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Research Article

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Effect of water jet arrangement on conical cutter cutting performance

K. D. Gao, C. L. Du and H. X. Jiang

College of Mechanical & Electrical Engineering, China University of Mining & Technology, Xuzhou, China

ABSTRACT

In order to study the effect of water jet arrangement on conical cutter cutting performance, rock broken mechanisms under the three arrangement modes(no water jet mode, water jet praevia mode and water jet lateral mode) were analyzed based on Evans theory, and mathematical model of the hole compressive stress was obtained. According to the model, water jet praevia mode can reduce the conical cutter cutting force more obviously than water jet lateral mode, and the correctness of above mentioned research results were confirmed in cutting test. The cutting test also showed that: in the condition of this paper, water jet praevia mode could reduce 37.52% cutting force and increase 6.9% fractal dimension of the broken rock compared to no water jet mode; water jet lateral mode could reduce 24.36% cutting force and increase 4.6% fractal dimension of the broken rock compared to no water jet mode, but this combination mode had obvious effect on improving proportion of big lump detritus.

Key words: Water jet; conical cutter; rock broken; rock broken mechanism; size distribution; fractal dimension

INTRODUCTION

The technology of cutter cutting rock combined with water jet has been researched for nearly 40 years, which aims to reduce the pressure on cutter body, extend service life of cutter and increase rock broken efficiency. The main research achievements were stated in following passage.

The radial cutter cutting experiment which combined with water jet was carried out by M. Hood[1], which indicated that water jet arranged in the head position of the radial cutter could get better cutting performance; The performance of high-pressure jet in assisted drilling was researched by D. A. Summers *et al*[2]and S.D. Veenhuizen *et al*[3], in their research they found that ultra-high pressure water jet assist drilling can improve the drilling efficiency of 1.5~1.6 times; The experiment of cutting rock by disc cutter combined with water jet had been done by D.Z. Cheng[4], and this experiment indicated that the rock crack produced by disc cutter could be extended by following water jet, which resulted in broken rock quantity’s increasing; 150 MPa water jet was applied in assisting PCD cutter excavation test by R.J. Fowell *et al*[5] and R. Ciccu *et al*[6], the tests shown that with the high water jet help, wear loss of cutter could reduce obviously, and the cutters’ service time could improved 80%; Experimental research of free-rolling cutters assisted by water jet in hard rock cutting was conducted by O. Fenm[7], which indicated that cutting force was decreased with the jet pressure’ increasing, when the pressure reached 40 MPa, the cutting force would reduce 40%; Numerical simulation method was introduced into the research of high water jet assist mechanical cutter in rock excavation by W.H. Zhang *et al*[8] and Chandrakanth S. *et al*[9], which indicated that combined cutting method could double the cutting efficiency and the optimum space between cutter and water jet is 13 mm; Experiment investigation on the breakage of hard rock by PDC cutters with different combined action modes was carried out by X.B. Li *et al*[10], which indicated that water jet could efficiently enhance the PDC cutters’ performance in hard rock cutting; High pressure water jet assist cutter cutting also was applied in cobalt-rich excavation by Z.H. Huang and Xie Y.[11],which indicated that the method of water jet and cutter action on the same point could decrease the minimum and maximum cutting force at the same time.

From the above statement, we can see that the research work of water jet assist mechanical excavation have been heavily focused on oil drilling area, rarely on mining area, especially of coal mining area. Great cutting force and short service life of cutters were still the main problems which influence the excavation efficiency in coal mining. With the help of coal mining technology development and their own advantages, conical cutters have been widely promoted and applied. Therefore, the methods research of reducing conical cutters' cutting force and wear become the key point, and introducing the water jet into the process of conical cutters' excavation will be an appropriate solution in current researches. As such, rock broken mechanism analysis and cutting tests under the three arrangement modes (no water jet mode, water jet praevia mode and water jet lateral mode) were carried out in this paper.

ROCK BROKEN MECHANISM UNDER THE THREE ARRANGEMENT MODES

In the present study about water jet assist cutter cutting rock, the arrangements of cutter with water jet could be mainly divided into three modes. The first mode: water jet was positioned in the front of the cutter (water jet praevia mode); The second mode: water jet was positioned in the side the cutter (water jet lateral mode); The third mode: water jet channel was positioned in cutter and the water was jetted from the cutter head. The third mode was also called hydro-cutter and its fundamental form was shown by Fig.1. But, high processing technology was requested in manufacture of the third mode, and blocking phenomenon was occurred easier as the water jet exit contact with rock directly, so the first mode and the second mode were used more widely. The basic idea of using the two modes cutting rock was like that: using wedge effect of water jet, crack or free surface was produced in rock to reduce cutting force of cutter. Compared with pure cutter cutting, stress state of rock was changed by water jet, and force distribution on the cutter was also changed. So in this paper, referring to Evans rock cutting theory, rock broken mechanisms were discussed under the three arrangement modes (no water jet mode, water jet praevia mode and water jet lateral mode, which were shown by Fig.2).

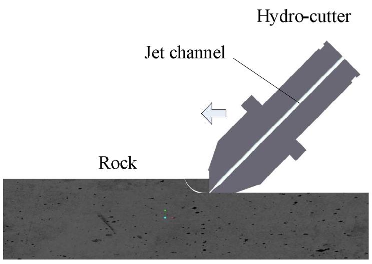


Fig.1: Structure of hydro-cutter

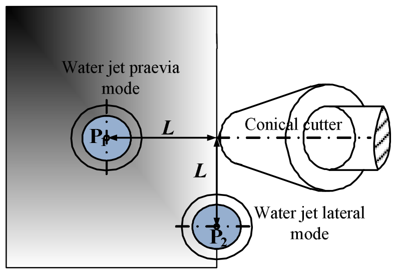


Fig.2: Two water jet arrangement modes

Rock broken model of no water jet mode

Evans rock cutting model was a classical model, many scholars had used this model to develop further researches on rock cutting [12-14]. The fundamental form of Evans rock cutting model was shown by Fig.3, and this model was also the rock broken model of no water jet mode.

In this mode, stress state of cutter presented symmetrical distribution along AB, and cutting force could be obtained just by discussing one side stress state of AB. In the Evans research, torque balance equations were obtained by taking the torque of force R, rock tensile force P1 which along the symmetrical line AB and rock tensile force F1 which along the caving line BO to O point. where, T1,T2 is the torque of P1,F1 to O point respectively, and were shown as the Eq(1) and Eq(2).

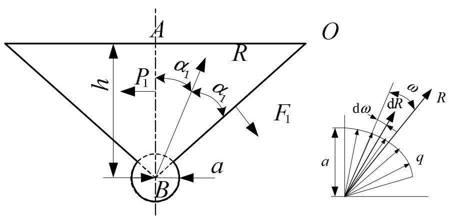


Fig.3: Rock broken model of no water jet mode

$$T_1 = P_1 L_{PO} = t\int_a^h (h-e)\mathrm{d}e \quad (1)$$

Where, *t*- rock tensile stress, in normal condition, t=(0.03~0.1)σ, σ is rock compressive strength;
a - radius of broken hole;
h- cutting depth;

e- distance to B point.

$$T_2 = F_1 L_{F_1 O} = t\frac{h}{\cos 2\alpha_1}\frac{1}{2}\frac{h}{\cos 2\alpha_1} \quad (2)$$

Where, α_1 - half break angle.

Torque balance equations was shown by Eq(3).

$$R\frac{h}{\cos 2\alpha_1}\sin\alpha_1 + t\int_a^h (h-e)\mathrm{d}e = t\frac{h}{\cos 2\alpha_1}\frac{1}{2}\frac{h}{\cos 2\alpha_1} \quad (3)$$

Just because a was very short and $h \gg a$, $t\int_a^h (h-r)\mathrm{d}r$ could be instead by $t\int_0^h (h-r)\mathrm{d}r$. So, force R as shown by Eq(4) could be obtained by solving Eq(3).

$$R = \frac{th\sin^2 2\alpha_1}{2\cos 2\alpha_1 \sin\alpha_1} \quad (4)$$

According to figure 3, the force R also can be expressed by Eq(5).

$$R = \int \mathrm{d}R = \int_{-\alpha_1}^{\alpha_1} qa\cos\varpi \mathrm{d}\varpi = 2qa\sin\alpha_1 \quad (5)$$

The compressive stress of hole q can be obtain by solving Eq(4) and Eq(5), and it was shown as Eq(6)

$$q = \frac{th\sin^2 2\alpha_1}{4a\cos 2\alpha_1 \sin^2\alpha_1} \quad (6)$$

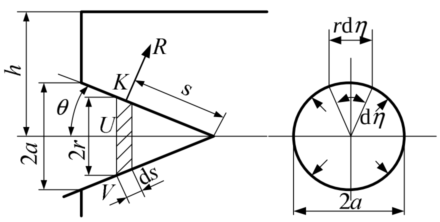


Fig.4: Calculation diagram of cutting force

The Fig.4 was the calculation diagram of cutting force. As Fig.4 showing, the infinitesimal area d*A* could be expressed by Eq(7).

$$\mathrm{d}A = r\mathrm{d}\eta\mathrm{d}s \quad (7)$$

Where, *r*-the length of UK, and it could be instead by *a*;
d*η*-the included angle of infinitesimal radian;
d*s*-the infinitesimal of length s .

The infinitesimal force d*R* could be get and it was shown by Eq(8).

$$\mathrm{d}R = \frac{q}{\cos\theta}\mathrm{d}A = \frac{th\sin^2 2\alpha_1}{4a\cos 2\alpha_1 \sin^2\alpha_1 \cos\theta} r\mathrm{d}\eta\mathrm{d}s \quad (8)$$

Where, θ – half cone angle.

The infinitesimal cutting force d*Q* could be get and it was shown by Eq(9).

$$\mathrm{d}Q = \mathrm{d}R\sin\theta = \frac{th\sin^2 2\alpha_1}{4\cos 2\alpha_1 \sin^2\alpha_1 \cos\theta}\mathrm{d}\eta\mathrm{d}r \tag{9}$$

The cutting force Q could be shown by Eq(10).

$$Q = \int \mathrm{d}Q = \frac{th\sin^2 2\alpha_1}{4\cos 2\alpha_1 \sin^2\alpha_1 \cos\theta}\int_0^{2\pi}\mathrm{d}\eta\int_0^a \mathrm{d}r = \frac{ath\sin^2 2\alpha_1\pi}{2\cos 2\alpha_1 \sin^2\alpha_1 \cos\theta} \tag{10}$$

The cutting force Q should overcome the compress stress caused by the rock which contacted with the conical surface, and the Q was approximately equal Eq(11).

$$Q = \pi a^2\sigma \tag{11}$$

According to the Eq(10) and Eq(11), the cutting force was was shown as Eq(12).

$$Q = \frac{\pi t^2 h^2 \sin^4 2\alpha_1}{4\cos^2 2\alpha_1 \sin^4\alpha_1 \cos^2\theta\sigma} \tag{12}$$

From above, we could get the conclusion like that the cutting force Q was mainly determined by the hole compressive stress q.

Rock broken model by water jet praevia mode

Due to the water wedge effect of jet, when the water jet set in front of the cutter, the crack was produced in symmetrical line *AB* of rock, then free surface was formed. The crack depth h1 was determined primarily by water jet pressure, jet distance and nozzle shape. Due to the free surface, cutter stress state changed when cutter cutting rock, and its rock broken model was shown by Fig.5. As the crack is in symmetrical line *AB*, stress state of the rock on the sides of *AB* also could be regarded as the same, so only one side cutting force research was needed. By referencing to research methods of Evans cutting theory, torque balance equation of water jet praevia mode cutting force could be obtained, and it was shown by Eq(13).

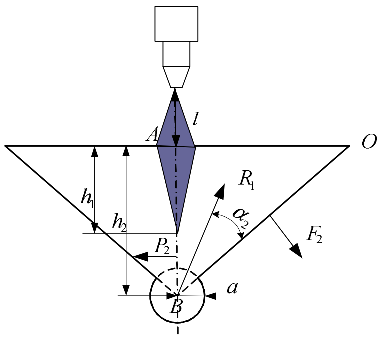


Fig.5: Rock broken model by water jet praevia mode

$$R_1\frac{h_2}{\cos 2\alpha_2}\sin\alpha_2 + t\int_a^{h_2-h_1}(h_2-e)\mathrm{d}e = t\frac{h_2}{\cos 2\alpha_2}\frac{1}{2}\frac{h_2}{\cos 2\alpha_2} \tag{13}$$

Where h_2- cutting depth, h_2=h;
h_1- crack depth;
α_1- half break angle.

Force R_1 as shown by Eq(14) could be obtained by solving Eq(13).

$$R_1 = \frac{th_2\sin^2 2\alpha_2}{2\cos 2\alpha_2 \sin\alpha_2} - \frac{th_1^2\cos 2\alpha_2}{2\sin\alpha_2 h_2} = \frac{th_2^2\sin^2 2\alpha_2 - th_1^2\cos^2 2\alpha_2}{2\cos 2\alpha_2\sin\alpha_2 h_2} \tag{14}$$

As the hole compressive stress q_1 could be expressed by Eq(15).

$$q_1 = \frac{th_2^2 \sin^2 2\alpha_2 - th_1^2 \cos^2 2\alpha_2}{4a\cos 2\alpha_2 \sin^2 \alpha_2 h_2} \tag{15}$$

From Fig.5, Eq(6) and Eq(15), we could see that：the angle α_2 would be smaller than angle α_1, because the pressure spread on line *AB* in fig.5 was smaller than that in fig.3; With the crack depth h_1 value's increasing, the half break angle α_2 would become more and more small; when half break angle $2\alpha_2$ was smaller than cutter half cone angle θ, the contact of the cutter head and rock will become very complex, and the calculate cutting force would be much smaller than real force which used the Evans rock broken theory to calculate. But, whatever above mentioned, we still could concluded that the water jet exiting was able to reduce the cutting force on occasion of water jet praevia mode ($R_1<R$).So, if cutter half cone angle $\theta\leq 2\alpha_1$, q_1 could be expressed by Eq(15).

Rock broken model by water jet lateral mode

When the water jet was set in a side of the cutter, the crack was produced, and the rock broken model was shown by Fig.6. As the water jet impinging was unilateral form, the force state on both sides of symmetrical line AB should be analyzed separately. The torque balance equation of one side with water jet was shown by Eq(16) , The torque balance equation of the other side could be shown by Eq(17).

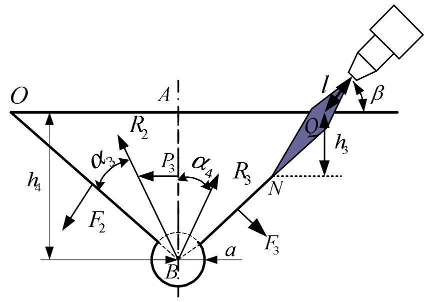


Fig.6: Rock broken model by water jet lateral mode

$$R_2 \frac{h_4}{\cos 2\alpha_3} \sin\alpha_3 + t\int_a^{h_4} (h_4 - e)\mathrm{d}e = t\frac{h_4}{\cos 2\alpha_3} \frac{1}{2} \frac{h_4}{\cos 2\alpha_3} \tag{16}$$

where h_4- cutting depth, h_4=h;
h_3- crack depth, h_3= $h_1\sin\beta$;
β- incident angle of water jet;
α_3, α_4- half break angle, in normal condition, $\tan 2\alpha_4 = l / h_4$;
l -distance of water jet incident position to symmetrical line *AB*.

$$R_3 \frac{h_4 - h_3}{\cos 2\alpha_4} \sin\alpha_4 + t\int_a^{h_4} (h_4 - e)\mathrm{d}e = t\frac{h_4 - h_3}{\cos 2\alpha_4} \frac{1}{2} \frac{h_4 - h_3}{\cos 2\alpha_4} \tag{17}$$

Stress force of cutter R_2, R_3 could be separately obtained by solving the Eq(16), Eq(17), as shown by Eq(18), Eq(19).

$$R_2 = \frac{th_4 \sin^2 2\alpha_3}{2\cos 2\alpha_3 \sin\alpha_3} \tag{18}$$

$$R_3 = \frac{t(h_4^2 \sin^2 2\alpha_4 - 2h_3h_4 + h_3^2)}{2\cos 2\alpha_4 \sin\alpha_4 (h_4 - h_3)} \tag{19}$$

As R_2 and R_3 were shown by Eq(18) and Eq(19), the q2 and q3 could be gotten and shown as by Eq(20) and Eq(21).

$$q_2 = \frac{th_4 \sin^2 2\alpha_3}{4a\cos 2\alpha_3 \sin^2 \alpha_3} \tag{20}$$

$$q_3 = \frac{t(h_4^2 \sin^2 2\alpha_4 - 2h_3h_4 + h_3^2)}{4a\cos 2\alpha_4 \sin^2 \alpha_4 (h_4 - h_3)} \tag{21}$$

Just for the hole compressive stress q_2 and q_3 caused by the same cutter, the q_2 should be equal to q_3, and it was shown by Eq(22).

$$\frac{h_4 \sin^2 2\alpha_3}{\cos 2\alpha_3 \sin^2 \alpha_3} = \frac{(h_4^2 \sin^2 2\alpha_4 - 2h_3 h_4 + h_3^2)}{\cos 2\alpha_4 \sin^2 \alpha_4 (h_4 - h_3)} \tag{22}$$

According to rock broken model by water jet lateral mode, the moments to point *O* should achieve a balance which was shown by Eq(23).

$$\begin{aligned}(R_2 \cos\alpha_3 + R_3 \cos\alpha_4)h_4 \tan 2\alpha_3 + R_3 h_4 \sin\alpha_4 + F_3 \cos 2\alpha_4 (\frac{h_4 + h_3}{2}) = F_2 \frac{h_4}{2\cos 2\alpha_3} + \\ F_3 \sin 2\alpha_4 (h_4 \tan 2\alpha_3 + \frac{h_4 - h_3}{2} \tan 2\alpha_4) + h_4 R_2 \sin\alpha_3\end{aligned} \tag{23}$$

Also, in the whole process, the main forces should achieve balances, and they were shown by Eq(24) and Eq(25)

$$R_2 \cos\alpha_3 + R_3 \cos\alpha_4 = F_2 \sin 2\alpha_3 + F_3 \sin 2\alpha_4 \tag{24}$$

$$R_2 \sin\alpha_3 - R_3 \sin\alpha_4 = F_3 \cos 2\alpha_4 - F_2 \cos 2\alpha_3 \tag{25}$$

The relationship of α_3 and α_4 could be obtain by solving Eq(23), Eq(24) and Eq(25), and it was show in Eq(26).

$$\frac{\cos 2\alpha_3}{\cos 2\alpha_4} = \frac{h_4}{h_4 - h_3} \tag{26}$$

The situation of the break angle smaller than cutter half cone angle which mentioned in water jet praevia mode might also happen in this mode. In order to avoid that, the incident angle β must be smaller than cutter half cone angle ($\theta \geq \beta$).But from Eq(26), we could conclude that the half break angle α_3 was smaller than the half break angle α_4. So, the α_3 also should meet the condition of $\theta \leq 2\alpha_3$.Beyond that, α_3 also should not be larger than α_1 which was the half break angle on occasion of no water jet mode. So, the incidence angle β should meet the request which was show as Eq(27).

$$\arccos(\frac{h_4 - h_3}{h_4}\cos\theta) \leq 90°\text{-}\beta \leq \arccos(\frac{h_4 - h_3}{h_4}\cos 2\alpha_1) \tag{27}$$

As seen from the Eq(6), Eq(15) and Eq(20), we can get the calculate result of that $q > q_2 > q_1$ when the effect of break angle on cutting force was ignored. However, in the actual situation, force balance state of cutter cutting was changed due to the presence of water jet. When water jet praevia mode was employed, the half break angle $\alpha_2 < \alpha_1$, and the difference between α_2 and α_1 is governed mainly by crack depth, cutting depth and rock property. But in general, the difference was not large. When water jet lateral mode was employed, half break angle α_4 was determined primarily by incident angle of jet, crack depth and rock property, and also, half break angle α_3 was influenced by α_4. According to the current researches, cutter break angle was less than the maximum break angle and was more than half cone angle of cutter alloy head in whatever situation. In normal condition, when the rock was hard(σ>25 Mpa), the half cutter cone angle should be more than 35°, and the rock break angle might be more than 50°. Within this scope, cutting force would not greatly affected by break angle. So, the conclusion could be got from the above established cutting force of cutter model: under the normal condition, cutter cutting force of the water jet praevia mode was less than that of no water jet mode and water jet lateral mode.

TEST REASEARCH OF THE THREE ARRANGEMENT MODES

In order to validate the correctness of the above theoretical analysis, the cutting process were experimental studied in three modes: no water jet mode, water jet preavia mode and water jet lateral mode. The test-bed was mainly consisted of four systems: hydraulic system, oil system, detecting system and mechanical system, and its structure diagram was shown by Fig.7. Water jet pressure, nozzle position and jet incident angle were adjusted by water system; Slide guide speed and cutter position were adjusted by oil system and mechanical system; Slide guide speed and main cutting force of cutter were detected by detection system.

In the test, jet outlet diameter was 3mm; jet target distance was 10mm; the type of conical cutter was U92 which was produced by Kennametal company; cutter cutting angle was 35°; cutting depth was 20 mm; compressive strength of artificial rock was 26.4 MPa; tensile stress was 1.48 MPa; slide guide speed was 4 m/min; water jet pressure was 20 Mpa. Rock breakage after being dried under the three arrangement modes were shown by Fig.8 (the parameters of water jet lateral mode: the height from nozzle to rock is 10 mm; jet incident angle β=40°, and it pointed to the cutter head). The cutting force of this three arrangement modes were shown by Fig.9. Main Statistic of cutting force in this test was shown by Table 1. Particle size classification under this three arrangement modes was shown by Table 2, and crushed rock weight was the weight after dried.

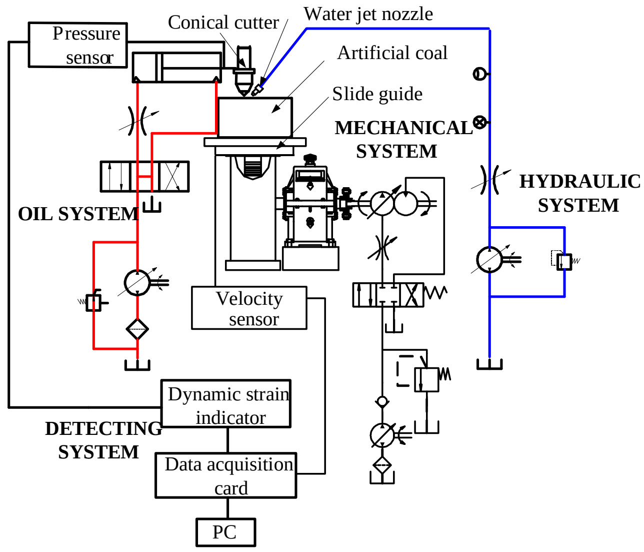
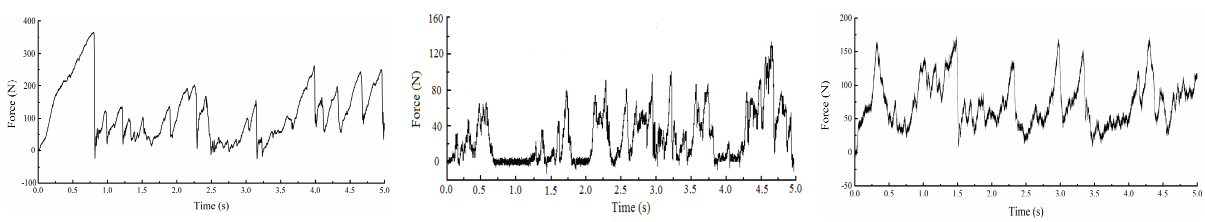


Fig.7: Structure diagram of the test bed

(a) no water jet mode **(b) water jet praevia mode** **(c) water jet lateral mode**

Fig.8: Rock breakage after being dried under the three arrangement modes



(a) no water jet mode **(b) water jet praevia mode** **(c) water jet lateral mode**

Fig. 9: Cutting forces of the conical cutter under the three arrangement modes

Table 1: Test statistic of the cutting forces

Project	no water jet mode	water jet praevia mode	water jet lateral mode
Maximum cutting force (N)	373.17	134.55	170.31
Mean cutting force (N)	108.57	67.83	82.12
Mean square error	41.09	8.01	15.26

Table 2: Particle size classification under the three arrangement modes (dry weight)

Particle size classification (mm)	no water jet mode		water jet praevia mode		water jet lateral mode	
	Weight (g)	proportion (%)	Weight (g)	proportion (%)	Weight (g)	proportion (%)
< 5	261.7	42.5	439.9	62.8	547.6	57.3
5 - 10	164.7	26.7	138.1	19.7	87.7	9.2
10 - 20	97.2	15.8	97.3	13.9	94.2	9.9
20 - 30	69.5	11.3	24.8	3.5	201.1	21.1
> 30	23.1	3.7	0	0.0	24.7	2.6
Fractal dimension	2.60		2.78		2.72	
Square error	0.940		0.911		0.958	

DISCUSSION

From Fig. 9 and Table 1, it can be seen that: the maximum cutting force, mean cutting force and mean square error of water jet praevia mode were less than others', its maximum cutting force was 63.94 percent smaller than no water jet mode, and its mean cutting force was 37.52 percent smaller than no water jet mode; the water jet lateral mode also could reduce the maximum cutting force, mean cutting force and mean square error, but it was inferior to water jet praevia mode, the maximum cutting force could reduce 54.36 percent value according to n water jet, and the mean cutting force could reduce 24.36 percent. From this conclusion, we can confirm that the theoretical analysis was correct. Simultaneously, the test results also indicated that the cutter cutting force and energy consumption could be reduced obviously when the water jet was added.

From the changes of cutting force in Fig.9, it can be seen that: The fluctuation period of cutter cutting force which added or not added water jet was totally different. Cutting force and the fluctuation period could be changed by water jet, this appearance was more obvious in Fig. 9-(a) and Fig. 9-(b). When cutter cutting the rock with water jet, more crack and free surface were produced in the rock by water jet, and it changed the rock broken form and broken energy which affects the fluctuation form of cutting force. In other word, the particle size classification of broken rock could be predicted by fluctuation form of cutting force. In this test, change cycles of cutting forces in Fig. 9-(a) and Fig. 9-(c) were much larger than that in Fig. 9-(b). Base on this point, we could concluded that the numbers of bigger size broken rocks which obtain from no water jet mode and water jet lateral mode were much larger than that from water jet praevia mode, and this conclusion was well proved by Table 2.

From Table 2, we could see that: On occasion of water jet praevia mode, the size of broken rock which smaller than 5mm or larger than 30mm didn't exist at all; But the large size broken rocks were easier to obtained on occasion of water jet lateral mode. For further quantitative analysis of the broken rock size distribution, the calculation formula of fractal dimension had been introduced from reference [15] which was shown by Eq(28). Correspondingly, the fractal dimension D of broken rock under this three conditions were obtain by Eq(28). The calculate results were shown by Table 2, and the fractal distribution of broken rock was shown by Fig.10.

$$\ln x_i / x_{\max} = (3-D)\ln m_i / m \quad (28)$$

Where x_i-particle diameter of broken rock, mm;
$x_{\max}$-maximum size, this test was 40mm;
m_i-weight of broken rock whose size was smaller than x_i, kg;
m-total weight of broken rock,k g.

From the fitting line of Fig.10 and square error in Table 2, it can be seen that: the particle size of broken rock in the three modes all had the fractal feature, and the fractal characteristic was more apparent on occasion of no water jet mode and water jet lateral mode. As seen in Table 2, fractal dimension of water jet praevia mode was largest, and water jet lateral mode occupied the second. This situation occurred just because the water jet could increase the rock breaking degrees. But it was also different under the two arrangement mode. Small size broken rock (< 5 mm) was led to increased by water jet praevia mode, while the proportion of large size broken rock (>20 mm) was reduced; Although water jet lateral mode brought a certain increase in the number of small size broken rock, the effect on large size broken rock number increase was more obvious. The main reason was that: crack would be generated when the rock was directly impacted by water jet, and the crack generation was due to the small size broken rock, so small size broken rock number would be increased as long as water jet existed; On occasion of water jet praevia mode, the crack was first generated in the middle position of the rock, and the probability of breakage in rock middle position was increased which was disadvantage to the generation of large size broken rock; But beyond that, As the cutter cutting the rock, the crack in the middle position was in direct contact with cutter which caused the increasing of the cutter and rock contact area, and the more complicated friction and extrusion effect would bring more small size broken rock; On occasion of water jet lateral mode, the producing crack was located in the left of the cutter which would bring larger lateral force, and when the cutter cutting the rock, more large size particles would be pried and generated from the rock.

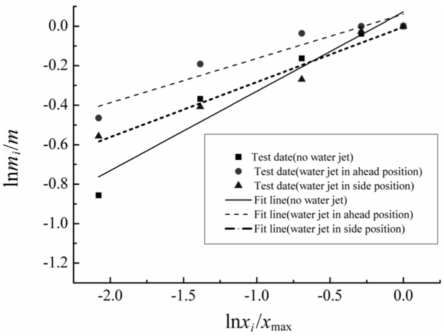


Fig.10: Fractal distribution of broken rock

CONCLUSION

(1)Base on Evans rock cutting theory, rock broken mechanisms of no water jet , water jet in ahead position and water jet in side position were researched, mathematical model of the hole compressive stress was obtained; According to the model, we could concluded that the cutting force of water jet praevia mode was minimum, and no water jet mode was maximum.

(2)The cutting tests of the three water jet arrangement mode were carried out, and the tests indicated that: water jet praevia mode could reduce 37.52% cutting force and water jet lateral mode could reduce 24.36% cutting force compared to no water jet mode; With water jet, conical cutters work environment could be obviously improve and their service life would be extended.

(3) The fractal characteristic of broken rock under different conditions were investigated. The results shows that: the fractal dimension of broken rock was enlarged as a result of the water jet existence, and the rock broken degree was improved; The percentage of small rock fragments increased dramatically when the rock breaks under water jet praevia mode; On the contrary, water jet lateral mode could enhance the percentage of big rock fragments distinctly.

(4) According to the effects of water jet arrangement mode on cutting force and the broken rock size, the water jet praevia mode is suggested to apply in the design of hard rock cutting mechanism for improving the rock broken degree and reducing the tool consumption. However, the water jet lateral mode is recommended to apply in the design of soft rock cutting mechanism to reduce the equipment power and improve the rock fragments size.

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