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Experimental investigation on friction and squeezing of roof structure key blocks corner upon long-wall face

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Abstract: The coefficients of friction and squeezing of the key blocks comer in the roof structure of underground coalface are key factors to roof structure stability quantitative analysis. In this paper, through the special test of three-type corner friction and squeezing of real rock specimens, and physical simulation test on the roof key blocks of roof structure as well as the finite element calculation of the corner stress distribution and failure mechanism, the characteristics of friction and squeezing of the roof key blocks comer are revealed. It is found that the friction angle of the roof key blocks corner is the residual friction angle, and the frictional angle of the roof key blocks is 22-32° (average 27°), so the friction coefficient is determined as 0.5. It also found the squeezing strength is less than the uniaxial strength, and the squeezing coefficient of the roof blocks corner is determined as 0.4. Based on the results, the ground control theory can be updated from qualitative analysis to quantitative analysis.

Key words: roof structure key blocks; friction; squeezing; blocks corner

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1 Introduction

There are two important parameters in the criterion of roof key structure stability. One is the friction coefficient $\tan\varphi$ at the squeezing corner of roof key blocks. The other is the squeezing coefficient η of the roof block corner [1]. The two parameters are very important to the development of roof control theory from qualitative analysis to quantitative analysis.

Up to now, there is no specific study on the determination of friction coefficient at the roof key blocks corner. And there is only little primary research about the squeezing strength of the blocks corner. The past research showed that the squeezing strength was less than the standard tensile strength of testing blocks [2], but the tests were only based on the continual medium. So, the mechanism of roof key blocks squeezing and its parameters should be studied to meet the real case. With the development of roof control theory from qualitative analysis to quantitative analysis [3], it is necessary for us to study the two key parameters of ground control.

2 Determination of friction coefficient

The rock blocks formed by key roof breaking during longwall mining can come out squeezing rotation by their weight and overburden during roof weighting, leading to that the rock blocks contact with the front layer in the corner state (figure 1). Essentially, this causes a plastic zone in the corner. The height of squeezing in the corner, a, increases with the rotation of the roof key blocks, and the value of a is related to the height h, length l and the rotation angle θ_1 of the roof key blocks.

$$a = \frac{1}{2}(h - l_{01}\sin\theta_1).$$

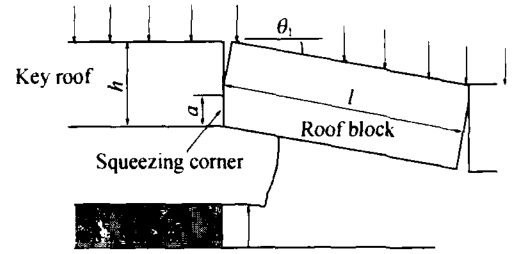

Figure 1 Squeezing of the roof key blocks corner.

Because the blocks are formed by the key roof natural broken, the squeezing face of the blocks corner is rough. The squeezing is in limit pressure, so it belongs to the friction of restricting normal displacement by high stress. According to the research of Goodman, shear stress has no strain softening when the normal displacement is limited, and the residual strength is equal to the initial strength [4]. Reference [4] shows that the friction angle of a rough rock surface is gener-

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ally made up of three parts: the angle of peak dilation d_n, the angle of residual friction φ_b and the salient step strength S_n. Thus, the relationship of the shear stress τ and normal stress σ_n is

$$\tau = \sigma_n \tan(\varphi_b + d_n + S_n) \quad (1)$$

This formula is suitable for the friction of the roof key blocks corner, because the friction between roof key block corners is in limit press and restricting normal displacement.

In the process of the roof key blocks rotating and sliding down, the friction at the roof block corner is dynamic, and the salient step of the rough face can be snipped, so $S_n = 0$. According to formula (1), the friction angle of the roof key blocks corner is the residual friction angle. It is

$$\tan\varphi = \tan\varphi_b = \frac{\sigma_n}{\tau} \quad (2)$$

(1) Rock blocks tests.

The rock blocks were sandstone got from the key roof of Daliuta coalmine, Shenfu coalfield. The friction face of the specimen was 5 cm x 5 cm. The residual frictional angles gained experimentally are listed in **table 1.**

Table 1 Residual friction angles of the rough surface of sandstone

Stress level	$0.2\sigma_c$	$0.4\sigma_c$	$0.6\sigma_c$	$0.8\sigma_c$ (Residual friction state)
Dry friction angle / (°)	30.6	31.1	30.5	32.6
Wet friction angle / (°)	31.0	31.0	30.5	28.4

Note: σ_c is the uniaxial compressive strength.

It is found that when the normal stress is small, the dry frictional angle is smaller than the wet frictional angle. But when the normal stress becomes greater, the two kinds of frictional angles are approximately equal to each other. When the normal stress is up to the compressive strength, the dry frictional angle becomes greater, and the wet frictional angle declines. The friction under 0.8 σ_c is similar to the condition of roof key blocks friction, so the dry frictional angle of the blocks corner is 32.6°, and the wet frictional angle is 28.4°.

(2) Rock mass simulation tests.

In order to study the friction of rock mass, the simulation tests were carried. The simulation specimens were made of quartz sands, gesso and mica powder with a mass ratio of 9:1:0.1 adding 10% water. The mica powder was used to simulate the fracture and joints in the rock mass.

The rock mass simulations were in three groups by the friction faces of 5 cm × 10 cm, 5 cm × 5 cm and 5 cm × 2.5 cm. The result shows that the dry frictional angle is 35° and the wet frictional angle is 31.7°.

(3) Analysis and conclusions.

The research work of other Chinese scholars shows that the average residual angles of dry and wet rock friction are 32.7° and 30.7°, respectively [5]. Based on abundant experiments, Barton pointed out that the residual friction angle of sedimentary rock is 25°-35°, generally is 30° [6].

According to the tests and analysis, the residual frictional angle in the rough rock face, achieved both **here and** abroad, is in an agreement within the range of 25°-35°. In general situation, it is suggested to use 30°. The value will decline 2°-4° (average 3°) in wet environment. Considering the underground environment is wet, the frictional angle of the roof key blocks is suggested to use 22°-32°, the average is 27°. Therefore, the friction coefficient of roof key blocks is 0.4-0.6, generally takes 0.5 in calculating.

3 Determination of squeezing coefficient

In the process of key roof weighting, a plastic zone will be formed at the blocks corner by squeezing, and it causes the rotation instability of the key roof structure. The conception of squeezing coefficient is set up by the discovery that the squeezing strength at the corner is less than the uniaxial compressive strength.

$$\eta = \frac{\sigma_{nj}}{\sigma_c} \quad (3)$$

where η is the squeezing coefficient of the blocks corner, σ_{ni} the squeezing strength of the blocks corner, σ_c the uniaxial compressive strength.

Generally, the natural weaker-planes in the key roof affects the strength of the roof key blocks corner, but there are less experiments that deal with the effect of weak plane. In order to get reliable experiment, the comprehensive analysis method of the finite element calculation and the physical experimental test is employed.

(1) Numerical simulation of corner squeezing.

According to the structure model of key roof "voussoir beam" [1], the mechanical model is given in **figure** 2(a). Meanwhile, the compression **model with** only normal compressive stress at the squeezing face (figure 2(b)) and the uniaxial compression model (figure 2(c)) are listed to make contrast.

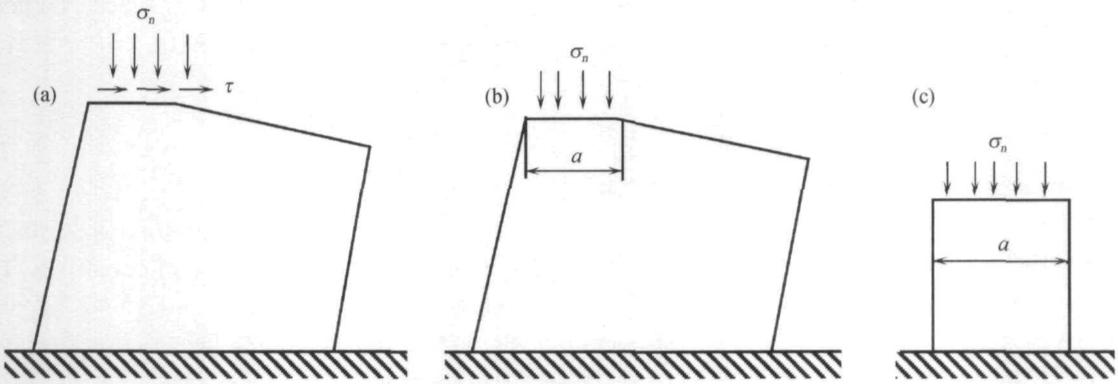

Figure 2 Contrast models for squeezing at the blocks corner: (a) squeezing model; (b) compression model; (c) uniaxial model.

In numerical simulation, the Algor98 calculation software is employed. The Drucker-Prager criterion is applied here to determine the failure zone **(figure 3).** The rupture strengths of the uniaxial compression model, the compression model and the squeezing model are 30, 18.6 and 13.5 MPa, respectively. So, the coefficient of the corner squeezing is numerically simulated as 0.45.

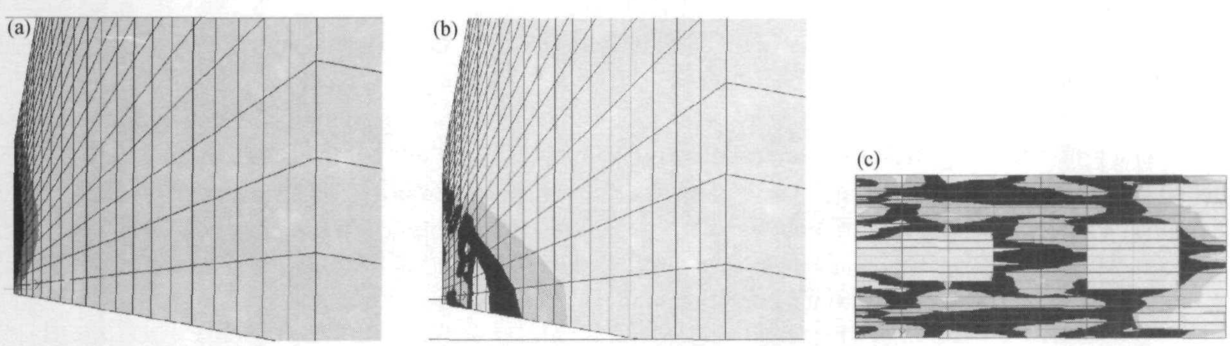

Figure 3 Contrast of squeezing failure at the corner: (a) squeezing model (part); (b) compression model (part); (c) uniaxial model.

(2) Squeezing tests.

The simulation material blocks are divided in two types. One is made of quartz sand and gesso to simulate continuous medium. Another adds extra mica powder to simulate the weakness in rocks. The specimen for the uniaxial compression test is cuboid in a size of 5 cm× **5** cm × 10 cm. The specimen for the corner squeezing is rectangle cube with a size of 5 cm × 10 cm × 15 cm. The rotation angle is 10°, and the component of shear stress is set by 0.5 times to normal stress that is similar as large as numerical simulation. The test models are shown in **figure 4.**

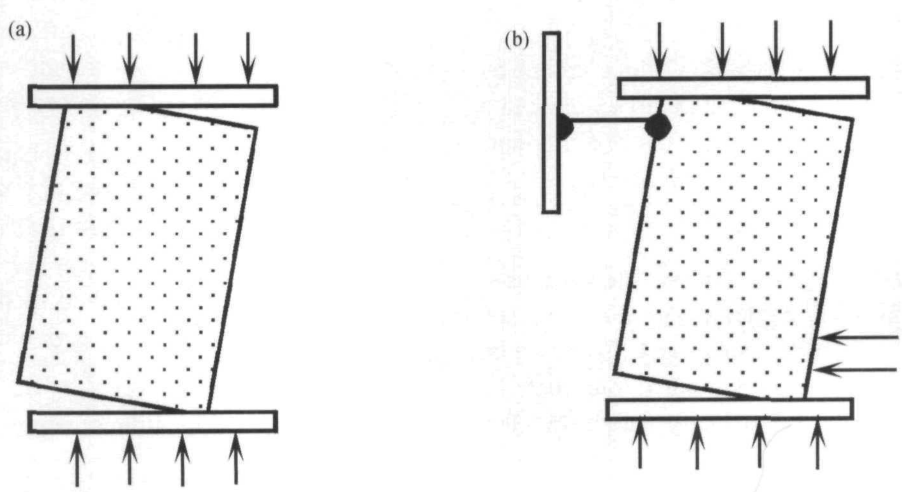

Figure 4 Simulation of the loading form in squeezing tests at the rock blocks corner: (a) compression test; (b) squeezing test.

The experimental result is listed in **table 2.** The law is similar to sandstone experiment, when the specimen has good continuity the coefficients of squeezing and compression at the corner are greater, and when the weaker planes are put in the blocks the squeezing coefficient of blocks corner becomes smaller. By testing, the squeezing coefficient is 0.36-0.42, the average is 0.4; it is very close to the data 0.45 derived by numerical simulation.

Table 2 Simulation tests of squeezing on the blocks corner

Rock type	Mass ratio	Group	σ_c / MPa	η	
	Quartz sands : Gesso : Mica powder			Compression test	Squeezing test
Dense and hard	7 : 1 :0	3	0.70	0.87	0.69
Weak and discontinuous	9:1:0	3	0.42	0.67	0.41
	7:1:0.1	3	0.66	0.86	0.42
	7: 1 :0.3	3	0.57	0.79	0.36
Average	—	—	—	0.77	0.40

4 Conclusions

(1) The friction at the rock blocks corner of key roof structure is in a higher stress and limiting normal displacement, its friction angle is the residual frictional angle.

(2) Based on the experiments, the frictional angle of roof key blocks is 22°-32° (average 27°). Generally, the friction coefficient is suggested to take 0.5.

(3) It is determined experimentally that the average squeezing coefficient is 0.4.

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