment of PDC cutter are used as independent variables, and the crushing work and average tangential force formed by PDC cutter cutting rocks are used as evaluation indexes of rock breaking efficiency of PDC cutter [4]. Summary and analysis of the mechanism of action of the influencing factors of PDC cutter breaking.

3.1 Cutting parameters

In evaluating the rock-breaking efficiency of PDC cutter, the cutting parameters of PDC cutter should be determined first, and the cutting parameters that can characterize PDC cutter are the relevant parameters that affect the rock-breaking of PDC cutter.

3.1.1 Depth of cutting

The tangential force is proportional to the cutting depth, the cutting depth increases, the cutting arc length and cutting area increases, the crushing volume increases, and the tangential force increases. Rock breaking work is inversely proportional to the cutting depth, which seriously affects the rock breaking efficiency of PDC cutter. Cutting depth increases, forming a larger crushing pit, cutting rock chip large area flaking, thus reducing the specific work of breaking rock.

3.1.2 Front camber angle

The front inclination angle is one of the important parameters of PDC cutter, the appropriate front inclination angle not only has a self-sharpening effect on PDC cutter, but also can improve the ability of PDC cutter to eat into the ground and maintain a high efficiency of rock breaking. The tangential force increases non-linearly with the increase of the front inclination angle, in the case of constant cutting depth, the front inclination angle increases, the axial force of PDC cutter acting on the rock surface will increase, the rock is compacted, the friction force increases, the tangential force naturally increases [5]. However, the rock breaking ratio work shows a general trend of decreasing and then increasing with the increase of the forward inclination angle. With the increase of forward inclination angle, the axial force of PDC cutter will increase, which will improve the ability of PDC cutter to eat into the formation and form a larger damage area and rock crushing; after the forward inclination angle increases to the optimal angle, the crushing ratio work is the smallest, which is because the effective damage area of the rock caused by PDC cutter is the largest at this time; when the forward inclination angle continues to increase, the self-sharpening effect of PDC cutter is not obvious, which reduces the ability to eat into the formation, and the PDC cutter produce ineffective plastic strain and damage to the rock. The PDC cutter produce ineffective plastic strain and damage to the rock, and the rock debris is not easy to remove, causing secondary crushing, increasing the crushing ratio work and reducing the crushing efficiency [6]. Therefore, in the process of PDC cutter breaking, the relationship between the forward inclination angle and the rock damage area should be considered.

3.1.3 Cutter diameter

Cutter diameter is an evaluation criterion to measure the size of PDC cutter. The tangential force is a non-linear function of the cutter diameter, and increases as the cutter diameter increases [7]. In the case of the same depth of cut, as the cutter diameter decreases, the curvature of the cutting edge increases, the cutting area decreases, and the PDC cutter contact with the rock to form a stress concentration, increasing the degree of damage to the rock below the contact area. Under the same conditions, small diameter PDC cutter are more likely to damage the rock than large diameter cutter. Rock breaking ratio work with the increase in cutter diameter is first decreasing and then increasing

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trend, mainly due to the increase in cutter diameter, in the case of the same cutting depth, cutting area and cutting arc length will increase, increasing the volume of broken rock, but too large cutter diameter will increase the difficulty of eating into the strata, it is difficult to achieve the same cutting depth, cutting area and cutting arc length will be correspondingly reduced, thereby reducing the efficiency of rock breaking [8]. Therefore, the size of the PDC cutter diameter has been standardized and is stratigraphically dependent.

3.1.4 Cutting speed

With the increase of cutting speed, there is a corresponding increase of tangential force, mainly with the increase of cutting speed, the rock breaking contact cutting time decreases and the tangential force increases. With the increase of cutting speed, the rock breaking specific work increases, the reason is that the mechanical properties of the rock are related to the strain rate, with the increase of strain rate, the strength limit of the rock increases to a certain extent, which leads to the difficulty of rock breaking and the increase of rock breaking specific work.

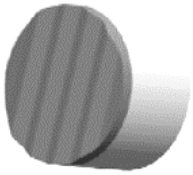
3.2 Cutter shape

With the development of PDC cutter breaking technology, a type of shaped cutter is designed by changing its cutter shape on the basis of conventional PDC cutter in order to optimize its rock breaking performance, as shown in Figure 2. Cutter shape directly affects its rock breaking performance, and when evaluating the rock breaking efficiency of shaped cutter, it is necessary to understand the mechanism of action of shaped cutter in breaking rock first. There are many kinds of shaped cutter, and the influence mechanism of conical cutter, ridged cutter, rotating cutter and bionic cutter on rock breaking is mainly analyzed in this paper.

(a) Tapered cutter

(b) Ridge-shaped cutter

(c) Rotating cutter



(d) bionic cutter

Fig. 2 Shaped cutter

3.2.1 Conical cutter

The conical cutter is designed according to the cutter shape of the cutter wheel cutter and conventional PDC cutter, as shown in Fig. 2(a). The conical cutter breaking process is to use its axial force to make the rock under the contact area devolved to form a greater contact stress and damage to the rock below under the stronger pressure and shear effect [9]. The tapered cutter are easier to eat into the rock, and scrape the rock under the tangential force and have extrusion effect on both sides of the rock, breaking the rock by tensile stress. Usually the tensile strength of the rock is smaller than the shear strength so the required tangential force is small, and the crushing ratio work is small which can obtain a high efficiency of rock breaking.

3.2.2 Ridge-shaped cutter

The ridge cutter is a shaped cutter introduced by Smith, as shown in Fig. 2(b). The ridge cutter shape is formed by changing the shape of the diamond layer of the conventional PDC cutter and increasing

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the thickness of the diamond layer by applying the principle of stress concentration of the tapered cutter to form a ridge. The ridged cutter uses the intersection of the prismatic ridge and the cylindrical side to form a "sharp point" and intrudes into the rock with a strong point load, which is driven by the tangential force to break the rock, improving the rock breaking performance of the ridged cutter. In the process of breaking rock, the ridge cutter requires less tangential force than conventional PDC cutter because the ridge cutter is suitable for eating into the stratum with point load, and the two cutting cutter surfaces have extrusion and stretching effect on both sides of the rock, so the tangential force is small, the crushing ratio work is small, and the rock breaking efficiency is high.

3.2.3 Rotating cutter

Rotary cutter can rotate 360 degrees freely during drilling and rock breaking [10], Thus, the cutting edge cuts the rock evenly, as shown in Fig. 2(c). As the rotating cutter can realize the rotation during the cutting process to make the compound piece have a longer cutting edge, so that the cutting edge can wear evenly and avoid the bias grinding of the rotating cutter, which improves the ability of the rotating cutter to eat into the strata and the rock breaking efficiency, and effectively prolongs the service life of the rotating PDC cutter. [11]

3.2.4 Bionic cutter

Bionic cutter is a kind of shaped cutter designed according to biological structure and morphology, and the most typical one is a bionic cutter designed based on shell grooves, as shown in Fig. 2(d). In the process of PDC cutter breaking, the PDC cutter keeps eating into the stratum and the contact area keeps increasing, and the "tip" of the bionic cutter eats into the stratum to form multiple crushing pits, and multiple crushing pits are connected with each other to form a larger crushing pit, so the bionic cutter requires less tangential force and has higher breaking efficiency compared with the conventional PDC cutter.

3.3 Rock properties

There are many rock properties that affect PDC cutter breaking [1]. As long as the mechanical properties of the rock, its complex mechanical properties lead to the need to select the corresponding rock-breaking tools for specific strata in engineering applications. The drill ability grade of the rock can reflect the difficulty of PDC cutter breaking and the comprehensive strength of the rock, it can reflect the comprehensive ability of the rock to resist mechanical damage, the lower the drill ability grade of the rock, the higher the efficiency of PDC cutter breaking.

3.4 Working Environment

After determining the action mechanism of cutter shape and cutting parameters on PDC cutter breaking factors, the working environment of PDC cutter breaking should also be considered. the external temperature and surrounding pressure of PDC cutter and rock are important factors affecting PDC cutter breaking.

3.4.1 Surrounding pressure

The specific work of breaking increases non-linearly with the surrounding pressure and the rate of increase decreases, indicating that in the low perimeter stage, the difficulty of breaking the rock increases significantly compared with zero perimeter pressure; from low to high perimeter pressure, the specific work of breaking increases slowly [5]. The lower the enclosure pressure, the higher the rock breaking efficiency; after the enclosure pressure increases, the rock strength increases due to the plastic deformation of the rock and the compaction of the crushed rock chips. Therefore, the crushing ratio work increases significantly and the rock breaking efficiency decreases significantly.

3.4.2 Temperature

The specific work of breaking rock decreases with the increase of temperature. The main reason is that the rock has anisotropy and different sensitivity to temperature, which causes uncoordinated thermal expansion inside the rock and produces tensile and compressive stresses, causing damage to the rock, and the temperature rises, the composition of the rock will undergo certain physical and

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chemical reactions, which may produce new tiny cracks inside the rock or make the primary microcracks further increase, which will reduce the strength of the rock, so the temperature rises will improve the rock breaking of PDC cutter efficiency.

4. Conclusion

PDC cutter breaking is the process of PDC cutter shearing and crushing rock, and the factors affecting PDC cutter breaking are divided into four aspects: cutting parameters, cutter shape, rock properties, and working environment, and the analysis summarizes the influence mechanism of the relevant sub-factors contained in each factor on PDC cutter breaking.

Although a lot of research has been done on the influencing factors of PDC cutter rock breaking, there are still many challenges in optimizing the design of PDC drill bit, improving the rock breaking efficiency and prolonging the service life, etc.

(1) In the experiments to study the influence factors of PDC cutter on rock breaking, different scholars have used different PDC cutter with different cutting parameters to cut different nature of rocks under different cutting environments, and no quantitative conclusion can be given for the same influence factor, and the perfect influence mechanism needs to be further explored.

(2) There are many factors influencing PDC cutter to break the rock, and the mechanism of action of the influencing factors is different, so screening the main influencing factors is still a difficult technical problem to solve.

(3) PDC cutter breaking is essentially the process of interaction between PDC cutter, rock and fluid, and the analysis of multi-factor coupling and coordination of multi-factor joint action is the development direction to improve the efficiency of PDC cutter breaking.

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