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Research on Properties and Application of New Grouting Material Based on Lake Mud

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Abstract: *In order to study the effect of karst fracture blocking water, the material selection and ratio of lake mud cement slurry was studied by indoor test and in-site test, the diffusion mechanism of lake mud cement slurry was analyzed, and its performance is evaluated by pressing water test, drilling stone body and filling rate. The results show that the maximum average unit permeability rate of 1.39Lu, is 2.46Lu, meets the design requirements (less than 5Lu); the stone body is full filling, 68.75%, 5.25%, 31.25%, diffusion radius of 5-10m, slurry diffusion filling effect is good; the blocking rate is 95.66% and the grouting rate exceeds 85%.*

Keywords: *lake mud, slurry; new materials; pressure water test; water blocking rate*

1. Introduction

In 2017, Jiangxi Chengmenshan Copper Mine responded to the call of Jiujiang Municipal Party Committee "New Industrial Decade Action" and began to implement the third phase of the expansion project. Chengmenshan copper deposit exists in crack karst limestone, the mining area adopts open air mining, large pit mining depth is about 150m[1~2], and the mining area is close to Chengmen Lake and Sai Lake, the engineering geology and water level geological conditions are complex (as shown in Figure 1).The underground water inflow on the-58m platform is 29,753 m3/d,, and the groundwater inflow on the east of the open pit is 3,960 m3/d, west, northeast and north of the open pit is 25,793 m3/d. Groundwater inflow of-130m platform is 37,300 m3/d, and the groundwater inflow in the east of the open pit is 5,874 m3/d, west, northeast and north of the pit is 31,426 m3/d. With the increase of pit mining depth, the increase of the original drainage capacity, increases the drainage cost of the mining area, more importantly, increases the difficulty of karst water drainage, a large number of excavation projects face the danger of water surge, affecting the mining safety of the mining area [3~4].Therefore, it is one of the key contents of water prevention and control work in the mine area to explore the groundwater access passage into the mining area and effectively block the crossing passage and reduce the groundwater access pit in the mining area.

Curtain grouting and blocking technology is mainly used for the control of mine groundwater. With the requirements of environmental protection and effect, the application of new materials and technologies has emerged. Curtain grouting in China mainly adopts cement slurry, cement water glass double paste, clay cement paste, paste and other slurry, and the fluids of these slurry are mainly Newtonian fluid, Binghan fluid and power-law fluid [5~7].Foreign scholars are mainly called Baker, G.Lombardi, Hassler et al. mainly studies on the theory of slurry rheology, diffusion mechanism and other aspects.The flow of curtain grouting slurry in the crack is affected by the crack size, crack surface roughness, crack surface angle, groundwater level and groundwater flow direction. From the perspective of slurry performance, different slurry rheological characteristics and the complexity of formation factors during grouting, it is difficult to accurately describe the diffusion law in the crack.

In the sudden water surge accident of the open pit mine pit, the cracks in the surrounding rock formation will import a large amount of groundwater into the pit to form a water burst or cause the pit to collapse, thus bringing huge property losses and disaster accidents. In order to meet higher environmental protection requirements and effects, lake mud and cement slurry were used to match lake mud materials with local materials, and cement slurry materials were not only cheap and

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environmental protection, and the grouting effect of new grouting materials of lake mud slurry was studied from theoretical analysis and test verification.

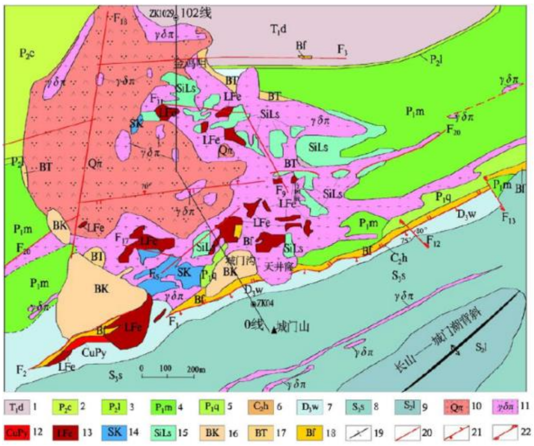

Figure 1 Geological Map of Chengmenshan Mining Area

2. Flow Model of Lake Mud and Cement Slurry

In order to study the diffusion mechanism of lake mud cement slurry, the flow model is studied.

2.1 Basic Assumption

When the mud cement slurry spreads in the fissure stratum, the following assumptions should be assumed: ①Suppose the rock body crack is long enough to meet the diffusion of the slurry in the crack, regardless of the splitting effect of the slurry on the rock body; ② t The flow velocity in the rock fissure and the flow velocity is small;③ The flow type of the slurry remains unchanged during the diffusion process;④ Ignoring the roughness on the crack surface, the slurry flow state in the crack is laminar flow.

2.2 Diffusion Model of Lake Mud and Cement Slurry

Lake mud cement slurry moves forward along the x axis in the cracks, and the grouting hole is a symmetrical axis, and x long is a fluid fracture unit. The pressure at both ends of the fluid microsegment is on p + dp and p, segment of dp. The shear stress on the upper and lower surface of the fluid unit is τ , in the direction to the left, as shown in FIG. 2, in the opposite direction of the flow velocity. Without gravity, hydraulic equilibrium conditions by fluid units:

$$\tau = \frac{r}{2}\frac{\Delta P}{L} \tag{1}$$

In formula: L is crack length (m); ΔP is fluid pressure difference (MPa) in the crack; τ is shear stress (MPa) at any height r of the crack.

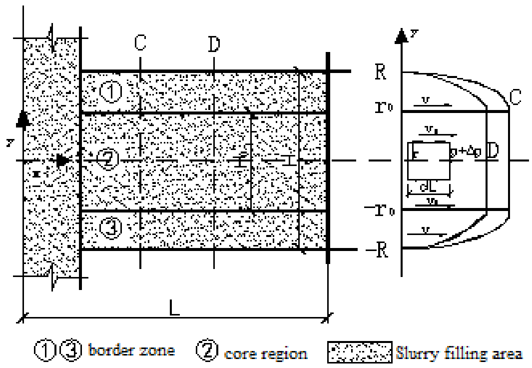

Figure 2 Schematic diagram of slurry flow in cracks

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The shear stress at the top of the crack is:

$$\tau_w = \frac{d}{4}\frac{\Delta P}{L} \tag{2}$$

In formula : τ_w is the crack top shear stress (MPa); $d = 2R$ is the crack height (cm).

At the core height r_0, assuming the slurry begins to flow, the shear stress τ is equal to the yield shear stress τ_y of the slurry, so the r_0 can be determined by the following formula:

$$r_0 = \frac{2\tau_y l}{\Delta P} \tag{3}$$

In the formula: τ_y is the yield shear stress (Pa) of the slurry.

The following differential equations can be listed according to the coordinate system in Equation 1, 2, 3 and Figure 2:

$$\gamma = \frac{dV}{dy} = \frac{dV}{dr} = \frac{\frac{\tau_y}{A}(\tau - \tau_y)}{1 + \frac{B}{A}\tau_y - \frac{B}{A}\tau} = \frac{\frac{\tau_y}{A}(\frac{\Delta \mathrm{Pr}}{2L} - \tau_y)}{1 + \frac{B}{A}\tau_y - \frac{B\Delta P}{2AL}\tau} \tag{4}$$

After simplified reasoning, it can be seen that

$$\frac{\Delta P}{L} = \frac{20}{3\pi\tau_y} \bullet \frac{6Q(A + B\tau_y)^2 + 9A\pi R^4 \tau_y{}^2 + 2\pi R^3 \tau_y{}^2 (A + B\tau_y)}{24AR^5 + 5R^4(A + B\tau_y)} \tag{5}$$

According to formula 5, the diffusion distance of lake mud cement grout in fractures is related to grouting pressure, grouting amount, fracture height of formation and rheological parameters of lake mud cement grout.

3. Study on the Preparation and Rheological Characteristics of the Lake Mud and Cement Slurry

Lake mud cement slurry is composed of water, lake mud, cement and quick agent, among which lake mud and cement are the main components of lake mud cement slurry, added to the lake mud cement slurry, so that the slurry gel time is adjustable, thus forming the lake mud cement slurry can be injected under different groundwater conditions. The properties of lake mud cement slurry in lake mud cement slurry have different diffusion rules in stratum. In order to study the blocking law of the lake mud cement slurry on the formation cracks, considering that the rheological characteristics of the slurry greatly affect the movement law of the mud in the pore stratum.The study found that the shear force and shear rate during the flow, so the rheological characteristics of lake clay slurry were studied by hyperbolic model.

3.1 Rheological Model Calculation Formula of the Slurry

To study the rheological characteristics of the shear stress and shear rate of the slurry must analyze the rheological model of the cement slurry. For different rheological models, different calculation methods and formulas are used when calculating each rheological parameters. Generally, their parameters are determined according to the ZNN-type electric six-speed rotating viscometer.

Introduction of the ZNN-type electric six-speed rotating viscometer

Type ZNN electric six-speed rotating viscometer can be measured for the rheological parameters of various slurry. The instrument parameters are as follows: the range of Newton fluid viscosity measurement range is 0-300mPa•s, Non-Newtonian fluid viscosity measurement range is 0-150 mPa•s, shear stress measurement range is 0-153.3Pa, shear rate measurement range is 5-1022s-1, instrument speed is shown in Table 1.

Table 1 Type ZNN electric six-speed rotating viscometer speed distribution table

Speed number	1	2	3	4	5	6
Rotation speed(r/min)	3	6	100	200	300	600
Shear rate(s-1)	5	10	170	340	511	1022

(1) Rheological model calculation formula of the hyperbolic model of slurry

The hyperbolic model is a three-parameter equation, and the relation between the shear stress and the shear rate is as follows:

$$\tau = \tau_y + \frac{a\gamma}{1+b\gamma} \tag{5}$$

In the formula: τ_y is yield stress (Pa); a is consistency coefficient (Pa•s); b is shear dilution coefficient (s); γ is slurry shear rate (s-1).

When using type ZNN electric six-speed rotating viscometer, the calculation formula of each rheological parameters is as follows:

$$\tau_y = 5\varphi_3 \tag{6}$$

$$a = \frac{1}{200}\frac{(\varphi_{600} - \varphi_3)(\varphi_{300} - \varphi_3)}{(\varphi_{600} - \varphi_{300})} \tag{7}$$

$$b = \frac{1}{1000}\frac{2\varphi_{300} - \varphi_{600} - \varphi_3}{\varphi_{600} - \varphi_{300}} \tag{8}$$

In the formula φ_3 , φ_{300} and φ_{600} are the instrument reading when the ZNN type electric six-speed rotating viscometer speed is 3r/min, 300r/min and 600r/min.

3.2 Experimental Study on the Rheological Characteristics of the Lake Mud and Cement Slurry

Lake mud cement slurry is a mixture of lake mud raw slurry and cement slurry, and the rheology of its slurry has something similar to the clay curing slurry. Considering the nature of the site lake mud, the slurry ratio and the characteristics of the lake mud slurry making technology, in order to find the best and suitable slurry ratio, it is necessary to test and study the rheological characteristics of the slurry under different ratios.

(1) Selection of lake mud

The lake mud of Chengmenshan Lake is affected by the sedimentation environment, and the mined properties of lake mud are greatly different. According to the current distribution of lake mud at the two mud mining points, the characteristics of lake mud are mainly divided into two categories (see Figure 3 and 4), and the characteristic parameters of lake mud are shown in Table 2.

Figure 3. Picture of the Class I lake mud

Figure 4. Picture of the Class II lake mud

Table 2 Characteristic parameters of lake mud

Lakemud characteristics	Plastic index (%)	Organic matter Content (%)	Sand content (%)	Specific gravity of the lake mud particles
Class I lake mud	10.2-12.2	3.96-12.61	4-10	2.69
Class II lake mud	17.69-18.5	0.86	2-3.5	2.71

The properties of lake mud slurry configured with different slurry density in the lake area are determined. See in Table 3.

Table 3 Statistics of funnel viscosity test results

The Lake Mud category	Base slurry Density (g/cm3)	1.1	1.12	1.15	1.2	1.3	1.35
Class II lake mud	Funnel viscosity (s)	17.02	18.94	20.44	32.70		
Class I lake mud				15.27	16.29	17	18.66

Table 4 Statistical Table of plastic viscosity test results

The Lake Mud category	Base slurry Density (g/cm3)	1.1	1.12	1.15	1.2	1.3	1.35
Class II lake mud	Plastic viscosity (mPa.s)	4.1	5.9	7.3	12.2		
Class I lake mud				4.1	4.3	5.2	8.1

It can be seen from Table 2, 3 and 4 that the second type of lake mud sample has more clay particle content and the configured base slurry has better stability. At the same base slurry density, the base slurry made from the second type of lake mud has better fluidity. Therefore, the second type of lake mud is used as the grouting material of the lake mud cement slurry in this test.

(2) Slurry ratio of lake mud cement

The slurry is arranged according to the ratio used on site, and the rheology of the slurry is tested. The ratio of lake mud cement slurry used for the site grouting is shown in Table 5.

Table 5. Slurry ratio of each test hole

NO	Slurry density (g/cm3)	Cement content (kg/m3)	Sodium silicate content (L/m3)
1	1.15	100	10
2	1.2	100	10
3	1.2	150	10
4	1.2	200	10
5	1.3	100	6
6	1.3	100	10
7	1.3	100	20
8	1.4	100	10

(2) Analysis of rheological characteristics of different ratio of mud cement slurry

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ZNN electric six-speed rotary viscometer was used to measure the rheological parameters of the slurry ratio of the 8 field grouting in Table 5. According to the test results, the shear rate was taken as the horizontal axis and the shear stress as the vertical axis to draw a curve. According to the change rule of the rheological curve, the rheological properties of the slurry of lake clay cement were analyzed.

Table 6 Verification results of model tests of different slurry rheological hyperbola

Ratio of slurry	The rheological parameters	The correlation coefficient
Lake mud base slurry density 1.15g/cm^3, The amount of cement added is 100kg/m^3, Add the sodium silicate 10L/m^3	a =0.156, b =0.011, τ_y =2.5	0.9938
Lake mud base slurry density 1.2g/cm^3, The amount of cement added is 100kg/m^3, Add the sodium silicate 10L/m^3	a =0.168, b =0.002, τ_y =37.5	0.9637
Lake mud base slurry density 1.2g/cm^3, The amount of cement added is 200kg/m^3, Add the sodium silicate 10L/m^3	a =0.288, b =0.0038, τ_y =33	0.9715
Lake mud base slurry density 1.3 g/cm^3, The amount of cement added is 100kg/m^3, Add the sodium silicate 6L/m^3	a =0.282, b =0.0036, τ_y =33.5	0.9691
Lake mud base slurry density 1.3g/cm^3, The amount of cement added is 100kg/m^3, Add the sodium silicate 10L/m^3	a =0.846, b =0.008, τ_y =50.5	0.9935
Lake mud base slurry density 1.3g/cm^3, The amount of cement added is 100kg/m^3, Add the sodium silicate 10L/m^3	a =7.81, b =0.07, τ_y =41	0.9762
Lake mud base slurry density 1.3g/cm^3, The amount of cement added is 100kg/m^3, Add the sodium silicate 20L/m^3	a =1.48, b =0.016, τ_y =61.5	0.9855
Lake mud base slurry density 1.4g/cm^3, The amount of cement added is 100kg/m^3, Add the sodium silicate 10L/m^3	a =0.466, b =0.004、τ_y =49	0.9879

Table 6 shows that the hyperbolic model is the best model for rheological properties of cement slurry.

4. Application Effect Evaluation of Lake Mud and Cement Slurry

To verify the effect of cement slurry, the pressure test and stone blocking rate were evaluated.

4.1 Pressure-Water Test

Inspection hole construction shall be conducted 14 days after completion of grouting. The pressure water test results are shown in Table 7. It can be seen from Table 7 that the maximum total hole average unit water permeability of the inspection hole is 1.39Lu,. The secondary maximum water permeability of the whole hole section of 2.46Lu, meets the design requirements (less than 5Lu). The pressure water test results of the inspection hole show that the curtain grouting meets the water blocking effect of the design requirements.

Table 7 Check the hole pressure-water test results

Number of Hole	Section of pressure water(Lu)		Average unit water permeability of the whole hole(Lu)	Position of inspection hole
	Maximum value	Minimum value		
J1	2.46	1.19	1.61	Between SK16 and SK2
J2	1.58	0.90	1.17	Between SK5 and SK6
J3	1.71	1.21	1.39	Between SK14 and SK7

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4.2 Slurry Stones

In the process of grouting hole construction and inspection hole core-taking, slurry stones were found in grouting holes and inspection holes with different hole sequences for many times (see Figure 5). The distribution positions of slurry stones in each grouting hole are shown in Table 8.

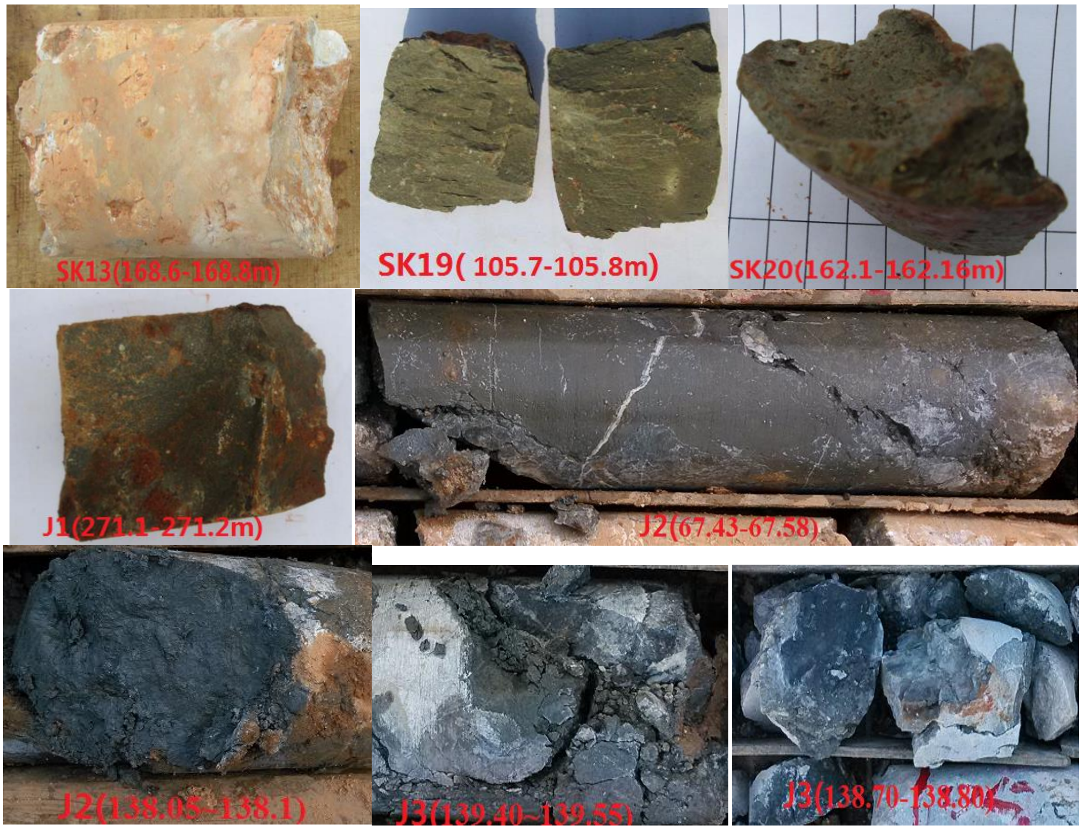

Figure 5 Photos of slurry stones

Table 8 Statistics of slurry stone mass distribution

Number of Hole	Distribution depth (m)	Thickness (m)	Fill-in status	Number of Hole	Depth (m)	Thickness (m)	Fill-in status
SK19	105.7-105.8	0.10	Full filling	J2	138.05-138.1	0.05	Full filling
SK20	162.1-162.16	0.06	Full filling	J2	323.57-323.59	0.02	Half filling
SK13	141-141.1	0.10	Full filling	J2	325.95-325.98	0.03	Half filling
SK13	168.6-168.8	0.20	Full filling	J3	98.37-98.4	0.03	Half filling
J1	271.1-271.2	0.10	Full filling	J3	105.57-105.6	0.03	Half filling
J2	56.85-57	0.15	Full filling	J3	120.78-120.80	0.02	Half filling
J2	67.43-67.58	0.15	Full filling	J3	139.40-139.55	0.15	Full filling
J2	74.85-74.95	0.10	Full filling	J3	138.70-138.80	0.10	Full filling

The drilling core shows that the slurry stones are mostly lake mud cement slurry stones, and the stone body is fully filled with 68.75% and half-filling with 31.25%. See the semi-filling section.The grouting hole distance near the drilling hole is 10m, and 10 m, from the inspection hole is 5m, shows that the discovery that the slurry diffusion distance has reached more than 5m, the aquifer crack of some curtain line is developed, with good connectivity, and the slurry diffusion range is large, reaching more than 10m.

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4.3 Water Blocking Rate

The pit boundary is simplified by the hydrogeological method without changing the situation of the groundwater flow field. The calculation formula of the pit inflow before grouting is as follows:

$$Q_0 = \frac{2\pi K_1 (S_1 + S_2)}{\ln R - \ln r_0} \tag{9}$$

After grouting, the seepage water into the pit is:

$$Q_1 = \frac{2\pi K_2 S_2}{\ln R - \ln r_0} \tag{10}$$

The formation water blocking rate after curtain grouting is:

$$n = 1 - \frac{Q_1}{Q_0} = 1 - \frac{K_2 S_2}{K_1 (S_1 + S_2)} \tag{11}$$

In formula: n is the curtain grouting plugging rate; K_1, K_2 is the pre-grouting formation and post-grouting curtain permeability coefficient (cm/s); S_1, S_2 is the decreasing depth of the outer water level inside the curtain (m).

The water blocking rate of curtain body is calculated according to formula 11, is 95.66% and meets the requirement of 85% of the mine after grouting.

5. Conclusion

Through indoor test and field test, the second lake mud cement has more particle content and better stability and mobility, and the diffusion mechanism is the best calculation model.Finally, the application effect is evaluated by pressing water test and drilling core. The results are as follows:

The average unit permeability of whole hole is 1.39Lu, The maximum permeability of all inspection holes is 2.46Lu, meeting the design requirements (less than 5Lu);

The stone body is full and half filling, among which full filling accounts for 68.75%, half filling accounts for 31.25%, diffusion radius of 5-10m, slurry diffusion filling blocking effect is good;

The water blocking rate is 95.66%, and the water blocking rate after grouting meets the requirements of over 85% of the mine.

Description

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