Experimental Study on Mechanical Properties of Fly Ash Cemented Fire Prevention Materials

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Experimental Study on Mechanical Properties of Fly Ash Cemented Fire Prevention Materials

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Abstract. Fly ash cemented fire-prevention materials are mainly composed of curing agent, fly ash filling aggregate and other additives. The fire-prevention material has the characteristics of expansibility and adjustable solidification time, strong support ability and low economic cost, which is suitable for leaking stoppage and preventing fire in coal mine. Through the experimental study, the strength and rheological properties of the material are analyzed, and the mechanical parameters of the fly ash cemented fire-prevention filling materials are obtained. The correct and reasonable use of this fire-prevention filling technology will lay a good foundation for the wide extension of the fire prevention and extinguishing technology.

1. Introduction
Spontaneous combustion of coal seam is an important hidden danger in coal mine safety production, the fire rate is higher especially for mine with spontaneous combustion coal seam [1]. How to control the spontaneous combustion of coal seam has become the key project of mine safety production. As an effective technology of mine fire prevention, fire-prevention filling materials have been widely used. At present, the main fire-prevention filling materials used in the actual production of mine are as follows: yellow mud filling material, cement mortar filling material, coal gangue mud filling material, fly ash filling material, plaster filling material and so on [2]. In addition, the imported technology and materials from abroad include Rocsil Foam, Marithan materials and expansive cement filling [3]. A new fire-prevention filling material has been developed with fly ash as the aggregate, and the cementitious material adopts KDB high efficiency curing agent, and the other addition materials are made up of the appropriate proportion. In order to make better use of this technique, the rheological properties and strength characteristics of this material are studied experimentally, which provides reference for its engineering application.

2. Strength characteristics of fly ash filling material

2.1. Uniaxial compression test of fly ash filling slurry consolidation body
The loading device of the uniaxial compression characteristic of filling slurry consolidation body is selected by WEP-600 microcomputer control panel display universal testing machine. In the experiment, the stress strain experiment on the filling slurry with solid cement ratio of 1:2 and 1:3 was
carried out under uniaxial compression conditions, and the full stress-strain curve of the material was obtained as shown in Figure 1.

![Stress-strain curve of filling material.](image)

Figure 1. Stress-strain curve of filling material.

It can be seen from the figure, the stress-strain relationship of the material has the following characteristics:

1. In the initial stage of compression, the curvature of the curve is concave, and the internal cracks of the material are compacted;
2. After the internal cracks of the material are compacted, the stress-strain relation is similar to the line, indicating that the material is in the elastic deformation stage;
3. After the elastic stage, the curvature of the curve becomes concave and the material enters the yield stage. After reaching the peak of stress, the yield platform emerged.
4. After yielding, the material still has high residual strength and plastic deformation ability.

2.2. Triaxial compression test of fly ash filling slurry consolidation body

TYS-500 triaxial stress testing machine is used for triaxial compression test equipment. The triaxial stress-strain test adopts the normal triaxial stress of the three axes, and the three axial axial stress $\sigma_1$-axial strain $\varepsilon$ relations of the two kinds of filling materials are shown in figure 2.

![Triaxial test $\sigma_1-\varepsilon$ relation curves.](image)

Figure 2. Triaxial test $\sigma_1-\varepsilon$ relation curves.

As can be seen from figure 2:

1. The stress-strain curve of the material is similar to the straight line and the material is in elastic state at the beginning of the three-way compression.
2. Under the condition of lateral pressure, the axial compressive strength of the material is greatly improved.
3. Under the condition of lateral pressure, when the filling material is damaged, the bearing capacity is not reduced immediately, but it still has a high residual strength. The larger the lateral
pressure is, the higher the residual strength becomes. This kind of mechanical property is of great significance for underground support and maintenance of surrounding rock stability.

2.3. Shear strength of fly ash filling slurry consolidation body

Based on the principal stress data obtained from the three axis test, the limit Mohr circle and the Mohr circle tangent envelope are set up on the $\tau-\sigma$ coordinates, as shown in Figure 3. The friction angle and the bond force value of the material are obtained.

\[ \tau = 0.73\sigma + 1.94 \]

\[ \tau = 0.62\sigma + 1.16 \]

From Figure 3, it can be obtained:
(1) The shear strength of the filling material is expressed in the following formula [3]

\[ \tau = \sigma \tan \phi + C \quad (1) \]

Where, $\tau$ is shear strength, $\sigma$ is shear failure surface pressure, $\phi$ is material internal friction angle, and $C$ is bonding force of the material.

(2) With the increase of solid cement ratio, cohesive force and internal friction angle of filling material also increase correspondingly.

3. Expansion characteristics of fly ash filling slurry

The expansion performance is an important performance of KDB high efficiency curing agent, and it plays an important role in engineering practice, such as the sealing effect of filling and sealing. For this reason, the compressive strength experiment of filling airtight material with different expansion rate was carried out. The results of the experiment are shown in Table 1 (the ratio of cement to fly ash is 1: 3, and the concentration is 60%)

| Mixture ratio | Expansivity | Curing agent content / (kg/m³) | Initial setting time /min | Compressive strength /MPa |
|--------------|-------------|-------------------------------|---------------------------|--------------------------|
| Mixture ratio 1 | 0           | 198                           | 56                        | 1.96, 2.62, 4.14         |
| Mixture ratio 2 | 10%         | 180                           | 45                        | 1.31, 1.82, 3.19         |
| Mixture ratio 3 | 30%         | 152                           | 30                        | 0.92, 1.21, 1.56         |
| Mixture ratio 4 | 100%        | 99                            | 20                        | 0.26, 0.49, 0.55         |

It can be seen from table 1 that with the increase of the expansion rate, the strength of the filling body also decreased obviously.

4. Rheological properties of fly ash filling slurry

The rheological properties of fluid mainly refer to the relationship between shear stress and shear rate during shear failure, and rheological parameters are the most basic elements of the rheological
properties [4]. By analyzing the rheological properties and determining the rheological parameters of the slurry, we can design the filling process system and determine the optimum ratio of filling slurry. These are of great significance for the management and implementation of the whole filling system.

The apparatus used for the experiment is NXS-11A type rotary viscometer. The cementitious curing agent used in the experiment uses KDB high efficiency curing agent. The physical properties of the aggregate used in the power plant fly ash are as follows: relative density 1.9, loose bulk density 700kg/m$^3$. The rheological curves and rheological parameters of filling slurry with solid cement ratio (the quality ratio of curing agent and fly ash) of 1:2 and 1:3 and slurry concentration of 60% to 65% were tested.

By adjusting the speed and recording the torque readings at different speeds, we can obtain the corresponding shear stress at each shear rate. Through regression analysis, the rheological curves of filling slurry with different concentrations are shown in figure 4 and figure 5 (in each regression equation, Y represents shear stress and X represents shear rate), the test results of rheological parameters are shown in table 2 and table 3.

![Rheological characteristic curve of filling slurry with solid ash ratio of 1:2.](image)

(a) concentration from 60% to 62%.

![Rheological characteristic curve of filling slurry with solid ash ratio of 1:2.](image)

(b) concentration from 63% to 65%.

Figure 4. Rheological characteristic curve of filling slurry with solid ash ratio of 1:2.
(a) concentration from 60% to 62%.

(b) concentration from 63% to 65%.

Figure 5. Rheological characteristic curve of filling slurry with solid ash ratio of 1:3.

Table 2. Rheological parameters of filling slurry with solid cement ratio of 1:2.

| Rheological parameters | Slurry concentration |
|------------------------|----------------------|
|                        | 60% | 61% | 62% | 63% | 64% | 65% |
| Plastic viscosity /\eta (Pa·s) | 0.2023 | 0.2566 | 0.3005 | 0.4064 | 0.6218 | 0.9698 |
| Initial shear stress /\tau_0 (Pa) | 9.047 | 9.1141 | 11.37 | 9.8468 | 8.7876 | 5.7228 |

Table 3. Rheological parameters of filling slurry with solid cement ratio of 1:3.

| Rheological parameters | Slurry concentration |
|------------------------|----------------------|
|                        | 60% | 61% | 62% | 63% | 64% | 65% |
| Plastic viscosity /\eta (Pa·s) | 0.2439 | 0.2713 | 0.3572 | 0.8418 | 1.0991 | 1.3491 |
| Initial shear stress /\tau_0 (Pa) | 7.4912 | 11.326 | 12.474 | 5.9608 | 2.7951 | 5.216 |

As can be seen from Figure 4 and figure 5, the rheological characteristic curve of the filling slurry is a straight line with an intercept on the shear stress axis. The flow pattern is similar to that of Bingham plastic, and the curvilinear formula of the rheological relationship is as follows [5]:
\[ \tau = \tau_0 + \eta \gamma \quad (2) \]

Where, \( \tau \) is shear stress, \( \tau_0 \) is yield stress, \( \eta \) is stiffness coefficient or plastic viscosity coefficient, and \( \gamma \) is shear rate.

Through the analysis of the data in the graph and table, the yield stress and viscosity coefficient of the slurry increased with the increase of slurry concentration.

5. Conclusion
The content of solidified agent (solid cement ratio), slurry concentration and expansion rate of filling materials have great influence on the strength of backfill. Filling sealing material has good plastic deformation ability. Under the condition of compression, the material still has high residual strength after yield failure, and it has a very strong plastic deformability under the condition that the bearing capacity is very small, and the mechanical properties are more prominent under the action of lateral pressure. The rheological parameters of filling slurry with solid cement ratio of 1:2 and 1:3 with a concentration of 60%~65% were tested and analyzed. On the basis of this experiment, the rheological model of slurry was analyzed. The results showed that the slurry presented Bingham model, and the yield stress and viscosity coefficient of the slurry increased with the increase of slurry concentration.

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