Cutting Mechanical Study of Pick Cutting Coal Seams with Coal and Rock Interface

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Research

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Cutting Mechanical study of pick cutting coal seams with coal and rock interface

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Abstract: Shearer provide an effect solution for mining coal, and the cutting performance of pick largely accouts for the ability of a shearer and mining performance. We conducted pick cutting coal experiments in different seam forms on the coal and rock cutting teasted. According to the rotary cutting mechanical model of single pick cutting coal seam, combined with the strength condition of coal seam and coal-rock interface, the rotary cutting mechanical model of pick cutting coal seam with coal-rock interface is established. The stress strain and strength condition of the area in and around the interface are analyzed based on the coal-rock interface crushing theory, which provides basis for further research on the cutting mechanical model of single pick crossing the coal-rock interface. According to the analysis on the ampulitude domain, the phenomenon that force increment between the pick cutting rock and uniform coal seam linearly increases with the increase of compressive strength difference between coal seam and coal-rock interface, and the load fluctuation keep a positive correlation with the compressive strength. Analysis on the signals of the pick cutting coal seam with coal and rock interface at different conditions shows that some basic properties of the cutting load changes over times. In addition, the coal seam with coal-rock interface appears larger impact load and other time-domain characteristics.
Keywords: helical vanedrum; coal-rock interface; pick; coal seam, cutting load

1. Introduction

Shearer is an important part of the comprehensive mechanized coal mining. Research on dynamic characteristics of drum shearer cutting coal seam with coal-rock interface was proposed, and the existent problems of present researches were analyzed based on two project requirements described in the shearer engineering background and combined with the related technology of drum shearer Based on the maximum tensile stress theroy, Evans established the first predicted model of the peak cutting force of conical pick. [1], then Roxborough et al. [2] and Goktan [3] had modified the Evans mathematical model appropriately. The regression expressions of the relationship between peak cutting force of conical picks and various parameters, like rock compressive strength, tensile strength, dynamic and static modulus of elasticity and brittle index, analzing the data of experiments cutting different structural rock by conical picks. The rock compressive strength has the greatest influence on me the cutting performance of the pick [4-7]. So the study on pick cutting forcecan provide relevant basis for the design of shearer drum.Scholars at home and abroad both have done a large number of experiments on pick cutting force. [8-10]. On the basis of coal cutting experiments of five drums with different types of picks [11,12]. Xia et al. [13, 14] using simulation methods studied the load characteristics of picks and load distribution They provided a theoretical guidance for the study of stress distribution of picks. Mishra [16] studied the influence of pick types on the cutting effect and built the relationship between the heat produced by pick during rock cutting and the cutting parameters.

Du et al. [17] obtained the fluctuation coefficient of different pickarrangement drum on the basis establishing the relationship between the new pick cutting force, and provided atheoretical basis to choose and use the drum and pointed out that the pick with a punnett square arrangement has a smaller cutting load fluctuation than that of other pick arrangement forms. Li et al. [18] established different kinds of dynamic model: the cutting unit for continuous miner and drum type shearer, which provides the basis for the research, that numerical methods for solving continuous miner cutting unit vibration state differential equation, under different working conditions and loading conditions of various mass, stiffness and damping factor of each part of the cutting unit vibration impact on the continuous miner. Liu et al. [19-21] studied studied the dynamics of spiral cutting method based on rock breaking, pointing out its load fractal.

There are relatively few research on the load characteristics of pick cutting complex-structure coal seams. Liu et al. [22-24] studied on the coal cutting test-bed, using the embedded wireless testing system for related to study the influence on cutting load of cutting material parameters and the pick parameters. It can provide theoretical basis for design the better pick cutting performance type cutting pick. Zheng KH et al. [25-26] proposed a numerical three-dimensional (3D) mesoscopic approach of pick cutting complex coal seams, which could investigate the effects of the 3D meso-structure on the failure patterns and fracture mechanism.

In this paper, we make the following assumptions, there is the adhesion force between coal and rock bedded junction (or called cohesion), namely the adjacent coal and rock was firmly joint as a whole, and after deforming of two adjacent coal and rock it won't produce relative move. Each layer of coal and rock parameter of elastic modulus, poisson ratio, shear modulus and ultimate strength is generally not the same, regardless of the width of the rock interface condensate.

2. Coal seam with coal and rock interface single pick cutting mechanics model

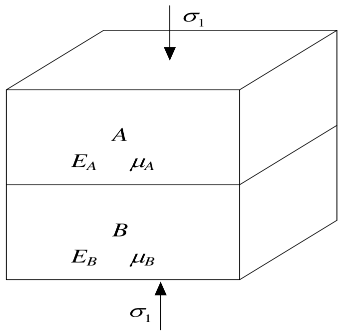
At present, there are two main types of pick for cutting coal and rock: knife pick and conical pick. Contrast with knife picks, the conical picks have long service life, and also have simple and reliable installation, therefore it is more widely used in modern coal mining machine drum. In the process of producing shearer, install the picks reasonably can improve the pick cutting performance, but also can extend the service life of picks.For example, when install the picks, thepick body should be the acute angle with shearer drum radial direction, basic at the tangent line of pick tip movement locus, thus the pick body under the influence of bending moment is small, then it is not easy to broken the picks[27-28].

In conditions of shearer cutting such coal seam, it will have a larger impact load, and then it has an influence on the whole shearer performance. In the process of the single pick cutting the above several types of coal seam with coal and rock interface, there will be a clear transition, namely pick from the transitional process of coal cutting into the rock seam, or from the transition process of rock cutting into the coal seam. In order to better known the mechanical properties of pick cutting this kind of coal seam, you first need to understand the coal and rock mechanics performance and status on coal and rock interface.The four kinds of structure form in coal seam with coal and rock interface can be summerized as layer of coal and rock, this section will give a related theoretical analysis of stress and strain state of stratified coal and rock mass.

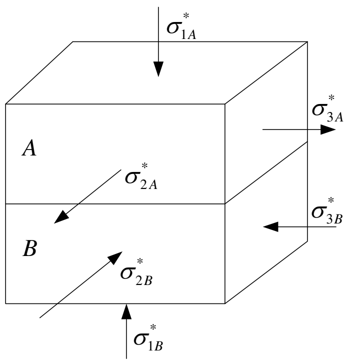
2.1 Layer of coal and rock stress analysis and strength conditions

Layered coal and rock mass as shown in Figuer1, which is composed of rock A and coal seam B, superposition of these two in turn, and make them closely integrated as A whole. After the rock mass stress A and B are closely integrated. The elastic modulus and poisson ratio of A and B is respectively E_A、E_B、μ_A、μ_B, and the relationship between them are $E_A > E_B$ and $\mu_A < \mu_B$.

In coal and rock cutting conditions, the analysis of lateral strain between rock A and coal seam B under uniaxial stress, considering that due to the elastic modulus relationship between A and B, so A contingency should be less than B.But it is important to note that because the two are together, so at the interface the lateral strain will constraint each other, so must make lateral restraint stress on both sides of the interface, therefore it needs to study the combination form of rock stress state and strength condition.



Figuer 1. Schema of layered coal and rock



Figuer 2. Three dimensional element body at rock A-coal B interface

2.2 Stress and strain analysis and calculation of boundary layer in coal and rock

In oder to study the laminar boundary layer of coal and rock stress state, form the interface of rock A and coal seam B takes out a elastic modulus and poisson ratio of three dimensional unit cell firstly, as shown in Figuer 2.

Figuer 2 layered coal and rock mass strength condition based on the Griffith strength theory, on the borders between A and B, when A and B are in the limit stress balanced state respectively, the limit stress as follow.

$$\begin{cases} \sigma_{1j}=\sigma_{1A}^{*} \\ \sigma_{3j}=K_{AB}\sigma_{1A}^{*} \end{cases}, \begin{cases} \sigma_{1J}=\sigma_{1B}^{*} \\ \sigma_{3j}=K_{AB}\sigma_{1A}^{*} \end{cases} \tag{1}$$

where

$$K_{AB} = \frac{E_A\mu_B - E_B\mu_A}{E_A\left(1-\mu_B\right)+E_B\left(1-\mu_A\right)} \tag{2}$$

From the formula (2)can be known that K_{AB} changes with the changing of elastic modulus and poisson ratio value of A and B. Based on the above analysis, in rock A and coal seam B border, rock A due to lateral deformation produces horizontal tensile stress, so rock A changes from the unidirectional stress state into the three directional stress state, and its axial compressive ultimate strength σ_{1Aj}^{*} will be less than the strength σ_{1Aj} of the outside area on the interface, so it can be determined that the strength of the rock A decreases. As for coal seam B, because of it also changes from unidirectional stress to three directional stress state, and its axial compressive ultimate strength σ_{1Bj}^{*} is bigger than the strength σ_{1Bj} of the side area on the interface, it reflects that the strength of the coal seam B is improved. The adjacent rock stress state of rock boundary layer in layered rock and coal depends on the coefficient numerical size of K_{AB}. Obviously, in the boundary layer of rock A and coal seam B, the bigger of K_{AB}, the larger of lateral restraint stress is, and coefficient of K_{AB} changes with the changing of of elastic modulus and poisson ratio of rock A and B.

In conditions of cutting coal seam with coal and rock interface, when picks following drum rotation and traction movement enter into the whole process of coal cutting, the loads as the change of pick cutting thickness changes, this rule is also consistent with the change of the homogeneous coal seam.When meeting coal and rock interface the cutting load will change, this is because in the area near the interface, the coal seam property changes, so for the analysis of the pick cutting load must be considered the related factors, its main characteristic parameters are compressive strength, tensile strength and friction coefficient.

Based on the formula,

$$F_c = \frac{8\pi\sigma_t^{\,2}(\sin\theta+\mu\cos\theta)}{\sigma_c(\cos\theta+\mu\sin\theta)^2\sin 2\theta}\frac{h(t)^2(\cos\theta+\cos(\theta+\beta_0(t)))}{\cos\beta_0(t)} \tag{3}$$

where，

$$\begin{cases} \beta_0(t) = \dfrac{\pi}{2} - 2\theta - \arcsin\left(\dfrac{v\sin(wt)}{\sqrt{v^2+2vrw\cos(wt)+r^2w^2}}\right) \\ h(t) = \sqrt{(x_1(t_1)-x_2(t))^2+(y_1(t_1)-y_2(t))^2} \\ y_1(t_1)-y_2(t) = \dfrac{v_q + r\omega\cos(\omega t_2)}{r\omega\sin(\omega t_2)}(x_1(t_1)-x_2(t)) \\ x_2(t) = v_q t + R\sin\omega t \\ y_2(t) = R\cos\omega t \\ x_1(t_1) = v_q t_1 + R\sin\omega t_1 \\ y_1(t_1) = R\cos\omega t_1 \end{cases} , \; t\in(t_s^2,t_e^2),\; t_1\in(t_s^1,t_e^1)$$

combining with theoretical analysis of formula (2), the instantaneous cutting resistance of a single pick rotation cutting coal seam with coal and rock interface can be obtained.

In the coal seam:

$$F_{c1} = \frac{8\pi\sigma_{tc}^{\;2}(\sin\theta+\mu_c\cos\theta)}{\sigma_{cc}(\cos\theta-\mu_c\sin\theta)^2\sin 2\theta}\frac{h(t)^2(\cos\theta+\cos(\theta+\beta_0(t)))}{\cos\beta_0(t)} \tag{4}$$

In the coal seam side which is close to boundary layer of coal and rock interface:

$$F_{c2} = \frac{8\pi K_{AB}\sigma_{tc}^{\;2}(\sin\theta+\mu_c\cos\theta)}{\sigma_{cc}(\cos\theta-\mu_c\sin\theta)^2\sin 2\theta}\frac{h(t)^2(\cos\theta+\cos(\theta+\beta_0(t)))}{\cos\beta_0(t)} \tag{5}$$

In the rock seam:

$$F_{r1}=\frac{8\pi\sigma_{tr}{}^{2}(\sin\theta+\mu_r\cos\theta)}{\sigma_{cr}(\cos\theta-\mu_r\sin\theta)^2\sin2\theta}\frac{h(t)^2(\cos\theta+\cos(\theta+\beta_0(t)))}{\cos\beta_0(t)} \tag{6}$$

In the rock seam side which is close to boundary layer of coal and rock interface:

$$F_{r2}=\frac{8\pi K_{BA}\sigma_{tr}{}^{2}(\sin\theta+\mu_r\cos\theta)}{\sigma_{cr}(\cos\theta-\mu_r\sin\theta)^2\sin2\theta}\frac{h(t)^2(\cos\theta+\cos(\theta+\beta_0(t)))}{\cos\beta_0(t)} \tag{7}$$

where,

σ_{tc} 、 σ_{tr} —Tensile strength of coal and rock,Mpa.

σ_{cc} 、 σ_{cr} —compressive strength of coal and rock,Mpa.

μ_c 、 μ_r —friction coefficient between pick and coal， pick and rock.

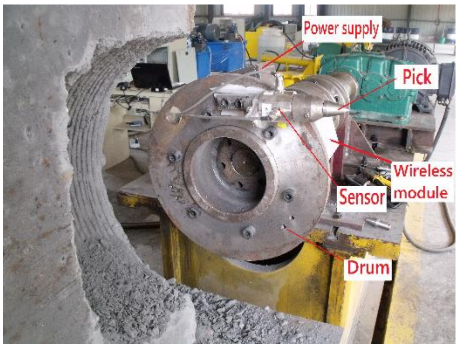
According to the analysis of stress and strain and intensity conditions of layered coal and rock mass, the picks from coal mass entering into rock mass is the changing process of increasing the compressive strength of coal and rock, so in the cutting area outside on interface, cutting parameters and cutting performance is almost the same with homogeneous coal and rock cutting, when cutting the area near the interface, due to the strength of the coal is lower than the strength of the rock, so the crack extension including the formation of caving will stop at the interface.The cutting process, it is equivalent to the insTable and failure process of the combination of coal and rock mass, compared with unidirectional compressive damage of coal sample or rock sample monomer, the strength of combination is reduced. At the same time, the instability and failure of specimen is more all of a sudden and violent, buckling failure mode from the instability of a single coal or rock become into the unstability of the combination of the whole structure which is caused by the instability of coal and rock material. In the process of the instability of combination structure, the coal material has been broken, at the top or top and bottom rock, the accumulated elastic energy releases in a sudden and accelerates the rupture of coal sample, and also promptes some coal caving.

The picks from coal seam enter into rock seam or from rock seam enter into coal seam, the change of cutting force will be different. Because of the strength of the coal is lower than the strength of the rock, so near the interface the destruction of the coal have little impact on the rock, but the destruction of rock have great impact on the coal. According to the above formula, when the pick cutting coal with the coal and rock interface, cutting resistance will rise by the cohesive force between coal and rock. When the pick cutting rock with coal and rock interface, cutting resistance will decrese the cohesive force between coal and rock, this is because when pick cutting coal seam with coal and rock interface, the cutting load has a transition.

3. Introduction of a test system for cutting coal-rock seams

Experiments were conducted on a cutting testbed of coal and rock (CTCR) (shown as Figuer.3), which was described in [19]. The rotary speed *n* (r/min) of the pick is within the range of [0, 120], the velocity of the coal seam v_1 (m/min), which is moving close to the drum along its axial direction, is within [0, 2], the velocity of the coal seam v_2 (m/min), which is moving along the direction perpendicular to the drum axis, is within [0, 1]. The pick used in the experiment and its motion mode is shown in Figuer. 4), from which it can be seen that half the picks on the pick are cutting coal simultaneously during the pick rotating and going deep into the coal seam. The structural parameters of the pick are listed in Table 1.

Figuer 3. A cutting testbed of coal and rock



Figuer 4. A pick used in the experiments and pick sensor and wireless data transmission module

Table 1. Structure parameters of the pick

Parameter	Diameter D (mm)	Vane number n (-)	Helical angle e (° .)	Pick impact angle a (°)	Cutting line space t (mm)
Value	560	2	75	25	30

The process of a shearer pick cutting seams containing coal and coal seam with coal-rock interface is very complicated, especially when the pick is encountering the coal-minor fault interface. At that moment, the pick will transit its status from only cutting coal to cutting rock suddenly. Due to the fact that coal and rock are different in physical properties, such as hardness and compressive strength, large load fluctuations of the pick will occur in this situation, which can affect the cutting performance and reliability of the shearer. In this case, pick will cut coal and coal seam with coal-rock interface simultaneously. Homogeneous coal seams and coal seam with coal-rock interface with different compressive strength are made with different ratios of coal and cement, according to the method of manufacturing artificial rock seams in [19].

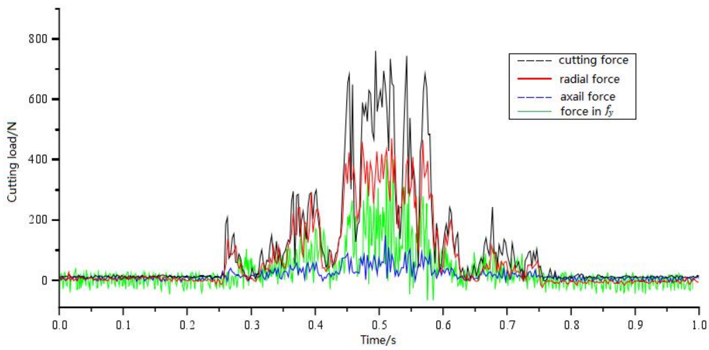
4. Experimental study on pick cutting differen type of coal seam

We conducted pick cutting tests in coal seam, rock seam and coal-rock interface respectively, the results of pick cutting load in these tests were shown in Figure 5, Figure 7 and Figure 9.

As for cutting load analysis, it can according to cutting mechanics model of the coal seam with coal and rock interface, the cutting load of coal seam with coal and rock interface will changes in the interface, at the place which is away from the interface, the cutting load change trend and load change state in the homogeneous coal or rock seam is same, therefore, this section through the experimental study of coal rock cutting mechanics model to provides the theory basis for the follow-up study of cutting load. In coal or rock seams, it mainly corrects the material parameters which is related to the compressive strength. Establish a correction factor for $K_{r(c)}$, the subscript for c on behalf of the coal seam, the subscript r on behalf of the rock, there are:

$$F_{r(c)1}=\frac{8K_{r(c)}\pi\sigma_{tr(c)}{}^{2}(\sin\theta+\mu_{r(c)}\cos\theta)}{\sigma_{cr(c)}(\cos\theta-\mu_{r(c)}\sin\theta)^{2}\sin 2\theta}\frac{h(t)^{2}(\cos\theta+\cos(\theta+\beta_{0}(t)))}{\cos\beta_{0}(t)} \tag{8}$$

4.1 Homogeneous coal cutting mechanics model test amendment



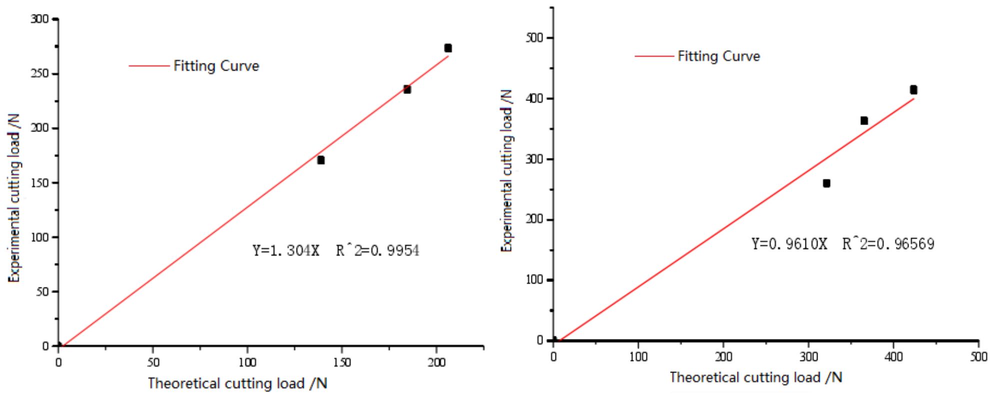
Figuer 5. Pick cutting load for coal seam

According to the theoretical research and experimental study, in order to obtain the accurate cutting mechanics model with test basis, this section is to carry out the comparison of theoretical value of cutting load and calculated value of cutting load, while considering the theoretical formula is derived by assuming condition, and contrast with the experimental condition it will miss some influencing factors. The author expects through comprehensive analysis for cutting load test value and the theoretical calculation value to improve the accuracy of theoretical analysis, which can provide certain guidance for the study of the roller cutter tooth design. According to the test data and the condition of time domain analysis, a measured cutting resistance peak value and mean value in experiment and theory formula calculated results is counted, as shown in Table 2.

Table 2. Cutting load statistics comparison for coal seam

Coal compressive strength (MPa)	Mean cutting force（ N ）	Peak average cutting force（ N ）	Mean radial resistance（ N ）	Peak average radial resistance（ N ）
0.69	139.01	170.54	321.41	260.32
1.58	184.55	235.59	365.56	363.062
2.73	206.21	273.6	423.75	414.7

According to the foregoing chapters to compare the cutting load time domain waveform curve and the cutting load is calculated by cutting mechanics model, can be known that cutting force calculation value with the same condition test value on the overall ttrend is almost the same, but there is a obvious difference in the peak, because the considering working condition of the calculated value of the theoretical formula is ideal hypothesis condition, so it needs to be revised according to the test results. In this section, according to a contrast between experiment and theoretical analysis can be concluded that theoretical calculation of load amplitude and experimental load amplitude difference mainly reflects on the difference of cutting parameters and cutting mechanism parameters during the cutting process, so add corresponding correction coefficient to the obvious parameters in the above analysis, through the modification coefficient can get more nearly to the test results of cutting load. According to Table 2, theoretical value of cutting resistance and the corresponding test value relationship fitting curve as shown in Figuer 6.

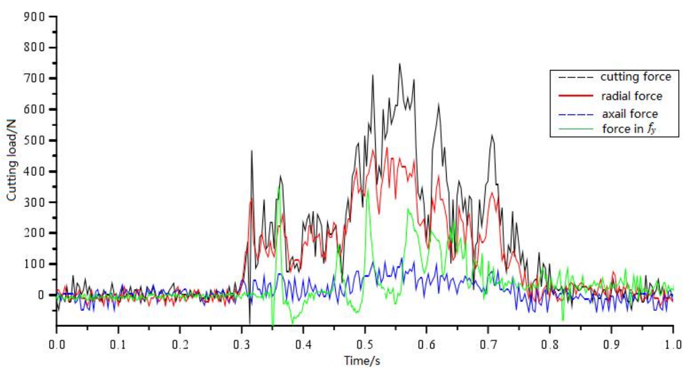


(a) Comparison of mean cutting load (b) Comparison of peak cutting load

Figuer 6. Relationship between theoretical and experimental cutting force for coal seam

From Table 2 can be clearly seen that there is a difference between the theoretical value and experimental value of cutting load , the mean cutting resistance test value is less than the theoretical value, but the mean peak cutting resistance significantly bigger than the theoretical value.This is because in the process of cutting, the pick cutting load is random, the peak value has a very close relationship with coal block degree and dense nuclear formation, and there will be a short light after the coal caving, this leads to the difference value between peak value and average value of the load is larger, compared with the theoretical calculation results can produce the difference as shown in Figuer 6. So through above analysis can get the relationship between cutting theory calculated value and test peak value and average value, as shown in Figuer 6, the slope can be used as coal cutting mechanical models formula (8) correction coefficient Kc and also provides guidance for further research.So in the scope of this experimental study, join the correction coefficient of theoretical formula can be used as coal cutting load calculation, and also can provide theoretical guidance for the drum design.

4.2 Homogeneous rock cutting mechanics model test amendment



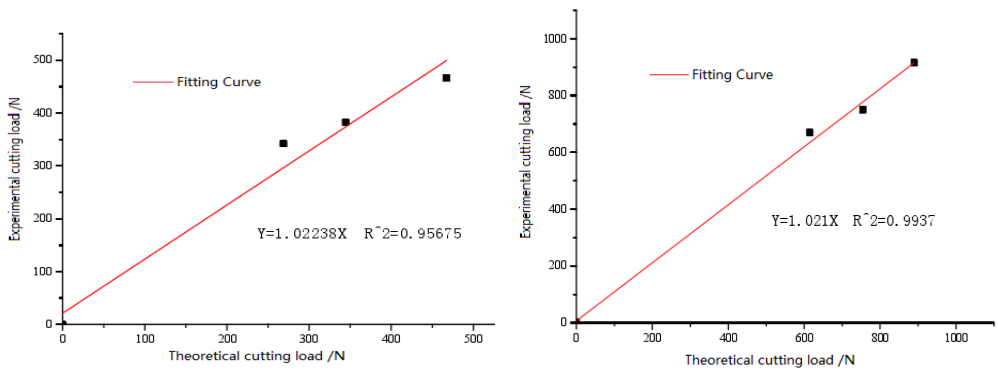
Figuer 7. Pick cutting load for rock seam

Under the conditions of homogeneous rock cutting, the relationship between cutting load test value and the theoretical value is divided into the cutting resistance mean value and peak value two statistic analysis. According to the test conditions on theory and experiment of peak and average value, the statistics is shown in Table 3. According to the data in Table 3, it can be seen that the difference between changing trends of cutting resistance and homogeneous coal seam cutting load is very small, while the cutting resistance peak value and homogeneous coal seam cutting load is bigger, this kind of difference shows that under the condition of rock cutting, loads are greatly influenced by thickness of cutting, and rock crushing force and energy for the picks were bigger, it also verify the rock seam material is more dense than coal seam material, and it hards to broken.

In homogeneous rock seam, the relations of cutting resistance theoretical value and the corresponding condition test value is shown in Figuer 8. From Table 3 and Figuer 8, it can be seen that under the condition of homogeneous rock cutting, tested value of cutting resistance peak value and cutting resistance mean value are greater than their calculated value, it is different from the load state which is under the condition of coal cutting. It shows that in cutting rock conditions, for the theoretical calculation values, only consider rock compressive strength is very limited, so in the following study, the experimental study on other material properties of rock is needed, in order to obtain more accurate cutting load theory model. In addition, the proportional relationship between pick cutting load test value and theoretical value can be shown in Figuer 8, that is Kr (the slope of fitting line). The scope of this experimental study can be got by fitting formula, after adding correction coefficient the theory analysis model can be applied to the cutting load calculation, so as to provide guidance for the research of cutting mechanism design.

Table 3. Cutting load statistics comparison for rock seam

compressive strength (rock MPa)	Mean cutting force（N）	Peak average cutting force（N）	Mean radial resistance（N）	Peak average radial resistance（N）
4.55	269.01	341.66	615	643.08
8.71	344.55	382.77	755	740.46
11.64	467.34	466.7	890	908.42

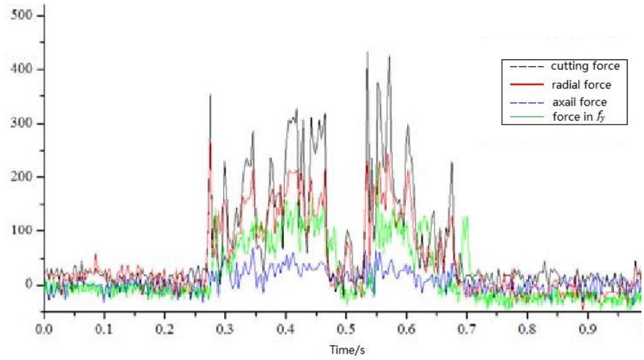


(a) Comparison of mean cutting load (b) Comparison of peak cutting load

Figuer 8. Relationship between theoretical and experimental cutting force for rock seam

Contrast with Table3, you can see that the changing regularity of rock cutting load and the coal cutting load is different, coal cutting loads are relatively uniform, the difference value between rock peak value and average value is bigger, while the difference value between coal peak value and average value is smaller. This is due to in rock cutting conditions, rock crushing force and energy for the caving are bigger, and the fissure inside rock is less than the coal seam, so coal cutting load test value is lower than the theoretical value, while the rock cutting load test value and the theoretical value difference is very little. In addition, by the fitted curve slope of Figuer 6 and 8, the uncorrected cutting mechanics model to describe the cutting rock load is relatively accurate, but to the homogeneous coal seam description is not accurate, it needs to add bigger correction coefficient, this further illustrates that the influence factor of the homogeneous coal cutting load is more complicated.

4.3 Coal seams with coal and rock interface cutting mechanics model test amendment



Figuer 9. Pick cutting load for coal seam with coal-rock interface

According to the analysis of the above experiments, in order to study the change rule of cutting load of coal seam with coal and rock interface based on test of different interface layer material for a single pick cutting. Cutting institutions related parameters is the same as homogeneous coal rock cutting parameters, experimental coal and rock material parameters are shown in Table 1. When cutting coal seams with coal and rock interface, the picks not only cut the coal seams but also cut the rock seams in a cutting cycle, in order to study the influence of the existence of the interface to coal and rock cutting load, the cutting load statistical values of this section are different from the foregoing chapters. In study the loads are divided into two parts, that is load statistics of cutting coal seams and load statistics of cutting rock seams, for short, there are the coal interface and rock interface. And under the same conditions the corresponding cutting load of homogeneous coal seam and rock seam are referred to as the homogeneous coal and the mean rock. the above statistics shown in Table 4, through the further analysis in order to obtain more meaningful research results, and to provides an experimental basis for the establishment of coal seam with coal and rock interface cutting mechanics model.

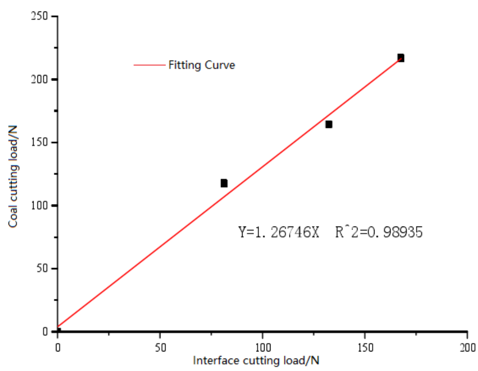
Table 4. Cutting load statistics comparison under different cutting condition

Test type	Mean cutting force（N）	Peak cutting force（N）	Standard deviation	Test type	Mean cutting force（N）	Peak cutting force（N）	Standard deviation
Coal with interface I	81.34	235	11.08	RockI	278.15	614.23	16.35
CoalI	117.55	270.23	13.74	Rock with interfaceI	284.81	615	17.11
Coal with interface II	132.44	249	11.68	Rock II	396.33	757.51	15.38
CoalII	164.32	325.64	14.99	Rock with interfaceII	391.34	755	14.23

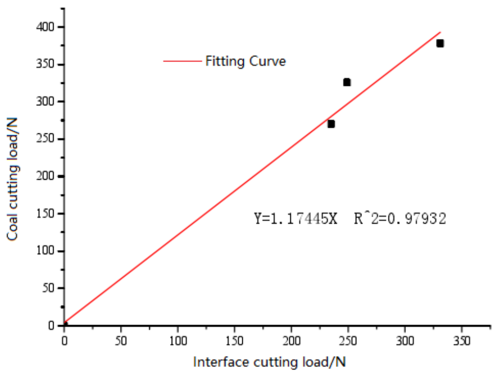
Coal with interface III	167.65	331	12.53	Rock with interfaceIII	519.12	889	18.16
CoalIII	217.11	378.35	15.64	RockIII	527.34	890	16.79

From Table 4 can be seen that pick cutting load of coal seam with coal and rock interface, in the part of pick cutting coal seam load of the mean value and the peak mean value are lower than that of homogeneous coal cutting load.Analysis its reason mainly is when cutting homogeneous coal seam is not influenced by rock seam, cutting coal seam will appear the extrusion of coal seam, but the extrusion of inner coal seam can produce extrusion deformation as a result of the coal seam toughness, so it is not easy caving broken, there will be a higher load or a large degree of coal caving broken, load will be bigger. In coal seam with coal and rock interface, the pick cutting coal seam is equivalent to the coal seam existing between pick and rock seam, coal seam is easily squeezed then produces caving broken, and not produce extrusion load cumulative, so cutting load will be smaller.

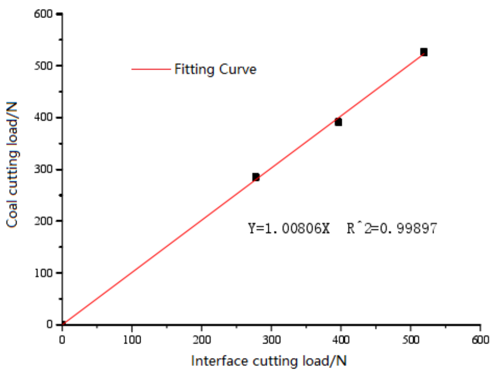
Figuer 10 is the relations of theorical cutting load value and the test results under the condition of cutting the coal seam with different coal and rock interface, it can be seen from the relationship of cutting load , in the coal seam with coal and rock interface the cutting load mean value and peak mean vaue of cutting rock seam is almost the same as loads in the homogeneous rock seam, and the numerical change is not obvious. In the process of cutting coal seam withcoal and rock interface, the volatility of cutting load and intensity of the impact load from rock transition to homogeneous formations, this suggests that in the conditions of cutting coal seam with coal and rock interface, the effect on the phrase of coal seam cutting load is obvious by the interface, while the rock seam affected by the interface is not obvious.



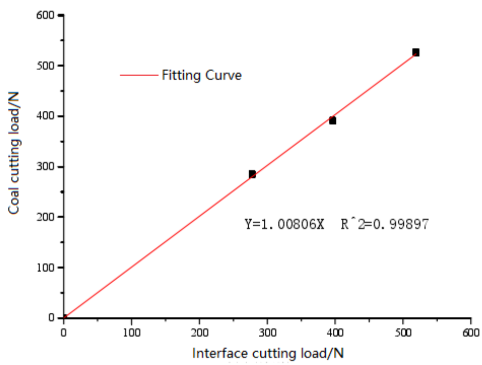
(a) Comparison of mean coal cutting load



(b) Comparison of peak coal cutting load



(c) Comparison of mean rock cutting load



(d) Comparison of peak rock cutting load

Figuer 10. Relationship between theoretical and experimental cutting force under different cutting condition

It can be seen from Figuer 10, the relations of cutting homogeneous coal seam and cutting the load of coal seam with interface, which can be obtained when using theoretical mechanics model to calculate, you need to consider the main factors is material parameters, but also need to consider the influence on load during the process of throughing interface, and the impact of relationship is shown in Figuer 10, the linear fitting formula can be expressed, that is, within the scope of this section study, the slope of the fitting formula between the loads can be used as the existence of interface effect coefficient of load. For cutting resistance formula derivation, this section first analysis the process of coal seam into rock seam, the change of cutting load is not only related to the cutting material, and also will be influenced by other cutting factors, in this section, the impact of these factors on the load is reprsented by a coefficient K_{AB}, through the study of the above, the fitting curve slope is right the influence coefficient of this test. According to the coefficient can be quantitative analysis on the cutting load, and provides the basis for the theory research of cutting load for coal seam with coal and rock interface. Combined with theoretical analysis, the theoretical formula of the coal seam side close to the boundary layer of coal and rock seam is,

$$F_{c2}=\frac{8\pi K_{AB}\sigma_{tc}^{2}(\sin\theta+\mu_c\cos\theta)}{\sigma_{cc}(\cos\theta-\mu_c\sin\theta)^2\sin 2\theta}\frac{h(t)^2(\cos\theta+\cos(\theta+\beta_0(t)))}{\cos\beta_0(t)} \tag{9}$$

Among them, K_{AB} is the load variation coefficient of coal seam entering into the rock seam, so this coefficient is reasonable within the scope of this experimental study, the formula in the actual application needs to be determined by testing. For the section of rock seam entering into the coal seam, the changing state of cutting load also can be obtained by this method, the theoretical formula of the rock seam side close to the boundary layer of coal and rock seam is,

$$F_{r2}=\frac{8\pi K_{BA}\sigma_{tr}^{2}(\sin\theta+\mu_r\cos\theta)}{\sigma_{cr}(\cos\theta-\mu_r\sin\theta)^2\sin 2\theta}\frac{h(t)^2(\cos\theta+\cos(\theta+\beta_0(t)))}{\cos\beta_0(t)} \tag{10}$$

Among them, K_{BA} is the load variation coefficient of rock seam entering into the coal seam, through the theoretical analysis of cutting load, load will be increase to a certain extent in this area, but compared with load decrese amplitude and variation time of rock seam entering into coal seam, the difference is very small, K_{BA} is determined by the influence coefficient of rock seam material and coal seam material parameter and the influence coefficient of cutting with interface, so that part of the proportional coefficient can be obtained by fitting formula of above Figuer 10, and the coefficients in this experimental study on the reasonable range.

5. Conclusions

(1) On the basis of coal cutting theoretical research, the different forms of pick crushing coal and rock are analyzed, the layered rock mass model of coal seam with coal-rock interface is establised, the stress strain and strength condition of the area in and around the interface are analyzed based on the coal-rock interface crushing theory, which provides basis for further research on the cutting mechanical model of single pick crossing the coal-rock interface. According to the rotary cutting mechanical model of single pick cutting coal seam, the rotary cutting mechanical model of pick cutting coal seam with coal-rock interface is established combined with the strength condition of coal seam with coal-rock interface.

(2) In order to study the load characteristics of different cutting condition, the theory formula correction factor was obtained by comparing the cutting loads of homogeneous coal seam, rock seam and coal seam with coal-rock interface. All the force time curves show a trend of fluctuation around a lower level when the pick only cuts uniform coal-seam, rising continuously when cutting coal seam with coal-rock interface and finally fluctuating around a higher level when cutting coal

seam with coal-rock interface steadily. The research concluded some basic properties of the cutting load changes over times. Plus, finding out the coal seam with coal-rock interface appears larger impact load and other time-domain characteristics. From the above, analyzing the cutting load statistics in the time domain, cutting load variation with cutting material parameters is obtained.

(3) Based on the test system and theoretical analysis, taking the cutting loads of single pick cutting as measure indexes of cutting performance, the influences of cutting material parameters, on the single pick cutting efficiency were studied under different cutting condition. The results show that in the scope of this test study, the cutting loads increase with the increase of coal and rock compressive strength. the results also show that the location of the interfacial layer interface seam of coal-bearing rock has a significant effect on cutting load. Both the maximum cutting load and mean cutting load are increasing with the increase of compressive strength, and the change law consistent with the above basic theory. Cutting load in the rock cutting significantly greater than homogeneous coal, but cutting load of coal seam with coal-rock interface average value is less than load in the pure rock cutting condition, it explains that the cutting load presents the different forms of increase trend with cutting material compressive strength.

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Figures

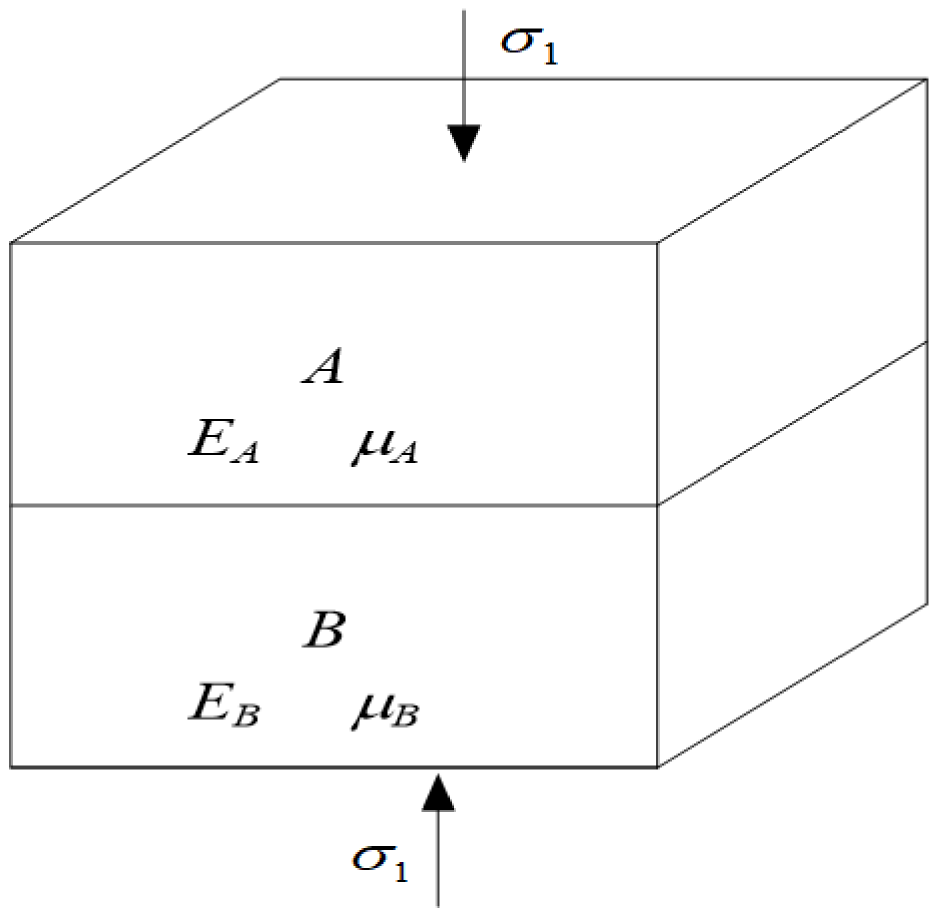

Figure 1

Schema of layered coal and rock

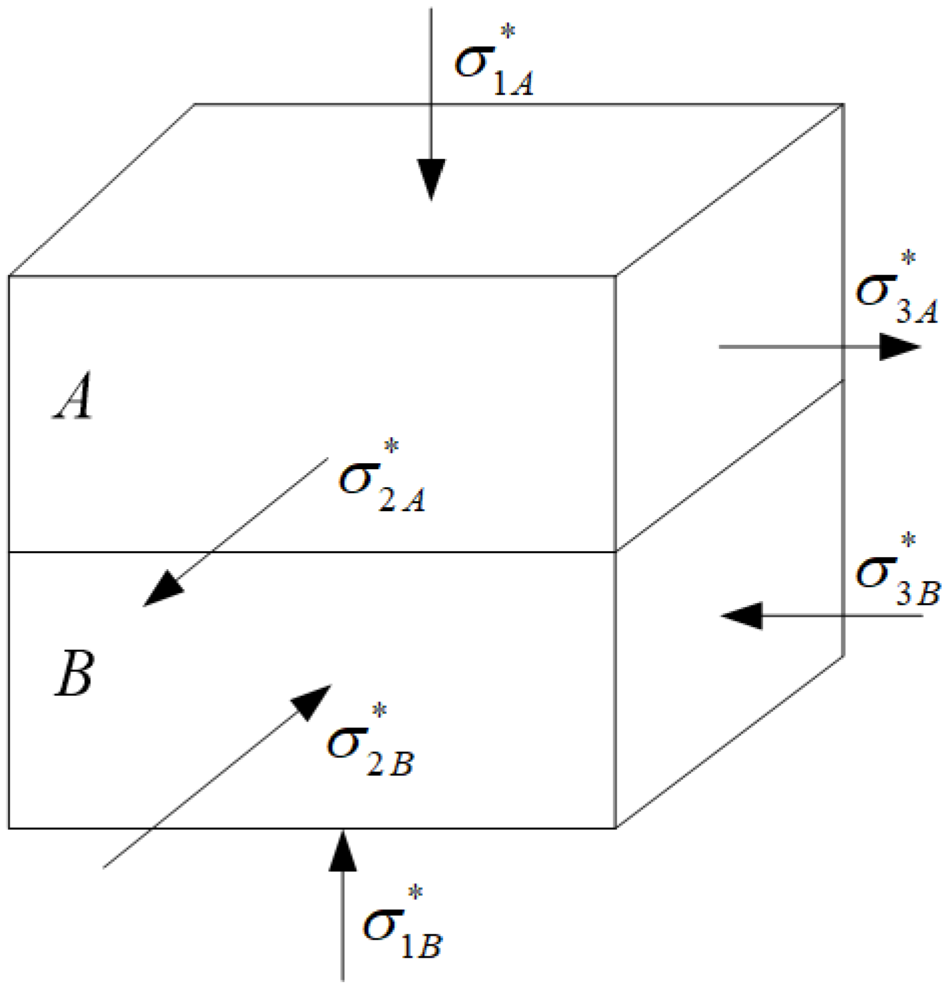

Figure 2

Three dimensional element body at rock A-coal B interface

Figure 3

A cutting testbed of coal and rock

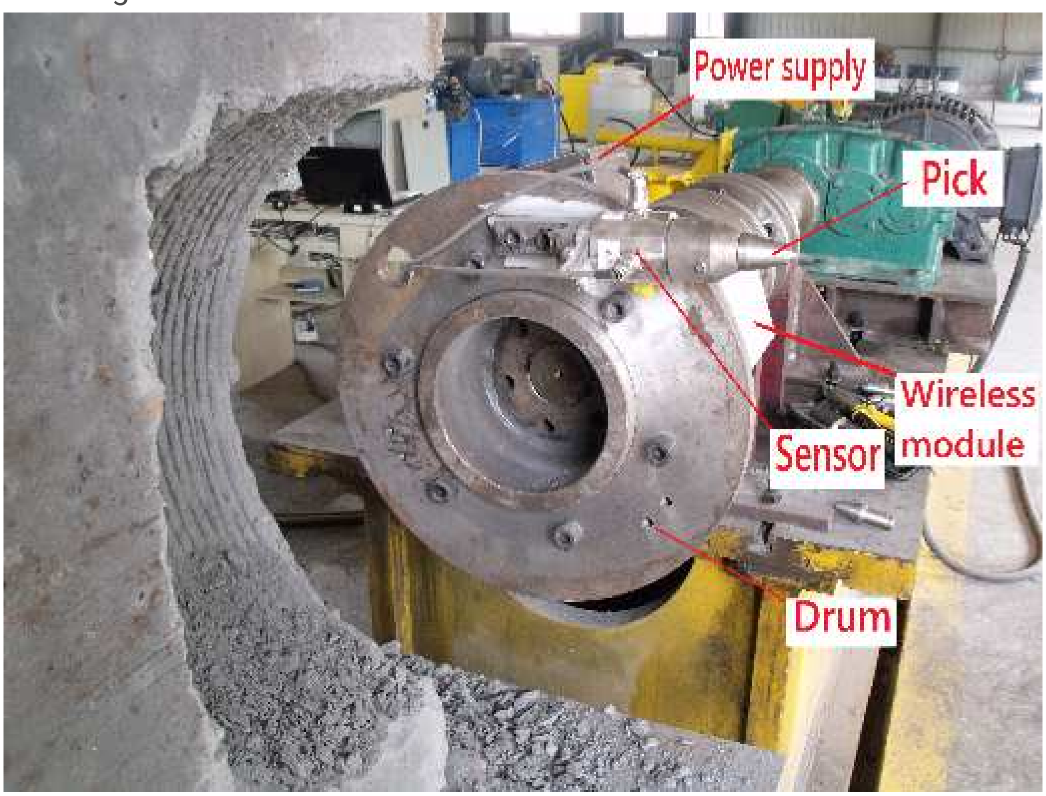

Figure 4

A pick used in the experiments and pick sensor and wireless data transmission module

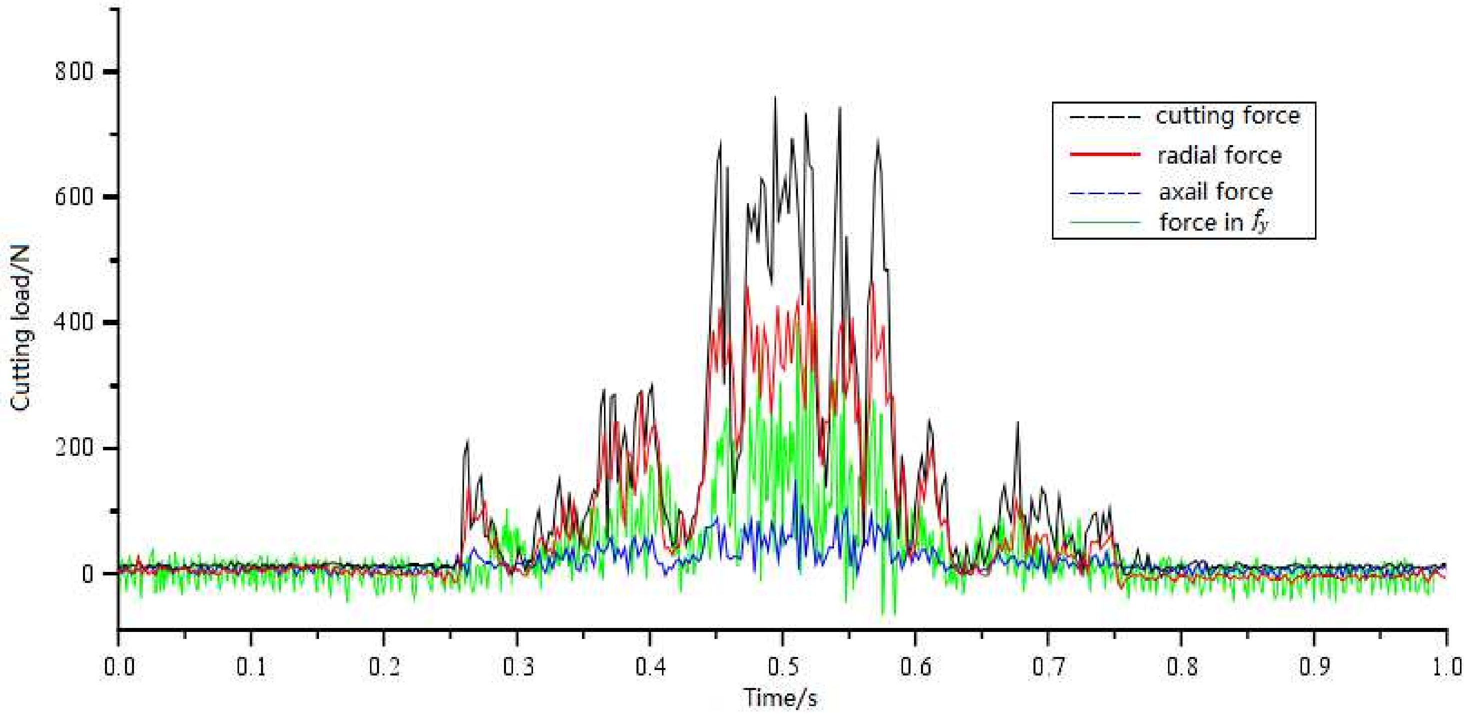

Figure 5

Pick cutting load for coal seam

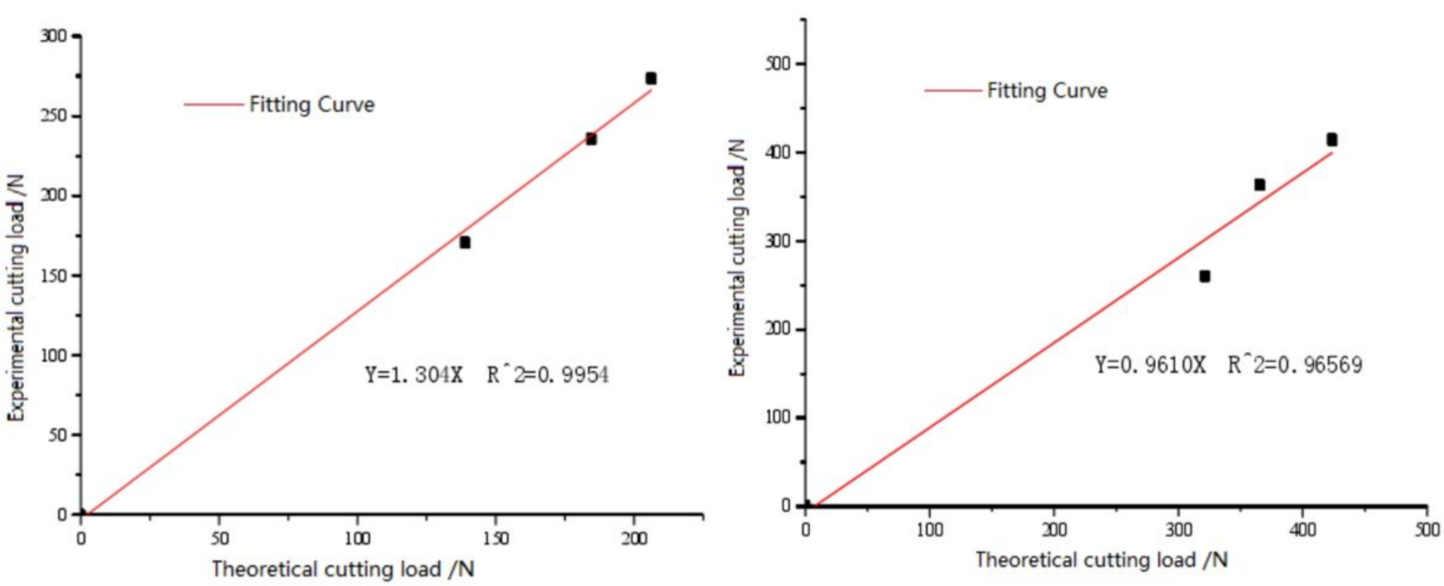

Figure 6

Relationship between theoretical and experimental cutting force for coal seam (a) Comparison of mean cutting load (b) Comparison of peak cutting load

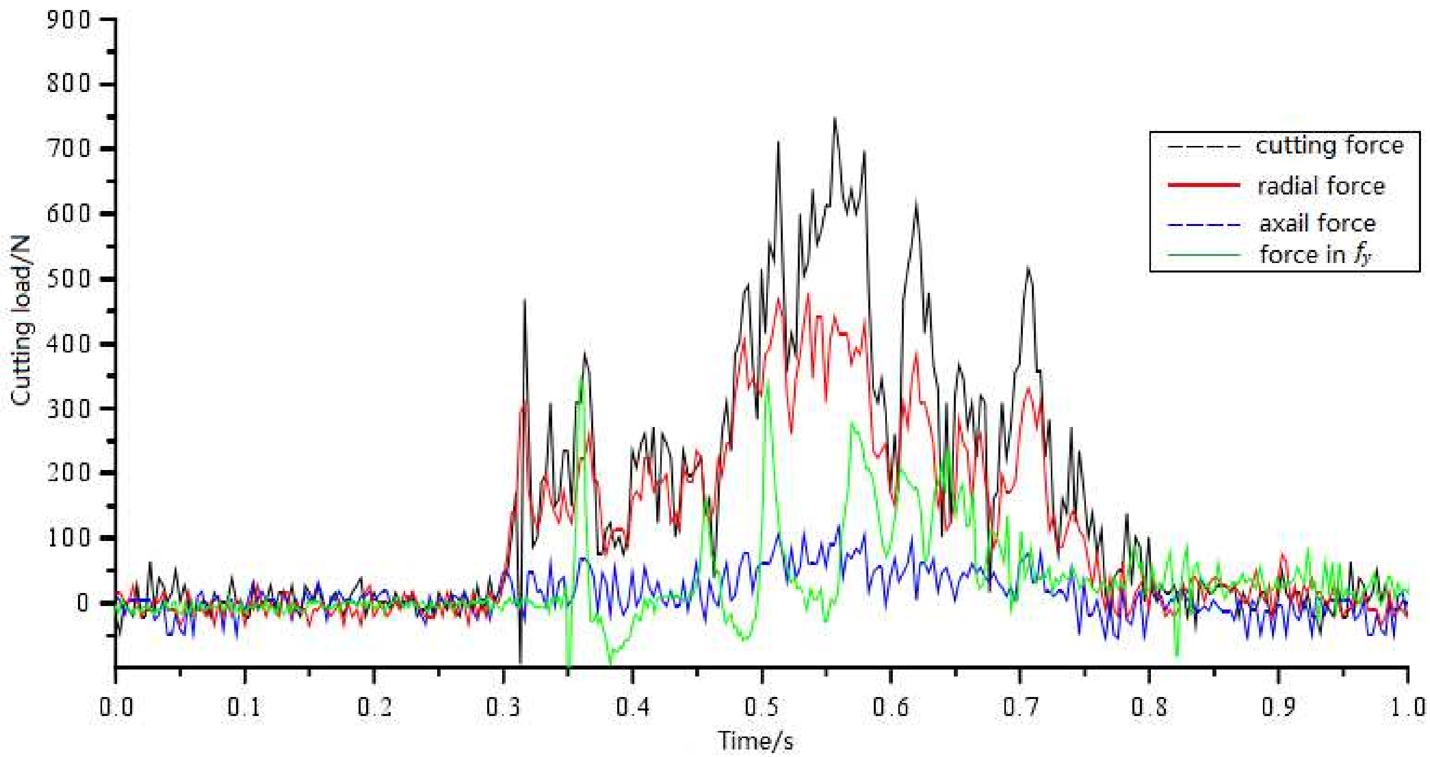

Figure 7

Pick cutting load for rock seam

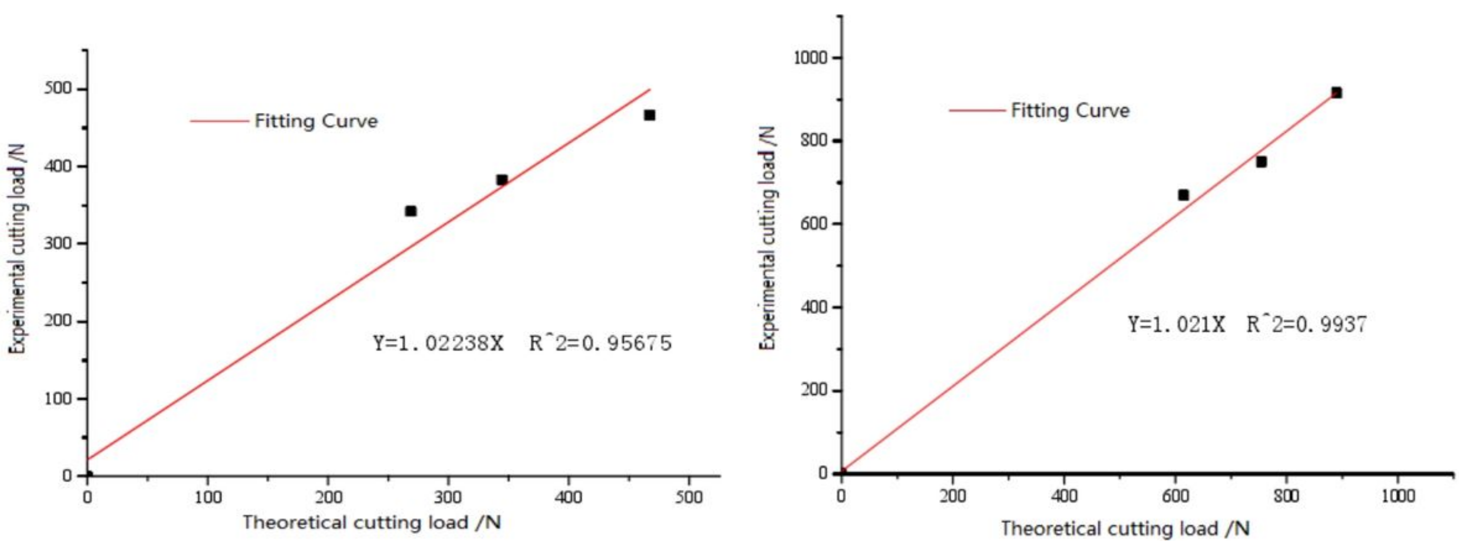

Figure 8

Relationship between theoretical and experimental cutting force for rock seam (a) Comparison of mean cutting load (b) Comparison of peak cutting load

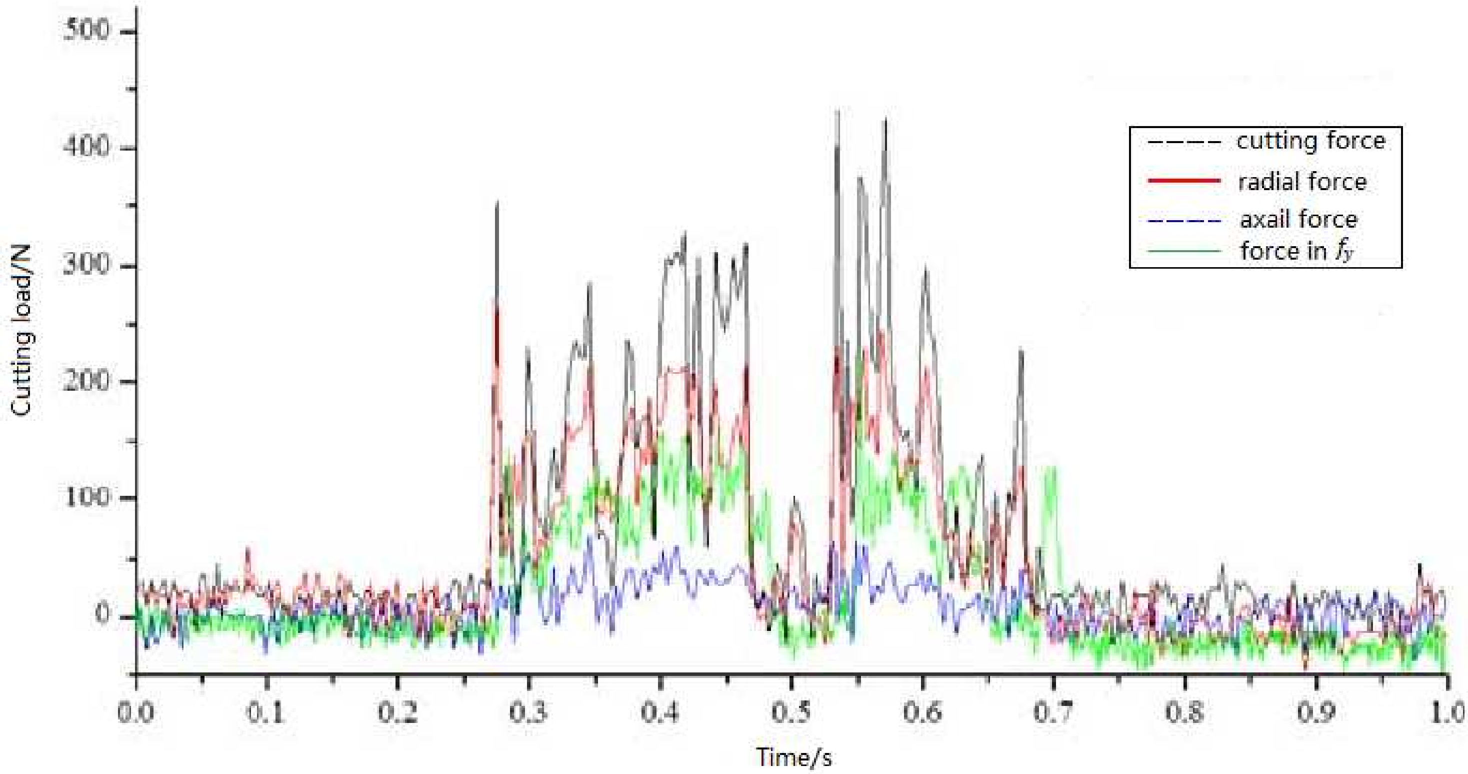

Figure 9

Pick cutting load for coal seam with coal-rock interface

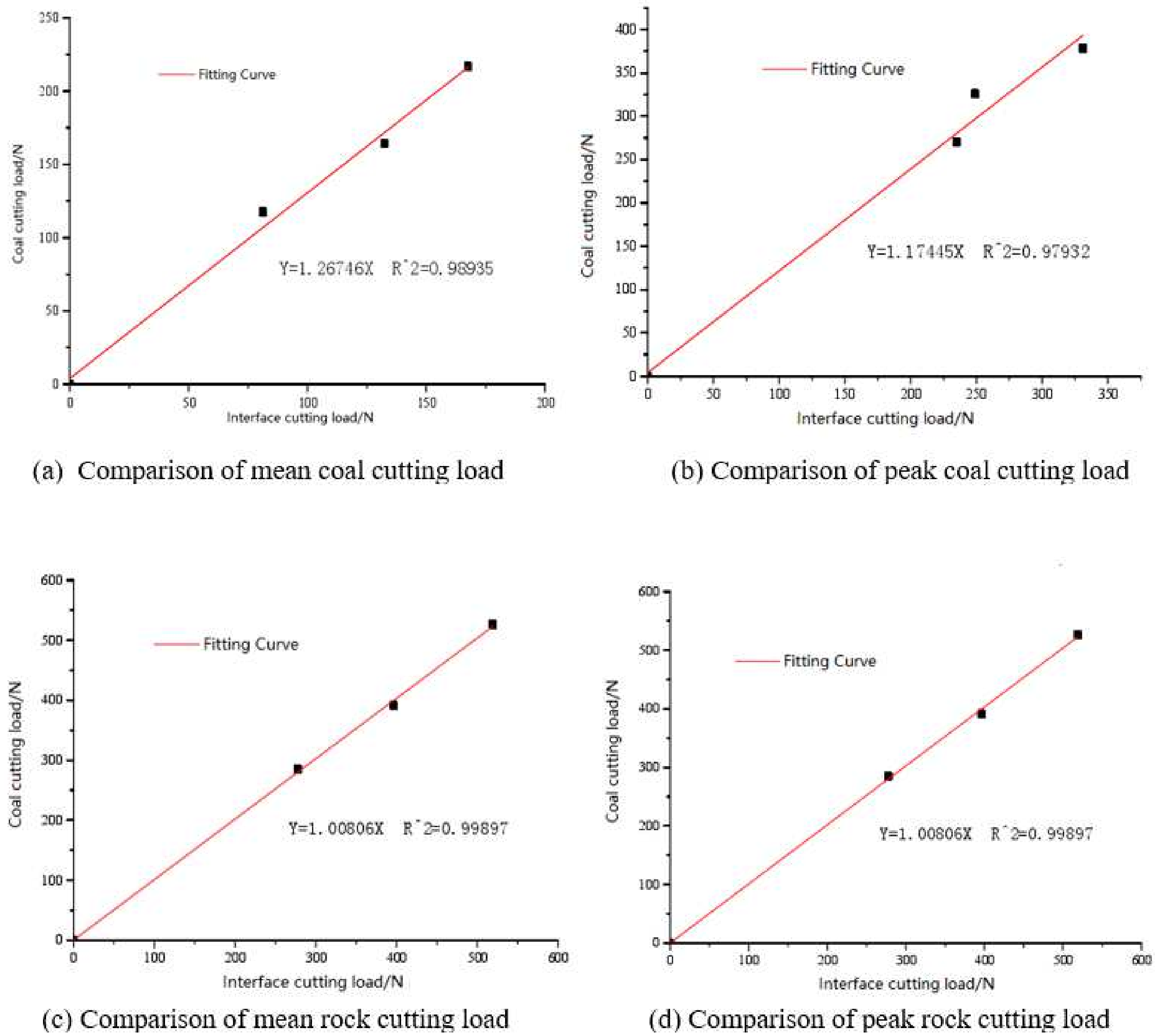

Figure 10

Relationship between theoretical and experimental cutting force under different cutting condition