Research on Rock Breaking Mechanism of the Particle Impact Drilling

Guozhen Yang, Xueyang Xing *

Binzhou University, Department of Architectural Engineering, 391-5th Huanghe Road, Binzhou District, Binzhou, Shandong, 256600, China

Abstract

Particle impact drilling (PID) technology can effectively improve the speed of drilling in deep and hard formations. It is important to study the erosion characteristics in flow channels of the particle impact drilling bit. In this paper, experimental and numerical methods are used to study the laws of motion in flow channels. On this basis, the reasonable parameters of the inner flow channel structure for PID bit are obtained. This study finds that the acceleration effect of the particle-jet is obvious in the inlet nozzle, which can be effectively accelerated particles and shocked rocks at the bottom wellbore. The optimal jet particle speed, concentration, rotating speed and drill speed are obtained in the PID. The test shows that reasonable design of inner flow channel structure is beneficial to the field application of particle impact drilling.

Keywords

Particle impact drilling; particle impact rock; drilling bit; nozzle; rock breaking mechanism.

1. Introduction

Particle Impact Drilling (PID) is a new oil drilling technology developed for the development of oil and gas resources in deep, extremely hard and highly abrasive formations.Particle impact drilling refers to adding steel particles with a volume concentration of 1%-3% and particle size of 1-3 mm to the drilling fluid while the conventional drill rotates to break the rock, and uses a drill nozzle to impact the fracture in the form of high-frequency jets. The rock at the bottom of the well plays an auxiliary role in breaking the rock, which in turn drastically increases the ROP and accelerates the production of oil and gas wells.

At present, only PDTI Inc. In the United States [4-6] conducted field tests in North America, the most hard and wear-resistant strata in North America and Utah, and the results showed that under the same conditions, the drilling speed increased by 3 to 4 times. Therefore, particle impact drilling has great potential in improving the drilling rate of hard walls in deep wells. It has broad application prospects in areas where hydrocarbon resources are abundant but where they are buried deep and hard and hard.

In this paper， Grain drill Fukui Ichiwa Rock grain Altar crackle Weave involved. Impact and grain huge underwater rock disintegratable number of participating studies study， reveal the mechanism of rock breaking by particle impact drilling, and provide a theoretical basis for efficient rock fragmentation technology with particle impact drilling.

2. Study on numerical simuslation of rock beraking by practical jet

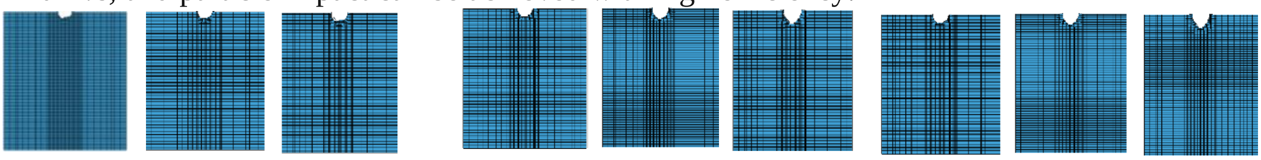
Changes in particle jet parameters, such as particle jet velocity, impact time, and the particle concentration, can directly affect rock fracture damage effects. To intuitively understand the effects of particle jets on rock fracture damage, a smooth particle hydrodynamics (SPH) algorithm was used to simulate the whole process of particle jet rock fragmentation, and the effect of particle jet impact on rock fracture damage was preliminarily explored.

2.1 Influence of Particle Impact Velocity on Rock Damage

At a particle concentration of 1%, a spray distance of 20 mm, and an impact time t are fixed, the rocks are impacted at particle jet speeds of 100 m/s, 150 m/s, and 200 m/s, respectively, and three time points in the process of extracting the particle jet impact rock are obtained. Under the size of the rock crushing pits, through the size of the crushing pits, the changes in rock fracture damage and rock breaking effects at different speeds are visually analyzed. The simulation results are shown in Figure 1

As shown in Fig. 1, the numerical simulation results show that in the same time period, the size of the rock breaking pit increases with the increase of particle jet velocity, and the degree of rock fracture damage gradually develops with the increase of particle jet velocity. The reason is that the greater the particle jet velocity, the greater the impact load on the rock when it contacts the rock. When the velocity reaches a certain value, it exceeds the critical value of rock fracture damage expansion, causing the rock fracture damage to expand rapidly and make the fracture depth The crushing volume is greatly increased.

Therefore, in the practical application of particle drilling technology, through the rational design of the particle drill nozzle, there will be a critical value for the speed of the highest rock breaking efficiency, to meet the minimum speed requirements to achieve efficient rock breaking. Taking into account the actual pump pressure at the site of particle drilling and the minimum requirement for rock breaking, it is recommended that the particle velocity ejected by the particle nozzle is not less than 120 m/s, and particle impact can be achieved with high efficiency.

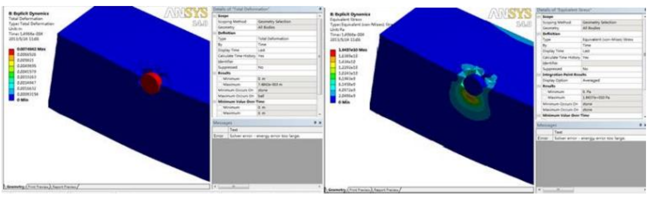


v=100m/s v=150m/s v=200m/s v=100m/s v=150m/s v=200m/s v=100m/sv=150m/s v=200m/s

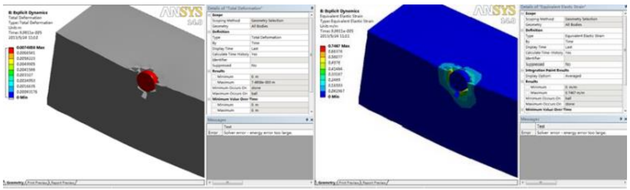
(a) t=2.38 ms (b) t=4.79 ms (c) t=7.19 ms

Fig.1 Broken pits of different speeds with time

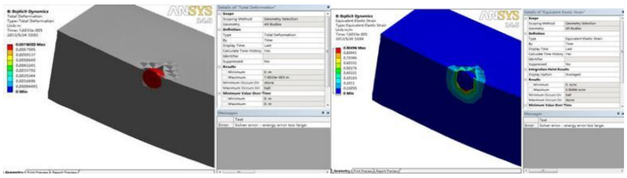
Based on the rock physical and mechanical parameters of Xujiahe River in Sichuan, the rock density is 2.6g/cm^3, compressive strength is 140MPa, elastic modulus is 46GPa, Poisson's ratio is 0.22, shear modulus is 18.8GPa, particle diameter is 1mm, and incidence speed is 50~ 175m/s, respectively, simulated particle breaking effect. The simulation results are shown in Figure 2 below.



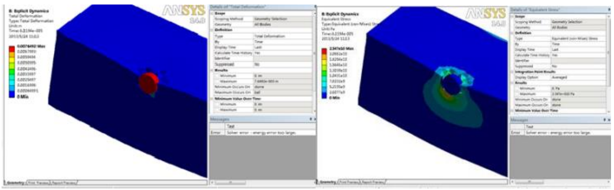
(a) Depth and stress distribution of 50m/s particle impact rock breaking



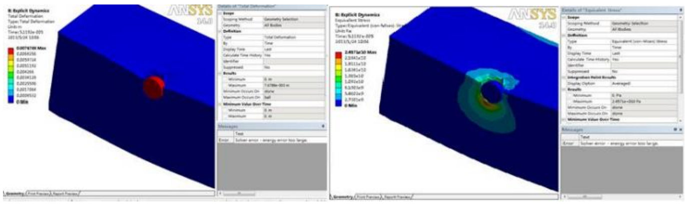
(b) Depth and stress distribution of rock breaking by 75m/s particles



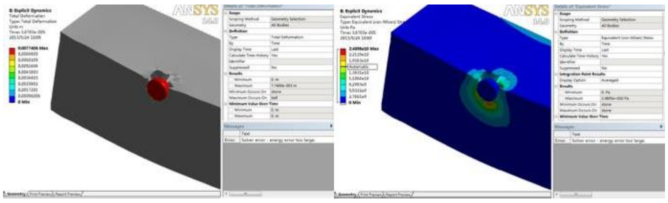
(c) Depth and stress distribution of 100m/s particle impact rock breaking



(d) Depth and stress distribution of 125m/s particle impact rock breaking



(e) Depth and stress distribution of 150m/s particle impact rock breaking



(f) Depth and stress distribution of 175m/s particle impact rock breaking

Fig.6 The particle impact erosion depth and rock stress distribution

Table3 Particles invasion depth in different velocity

Incident speed m/s	50	75	100	125	150	175
Maximum depth /mm	0.484	0.528	0.609	0.649	0.679	0.740

The numerical results simulation results are shown in Fig. 2 and Table 1. The results show that with the increase of the incident speed, the depth of intruding rocks also becomes larger . The volume of rock- breaking also increases correspondingly, and the effect of rock- breaking is better. When the particle velocity is less than 100m/s, the invasion depth changes rapidly with the velocity; when the particle velocity is between 100-150m/s, the intrusion depth continues to increase but is gentle; if the incidence velocity continues to increase to 175m/s It is possible that intrusion too deep can cause particles to leave the bottom of the well and remain in the bottom rock, which is not conducive to rock breakage. It also takes into account that the particle velocity is also limited by the mud pump displacement and pump pressure. Increase. Therefore, considering various factors, it is more appropriate to choose the speed of particle rock-breaking in the range of 100-125m/s. The above can indicate that when the particle nozzle accelerates the particles to about 120m/s, it can achieve the impact of the particles to crush the rock and meet the requirements of the rock drilling technology.

2.2 Effect of Particle Jet Concentration on Rock Damage

At a particle jet velocity of 200 m/s, a spray distance of 20 mm, and a constant impact time t, particle jets with a particle concentration of 1%, 3%, 5%, and 15% were impacted on the rock, respectively, and four particle jets were impacted during rock blasting. The size of the rock crushing pits at the time point, and through the size of the crushing pits, the rock fracture damage and rock breaking effect under different particle concentrations are visually analyzed. The simulation results are shown in Figure 6.

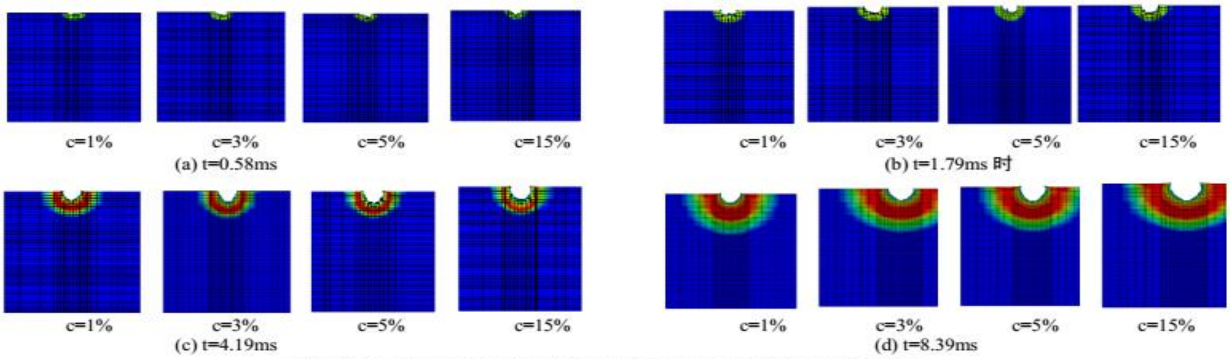


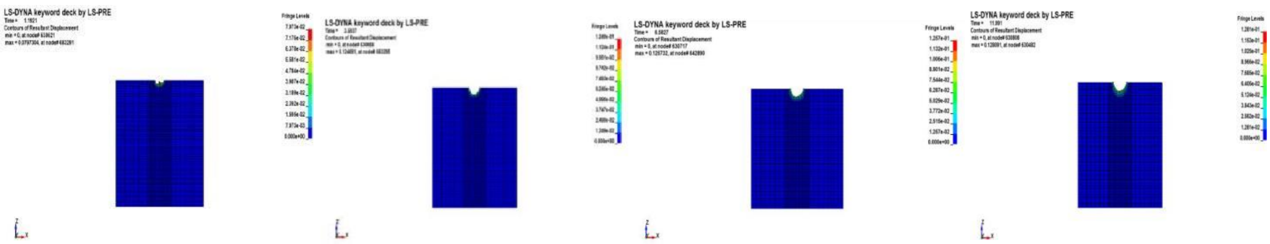
Fig.3 Broken pits of different concentrations with time

As shown in Fig. 3, the numerical simulation results show that when the particle concentration changes from 1% to 3%, the particle jet energy increases, the impact load on the rock increases, and the size of the rock breaking pit and the damage extension range rapidly increase with the increase of the concentration. Large; when the particle concentration changes from 3% to 5%, the size of the rock crater volume and the growth rate of the damage range are slowed down. The reason may be that the increase of particle concentration leads to mutual interference between particles, which cause loss of partial impact kinetic energy and affect rock damage. The rupture continues to develop, but the overall trend is still larger; when the particle concentration continues to increase to 15%, the energy of the particle jet impacting the rock is much greater than the energy of the inter-particle interference loss, and the size of the fracture pit is greatly increased.

Therefore, the concentration of 3% can meet the requirements of particle jet rock fragmentation, although the greater the particle concentration, the better the effect of particle jet rock fragmentation, but comprehensively consider the energy efficiency of particle jet, blockage of the drilling pipe, wear and bottom hole particles On the other hand,when particle drilling technology is applied in practice, the particle concentration should not be too large and should be kept within 5%.

2.3 Influence of Particle Impact Time on Rock Damage

In particle, jet velocity of 200 m/s, jet from 20 mm, the concentration of 1% certain conditions, respectively to simulate particles under different time jet impact of broken rock pit changes, intuitive analysis of rock under different impact times change and broken rock burst damage effect. The simulation results are shown in Figure 4.



t=1.19ms t=3.39ms t=6.58ms t=11.99ms

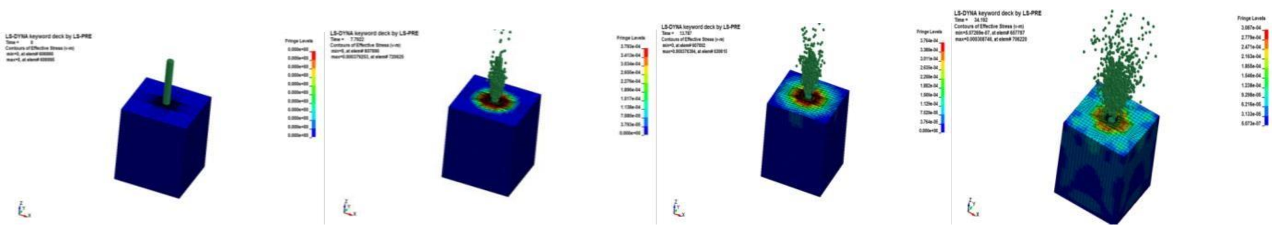
Fig. 4 Rock breaking volume changes with time

The numerical simulation results show that as the time increases, the particle jet continuously comes into contact with the rock, causing the rock to burst and the damage degree to expand continuously, and continuously breaking the rock, so that the rock's crater volume will always increase; the rock fracture damage expands. The increase in speed over time shows a change that tends to be stable after first rapid growth. The reason may be that the rock was initially damaged by the impact of particle jets and rapidly expanded. After a certain period of time, the rock was broken and damaged to a certain extent. Because of the long spray distance, reduced energy, and the accumulation of particles that cannot be discharged in time, the rock crushing speed tends to decrease.

Therefore, in the application of the actual particle drilling technology, there will be an optimal bit rotation speed and feed rate, which will enable the particle jet to fully break up the rock within a certain period of time and improve the rock breaking efficiency.

2.4 Analysis of Rock Damage Mechanism Caused by Particle Jet Impingement

Taking the process of particle jet velocity of 100m/s, particle concentration of 1% and spray jet of 20mm particles penetrating into the rock as an example, the damage mechanism of the rock under the action of particle jet impact is analyzed. The process of the particle jet impacting the rock is shown in Figure 5.



(a) t=0.0 ms (b) t=7.79ms (c) t=13.78ms (d) t=34.19ms

Fig. 5 Rock breaking process in particle jet

Figure 5 shows that the whole process of particle jet impinging on rock is basically divided into four stages: initial impact stage, rock damage initiation stage, rock fracture damage expansion stage, and rock volume fragmentation stage. When t = 0 ms, the particle jet is at rest, and the particle jet starts to impact the rock downwards as time increases. At t = 7.79 ms, the particle jet has contacted the rock and caused damage to the rock. At t = 13.78 ms, The particle jet continues to impact the rock, the rock fracture damage expands rapidly, and at the same time, the particles that impact the rock first collide with the rock and rebound upward at the reverse speed; t=34.19 ms. After a large number of collisions, the particles rebound upwards, and the rock exhibits a volumetric fracture and rock breaking process. Near the end.

The numerical simulation results intuitively reveal the mechanism of particle jet impingement on the rock: when the particle jet impacts the rock, when the rock first hits the rock, the impact load generated by the particle jet impacting the rock causes the stress of the rock to rise in a short time and produce strain. Compression appears in the longitudinal direction and tensile in the transverse direction, forming the initial rock fracture; with the continuous dynamic load impact of the particle jet, the rock is in the state of tension and compression of the alternating force, broken volume and depth will Increasingly, the diameter of the crushing pit is also expanding, and the rock will appear pitted. The crushing debris and the flaking debris formed by the shear wall of the particle jet will splash upwards with the return flow of the jet. The new rock is in contact with it. The face will thus be exposed and broken further under the impact of the particle jet.

At the same time, the crushing of the rock is mainly concentrated near the impact point of the particle jet, and the expansion of the rock fracture damage zone also begins around the impact point.Rocks begin to crack at the point near the impact point of the particle jet, and then the fracture expands until it penetrates, creating a volumetric fracture, forming a crushing pit. With the impact of the particle jet and the exposed new rock face, the rock damage continues to expand deeper.

3. Particle impact rock beraking test

3.1 Content and purpose of the test

The rock breaking experiment was conducted under different pressures of 6 MPa, 10 MPa, 14 MPa, and 18 MPa with the same nozzle distance. The rock breaking depth and rock breaking volume at different impact times of 10 s, 20 s, 40 s, 60 s, 80 s, and 100 s were measured to verify the particle nozzle. Whether the particles can be accelerated effectively break the rock.

3.2 Test equipment

The main equipment includes 100MPa high-pressure pump, water tank, particle jet nozzle, multi-function test bench, experimental box, rock sample and high-pressure pipeline, etc., as shown in fig.6.

Fig.6 Experimental equipment

3.3 Test method steps

Before the start of the experiment, the high pressure pipeline between the water tank and the high pressure pump, high pressure pump and particle jet nozzle were firmly connected, and the particle jet nozzle and rock sample were fixed on the experimental bench.

At the beginning of the test, open the outlet valve of the water tank, turn on the high pressure pump, and adjust the pump pressure until the pressure gauge on the particle jet nozzle shows the specified pressure. Turn on the timer and start the timer while simultaneously turning on the addition funnel valve so that the particles fall evenly.

When the time of each group of tests is stopped, stop timing and close the feed hopper valve.Stop the pump later and take the rock sample out of the measurement data and record it.

According to the above test conditions, change the pump pressure, perform each group of tests in turn, measure and record the data. To reduce the error, measure the intrusion volume and depth of each group three times.

3.4 Test Results and Analysis

The intrusion of rock samples by particles is shown in FIG. 7.

The data of particle breaking depth and rock breaking volume test data are shown in Table 2 and Table 3, respectively, and plotted as shown in Figure 1.1

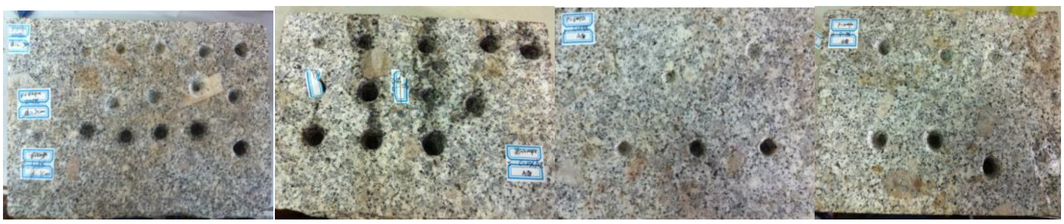


Fig.7 Rocks after the particle impact

Table 2 Relationship between pressure and erosion depth

Time/s Intrusion depth/mm		10	20	40	60	80	100
Pressure/MPa	6.00	5.60	7.30	9.80	12.00	13.60	12.90
	10.00	7.22	10.76	14.60	16.68	20.16	23.24
	14.00	10.10	12.96	19.32	21.84	25.30	30.42
	18.00	11.72	16.54	22.98	27.70	33.34	35.08

Table 3 Relationship between pressure and erosion volume

Time/s Broken volume/ml		10	20	40	60	80	100
Pressure/MPa	6.00	0.18	0.23	0.49	0.59	0.69	0.84
	10.00	0.41	0.52	0.78	1.16	1.36	1.62
	14.00	0.60	0.79	1.38	1.78	2.16	3.02
	18.00	0.61	0.97	1.86	2.21	3.12	2.78

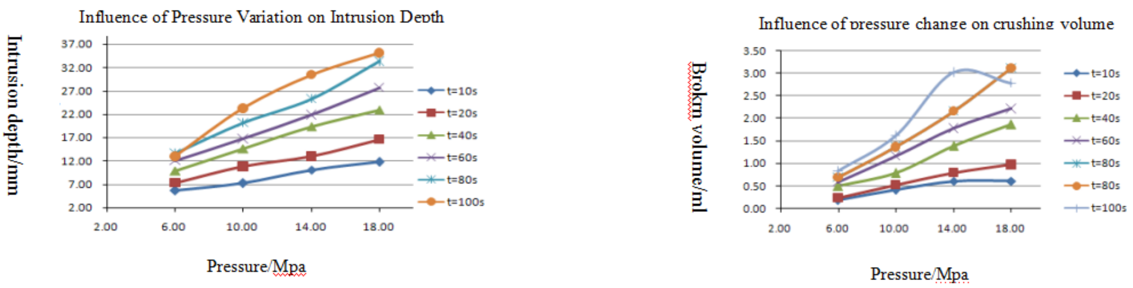


Figure 8 relationship between pressure and erosion depth and volume

Figure 8 shows the relationship between particle penetration depth and volume versus pressure. The results show that the depth and volume of the particle jet invading the rock increase with the pressure and increase substantially linearly; when the pump pressure rises, the particles As the jet accelerates in the nozzle, the particle velocity also increases, and the impact kinetic energy increases, so the depth of invasion and the fracture volume also increase correspondingly.

The results of rock breaking test show that particle impact can meet the requirements of particle acceleration, and play an ideal role in rock breaking. Particle drilling technology can efficiently break down the bottom hole rock and greatly improve drilling speed.

4. Conclusion

The following conclusions can be drawn from the study of particle drilling nozzle design and internal flow erosion characteristics:

The depth of particle crushing rock increases with the increase of particle incident velocity, concentration, and impact time. There is an optimal particle spray rate, concentration, bit rotation speed, and drill speed, which can make particle impact drilling reach higher Rock efficiency for fast drilling.

Numerical simulation results reveal the mechanism of particle jet impingement on rock: First, the impact load generated by particle jet impinging on the rock causes the rock stress to rise in a short time and produce strain, forming an initial rock fracture, and the fracture expands until it penetrates. The volume breaks up and forms a crushing pit. As the particle jet impacts and the new rock face is exposed, the rock damage continues to expand deeper.

The test results show that the impact of particles can play an deal rock-breaking effect can enand sure that the particle impact drilling technology can efficiently crush the bottom rock.

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