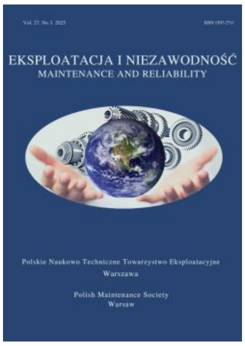

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Cutting load analysis and Optimization methods of the Bauxite Shearers

Indexed by: Web of Science Group

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Highlights

- Comparison of uniaxial compression and linear cutting tests with numerical simulations.
- Comparative Analysis of the Forces Acting on Each Conical Pick.
- Analysed the impact of the arrangement of vane conical picks on the cutting performance.
- Analysed the impact of radial retraction of end plate picks on the cutting performance.

Abstract

Bauxite shearers frequently face challenges such as difficult drum traction, significant load fluctuations, and a short lifespan of conical picks during operation, all of which adversely affect equipment stability. To improve the reliability of the bauxite shearers, rock fragmentation tests were conducted using a servo press and a cutting test equipment. The finite element method is employed to simulate the working process of the drum in order to determine the forces acting on both the total drum and each individual conical pick. Additionally, a method aimed at reducing the force on the drum is proposed and simulated. The research results indicate that the traction resistance of the drum can be reduced and the stability of equipment operation can be increased by appropriately increasing the cutting distance of the vane conical picks, adopting a sequential conical picks arrangement method, and retracting the end plate conical picks.

Keywords
bauxite shearers, traction resistance, conical picks, load fluctuation, arrangement of picks

1. Introduction

Since the mid-20th century, a range of rock-breaking techniques has been developed in succession. To enhance mining efficiency and production safety in non-coal mines, certain enterprises are investigating the application of fully mechanized coal mining equipment for bauxite extraction[1]. Traditional coal shearers can meet the needs of mining coal mines or bauxite with f=3-4, but for bauxite with f=8, although it has a certain degree of abrasion and higher cutting force, it still has a certain degree of cuttability. Compared to coal drums, bauxite shearers exhibits higher overall power and torque, operates at lower rotational speeds, and is equipped with more wear-resistant conical picks. However, the hardness of bauxite presents significant challenges for bauxite shearers regarding traction, leading to considerable load fluctuations. Prolonged use results in various failure modes for conical picks, including wear, breakage of the picks body, and detachment of alloy heads[2-3], as illustrated in Fig. 1. The wear of the picks body can reach 50%. These issues severely impact production efficiency. To improve the reliability of the drum, this article presents relevant research addressing these concerns.

In order to improve the efficiency of rock cutting and optimize cutting performance, many scholars at home and

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abroad has conducted extensive research on rock cutting related issues using simulation methods such as finite element and discrete element[4-9], also conducted a large number of rock cutting experiments through experimental devices to study the properties of rocks, cutting parameters, and the influence of conical picks on rock breaking[10-13].

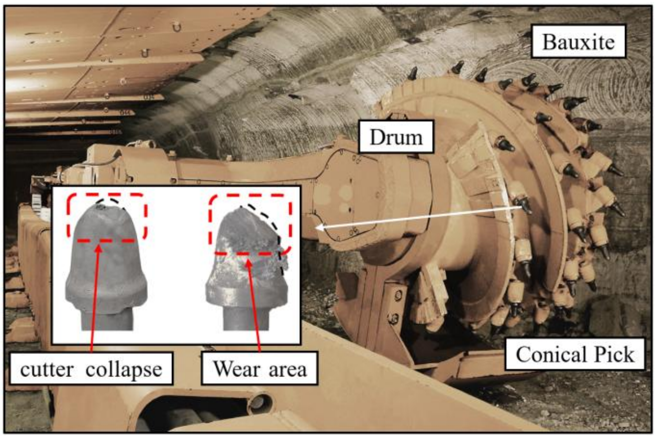


Fig. 1. Failure of conical picks.

Qiao[14] et al used finite element method to simulate the rock breaking process of the conical picks and obtained the optimal cutting angle, providing a theoretical basis for improving the picks life. Lu[15] et al established finite element models for static analysis and fatigue life analysis to extend the service life of conical picks, and subsequently developed a preliminary optimization model and a new type of pick. Liu[16] et al used PFC2D software to conduct a series of cutting simulations on rocks with different parameters at different cutting depths and confining pressures. The findings indicate that the cutting of brittle rocks is more favorable for preserving the stability of drum operations. Hu[17] et al. utilized the finite element software LS-DYNA to develop a model for cutting fractured rocks with a rolling cutter, subsequently validating the model's accuracy through experimental methods. They also investigated the variation of cutting force at different depths, demonstrating that cutting force can serve as an indicator of the wear condition of the cutting tool. Wang[18] et al used a new rock breaking method based on the combination of circular saw blades and conical picks to predict the working performance of picks. Wang[19-21] et al conducted experiments on rock using conical picks, investigating the relationship between rock cuttability and rock strength, their findings indicated that harder rocks tend to cause increased wear on picks. Li[22] et al conducted simulations and experiments on rock cutting, examining the impact of conical pick installation parameters and geometric configurations on cutting performance, and provided evaluation metrics for optimizing cutting efficiency. Tian[23] al. established a rigid-flexible coupling model for fully-mechanized coal mining equipment and conducted an analysis of the primary factors influencing their reliability through orthogonal simulation experiments. They proposed measures aimed at enhancing both the reliability and fatigue life of these machines. Liu[24] al conducted experimental research on the influence of vane picks arrangement and cutting distance on coal fragment size and cutting ratio energy consumption, Zhang[25] al reduced the consumption of conical picks by studying the arrangement of picks.

In addition, numerous scholars had conducted linear cutting experiments and simulations on conical picks, they have analyzed the stress and wear effects associated with these picks and proposed optimization methods[26-31], and compared the force and wear through the rotation cutting experiment and simulation of the drum, which is of great significance for improving the reliability of the equipment[32-35].

Based on the above research status, it is found that there is relatively little research on the influence of structural parameters of bauxite shearers on the overall load and single conical picks. Therefore, in order to improve the reliability of bauxite shearers in crushing ores, this paper uses finite element method to simulate the working process of drum mining bauxite to analyze the force and load fluctuation of the drum and single conical picks under various working conditions. It is of great significance to improve the traction efficiency of bauxite shearers, reduce load fluctuations, and enhance equipment reliability.

2. Construction of numerical model for drum cutting bauxite

2.1. Calibration and experimental verification of bauxite rock parameters

2.1.1. Parameters of the bauxite rock mass model

All finite element analyses presented in this article are conducted through numerical simulations utilizing LS-DYNA software. The B-D model material (* MAT-BRITTLE-DAMAGE) is selected to simulate bauxite deposits. This model is an anisotropic Brinell brittle damage model mainly used in materials such as coal, rock, and concrete. We define the failure criteria of the model by adding the keyword (* MAT_ADD_EROSION). When the rock mass element reaches the set equivalent strain under stress, it is judged not to have failed and removed from the model. The yield failure criterion is the D-P criterion, which is a widely used yield criterion that can well describe the yield behavior of materials under different stress states. The mathematical expression for the D-P criterion is usually written as:

$$f_m = \alpha_m I_{m_1} + \sqrt{J_{m_2}} - K_m = 0 \tag{1}$$

$$I_{m_1} = \sigma_{m1} + \sigma_{m2} + \sigma_{m3} \tag{2}$$

$$J_{m2} = \frac{(\sigma_{m1}-\sigma_{m2})^2+(\sigma_{m2}-\sigma_{m3})^2+(\sigma_{m3}-\sigma_{m1})^2}{6} \tag{3}$$

$$\alpha_m = \frac{2\sin\varphi_m}{\sqrt{3}\ (3-\sin\varphi_m)} \tag{4}$$

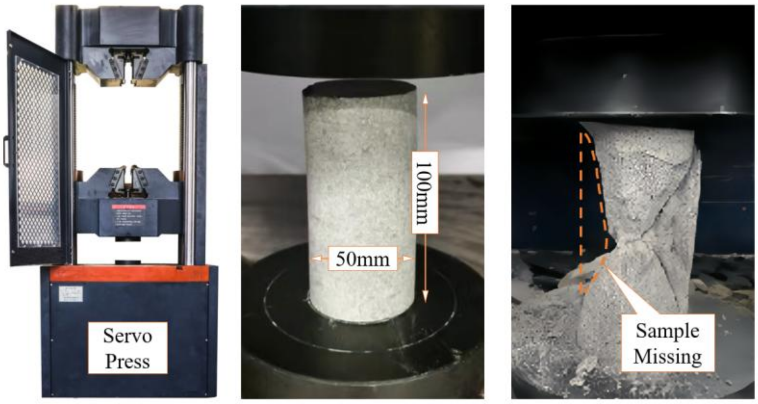
$$K_m = \frac{6\cos\varphi_m}{\sqrt{3}\ (3-\sin\varphi_m)} \tag{5}$$

In the formula: I_{m1} is the first invariant of stress. J_{m2} is the second invariant of stress deviation. α_m and K_m are experimental constants that are only related to the internal friction angle of the rock, denoted as φ_m. σ_{m1}, σ_{m2}, and σ_{m3} are the first, second, and third principal stresses, respectively.

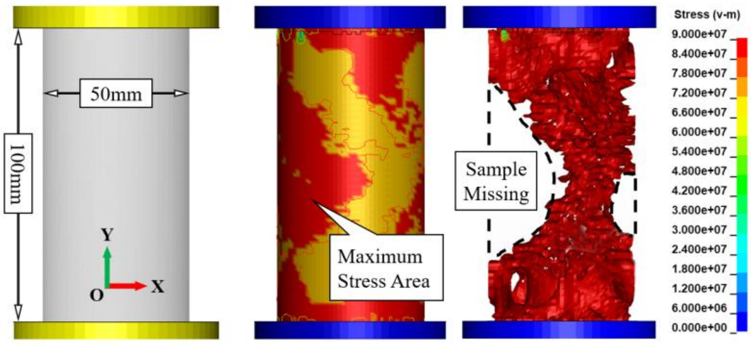
According to formula (1), under the squeezing force generated by the traction and rotation of the conical picks, the stress on the rock gradually increases and plastic deformation occurs. When the deformation reaches a certain critical value, the rock mass is damaged and eroded by the cutting teeth, and the cells are deleted. Therefore, equivalent plastic deformation is used as the rock breaking criterion.

In the process of drum cutting, the conical picks are cut and broken by making face-to-face contact with the bauxite ore body. Therefore, the face-to-face contact algorithm CONTACT-ERODING_SURFACE-TO-SURFAC is more suitable for the contact type. This algorithm is used to simulate the contact and interaction between one object and another erodible surface object. The pick is defined as the contact surface, and the bauxite rock mass is the target surface. The contact surface erodes the target surface. When the contact stress exceeds the failure stress of the rock mass, it causes the stress element to undergo linear strain. After exceeding the set value, the element will be automatically deleted.

2.1.2. Model parameter validation based on uniaxial compression test



(a) Servo press (b) Uniaxial compression test (c) Stone sample failure and missing



(d) Uniaxial compression simulation(e)Stress diagram(f)Simulation of missing stone samples

Fig. 2. Uniaxial compression test and simulation.

As shown in Fig. 2, uniaxial compression tests are conducted on bauxite samples using a 600 kN servo press, and a uniaxial compression finite element model is established. The correctness of rock parameters is verified by comparing the test results with simulation results. In this experiment, bauxite rock with good homogeneity is selected and processed into standard stone samples of 50 mm × 100 mm (diameter × height). The loading rate of the press is 1 kN/s (0.5 MPa/s). The stone sample shown in Fig. 2 (c) forms an hourglass shape after being crushed and fails, with more missing rocks in the middle and fewer missing rocks on both sides. The numerical model shown in Fig. 2 (d) is a rigid load-bearing plane, with the stone sample size consistent with the experimental size and a grid size of 1 mm. The pressure is applied at a speed of 0.5 MPa. Fig. 2 (e) shows the stress cloud map of numerical simulation, and Fig. 2 (f) shows the missing rock sample of numerical simulation. It can be seen that a large stress is generated on the left side of the rock sample and has already been missing, and there is also a certain area of rock missing on the right side. The missing situation of stone samples in numerical simulation is similar to that in the experiment.

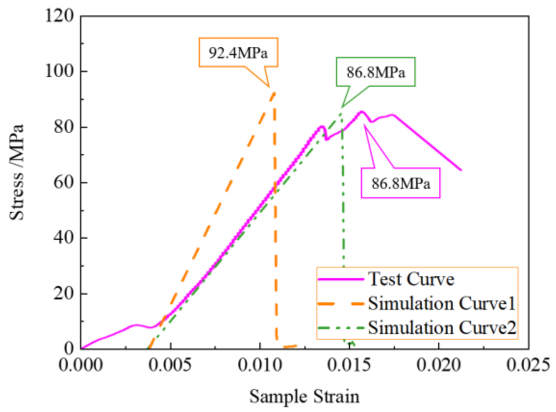


Fig. 3.Comparison of uniaxial compression test and numerical simulation data.

In numerical simulation, the rock model parameters are set based on the experimental results, and multiple simulations are conducted to compare with the experimental results. As shown in Figure 3, two simulated curves are compared with the experimental curve. Simulation curve 2 is similar to the experimental curve, while simulation curve 1 has a significant difference in elastic modulus as a control.

The simulation curve has a high degree of regularity, the experimental curve has a high degree of randomness. This is because the simulated stone sample is a homogeneous body and fails regularly under increasing pressure, but in the experiment, the curve has a certain degree of randomness due to the presence of voids and incomplete homogenization inside the stone sample.

The maximum compressive strength of the bauxite ore sample in the experiment was 86.8 MPa. After fitting with a linear increase stage, the elastic modulus was obtained to be 7.54 GPa. In simulation curve 1, the stone sample failed at 92.4 MPa, with a strain of 0.00723 and an elastic modulus of 12.78 GPa. In simulation curve 2, the stone sample failed at 86.8 MPa, with a strain of 0.01166 and an elastic modulus of 7.44 GPa. The result of simulating curve 2 is close to the experimental curve. Therefore, the model parameters in simulated curve 2 are selected. The above comparison indicates that numerical simulation of uniaxial compression can reflect the experimental results.

2.1.3. Model parameter verification based on linear cutting test

To further verify the correctness of rock parameters, a comparison is made between linear cutting tests and numerical simulations using the conical picks cutting test bench shown in Fig. 4. Linear cutting tests with different cutting depths of 4 mm, 6 mm, 8 mm and 10 mm are carried out on a rectangular stone sample with a side length of 130 mm, and the cutting speed was 30 mm/s. A linear cutting model is created to simulate the process of linear cutting. In the simulation, the compressive strength is set at 86.8 MPa and the elastic modulus is set at 7.44 GPa, the other parameters are the same as the test Settings.

As shown in Fig. 5, after the completion of the experiment and numerical simulation, compare the X-direction cutting force curve and the groove stress diagram. From the curve graph, it can be seen that as the cutting depth increases, the cutting force also increases. The load variation in the cutting force curve of the experimental data is comparatively minor, whereas the load variation in the cutting force curve of the simulation data is significantly greater. At each cutting depth, the peak cutting forces observed in both experimental and numerical simulations exhibit a high degree of similarity. From the groove diagram, it can be seen that the results of the two are similar, and the groove width also shows an increasing trend with the increase of cutting depth.

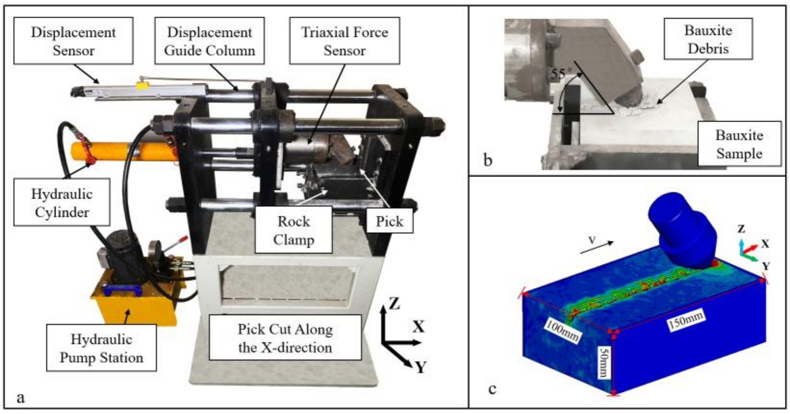
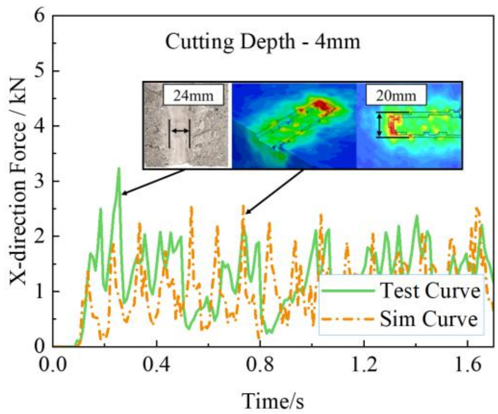
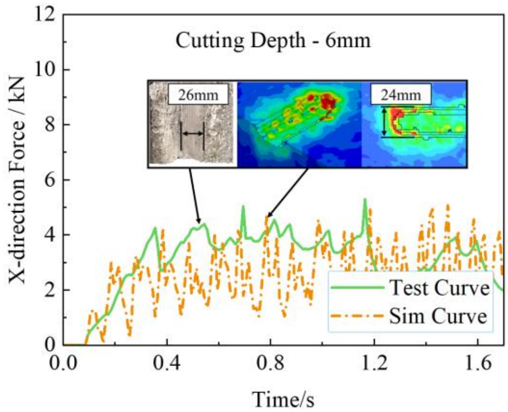


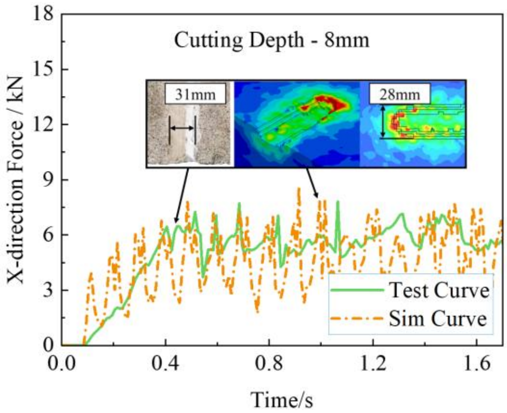
Fig. 4. Linear cutting test equipment and numerical model.



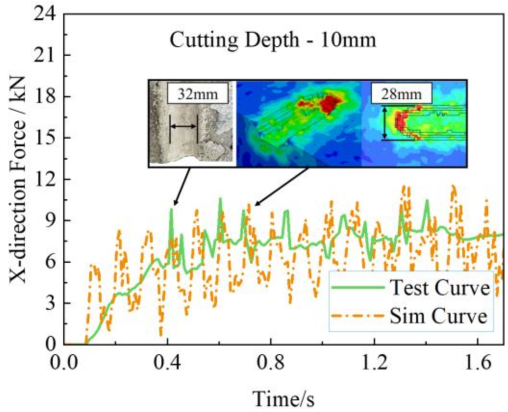
(a) Cutting depth of 4 mm



(b) Cutting depth of 6 mm



(c) Cutting depth of 8 mm



(d) Cutting depth of 10 mm

Fig. 5. Comparison of linear cutting test and simulation results.

As illustrated in Figure 6, the cutting force data obtained from both experimental and simulation analyses are evaluated to derive the mean and peak load values. It can be seen that the peak cutting force in the experiment is slightly smaller than that in the simulation, with a difference of within 20% at cutting depths of 4 mm, 6 mm, and 8 mm, and 23% at a cutting depth of 10 mm. The mean cutting force in the experiment is slightly higher than that in the simulation, which is due to the fact that the peak values of the two are similar, but the fluctuation of the test load is small and the fluctuation of the simulated load is large. At depths of 4mm, 8mm, and 10mm, the variation remains within 20%. However, at a depth of 6mm, this difference increases to 22%. After conducting a fitting and analysis of the mean force and peak force, it was observed that there exists a strong linear correlation between cutting depth and load value. Furthermore, the fitting results of the experiment and simulation are similar. The comparison presented above demonstrates that the linear cutting simulation accurately reflects the experimental results and validates the effectiveness of the parameters used in the bauxite finite element model.

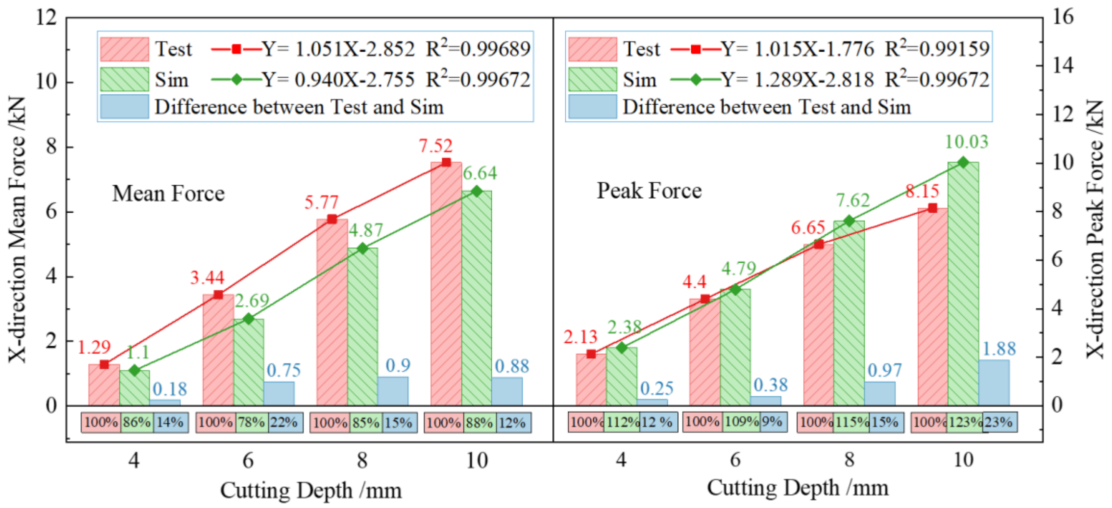


Fig. 6. Cutting force analysis of linear cutting test and simulation results.

After uniaxial compression and linear cutting tests and simulations, the rock parameters of bauxite were determined as shown in Table 1, with a density of 2509 kg/m3, an elastic modulus of 7.44 GPa, a Poisson's ratio of 0.3, and a compressive strength of 86.8 MPa.

Table 1. Model material parameters.

Material characteristics	Rock mass (bauxite)	Drum (rigid)
Density/(kg/m^3)	2509	7800
Elastic modulus/(GPa)	7.44	2.0×10^2
Poisson's ratio	0.3	0.25
Compressive strength/(MPa)	86.8	

2.2. Establishment of numerical model for drum cutting bauxite

The numerical model of the drum bauxite is illustrated in Figure 7. The specification of the drum is φ 1300 mm × 630 mm, while the dimension of the rock mass is 1800 mm × 1800 mm × 800 mm. To save simulation time, a semi cylindrical notch with a diameter of 1600 mm is set on the rock mass to enable the drum to reach a stable cutting state in a short period of time. Four sets of 16 conical picks are evenly arranged at the end plate of the drum, with the inclination angles of each set of conical picks being 3 ° for D pick, 15 ° for C pick, 30 ° for B pick, and 43 ° for A pick; The drum adopts double vanes arrangement, with 10 conical picks evenly distributed in sequence on each vane, named V1, V2... V10 in sequence. The entire drum has a total of 36 conical picks, with the model U82 conical pick. In the simulation model, output the three-axis force and total force experienced by each conical pick and the total drum, with the X direction being the cutting force, the Y direction being the axial force, and the Z direction being the traction force. The traction speed of the drum is set to 2 m/min according to the actual situation, and the rotation speed is 20.58 r/min. After the simulation is completed, analyze the mean and peak loads of the drum after stable cutting, and combine the simulation results with the analysis of the bauxite stress aera.

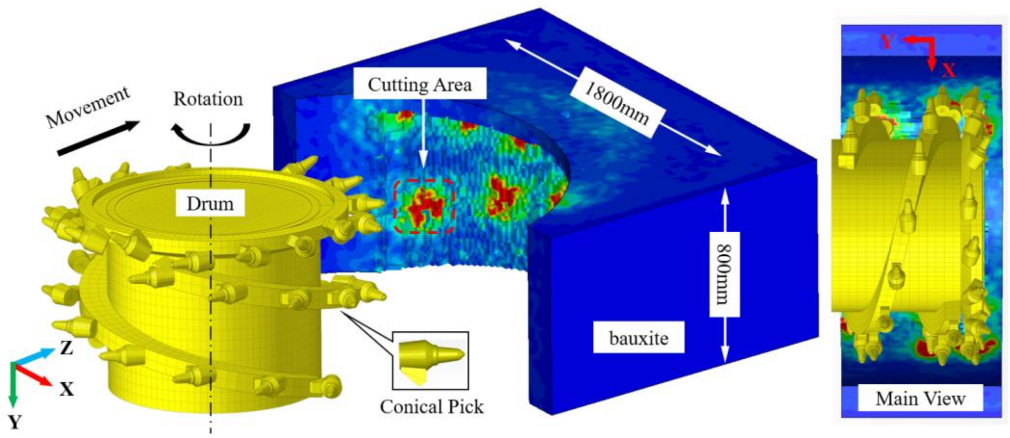
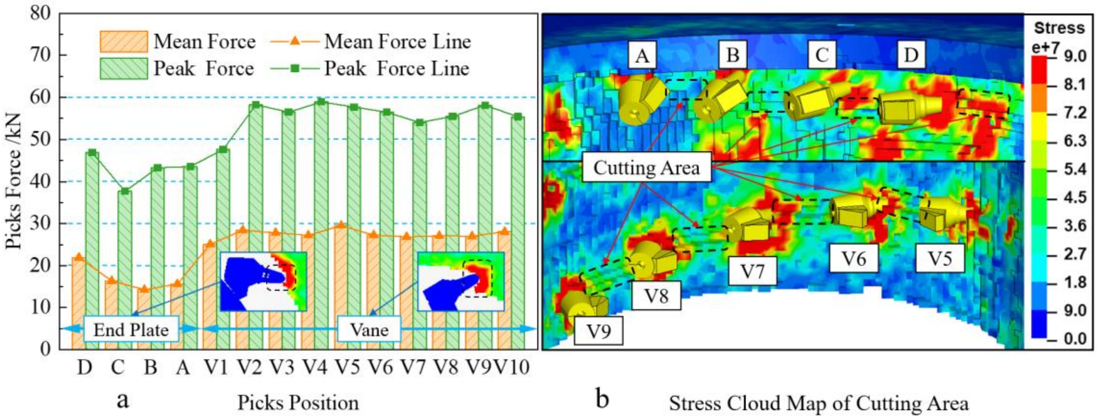


Fig. 7. Drum-bauxite simulation model

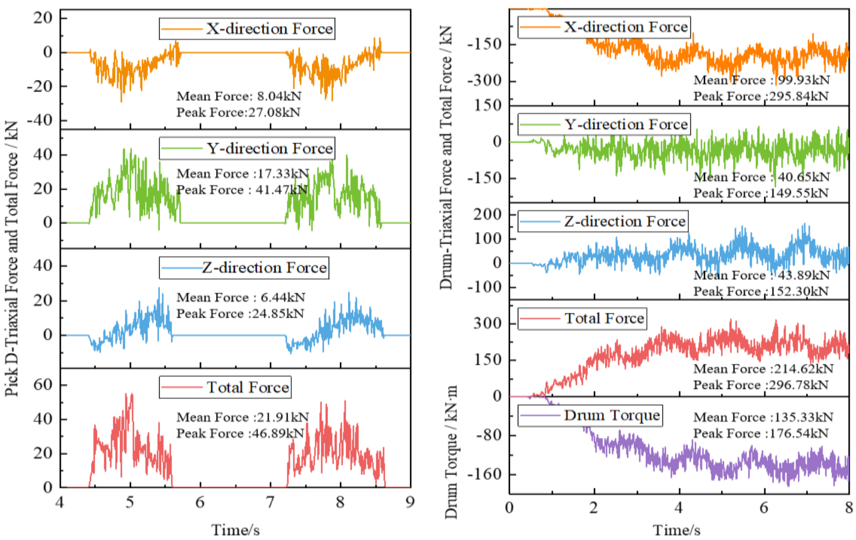
2.3. Analysis of Numerical Simulation Results

As shown in Fig. 8, (a) is a bar chart of the mean and peak loads on each conical pick, and (b) is a groove stress diagram of bauxite. From the figure, it can be seen that the load on the vane conical picks are significantly higher than the end plate conical picks. This is because there are 4 conical picks on each cutting line at the end plate of the drum, while the vane conical picks only have 2, resulting in more bauxite ore bodies to be broken by the vane conical picks. In the end plate conical picks, the load of pick D is significantly higher than that of other conical picks. From the stress diagram, it can be seen that in this conical picks arrangement, the end plate conical picks are arranged in sequence, the cutting groove generated by the front conical pick can effectively act on the rear conical pick to reduce the broken bauxite ore body, reducing its cutting force, as shown in conical picks A, B, and C. However, the distance between the position of conical pick D and that of front conical pick A is relatively significant. As a result, the influence of the cutting groove created by conical pick A on conical pick D is diminished. Consequently, conical pick D tends to crush more bauxite ore bodies compared to conical picks A, B, and C. In the vane conical picks, the load fluctuation of each conical pick is not significant and basically tends to be consistent, but the load of conical pick V1 is slightly smaller. This is because the distance between its cutting line and the end plate conical picks is small, and the end plate conical picks has broken some of the bauxite ore body on the upper side of conical pick V1, thus reducing the load of conical pick V1. From the groove stress diagram, it can be seen that the groove generated by the front conical pick has a significant effect on reducing the cutting load of the rear conical pick.



(a) Mean and peak load of each conical pick (b) Cutting groove

Fig. 8. Load and cutting groove of each conical pick.



(a) D conical pick (b) Total drum

Fig. 9. Each load curve

Fig. 9 illustrates the total load and three-axis force curves of conical pick D, as well as the overall drum. It can be observed that the force exerted on conical pick D initially increases and subsequently decreases, displaying a periodic pattern, which aligns with the cutting cycle of the drum. This is because the drum rotates while pulling forward, causing the rock mass intercepted by each conical pick to take on a crescent shape, initially increasing in size and then subsequently decreasing. Among the three-axis force, the force exerted on conical pick D in the Y direction is significantly greater than that in the X and Z directions, with its vector directed downward. Considering the arrangement of the end plate conical picks, it becomes evident that conical pick D cannot cut along the cutting groove sequence established by the preceding conical picks, unlike other conical picks. Consequently, it must endure a greater squeezing force from the bauxite ore body along the axial direction of the drum.

From the comprehensive analysis of the drum, it is evident that both force and torque initially experience a continuous increase. Upon entering the stable cutting phase, however, the force demonstrates periodic fluctuations. This phenomenon occurs due to the arrangement of double spiral vanes within the drum. As the drum rotates, the number of conical picks on the cutting surface varies, leading to periodic fluctuations in force that rise and fall. In the analysis of the three-axis force, it is evident that the force in the X direction on the drum is significantly greater than that in the other two directions. Conversely, the force in the Y direction on conical pick D is comparatively larger. It can be concluded that the force on each conical pick in the drum varies due to their different positions, resulting in differences in the three-axis force. Different forces can accelerate the failure of the conical picks and cause different forms of failure such as wear and breakage. Different forces can expedite the failure of conical picks, leading to various forms of failure, including wear and breakage. Therefore, it is crucial to arrange the conical picks in a rational manner to enhance their service life.

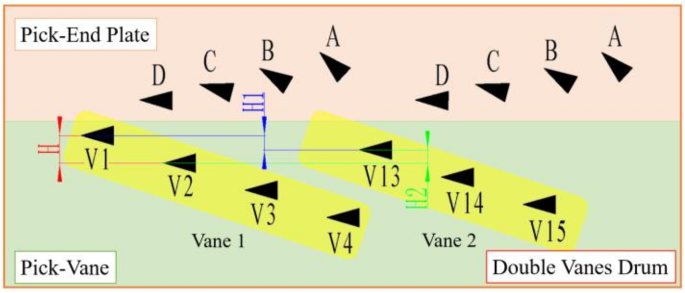
In the preceding text, relevant rock parameters are determined through a combination of experiments and simulations, and problems such as uneven force on the end plate conical picks and high traction resistance of the drum were discovered through the drum cutting model. Consequently, in the subsequent sections, we will examine the impact of cutting load by varying the arrangement of vanes and end plate conical picks.

3. The Influence of conical picks arrangement on cutting performance of drum

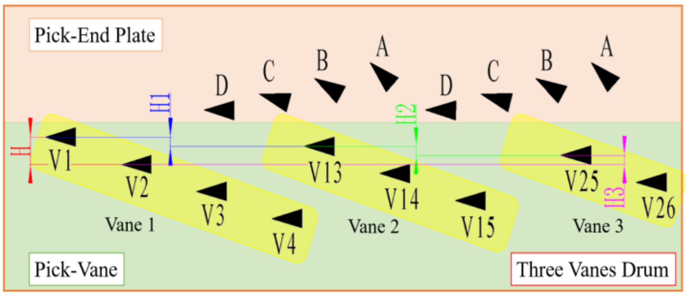
3.1. Design of conical picks arrangement scheme

3.1.1. Design of vanes conical picks arrangement scheme

By modifying the arrangement of the conical picks on the drum vanes, investigating their impact on drum load. This includes an analysis of factors such as the number of spiral vanes, the arrangement of vanes conical picks, and the cutting distance. The scheme is illustrated in Fig. 10, where (a) presents a schematic diagram of the arrangement of double vanes conical picks. In this context, H denotes the distance between adjacent picks on the same blade (for instance, V1 and V2), using H1 and H2 to represent the distance between adjacent picks of two vanes when arranging conical picks in a chessboard pattern with one conical pick per line(for instance, H1 denotes the intercept distance between V1 and V13, while H2 signifies the intercept distance between V13 and V2). When H1=0, it is represented as sequential type conical picks arrangement. (b) illustrates a schematic diagram of the conical pick arrangement featuring three vanes. The method employed to represent the intercept distance is consistent with that used for double vanes.



(a)Double vanes



(b)Three vanes

Fig. 10. Schematic diagram of vane conical picks arrangement

Table 2. Parameter table of vane conical picks arrangement vanes number

Drum S N	1	2	3	4	5	6
Vanes No	2	2	2	2	2	2
Picks Arr	Sequential 1 line 2 picks	Sequential 1 line 2 picks	Sequential 1 line 2 picks	Chessboard 1 line1 pick	Chessboard 1 line 1 pick	Chessboard 1 line 2 pick
Distance/mm	H=40 H1=0	H=50 H1=0	H=60 H1=0	H1=H2 =20	H1=H2 =25	H1=H2 =30
Vane Picks No	12	10	9	12	10	9
Drum S N	7	8	9	10	11	12
Vanes No	3	3	3	3	3	3
Picks Arr	Sequential 1 line 3 picks	Sequential 1 line 3 picks	Sequential 1 line 3 picks	Distortion 1 line 1 pick	Distortion 1 line 1 pick	Distortion 1 line 1 pick
Distance/mm	H=40 H1=H2=0	H=50 H1= H2=0	H=60 H1= H2=0	H1=H2= H3=13	H1=H2= H3=17	H1=H2= H3=20
Vane Picks No	12	10	9	12	10	9

(1.Drum S N: Drum Serial Number 2.Vanes No: Vanes Number 3.Picks Arr: Picks Arrangement 4. Vane Picks No: Vane Picks Number)

The specific parameters of the conical picks for vanes are presented in Table 2, with Drum 2 representing the original drum. The numbers 1-6 represent double vane drums, with numbers 1-3 featuring a sequential type arrangement of conical picks, organized in a one-line-two-picks format, the spacing between the vanes is set at 40 mm, 50 mm, and 60 mm in turn. In contrast, numbers 4-6 are arranged in a chessboard type with one conical pick per line, where the vane distance spacing measures 20 mm, 25 mm, and 30 mm in turn. The numbers 7-12 represent three vane drums, with numbers 7-9 featuring a sequential type arrangement of conical picks, organized in a one-line-three-picks format, the spacing between the vanes is set at 40 mm, 50 mm, and 60 mm in turn. In contrast, numbers 10-12 are arranged in a distortion type with one conical pick per line, where the vane distance spacing measures 13 mm, 17 mm, and 20 mm in turn.

3.1.2. Design of radial retracting scheme of conical picks on the end plate of drum

By employing the method of radial retracting scheme of conical picks on the end plate of drum to explore the influence of force on the drum. The schematic diagram of radial retraction with end plate of drum conical picks is shown in Fig. 11, where J1, J2, J3, and J4 represent the radial retraction distances between each pick. Using the parameter retraction as shown in Table 3 (the retraction value is positive, the expansion value is negative), a total of five drum models are established, with Drum 1 not retracting as the control group. Since this scheme does not involve the load at the lower end of the vanes, the drum load is set to the force of all end plate picks plus the pick V1 and V2 on the two vanes, in order to save simulation time.

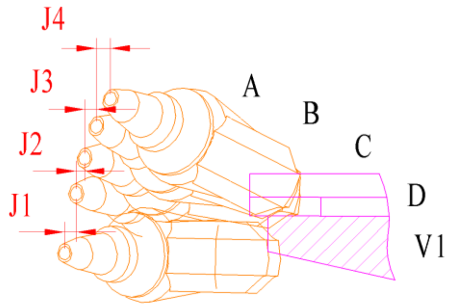


Fig. 11. Schematic diagram of radial retraction with end plate of drum conical picks.

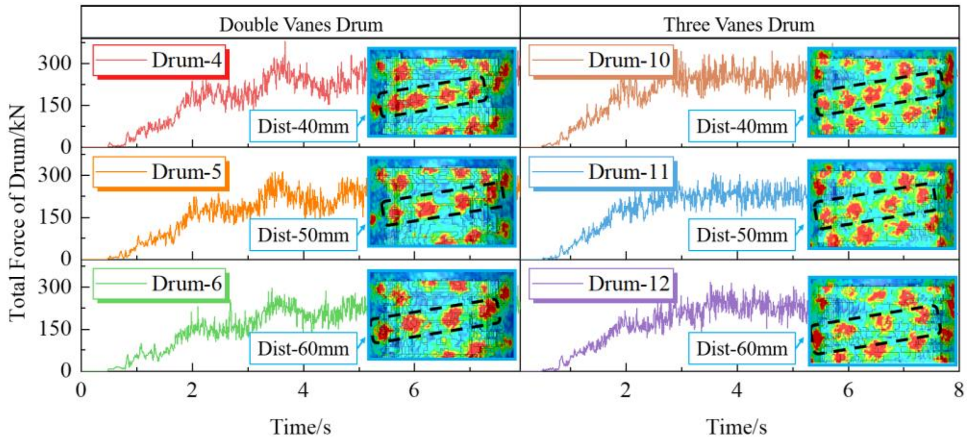
Table 3. Parameters table of radial retraction with end plate of drum conical picks.

Drum S N	1	2	3	4	5
J1/mm	0	5	10	15	0
J2/mm	0	5	10	15	0
J3/mm	0	5	10	15	0
J4/mm	0	5	10	15	-10

Analysis of Three-Axis Forces and Total Load on Each Drum (Drum S N: Drum Serial Number)

3.2. The impact of the arrangement of vane conical picks on the cutting performance of the drum

3.2.1. Analysis of three-axis force and total load on each drum



(Dist: Distance between adjacent picks)

Fig. 12. Load curves and groove stress diagrams of total drum with different vane conical picks arrangement

Comparing the load curve and groove stress diagram of some drums as illustrated in Fig. 12, it is evident that the total force on each drum continues to increase initially. After entering the stable cutting stage, the force on drums 4-6 shows periodic fluctuations, this is because the drums are arranged with double spiral vanes, and the number of conical picks on the cutting surface changes with the rotation of the drums. Consequently, the force shows periodic fluctuations of rising and falling. The force on drums 10-12 tends to stabilize, as they are arranged with three spiral vanes and have more conical picks. The number of conical picks on the cutting surface does not change much with the rotation of the drum, so the force fluctuation is not significant. From the groove stress diagram, it is evident that as the distance between picks increases, the number of single-vane conical picks decreases, while the stress area influenced by these conical picks expands. This observation indicates that the stress experienced by the conical picks rises in conjunction with an increase in distance. The stress area of a single conical pick is smaller than that of the double vanes picks arrangement when employing the three vanes picks configuration.

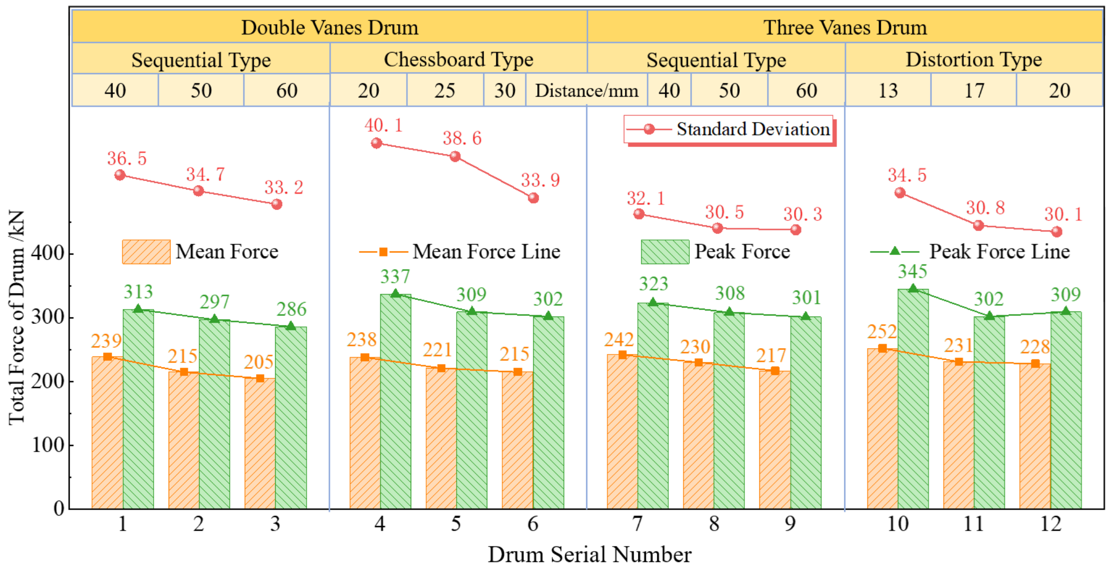


Fig. 13 Total load and standard deviation of drum with different vane conical picks arrangement.

By analyzing the load and standard deviation presented in Fig. 13, it is evident that increasing the distance between the conical vane picks can effectively reduce both the force and load fluctuation of the drum. When transitioning from double vanes to three vanes, the increase in the number of conical picks results in a greater force on the drum while simultaneously reducing load fluctuations. The force and load fluctuation of the drum with sequential type one line multi conical picks arrangement are smaller than those of the drum with chessboard type one line one conical pick arrangement. This indicates that reducing the number of conical picks reasonably to increase the picks distance and adopting a sequential type conical picks arrangement method can reduce the force and load fluctuations on the drum. When employing a three-vane arrangement, it is beneficial to increase the stability of the drum operation, but the number of single vane conical picks should be appropriately reduced to reduce the force on the drum. When employing a double vanes arrangement, it is recommended to ensure that the number of conical picks on the cutting side of the drum remains constant as much as possible to increase the stability of the drum.

The same methodology is employed to analyze the three-axis forces acting on each drum, as illustrated in Table 4. The variation trends of the forces in the X and Z directions experienced by each drum exhibit a similarity to the trend of the total load depicted in Fig. 13, but the Y direction force is different. During the process of increasing the distance between conical picks, the force in the Y-direction exhibits a trend of initially decreasing and then subsequently increasing, with the minimum lateral force observed at H = 50 mm. The Y-direction force of the drum with a sequential arrangement of picks is greater than the cutting force produced by the checkerboard arrangement of picks. This suggests that a reasonable reduction in the number of conical picks and an arrangement method that employs sequential type picks, can effectively decrease the cutting force in the X direction and the traction force in the Z direction of the drum. However, this approach lead to an increase in axial force along the Y direction.

Table 4. Three-axis force of drum with different vane conical picks arrangement.

Drum Serial Number		1	2	3	4	5	6	7	8	9	10	11	12
X-Force/kN	Mean	106	100	94	105	101	99	111	106	94	110	106	105
	Peak	304	296	276	304	294	289	292	290	266	304	281	288
Y-Force/kN	Mean	75	41	53	64	41	51	47	38	44	45	36	45
	Peak	184	150	153	176	150	159	147	117	146	134	113	143
Z-Force/kN	Mean	58	44	38	64	47	42	72	66	58	77	70	64
	Peak	156	152	141	167	151	137	153	142	130	168	148	141

From this, it can be observed that as the vane conical picks distance decreases, the overall force on the drum increases, but the stress area of a single conical pick decreases. Therefore, the stress area of a single conical pick should be analyzed to verify the changes in the stress area. So in the following analysis, taking V2 pick as an example to analyze its load mean and peak values in various drums.

Due to the similarity between the variation pattern of cutting torque and cutting force of each drum, further elaboration will not be provided.

3.2.2. Analysis of total load on V2 conical pick

After analyzing the overall force on the drum, taking the vane pick V2 as an example to analyze the force on a single conical pick, its load curve, load mean, and peak values are shown in Fig. 14.

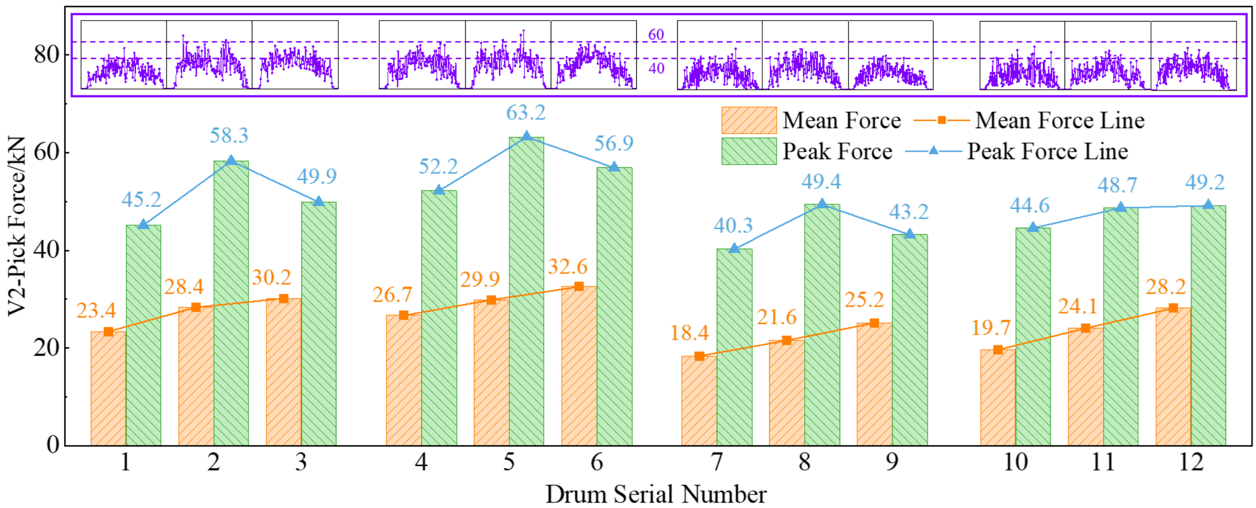
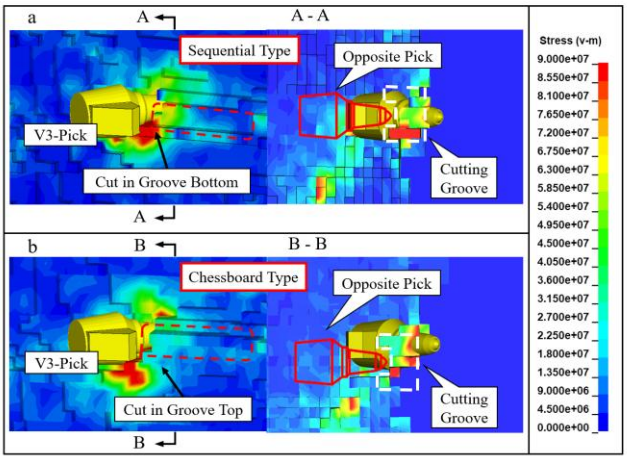


Fig. 14. Total load of V2 pick with different vane conical picks arrangement.

It is evident that the conical picks of V2 experience the highest force in drums 4-6, while exhibiting the lowest force in drums 7-9. During the process of increasing the distance between picks, the mean load on the conical picks exhibits an upward trend. In contrast, while the peak load increases initially and then decreases. The force intensifies during the transition from a sequential type arrangement to a chessboard type arrangement and decreases during the transition from a double vanes to a three vanes. From this, it is evident that the force on the conical pick V2 exhibits a trend similar to that of the stress area depicted in Fig. 12. By reducing the distance between picks, implementing a sequential type arrangement, and arranging multiple vanes, it can decrease the force acting on an individual conical pick.

To analyze the reason why the force on the conical pick V2 is greater than that on the sequential type arrangement in a chessboard type, the corresponding groove stress diagram is taken for comparison, as illustrated in Fig. 15.



(a) Sequential type(b) Chessboard type

Fig. 15. Groove stress diagram of V2 conical pick.

In the sequential type arrangement, the conical pick V2 is located on the same line as the front conical pick, when cutting, it can be cut along the bottom of the groove formed by the aligned conical pick, with a smaller cutting depth. Additionally, the first cutting of the conical pick V1 creates a certain cutting gap on the upper side of the conical pick V2, effectively reducing the cutting force. When arranging conical picks in a chessboard type, the conical picks are in the form of one line one pick, with each pick spaced apart and corresponding to a different picks line. Therefore, this cutting method causes the cutting groove formed by the front pick to be located on both sides of the rear pick. The conical pick V2 is cut along the top of the cutting groove formed by the aligned pick, with a larger cutting depth and partial interference with the pick body, thus increasing the cutting force.

3.3. The impact of the radial retraction of end plate conical picks on the cutting performance of the drum

3.3.1. Analysis of three-axis force and total load on each drum

The total load for each drum is illustrated in Fig. 16. Due to the successive retraction and increase in retraction of the conical picks on the end plate of drums 1, 2, 3, and 4, it can be observed from the comparison curve that there is a delay in the time at which the drum generates a large load, this indicates that the overall contact time between the end plates and the bauxite ore body is also prolonged. On the contrary, the outward expansion of conical pick A within drum 5 results in the drum experiencing a significant load prematurely. By comparing the mean and peak loads, it is evident that the total load of the drum decreases as the retraction of the end plate conical picks increases, demonstrating a certain linear relationship. Expand conical pick A by 10mm in drum 5 to increase its total load compared to drum 1. It can be found that the retraction of the end plate conical picks can reduce the force on the drum.

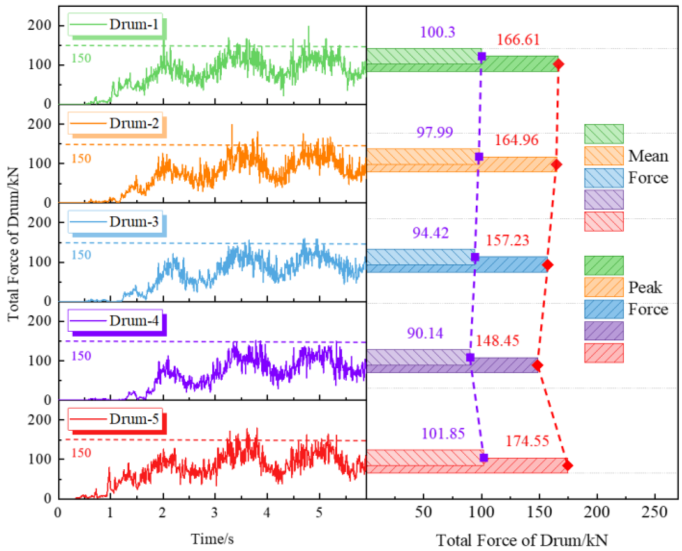


Fig. 16. Total load of drum on different radial retraction with end plate of drum conical picks.

As illustrated in Fig. 17, the mean and peak loads of the three-axis force to each drum are presented, it is evident that the cutting force in the X direction of the drum is the most significant, followed by the axial force in the Y direction, and the traction force in the Z direction is comparatively minimal. The trends observed in the mean and peak loads of the three-axis force on the drum align with those of the total load depicted in Fig. 16. Notably, the variations in force along the Y direction are more pronounced when compared to those in the X and Z directions. This phenomenon occurs because the conical picks D, C, B, and A are arranged sequentially. The groove of the front conical pick can exert an influence on the rear conical pick, thereby alleviating the squeezing force from the axial bauxite. When the conical picks retract, this effect becomes more pronounced, leading to a significant reduction in force. However, the cutting depth remains unchanged after retraction, so the force changes in the X and Z directions are relatively small.

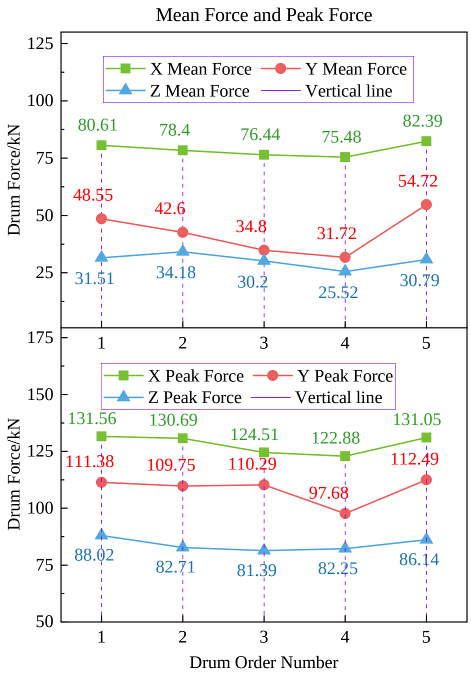


Fig. 17. Mean and peak values of the three-axis force of drum on different radial retraction with end plate of drum conical picks

3.3.2. Analysis of load on each conical picks

The comparison of the groove stress diagrams, mean and peak loads for conical picks A, B, C, and D is presented in Fig. 18. It is evident that the changing trends of conical picks A, B, C, and D are similar, showing a decreasing trend with the force of conical picks retraction. The reduction in force on each conical picks is proportional to the amount of retraction, and the greater the retraction, the more significant the reduction in force. Upon analyzing the groove stress diagram, it is observed that the overall groove cutting in Drum 1 closely resembles a vertical line. Subsequently, after the retraction of the end plate conical picks, a stepped groove gradually forms. Under this groove, it can be observed that the axial force on the conical picks of the end plate decreases sequentially following retraction. In Drum 1, the conical picks are subjected to both upward and downward axial forces. However, as retraction increases, the conical picks experience only a downward axial force and the force decreases. Therefore, the radial retraction of the end plate conical picks can effectively diminish axial forces, reduce wear, and extend their service life.

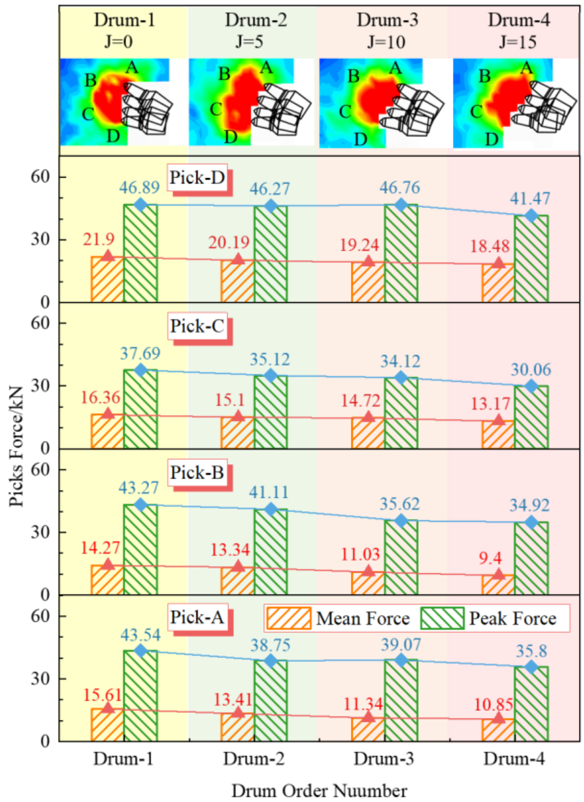


Fig. 18. Load and groove stress diagram of picks A,B,C,D.

4. Conclusions

To reduce the traction resistance of the bauxite shearers during operation, minimize load fluctuations, and extend the service life of the conical picks, the numerical simulation and experimental comparison verification methods of uniaxial compression and single conical pick linear cutting of bauxite ore were used to determine the parameters of the bauxite model. A numerical model of the bauxite shearers drum cutting bauxite is established to simulate the force on the drum and each conical pick. The effects of vanes conical picks arrangement, vanes conical picks distance, number of spiral vanes, and radial retraction of end plate conical picks on the force of the conical picks and drum are studied, and the following conclusions were obtained:

(1) During the cutting process of the bauxite shearers drum, the uneven force on the end plate conical picks is caused by the difference in arrangement, and the force on the vanes conical picks is significantly higher than that on the end plate conical picks, which will result in differences in the service life of the conical picks. Therefore, the conical picks should be arranged reasonably to balance the force between each conical pick.

(2) For the arrangement of vane conical picks, reducing the number of conical picks reasonably to increase the picks distance, and adopting a sequential type conical picks arrangement method can reduce the traction resistance and load fluctuation of the drum, which is beneficial for drum traction and increasing equipment stability. When employing a three-vane arrangement, it is beneficial to increase the stability of the drum operation, but the number of single vane conical picks should be appropriately reduced to reduce the Traction resistance on the drum. When employing a double vanes arrangement, it is recommended to ensure that the number of conical picks on the cutting side of the drum remains constant as much as possible to increase the stability of the drum.

(3) For the arrangement of end plate conical picks, compared with the drum without retracted end plate conical picks, the force on a single conical pick and the drum is significantly reduced for the drum with radial retraction of 5 mm, 10 mm, and 15 mm respectively, and the greater the retraction amount, the more obvious the effect of force reduction. Comparing the drum with expanded end plate conical picks and the drum without expanded end plate conical picks, it was found that the force on the expanded end plate conical picks and the drum increased significantly. Therefore, sequentially retracting the end plate conical picks radially can not only reduce the axial force of each conical pick to reduce wear and increase the service life of the picks, but also reduce the cutting resistance of the drum, which is beneficial for the traction cutting of the drum and the reliability of the bauxite shearers.

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