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Strength Calculation and Mechanical Characteristics Analysis of Knife-Shaped Teeth with Different Teeth Shapes

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ABSTRACT. *In order to explore the effect of the tooth structure of the cutter tooth on its strength and the mechanical properties of the cut coal rock, the cutter teeth of JBA69, GC-20116 and SrFc1007 were selected as the research objects, and the cutter tooth area and cutting surface area were calculated Strength and build a mechanical model. The ABAQUS finite element software was used to establish three finite tooth models of cutter teeth for cutting coal and rock. The mechanical characteristics and stress and strain were analyzed according to the simulation results. The results show that the maximum stress and strain of the cutter teeth is at the tooth shank at the port of the tooth seat. The average cutting force of the cutter tooth GC-20116 is the smallest, and the average cutting force and traction force of the cutter tooth SrFc1007 are the largest. SrFc1007 cutter tooth tip area is the least stressed, and JBA69 cutter tooth tip area is the most stressed. SrFc1007 cutter teeth are subject to the most stress.*

KEYWORDS: *Tooth structure, Abaqus, Strength, Mechanical properties*

1. Introduction

Knife-shaped teeth are one of the important cutters of coal shearers, and different types of knife-shaped teeth have different structural dimensions. Its structural strength and mechanical properties are of great significance to the design and development of knife-shaped teeth. A. Ordin, A. M. Timoshenko[1]According to the geological and technical requirements, the material and structure of the shearer pick are modified, and the strength is analyzed. Nguyen Van Xuan, NguenKhac Linh[2]By changing the arrangement of the picks, the cutting efficiency of the picks, the lump coal rate and the amount of dust are explored. Mao, J.[3]The analytical continuity principle is used to reconstruct the pick load. The conjugate gradient method is used to solve the reconstruction function. The results show that the welding place of the pick seat and the blade is under stress, and there is stress concentration, welding to eliminate residual stress and grinding process. Zhang Qiang[4]A method of fusion of multi-sensor feature information and picks is proposed to diagnose the wear and fault status of the shearer by testing the vibration signal and acoustic emission signal of the paddle under different wear degrees of the shearer. Dong Yude[5]A vibration

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signal, an acoustic emission signal and a temperature signal with different degrees of wear are tested and extracted. The optimal fuzzy membership function of each characteristic signal is calculated with the minimum fuzzy degree optimization model. The results show that: the system fusion effect Well, the test accuracy is higher..Chun Hong Zhang[6]Using experiments, the microstructure and mechanical properties of the pick were analyzed by quenching and tempering treatment, so as to extend the service life of the shearer pick by improving the comprehensive performance of the tooth material..Ning Zhang[7]The hard alloy YG15, 42CrMo steel and HL105 copper brazing film are used as the head, the substrate and the brazing material, and the furnace brazing is used as the pick of the shearer to increase the life.In this paper, JBA69 model blade teeth, GC-20116 model blade teeth and SrFc1007 model blade teeth were studied as the research objects, and their structural characteristics were analyzed. The tip strength, cutting surface strength and mechanical model of the cutter teeth were calculated respectively. Using ABAQUS, the cutter teeth are displayed to simulate the dynamic cutting of coal and rock, and their mechanical characteristics and stress and strain are analyzed.

2. Types and Characteristics of Knife-Shaped Teeth

The picks used by the shearer are divided into two types, which are knife-shaped knife teeth and pick-shaped teeth. There are different types of picks in knife-shaped teeth and pick-shaped teeth. The research object in this paper is the knife pick. According to the different tooth shape structure, the cutter teeth are mainly divided into JBA69 type cutter teeth, GC-20116 type cutter teeth, SrFc1007 type cutter teeth, and the corresponding structural sizes of different types of cutter teeth are also different. The blade teeth mainly rely on the cutting surface for crushing coal and rock. The cutting surface of the JBA69 model teeth is flat, the cutting and crushing part is a slender rectangular parallelepiped, the cutting part of the GC-20116 model teeth is a triangular prism, and the SrFc1007 model cutting The broken part is an oval half cylinder. And the tip of JBA69 and GC-20116 type cutter teeth is tapered, and the tip of SrFc1007 cutter teeth is semi-spherical. The specific three-dimensional model diagram is shown in Figure 1:

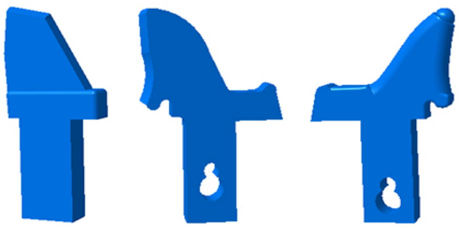

Fig.1 Cutter Tooth Model with Different Tooth Structure

3. Strength Analysis of Cutter Teeth with Different Tooth Shapes

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The cutter teeth mainly rely on the cutting surface to cut and crush the coal rock, and the cutting force will exert a shear stress on the cutting surface of the cutter teeth. When subjected to the same cutting force, the stress intensity experienced by the cutting surface varies with the shape and size of the cutting surface. Moreover, the cutting surfaces of different shapes, structures and sizes will also affect the lump coal rate and pulverized coal rate of the cut coal rock. The cutting surface of JBA69 type cutter teeth is flat, cutting and crushing coal rock is similar to pressing a rectangular block into coal rock. The cross-sectional model diagram of JBA69 type cutter teeth pressed into the crushed coal rock is shown in Figure 2, where k is the thickness of the cutter teeth and *l* is the height of the cutting surface.

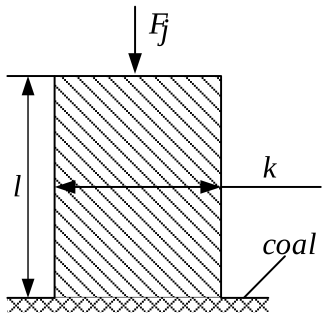

Fig.2 Cross-Section Model Diagram of Broken Coal Rock with Cutting Surface of Jba69 Cutter

The calculation formula for evaluating the strength of the cutting surface of the cutter tooth is:

$$\sigma=\frac{F_j}{A}. \quad (1)$$

In the formula: *A*--Cross-sectional area of cutting surface, mm^2;

σ --Workingstress, N/mm^2.

The tip of JBA69 cutter teeth is a conical pentahedron, then the strength calculation formula of its alloy head is:

$$s_1=\frac{k^2}{4\tan\frac{a}{2}},$$

$$\sigma_1=\frac{F_N}{s_1}. \quad (2)$$

The cutting surface of JBA69 cutter teeth is similar to a rectangular parallelepiped, then the formula for calculating the strength of the cutting surface is:

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$$\sigma_2 = \frac{F_j}{lk} . \qquad (3)$$

In the formula:s_1--Cross-sectional area of cutting surface of JBA69 cutter teeth, mm^2;

l_1--The distance of the alloy head along the front edge of the cutter tooth, mm;

α --Angle between front edge of cutter tooth alloy head, °.

GC-20116 cutter tooth alloy head shape is like a tetrahedron, and the cutting surface shape is like a triangular prism. The cross-section model of GC-20116 cutter tooth cutting surface for cutting broken coal rock is shown in Figure 3, where k is the thickness of the cutter tooth and β is the included angle of the cutting edge.

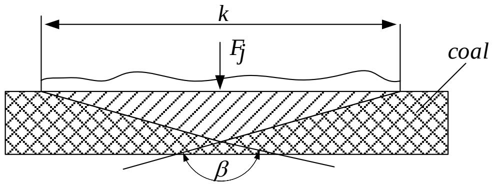

Fig.3 Cross-Section Model Diagram of Broken Coal with Cutting Surface of Gc-20116 Cutter

The tip of the tooth of GC-20116 is a tetrahedron, and the formula for calculating the strength of its alloy head is:

$$s_2 = \sqrt{[p(p - \frac{\cos\frac{\beta}{2}k}{2\sin\beta})(p - \frac{k}{2\tan\gamma})(p - \frac{k}{2\sin\gamma})]} ,$$

$$p = \frac{(\frac{\cos\frac{\beta}{2}k}{2\sin\beta} + \frac{k}{2\tan\gamma} + \frac{k}{2\sin\gamma})}{2} ,$$

$$\sigma_3 = \frac{F_N}{s_2} . \qquad (4)$$

The cutting surface of the cutter teeth of GC-20116 is similar to a triangular prism, then the formula for calculating the strength of the cutting surface is:

$$\sigma_4 = \frac{2F_j \cos\frac{\beta}{2}}{k} . \qquad (5)$$

SrFc1007 cutter teeth alloy head semi-spherical shape, and the cutting surface

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shape is like an oval semi-cylinder. The cross-sectional model of SrFc1007 cutter tooth cutting surface for cutting broken coal rock is shown in Figure 4.

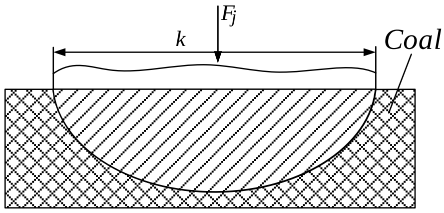

Fig.4 Model Figure of Broken Coal Rock with Cutting Surface of Srfc1007 Cutter

The tip of the SrFc1007 cutter tooth is a semi-spherical sphere, then the strength calculation formula of its alloy head is:

$$s_3 = \frac{\pi r^2}{2}, \sigma_5 = \frac{F_j}{s_3}. \tag{6}$$

The cutting surface of SrFc1007 cutter tooth is similar to an elliptical semi-cylinder, then the calculation formula of the strength of the cutting surface is:

$$s_4 = \frac{k\pi}{2}, \sigma_6 = \frac{F_j}{s_4}. \tag{7}$$

Based on the same thickness, the strength calculation model of the cutting surface of different tooth structure and the position of the alloy tip of the tooth tip is established. Suppose the radius r of the alloy head of the SrFc1007 cutter tooth is equal to the thickness k of the cutter tooth, and the strength of the tooth tip position of different tooth shapes can be compared. The stress intensity is the smallest. Under the action of the same size of cutting force, the stress intensity of the cutting surface of SrFc1007 cutter teeth is the smallest, and the stress intensity of the cutting surface of JBA69 cutter teeth is the largest. Because under the same thickness of the cutter teeth, the cutting surface area of SrFc1007 cutter shape is the largest.

4. Mechanical Model of Cutter Teeth with Different Tooth Shapes

In the process of cutting coal rock by the cutter cutting surface, the cutting surface interacts with coal rock. When the stress on the cutting surface of the cutter tooth is greater than or equal to the allowable stress of coal rock, the coal rock will be broken[8].That is, the mechanical action of the cutter teeth and coal rock should meet:

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$$\sigma_j \geq [\sigma] . \qquad (8)$$

In the formula: σ_j --Working stress of cutting surface of cutter tooth, N;

$[\sigma]$ --Allowable stress of coal rock, N.

The cutting surface of JBA69 cutter teeth is flat, and the pressure distribution model interacting with coal and rock is shown in Figure 5:

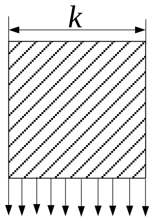

Fig.5 Jba69 No. Tooth Cutting Surface Section Pressure Model Diagram

The calculation formula of the cutting force formed by the broken coal rock of the cutting surface of JBA69 cutter tooth is:

$$F_1 = kl_1\tau . \qquad (9)$$

The calculation formula of the cutting force formed by the crushing coal rock of JBA69 tool tooth tip is:

$$s_5 = 2\sqrt{(\frac{k}{2})^2 + (2\sin al_1)^2} \times \sqrt{(\cos al_1)^2 + (\frac{(\frac{k}{2})^2 + (2\sin al_1)^2}{4})} , F_2 = s_5\tau . \qquad (10)$$

The cutting surface of the cutter teeth of GC-20116 is a triangular prism, and the pressure distribution model interacting with coal and rock is shown in Figure 6:

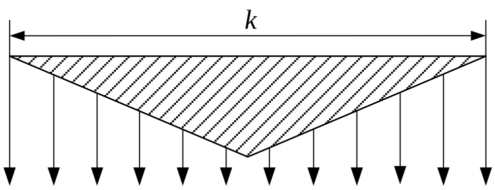

Fig.6 Gc-20116 No. Tooth Cutting Surface Section Pressure Model Diagram

The calculation formula of the cutting force formed by broken coal rock on the cutting surface of GC-20116 cutter tooth is:

$$F_3 = \frac{\sin\beta}{kl_4}\tau \;. \qquad (11)$$

In the formula:l_4--Cutting surface length distance, mm.

The calculation formula of the cutting force formed by the crushing coal rock of GC-20116 cutter tip is:

$$s_6 = \sqrt{[p(p-\frac{k}{2\sin\gamma})(p-\frac{k}{2\tan\gamma})(p-\frac{k}{2\sin\beta})]} \;,$$

$$p = \frac{(\frac{k}{2\sin\gamma}+\frac{k}{2\tan\gamma}+\frac{k}{2\sin\beta})}{2}$$

$$F_4 = s_6\tau \;. \qquad (12)$$

The cutting surface of SrFc1007 cutter tooth is an oval semi-cylinder, and the pressure distribution model interacting with coal rock is shown in Figure 7:

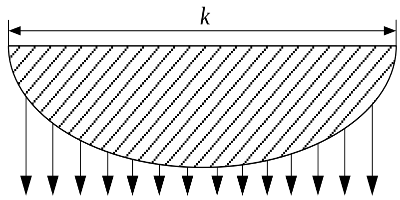

Fig.7 Srfc1007 Cutter Tooth Cutting Surface Section Pressure Model Diagram

The calculation formula of the cutting force formed by the broken coal rock of the cutting surface of SrFc1007 cutter tooth is:

$$s_7 = \pi\frac{kl}{2} \;,\; F_5 = s_7\tau \;. \qquad (13)$$

The formula for calculating the cutting force of SrFc1007 cutter tooth tip alloy head broken coal rock is:

$$s_8 = 4\pi r^2 \,, F_6 = s_8\tau \;. \qquad (14)$$

5. Establishment of Finite Element Model

The ABAQUS finite element software was used to establish JBA69 cutter teeth, GC-20116 cutter teeth, and SrFc1007 cutter teeth. And define the material properties of the tooth body and tooth tip area in the material definition module. Then establish

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the finite element model of coal rock separately and give the material properties. Then, the cutter teeth of different tooth structures are assembled with coal rock respectively. After that, the analysis step and the motion parameters are set to ensure that the working conditions and motion parameters of the cutting teeth with different tooth structures are the same. Finally, mesh the cutter teeth and coal rock. The specific steps are as follows:

(1)Definition of material properties of cutter teeth and coal rock

The finite element models of different types of cutter teeth are established according to the cutter structure parameters of different structure sizes. The structure size of coal rock is set to 130mm × 100mm × 200mm [11], and the size of the partition on the coal rock is 50mm × 55mm. The specific material property parameter settings of cutter teeth and coal rock are shown in Table 1 and Table 2:

Table 1 Material Parameters Of Tooth Body and Cemented Carbide

parameter	Tooth body	Alloy head
material	42CrMo	YG11C
density/kg·m^{-3}	7800	14600
modulus/GPa	207	600
Poisson's ratio	0.3	0.22

Table 2 Material Parameters Of Coal Rock

parameter	Coal rock
density/kg·m^{-3}	1500
modulus/GPa	1400
Poisson's ratio	0.3

(2)Establishment of analysis step

In the analysis step module, set the cutter teeth to cut coal rock for 0.07 seconds, and set the corresponding field output and history output during the interaction between the cutter teeth and coal rock. The output time interval is 20. The three-way load force is used as the history output, and the time interval is 200. The speed of the drum is set at 4m / min, and the pulling speed is set at 40r / min.

(3)Assembly constraints

The assembly module mainly sets the installation parameters of the cutter teeth in the drum and the initial cutting thickness of the cutter teeth to cut the coal rock. The circumferential tangential installation angle of the cutter teeth is set to 4 °, the axial tilt angle is 0 °, and the secondary rotation angle is 0 °. The initial cutting thickness of the teeth is 10mm. The finite element model diagram is shown in Figure 8 below:

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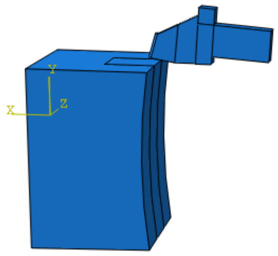
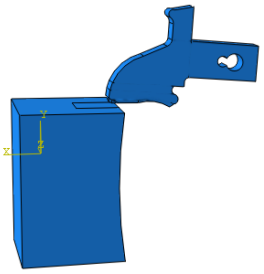


(a) JBA69 knife teeth cutting coal rock assembly model



(b) GC-20116 cutter tooth cutting coal and rock assembly model

(c)SrFc1007 cutter teeth cutting coal rock assembly model

Fig.8 The Assembly Model of Cutting Coal and Rock with Different Types of Cutter Teeth

(4)Meshing

The cell type used for meshing is C3D8R.

6. Results and Analysis

6.1 Analysis of Mechanical Characteristics of Cutter Teeth with Different Tooth Shapes

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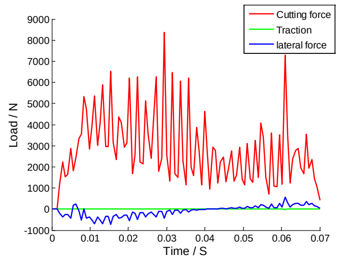
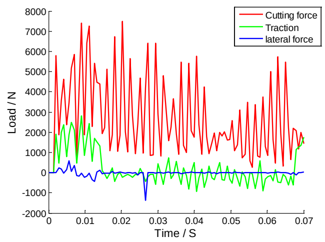
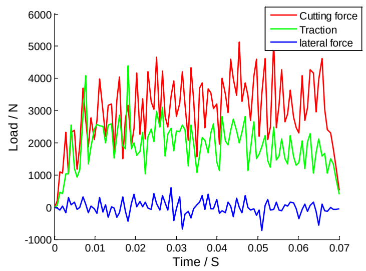
Using JBA69 cutter teeth GC-20116 cutter teeth and SrFc1007 cutter teeth as single-factor control variables, the relationship between cutter teeth with different tooth structures and mechanical properties during the cutting of coal and rock was explored. The ABAQUS finite element software derives the three-dimensional force of the cutter teeth during the cutting of coal and rock with different tooth-shaped structures, and uses MATLAB software to draw a time-domain diagram of the three-dimensional force and time of the cutter teeth, as shown in Figure 9.



(a)JBA69 cutter teeth cutting coal rock three-dimensional force time domain diagram



(b)GC-20116 Three-dimensional force time-domain diagram of coal-rock cutting



(c)Time domain diagram of SrFc1007 cutter teeth cutting coal rock three-way force

Fig.9 Three-Direction Load of Cutter Teeth with Different Tooth Structure

It can be seen from FIG. 9 that, in the comparison of the cutting force time

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domain diagrams of cutting teeth of JBA69 cutter teeth, GC-20116 cutter teeth and SrFc1007 cutter teeth, the cutting force time diagram of cutter teeth GC-20116 The curve fluctuation is more obvious. The reason is that the cutting surface of the cutter teeth of GC-20116 is shaped like a triangular prism. Compared with the teeth of JBA69 and SrFc1007, the contact area with coal and rock is small, and the flatness of contact with coal and rock is poor , Thereby affecting the state of coal rock collapse. It can be seen from the comparison of the traction force time-domain diagrams of cutter teeth with different tooth structures that the amplitude of the traction force time-domain diagram during the cutting of coal rock by SrFc1007 cutter teeth is higher. During the advancement of the cutter teeth, it mainly relies on the interaction between the tooth tip alloy area and the front edge of the cutter teeth and coal rock to generate traction. The tip of the SrFc1007 cutter tooth is a semi-spherical alloy head, and the total area of the tooth tip and front edge surface is larger than the JBA69 cutter tooth and GC-20116 cutter tooth.

It is difficult to see from the three-dimensional force time-domain diagram in Fig. 9 the effect of different tooth shapes on the mechanical properties of coal cutting with cutter teeth. Therefore, it is necessary to perform statistical processing on the data in the three-dimensional force time-domain diagram to calculate the mean, peak mean and standard deviation of the cutting force and traction force of the teeth of different tooth structures during the cutting of coal and rock. The statistical results are shown in Table 3:

Table 3 Statistics of Cutting Force and Traction Force of Various Types of Cutter Teeth

type	Statistics	Cutting force	Traction
JBA69	Peak mean	4557.97	287.84
	Mean	2809.35	78.00
	Standard deviation	1702.03	252.41
GC-20116	Peak mean	4679.21	626.25
	Mean	2691.99	213.63
	Standard deviation	1964.32	839.01
SrFc1007	Peak mean	3856.33	2432.47
	Mean	2972.09	1894.20
	Standard deviation	1052.78	732.51

According to the statistical data in the table, MATLAB is used to draw the average cutting force curve, the average traction force curve and the standard deviation of the cutting force with different types of cutter teeth. The difference between the types of cutter teeth mainly refers to the difference in the tooth shape of the cutting surface of the cutter tooth. The standard deviation can reflect the stability of the broken coal rock of the cutter cutting surface. As shown in Figure 10 and Figure 11.

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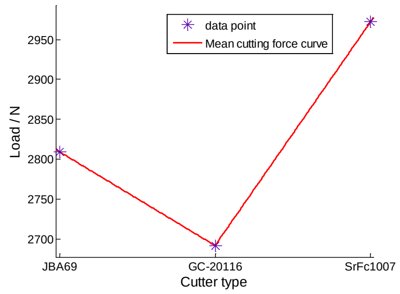
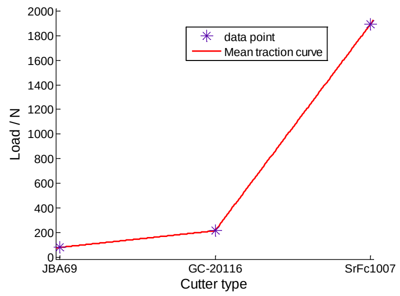


(a)Mean cutting force



(b)Mean traction

Fig.10 Mean Cutting Force Curve and Mean Traction Force Curve Corresponding to Cutter Teeth of Different Tooth Structure

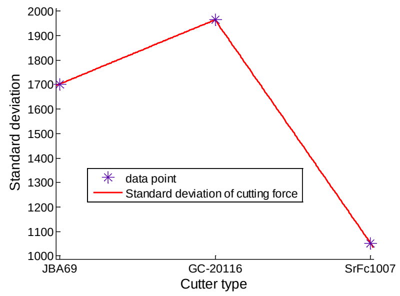


Fig.11 Standard Deviation of Cutting Force for Different Types of Teeth

As can be seen from Figure 11, in the process of cutting coal rock with JBA69 blade teeth, GC-20116 blade teeth and SrFc1007 blade teeth, the average cutting force of GC-20116 blade teeth is the smallest, and the cutting force of SrFc1007 blade teeth The mean and traction force are the largest. The main reason is that the

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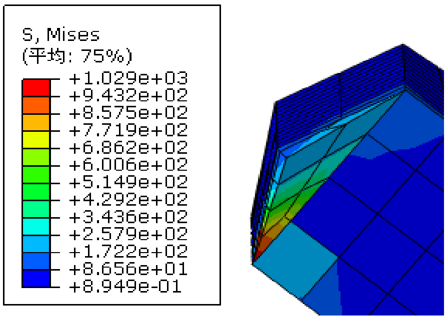
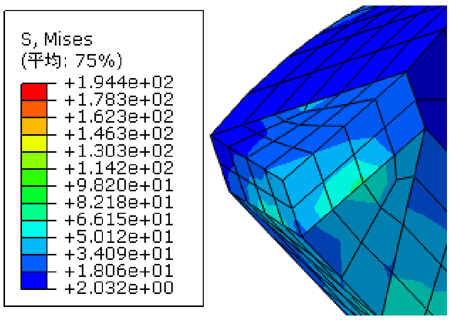
structure of the cutting surface of the cutter teeth is different. The cross section of the cutting surface of the JBA69 blade is flat, the cross section of the chip surface of the GC-20116 blade is triangular, and the cross section of the cutting surface of the SrFc1007 blade is oval. When the thickness of the cutter teeth is fixed, the contact area between the cutter teeth GC-20116 and the coal rock under the action of the cutting force is the smallest, and the contact area of SrFc1007 is the largest. The mean value of the traction force is mainly determined by the structural characteristics of the tooth tip alloy area of the cutter teeth and the front edge surface. Among them, JBA69 cutter teeth, GC-20116 cutter teeth and SrFc1007 cutter teeth front edge surface structure and the contact area with coal and rock interaction are not much different, the main difference is the tooth tip area of the cutter teeth. The tip of the JBA69 blade is a conical pentahedron, the tip of the GC-20116 blade is a tetrahedron, and the tip of the SrFc1007 blade is a semi-spherical sphere. Among them, SrFc1007 has the largest alloy area of the tooth tip.

6.2 Stress Analysis of Cutting Coal with Different Tooth Structure

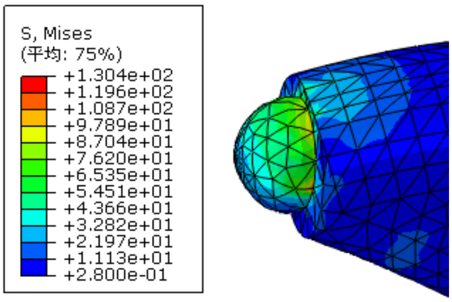
The maximum stress-strain diagram of the tooth tip area of the cutter tooth structure with different tooth shapes during cutting of coal and rock is explored, and the strength relationship of the tooth tip alloy head with different structural sizes to the process of cutting coal and rock is explored, as shown in Figure 12.



(a)The maximum stress cloud of JBA69 tool tooth tip



(b)The maximum stress cloud of GC-20116 cutter tooth tip

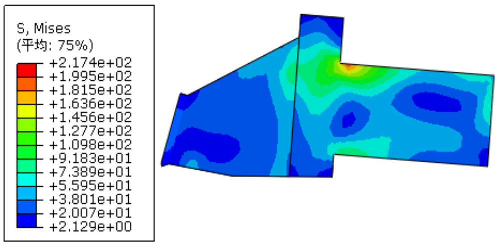


(c)Maximum stress cloud of SrFc1007 cutter tooth tip

Fig.12 the Maximum Stress Cloud of Various Types of Cutter Teeth

It can be seen from Fig. 12 that the maximum stress of the alloy area of the tooth tip of JBA69 tool can reach 1029MPA, the maximum stress of the surface area of the tooth tip of GC-20116 can reach 82MPA, and the maximum stress of the joint area of the tooth tip and tooth body can reach 114.2 MPA, SrFc1007 cutter tooth tip alloy head surface area maximum stress can reach 87MPA, alloy head and tooth body joint area maximum stress can reach 97MPA. The tip of the No. 13 cutter tooth is tapered, and under the same cutting force, the pressure is relatively large. The tip of the SrFc1007 cutter tooth is a hemisphere, which is relatively flat with a large area and low pressure in contact with coal and rock. And the contact area size and contact form of the cutter tooth tip and coal rock also reflect the lump coal rate of the cutter tooth. Therefore, the lump coal rate of SrFc1007 cutter teeth is large.

The cutter teeth crushing coal rock mainly rely on the cutting surface to cut and crush the coal rock. The cutting surfaces of different structure sizes cut the crushing coal rock, the stress and strain of the cutter teeth are also different, thus changing the strength of the cutter teeth. In the process of cutting coal and rock with the teeth of different tooth structures, the maximum stress and strain diagram of the cutting teeth is intercepted, as shown in Figure 13.



(a)JBA69 cutter teeth maximum stress

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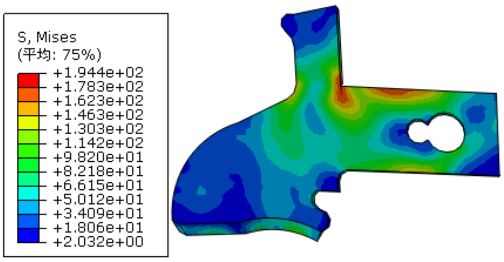
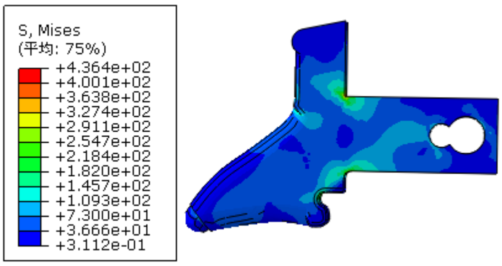
cloud



(b)GC-20116 cutter tooth maximum stress cloud



(c)SrFc1007 cutter teeth maximum stress cloud

Fig.13 the Maximum Stress Cloud of Various Types of Teeth

It can be seen from FIG. 13 that, whether it is JBA69 cutter teeth, GC-20116 cutter teeth or SrFc1007 cutter teeth, the position where the cutter teeth have the greatest stress and strain is at the shank of the gear seat port. Because the cutter tooth is subjected to the largest bending moment at the cutter tooth shank at the port of the cutter seat during the cutting of coal rock, the stress and strain at this place are the largest. It can be seen from the graph a of FIG. 13 that the maximum stress of the cutter tooth body of JBA69 reaches 217MPA, the maximum stress of the cutter tooth body of GC-20116 reaches 194MPA, and the maximum stress of the cutter tooth body of SrFc1007 reaches 291MPA. It can be obtained that the tooth body of SrFc1007 cutter teeth with a semi-elliptical cross-section has the largest stress, indicating that its contact area with coal rock is large and the corresponding lump coal rate is also high.

7. Conclusion

(1)According to the structure and size characteristics of JBA69 cutter teeth, GC-20116 cutter teeth and SrFc1007 tooth tip alloy area and cutting surface area, their strength and mechanical model were calculated respectively. Comparative analysis shows that the cutting force of SrFc1007 cutter teeth is relatively large.

(2)Through simulation comparison, it can be seen that the position where the stress and strain of the cutter tooth is the largest is at the tooth shank at the port of the tooth seat. The tip of JBA69 cutter teeth is tapered. Under the action of the same size of cutting force, the pressure is large, which is easy to cause the alloy head to wear. The tip of the SrFc1007 cutter teeth is hemispherical, and the contact with coal and rock is relatively flat, the area is large, and the pressure is small, so the SrFc1007 cutter teeth have a high coal rate and a long life.

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