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Simulation and Experimental Study on Rock Disintegration Characteristics of Special-shaped PDC Cutters

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Highlights

- This paper focuses on the rock disintegration characteristics of special-shaped PDC Cutters.
- The study was carried out by numerical simulation and micro-drilling test methods.
- The resutls of micro-drilling test and numerical simulation show the same law.

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Abstract

In order to analyze the rock disintegration characteristics of special-shaped Polycrystalline Diamond Compact (PDC) cutters, numerical simulation and micro-drilling test on four kinds of special-shaped PDC cutters are carried out. Simulation results show that, the surface stress of each PDC cutter is quite different. For the dual-chamfer PDC cutter, the second chamfer can expand the stress on the cutting edge to a larger area; for the conical PDC cutter, the maximum stress is concentrated at the tip of the cone; for the ridged PDC cutter, the stress is distributed in a triangular fan shape from the lower edge of the cutting edge upward along the ridge, and for the triangular ridge PDC cutter, the stress is mainly distributed on the lowermost ridge. The conical PDC cutter has advantages in rock disintegration stability and efficiency, but it requires a higher weight on bit; the ridged PDC cutter has advantage in rock disintegration efficiency, but it tends to swing sideways when breaking rock; the dual-chamfer structure of PDC cutter is beneficial to extend the cutter's life, but its rock disintegration efficiency is poor. Anchor bits with these special-shaped PDC cutters are produced, and electro-hydraulic micro-drilling test are carried out, the results of micro-drilling test and numerical simulation show the same law excluding conical PDC cutter. The research results can provide guidance for the application of special-shaped PDC cutters in drill bit.

1. INTRODUCTION

The Polycrystalline Diamond Compact (PDC) cutter is the most basic cutting unit of the PDC bit, it is responsible for the main task of breaking the rock, so its performance has a decisive influence on the rock disintegration effect of PDC bit [1]. Therefore, the improvement and innovation of PDC cutter is the main direction of PDC drill bit technology innovation, and it is easy to get the effect of rock disintegration with half the effort.

At present, the drilling effect of the PDC bit is very poor in complex formations with high hardness, strong abrasiveness, and serious heterogeneity. The phenomenon of severe wear and even chipping of PDC cutters are often occurred. Therefore, the bit life is short, and the rock disintegration efficiency is low [2]. Figure 1 is a photo of the PDC bit after severe wear.

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Figure 1. *PDC drill bit wear photo*

PDC cutter is composed of two parts: diamond layer and carbide layer. In the past decade, researchers have mainly focused on optimizing PDC cutters in terms of material, by improving material composition and introducing decobalt technology to improve the hardness, toughness and thermal stability of PDC cutter [3-5]. At the same time, researchers studied to reduce the residual stress and improve the strength of PDC cutter by enriching the interface structure between the diamond layer and carbide layer. They proposed the interface structure forms such as groove, zigzag, wave, etc., and achieved certain success in engineering [6-8].

However, looking at the achievements in the development of PDC cutter, in can be seen that the structure of most PDC cutter is still a cylindrical shape, and the cutting face is smooth. In recent years, researchers have begun to work on innovating the structural shape of PDC cutter, through introducing multi-dimensional structure of diamond layer to enhance the aggressiveness, hardness and toughness of PDC cutter, and finally improve the drilling efficiency and service life of PDC bit in complex and hard formations. Up to now, various new special-shaped PDC cutters such as conical, ridged PDC cutter have been developed [9]. Field drilling tests show that, special-shaped PDC cutters show certain advantages in hard rock drilling, for example, the conical PDC cutter developed by Smith Company can better concentrate the load on one point to break the rock, and its thicker diamond layer helps to improve the wear resistance and stability of the cutter [10,11]; the diamond layer of the ridged PDC cutter has a ridge-like structure, which shows higher hardness and toughness [12,13]; the multi-dimensional special-shaped PDC cutter developed by Baker Hughes Company (https://www.bakerhughes.com/) helps to improve the heat conversion efficiency, and maintain its aggressiveness for a long time [14,15].

Since the diamond layer surface of the special-shaped PDC cutter has a multi-dimensional structure, its rock disintegration process is significantly different from that of plane PDC cutter. Although major foreign oil companies have developed a variety of special-shaped PDC cutters, but the relevant literature focuses on the reports of their field application, and there are few theoretical studies on the characteristics of the cutters, which is difficult to effectively guide the application of special-shaped PDC cutters in drill bit design. Therefore, in the present study, four types of special-shaped PDC cutters are taken as research objects, through numerical simulation and micro-drilling test, to achieve the purpose of revealing the rock disintegration characteristics of these cutters. In addition, by grasping the key problems, new design ideas and theoretical basis are provided for the development of new PDC bit with special-shaped PDC cutter in hard rock formation.

2. ESTABLISHMENT OF NUMERICAL SIMULATION MODEL

The breaking of rock is a very complicated process, which cannot be described by precise analytical solutions. With the development of numerical simulation technology, the finite element simulation method is more and more widely used in the research of rock disintegration process, also the simulation results are relatively satisfactory [16-20].

2.1. Basic Assumptions

In order to facilitate the analysis, secondary factors are ignored according to the focus of the research, the following assumptions are made for the simulation process:

(1) Regardless of the influence of temperature and fluid on the rock disintegration process; (2) Regardless of repeated breaking, the rock unit is deleted immediately after broken; (3) The rock is isotropic, regardless of the existence of original cracks in the rock.

2.2. Material Model and Parameters

For the extended Drucker-Prager plastic model, it can well reflect the disintegration process of rock, so it is used to simulate the constitutive relationship of rock. By setting failure criteria in this material model, the fracture of rock can be well simulated. At the same time, the plastic damage-failure model is introduced to represent the separation of cuttings. It is believed that as the plastic deformation of the material intensifies, a series of microscopic defects are formed inside the material and gradually expand, and finally reach the complete failure point of the material, the material fails and is deleted. The model determines whether the material fails by defining the failure parameter ω_s:

$$\omega_S = \int \frac{\mathrm{d}\bar{\varepsilon}^{pl}}{\bar{\varepsilon}_S^{pl}(\theta_S, \varepsilon^{pl})} = 1 \tag{1}$$

$$\theta_S = (q + k_S p) / \tau_{\max} \tag{2}$$

where, $\bar{\varepsilon}^{pl}$ is the equivalent plastic strain, θ_s is the stress ratio, ε^{pl} is the strain rate, k_s is the parameter related to material properties, τ_{max} is the maximum shear stress.

In order to observe the surface stress distribution characteristics of the diamond layer, elastic material model is used to represent special-shaped PDC cutter, while for the elastic model, it only need to input the three parameters such as density, elastic modulus and poisson's ratio. The material parameters of the rock and cutter in the simulation are shown in Table 1.

Table 1. *Parameters of PDC cutter and rock*

	Density /kg·m^{-3}	Elastic modulus/GPa	Poisson's ratio	compressive strength/MPa	Shear strength/MPa	cohesion /MPa	Angle of friction/ °
PDC cutter	3560	850	0.07				
Rock	2460	24.5	0.25	75	10.0	27.2	35.0

2.3. Geometric Model

According to the application status, the rock disintegration process of four types of special-shaped PDC cutters are simulated, they are: dual-chamfer PDC cutter [21], conical PDC cutter [22], ridged PDC cutter [23] and triangular ridge PDC cutter [24], their structures are shown as Figure 2.

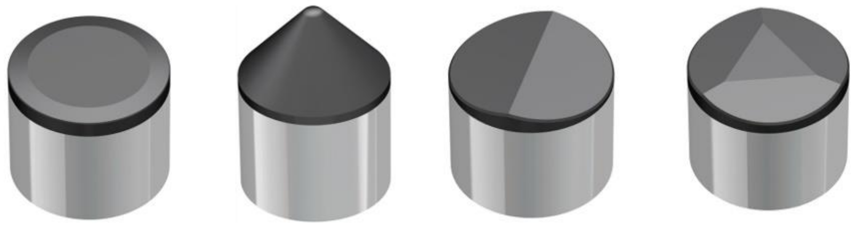


Figure 2. *3D model of special-shaped PDC cutter*

Both rock and PDC cutters are modeled by Solid 164 elements, and tetrahedral mesh is used to discretize the 3D model. The discrete mesh size of the cutters is set to 0.5mm, while the mesh size of the pre-fractured area in the middle of the rock is set to 0.1mm, and the mesh size of the rest area of the rock is set to 0.5mm. The size of the conical PDC cutter is Φ16×21mm, and the size of other special-shaped PDC cutters is Φ16×13mm; the rock size is 100×60×30mm.

The cutting depth of the special-shaped PDC cutters is set to 3mm, the cutting angle of the conical PDC cutter is 15°, while the cutting angle of the other cutters is -15°. Figure 3 shows the rock-breaking mesh model of PDC cutter.

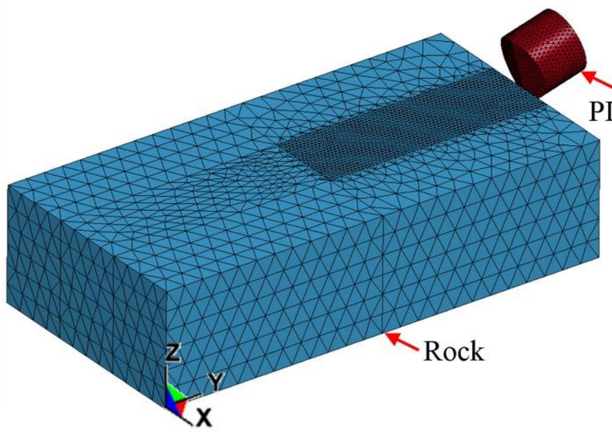


Figure 3. *Rock-breaking mesh model of special-shaped PDC cutter*

2.4. Boundary Conditions and Load Application

The special-shaped PDC cutters disintegrate rock at a translation speed of 50m/h along the Y axis, the degree of freedom in the other directions of the cutters is restricted. The rock is completely fixed, in order to eliminate the influence of boundary transmission wave, non-reflective boundary conditions are applied to the surrounding boundary of the rock. The erosion contact algorithm is set between the special-shaped PDC cutters and the rock element, when the failure parameter ω_s of the rock element reaches the preset critical value, the rock element failed and was removed from the rock mass.

2.5. Verification of Numerical Simulation Model

According to the experimental plan and results of literature 25 [25], the accuracy of the numerical simulation model established above is verified.

In literature 25, the structure size of the conical PDC cutter and the cutting rock model are shown in Figure 4. The cutter moves along a straight line to cut the rock at a cutting angle of 15° and a speed of 0.92m/s.

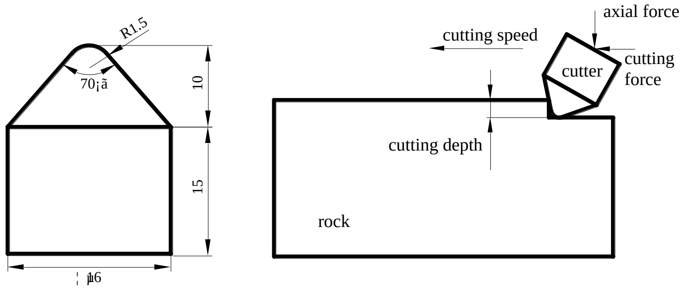
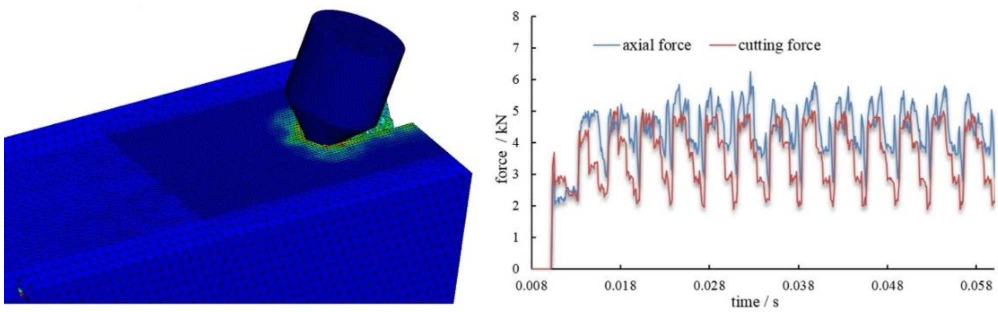


Figure 4. *Structure parameters and rock disintegration model of conical PDC cutter*

According to the experimental plan, simulation and analysis are carried out at the cutting depth of 1.0、1.5、2.0、2.5 and 3.0mm.

Figure 5 shows the rock stress cloud diagram and the load curves of the conical PDC cutter. In the rock disintegration process, the rock has to go through a process from small fragments to large fragments, the cutting load fluctuates periodically with time, which conforms to the characteristics of load change law of PDC cutter [26].



(a) Rock stress cloud diagram (b) Load curve of conical PDC cutter

Figure 5. *a) Rock stress cloud diagram b) cutter load curves*

Figure 6 is the load curves of conical PDC cutter at different cutting depths obtained through experiment and simulation. Whether it is axial force or cutting force, the force on the conical PDC cutter increases approximately linearly with the increase of cutting depth. The simulation results and the experimental results show similar changes. As the increases of cutting depth, for the experimental and simulation results, the linear increase slopes of axial force are 2.444 and 1.741 respectively, the deviation rate of the two is 28.76%; the linear increase slopes of cutting force are 0.481 and 0.435 respectively, the deviation rate between the two is 9.56%, both the deviation rates are within a reasonable range of ±30%.

The results calculated by numerical simulation are smaller than the experiment results, which are mainly caused by the difference between the rock material parameters given in the simulation and in the experiment, but the change laws obtained through the simulation and the experiment are in good agreement, which indicate that the established numerical simulation method is reliable and can be used to study the rock disintegration characteristics of special-shaped PDC cutters.

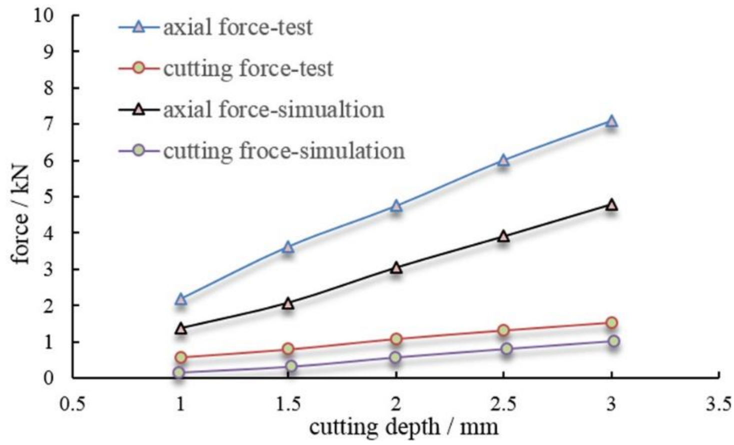


Figure 6. *The influence of cutting depth on the force of conical PDC cutter*

3. ANALYSIS OF SIMULATION RESULTS

By studying the surface stress distribution characteristics of cutters and change law of force, the rock disintegration characteristics of special-shaped PDC cutters are clarified, which can provide guidance on the application of special-shaped PDC cutters. At the same time, the plane PDC cutter is analyzed as a reference for comparison and description.

3.1. Surface Stress Characteristics of Special-shaped PDC Cutters

Figure 7 shows the cloud diagram of surface stress of the special-shaped PDC cutters. The stress on the plane PDC cutter is mainly distributed in the edge area where the cutter contacts the rock, and the maximum stress is concentrated at the lower end of the cutting edge and the upper ends of the two edges where the cutter contact the rock (Figure 7(a)).

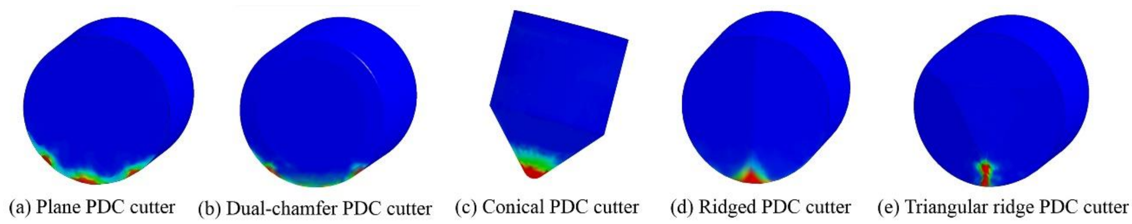


Figure 7. *Stress cloud diagram of special-shaped PDC cutters*

The stress on the dual-chamfer PDC cutter is mainly distributed in the area between the first and the second chamfers, the maximum stress area is similar to that of the plane PDC cutter. Compared with the plane PDC cutter, the existence of the second chamfer can effectively increase the supporting surface, expand the stress on the cutting edge to a larger area, which can effectively reduce the stress gradient, and reduce the cracking and peeling of the diamond layer of the cutter (Figure 7(b)).

The maximum stress of the conical PDC cutter is mainly distributed at the tip of the cone. The pointed cone structure is beneficial to better concentrate the load on the top of the cone, a compaction core is formed on the rock, which is helpful to produce compression failure on rocks (Figure 7(c)).

The stress of the ridged PDC cutter is mainly in the ridge part, and it is distributed in a triangular fan shape from the lower edge of the cutting edge upward along the ridge. The ridgeline of the cutter cuts the rock in the form of "axe blade", which is conducive to generating high line concentration stress and increasing the attack ability of the cutter (Figure 7(d)).

The stress of the triangular ridge PDC cutter is mainly distributed on the lowermost ridge, and it spreads symmetrically from the ridge to the wedge surfaces on both sides. Similar to the ridged PDC cutter, the shape of the triangular ridge is conducive to concentrating the stress on the very short ridges, and the cutter can disintegrate the rock more easily (Figure 7(e)).

Through the analysis of the above surface stress characteristics of special-shaped PDC cutters, it is possible to determine the vulnerable parts of each special-shaped PDC cutter, so as to provide guidance for optimal design and application of special-shaped PDC cutters in drill bits.

3.2. Load Change Law of Special-shaped PDC Cutters

By comparing and analyzing the rock disintegration loads of special-shaped PDC cutters, their load characteristics and changing laws were illustrated.

Figure 8 is the curves of the cutting force of the special-shaped PDC cutters with time. For the conical PDC cutter, the amplitude and frequency of the cutting force is relatively stable with time; for the dual-chamfer PDC cutter, the cutting force fluctuates most violently; the average cutting forces of plane and dual-chamfer PDC cutters are significantly higher than that of the other cutters. The average cutting forces of plane, dual-chamfer, conical, ridged and triangular ridge PDC cutters are 864.62N, 1028.25N, 436.54N, 560.73N and 688.35N respectively. In the case of the same cutting depth and cutting speed, the conical PDC cutter requires the least rock disintegration cutting force, and the dual-chamfer PDC cutter requires the greatest cutting force.

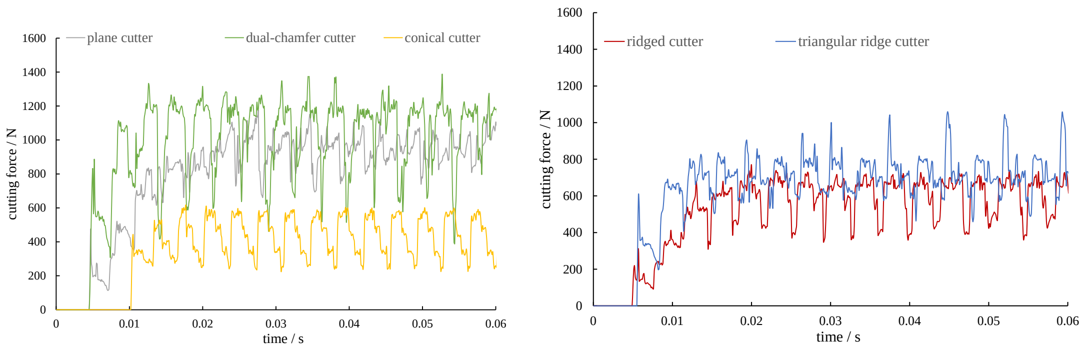


Figure 8. *Curves of cutting force with time of special-shaped PDC cutters*

Figure 9 shows the curves of axial force of special-shaped PDC cutters with time. For the dual-chamfer and conical PDC cutters, their axial forces fluctuate relatively sharply with time. The average axial forces of plane, dual-chamfer, conical, ridged and triangular ridge PDC cutters are 900.37N, 1090.46N, 1098.58N, 802.90N and 789.59N respectively. In the case of the same cutting depth and cutting speed, the triangular ridge PDC cutter requires the least rock disintegration axial force, while the dual-chamfer and conical PDC cutters require the greatest axial force, which means that the dual-chamfer and conical PDC cutters require greater drilling pressure to penetrate into the rock.

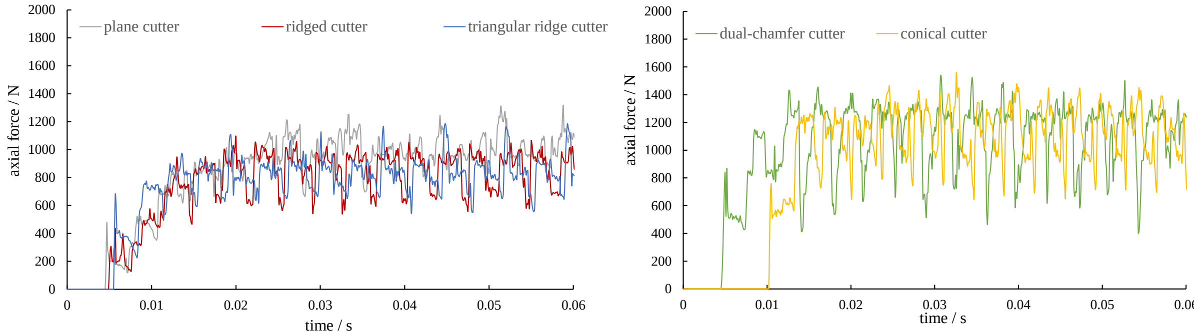


Figure 9. *Curves of axial force with time of special-shaped PDC cutters*

Figure 10 shows the curves of lateral force of special-shaped PDC cutters with time. For the conical and triangular ridge PDC cutters, their lateral forces fluctuate around 0, in the cutting process, the two cutters tend to be stable, and their drilling stability is better. For the other special-shaped PDC cutters, they show the tendency to deviate toward Y position direction, and the ridged PDC cutter shows the most obvious offset trend. The average lateral forces of plane, dual-chamfer, conical, ridged and triangular ridge PDC cutters are 52.83N, 45.69N, 8.91N, 100.31N and 6.21N respectively. In the case of the same cutting depth and cutting speed, the drilling processes of the conical and triangular ridge PDC cutters are the most stable.

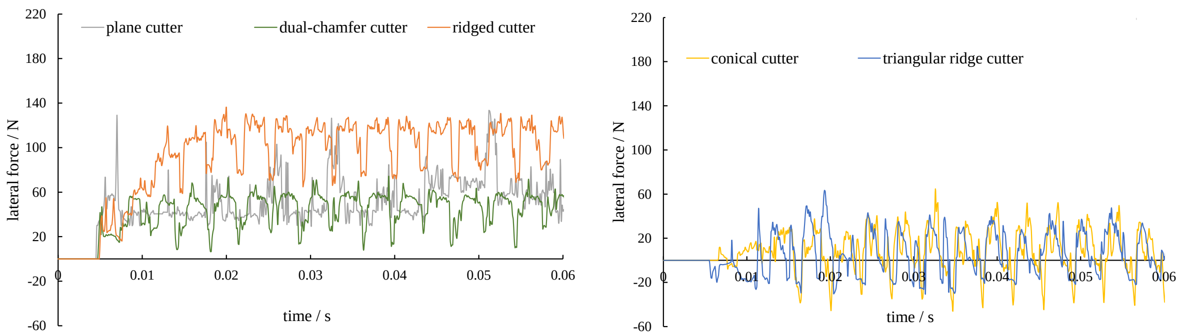


Figure 10. *Curves of lateral force with time of special-shaped PDC cutters*

3.3. Rock Disintegration Efficiency of Special-shaped PDC Cutters

The MSE is used as an index parameter to evaluate the rock disintegration efficiency of PDC cutters. MSE is defined as the work required to disintegrate rock of per volume. The smaller the MSE, the higher the rock disintegration efficiency of the cutter. The MSE formula is as follows:

$$MSE = \frac{Work\ Done\ in\ Cutting\ Action}{Volume\ of\ Rock\ Cut} = \frac{\int Force \cdot d(x)}{Volume\ of\ Rock\ Cut} \quad . \tag{3}$$

In the rock disintegration process, the cutters move only in the direction of cutting force, so only the cutting force does work.

Figure 11 shows the curves of rock volume with time of special-shaped PDC cutters. Due to the limitation of the cone tip structure, the disintegrated rock volume per unit time of the conical PDC cutter is the smallest. For the other special-shaped PDC cutters, their rock broken volume is similar. Within 0.06s, the rock broken volume of plane, dual-chamfer, conical, ridged and triangular ridge PDC cutters are 4.47e-6m^3, 4.41e-6m^3, 3.05e-6m^3, 4.56e-5m^3 and 4.41e-6m^3 respectively.

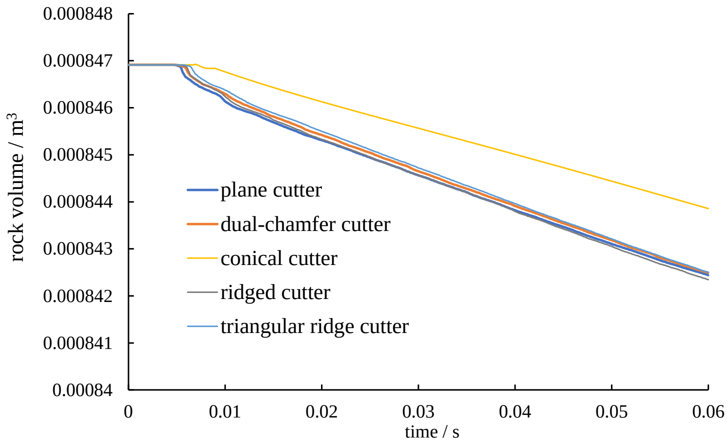


Figure 11. *Curves of rock volume with time of special-shaped PDC cutters*

According to Equation (3), the MSE of each special-shaped PDC cutter is calculated, and the results are shown in Figure 12. Under the same drilling conditions, the MSE of ridged PDC cutter is the smallest, and the rock disintegration efficiency of this cutter is the highest too. The MSE relationship of each special-shaped PDC cutter is: ridged PDC cutter<conical PDC cutter<triangular ridge PDC cutter<plane PDC cutter<dual-chamfer PDC cutter.

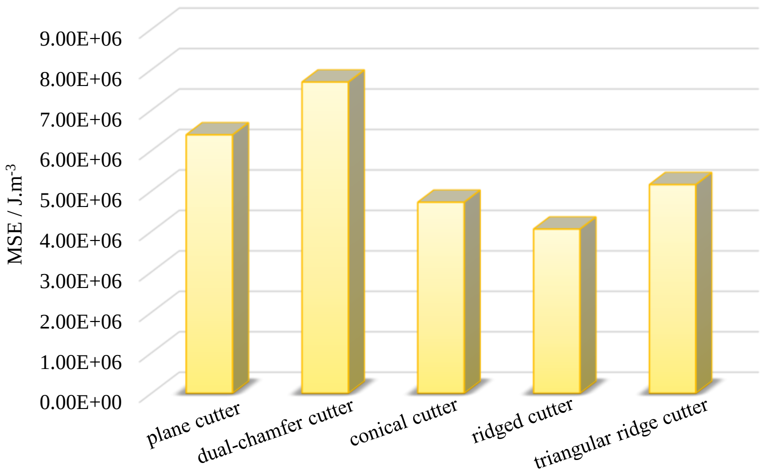


Figure 12. *MSE of special-shaped PDC cutters*

Summarizing the above rules, under the same drilling conditions, the conical PDC cutter has advantages in rock disintegration efficiency and stability, but it requires a higher weight on bit. The ridged PDC cutter has advantage in rock disintegration efficiency, but it tends to swing sideways when breaking rock. The performance of the triangular ridge PDC cutter is in the middle. Comparing with the plane PDC cutter, the dual-chamfer structure of PDC cutter is beneficial to extend the cutter's life, but its rock disintegration efficiency is relatively the worst.

4. MICRO-DRILLING TEST OF SPECIAL-SHAPED PDC CUTTERS

Laboratory micro-drilling tests were carried out to evaluate the rock disintegration effect of special-shaped PDC cutters, and the accuracy of simulation results was verified again.

4.1. Device of Electro-Hydraulic Micro-Drilling Test

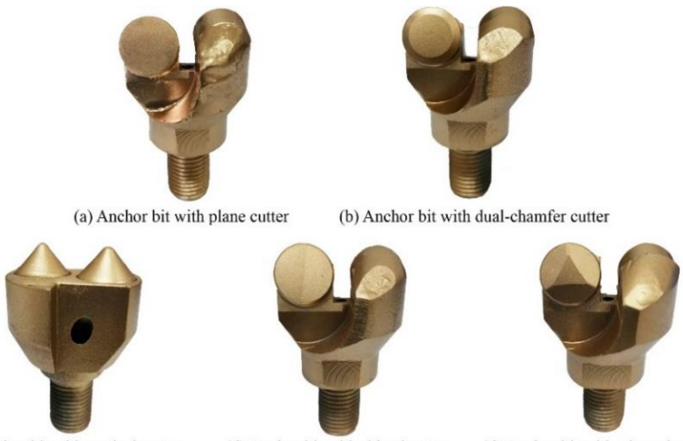
The device of electro-hydraulic micro-drilling test is mainly composed of drilling system, hydraulic pump station, operating table, and drilling parameter detection system. This test system integrates multiple functions such as real drilling simulation, rock sample transfer, drilling parameter detection and control, etc. Through setting mud pump flow, drilling pressure and rotation speed, the anchor bit can drill and break the rock. Figure 13 is the main components of the electro-hydraulic micro-drilling test device.

Drilling system Remote operating system Hydraulic pump station

Figure 13. *Main components of micro-drilling test device*

4.2. Drill Bit and Rock Sample

The special-shaped PDC cutters are welded to the anchor bit matrix by using a high frequency induction welding machine. Figure 14 are the photos of anchor bits with special-shaped PDC cutters: (a) Anchor bit with plane cutter; (b) Anchor bit with dual-chamfer cutter; (c) Anchor bit with conical cutter; (d) Anchor bit with ridged cutter; (d) Anchor bit with triangular ridge cutter.



(c) Anchor bit with conical cutter (d) Anchor bit with ridged cutter (d) Anchor bit with triangular ridge cutter

Figure 14. *Anchor bits with special-shaped PDC cutters*

Granite is selected as the test rock sample, and the size of the rock sample is 350×350×350mm^3. Figure 15 shows the rock sample and the photo after drilling.

Figure 15. *(a) Rock sample b) the photo after drilling*

4.3. Analysis of Test Results

The controlled variable parameter method is adopted to analyze the drilling efficiency of anchor bits with special-shaped PDC cutters. The more footage per minute the bit penetrates, the better the rock disintegration performance. By changing drilling pressure and rotation speed, the rock disintegration efficiency of anchor bits with different parameters is studied. The specific test scheme is as follows: (1) the rotation speed is set to 120rpm unchanged, and the drilling pressure is set to 2.0MPa and 2.5MPa respectively; (2) the drilling pressure is set to 2.5MPa unchanged, and the rotation speed is set to 120rpm and 125rpm respectively. Under each group of drilling parameters, the anchor bits with special-shaped PDC cutters drill 3 holes respectively, the effective depth of each hole is 200mm, and the pumping volume of mud pump is set at 20L/min.

Figure 16 shows the histogram of drilling efficiency of anchor bits with special-shaped PDC cutters under different drilling pressure at 120rpm. At different drilling pressures, the anchor bits with special-shaped PDC cutters show the same drilling efficiency relationship: anchor bit with ridged PDC cutter> anchor bit with triangular ridge PDC cutter> anchor bit with plane PDC cutter > anchor bit with dual-chamfer PDC cutter > anchor bit with conical PDC cutter.

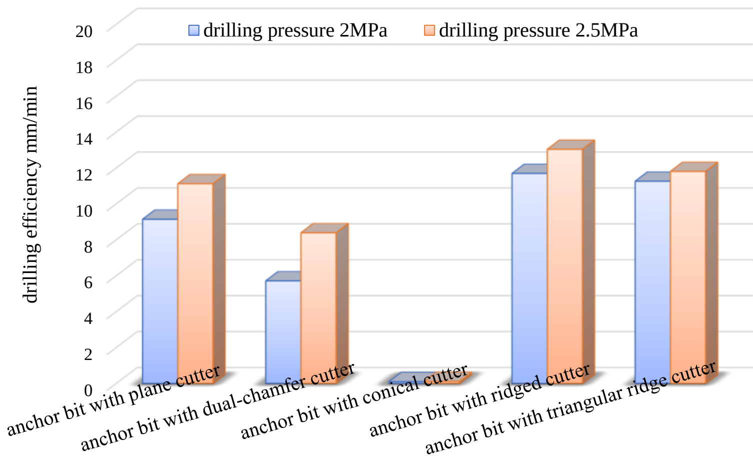


Figure 16. *Drilling efficiency of anchor bits under different drilling pressures*

Figure 17 shows the histogram of drilling efficiency of anchor bits with special-shaped PDC cutters under different rotation speed at 2.5Mpa. At different rotation speed, the anchor bits with special-shaped PDC cutters show the same drilling efficiency relationship: anchor bit with ridged PDC cutter> anchor bit with triangular ridge PDC cutter> anchor bit with plane PDC cutter > anchor bit with dual-chamfer PDC cutter > anchor bit with conical PDC cutter.

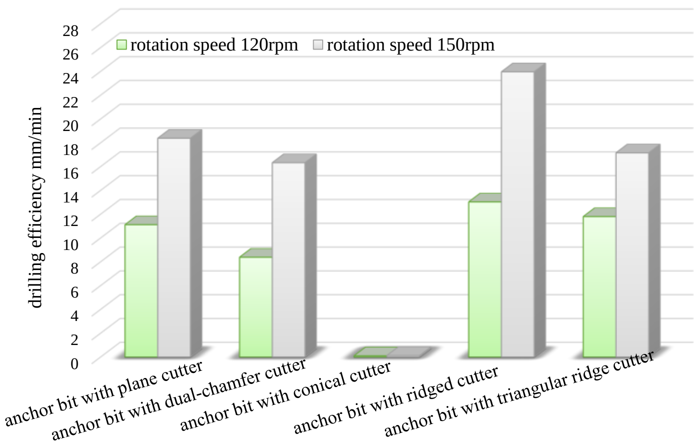


Figure 17. *Drilling efficiency of anchor bits under different rotation speed*

4.4. Comparative Analysis of Test Results and Simulation Results

Summarizing the simulation and test results, the rock disintegration efficiency of each special-shaped PDC cutter can be obtained, as shown in Table 2.

Table 2. *Rock disintegration efficiency obtained by simulation and test*

Rock disintegration efficiency / Special-shaped cutter	Simulation (J/m^3)	Test with rotation speed 120rpm (mm/min)		Test with drilling pressure 2.5MPa (mm/min)
		Drilling pressure 2.0MPa	Drilling pressure 2. 5MPa	Rotation speed 150rpm
Plane cutter	6.39e6	9.14	11.12	18.39
Dual-chamfer cutter	7.69e6	5.71	8.39	16.34
Conical cutter	4.72e6	0.09	0.11	0.13
Ridged cutter	4.06e6	11.70	13.04	23.97
Triangular ridge cutter	5.16e6	11.26	11.81	17.16

Comparing numerical simulation and test results in Table 2, except for the conical PDC cutter, the rock disintegration efficiency of the other special-shaped PDC cutters show the same magnitude relationship, which is: ridged PDC cutter> triangular ridge PDC cutter> plane PDC cutter > dual-chamfer PDC cutter. Analyzing the reason for the difficulty of drilling into rock with conical PDC cutter in the test, it can be summarized as follows: (1) the anchor bit with conical PDC cutter presses into the rock with the cutter's cone tip, the amount of the rock broken by the bit with one rotation is very small, which leads the bit is difficult to drill. (2) For the conical PDC cutter, it requires a higher drilling pressure to penetrate into the rock, which is consistent with the conclusion drawn by the simulation, therefore, during the micro-drilling test, the drilling pressure is small, which makes it difficult for the bit to drilling into the rock. So, the conical PDC cutter is more commonly used as a backup cutter in the bit to improve the bit's stability.

Therefore, except for the conical PDC cutter, the rock disintegration efficiency of the other special-shaped PDC cutters obtained from micro-drilling test agree with the numerical simulation results, which further shows that, the established numerical simulation method is accurate enough to be used to carry out the analysis of rock disintegration characteristics of special-shaped PDC cutters.

5. CONCLUSION

In order to improve the rock disintegration efficiency and life of PDC cutter in complex and difficult-to-drill formations, four types of special-shaped PDC cutters are taken as the research objects. Through numerical simulation and micro-drilling test, the rock disintegration characteristics, load distribution and rock disintegration efficiency of these four kinds of special-shaped cutters are evaluated and analyzed, which provides theoretical guidance for the field application of special-shaped PDC cutters.

(1) Numerical simulation method is used to simulate and analyze the rock disintegration process of plane, dual-chamfer, conical, ridged and triangular ridge PDC cutters. Simulation results show that, for the dual-chamfer PDC cutter, it is helpful to expand the stress on the cutting edge to a larger area, thereby prolonging the life of the cutter; for the conical PDC cutter, the stress on the cutting edge is concentrated on the top of the cone, which is conducive to forming a compacted core on the rock; for the ridged and triangular ridge PDC cutters, the stress on the cutting edge is concentrated on the ridge line, which is conducive to generating higher line concentration stress.

(2) For the conical PDC cutter, it has advantages in rock disintegration efficiency and stability, but it requires a higher weight on bit; for the ridged PDC cutter, it has advantage in rock disintegration efficiency, but it tends to swing sideways when breaking rock; the performance of the triangular ridge PDC cutter is in the middle; for the dual-chamfer PDC cutter, it is beneficial to extend the cutter's life, but its rock disintegration efficiency is relatively the worst. Also, the results of micro-drilling test and numerical simulation show the same law.

(3) This paper focuses on the research of rock disintegration performance of special-shaped PDC cutters, which can provide guidance for optimal design of these cutters, and their application on the bit. In the future, it is recommended to carry out the study on the design of PDC bit with special-shaped PDC cutters, through the cutter layout design of the new PDC bit, to enhance the adaptability of the bit to different formations, and improve the rock disintegration efficiency of the bit, finally create greater economic and social benefits.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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