

Research Article

New Chemical Grouting Materials and Rapid Construction Technology for Inclined Shaft Penetrating Drift-Sand Layer in Coal Mine

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Drift-sand layer is a common weak stratum in mine construction. The construction of the shaft passing over the drift-sand layer is very difficult. Traditional construction method faces many problems such as long construction period, high construction cost, poor working environment, and uncontrollability of the support effect. In view of the loose and fragile rock mass with great deformation of sinking and driving engineering penetrating drift-sand layers in coal mine, the reaction mechanism and shortcomings of conventional chemical grouting materials were analyzed. New-type polymer grouting materials were prepared with catalysts and vinyl epoxy resin, which was made from epoxy resin. A comprehensive chemical grouting construction technology was proposed, which comprises initiative closing, concentrated bypass flow, water plugging priority, and secondary sand curing for the inclined shaft passing over the drift-sand layer. Results show that new-type polymer sand-cured materials have lower viscosity, better grout ability, and fire resistance, and the solidified material has stronger bonding strength and better deformation resistance compared with traditional chemical grouting materials. The engineering application effect is very prominent in controlling water burst and leakage at the drift-sand layer; thus the on-site comprehensive construction progress and safety are guaranteed.

1. Introduction

With the increasing depth of underground coal mine and the deterioration of engineering geologic environment, weak or harmful strata (i.e., water burst, drift sand, and sludge) are frequently encountered and easily result in roof collapse, caving and deformation of permanent supports, thus presenting great difficulty for mine construction [1, 2]. Joints, mining-induced fractures, and poor geologic structure in surrounding rock mass provide good groundwater courses for groundwater, which often results in the abrupt increase of mine and water disasters and brings tremendous challenges for construction progress and safety [3]. Grouting consolidation technology has become the main method of controlling water burst disaster in the underground coal-mining projects [4, 5].

Traditional particle-type grouting materials (e.g., cement-water and glass-type grouting materials) easily become diluted and dispersed under water-flowing conditions because of their poor grout ability and cannot meet the engineering requirements [6]. So, the chemical grouting materials with lower viscosity, better liquidity and grout ability into microfissures, and adjustable range of curing time have been widely applied to the management of underground coal mine water bursts. The chemical grouting materials such as polyurethanes, urea resin, and epoxy resin are used commonly in grouting reinforcement projects. The polyurethane grouting materials have been widely applied because of their volume expansion and plastic deformation when curing. However, these materials have obvious defects, such as higher viscosity, weaker fire resistance, and

strength reduction, caused by foaming and reacting with water. Especially during the reaction with water, they release hazardous gas and bring serious harm to human health [7–11]. Urea resin is a water-dilatable resin produced by the reaction of urea with formaldehyde. It has the advantages of lower cost and viscosity, but its adhesive property and induration strength are weak. Moreover, urea resin decomposes with water, and a large quantity of free formaldehyde separates out, polluting the environment [12]. Conventional chemical grouting reinforcement materials have defects such as toxicity, high viscosity, weak grout ability, lower strength, and poor anticorrosion and fire resistance, and these defects restrict the large-scale engineering application. Because of the high TDS (total dissolved solid) and corrosive components in mine groundwater, the conventional chemical grouting reinforcement cannot meet permanent supporting requirements penetrating drift sands in the shaft, which will affect construction progress and safety in production.

Aiming at the special geologic conditions of sinking and driving engineering passing through the drift-sand layer, the polymer two-component chemical grouting materials and pregrouting construction technology, which have the functions of both water plugging and consolidation were put forward. Thus, the water burst passing over the drift-sand layer under complicated conditions was effectively controlled, and the shaft construction progress and safety were ensured.

2. Materials and Experimental Methods

A new type of the vinyl epoxy resin material is the compound organic grouting material, which consists of components A and B. Component A consists of epoxyite and an accelerant according to a certain proportion, and component B consists of epoxyite and a curing agent according to a certain proportion. The control of reaction progress and curing time is realized by adjusting the amount of component B. The basic components of epoxyite include A-type E-51 epoxy resin, unsaturated carboxylic acid, reaction-type fire retardant, catalyst, polymerization inhibitor, and chemical cross-link agent. These components were sufficiently stirred in a flask with a mixer, thermometer, and rectifying tower. The pale yellow epoxy resin grouting materials were obtained after gradual warming, cooling, and filtering. The epoxy resin components are listed in Table 1.

2.1. Viscosity. The grouting material was prepared by mixing components A and B with a standard matching ratio, and the viscosity under different temperature conditions was measured by a viscometer (NDJ-9S digital viscometer). The results show that the viscosity under ambient temperature (25°C) is 80~100 MPa·s, and the value slightly increases with the decrease of temperature. The chemical grouting viscosity is 150~300 MPa·s under 5°C. The viscosity can be regulated by changing the standard matching ratio of components A and B.

2.2. Curing Time. A two-component grouting material was selected. Components A and B were mixed based on

TABLE 1: Formula design of epoxy resins.

Raw material	Mass percentage
Epoxy resin	30~45%
Unsaturated monocarboxylic acid	5~20%
Fire retardant	10~20%
Catalyst	0.15~0.35%
Polymerization inhibitor	0.01~0.09%
Chemical cross-link agent	30~45%

TABLE 2: Main characteristics of the chemical grouting material.

Category	Material characteristics
Density	1.3 g/cm ³
Viscosity (25°C)	80~100 MPa·s
Point of flammability	>185°C
Flame-retardant property	MT113-1995 standard
Response time	2 min~200 min
Setting time	10 min~250 min

a certain proportion. The initial viscosity measured under ambient temperature condition (25°C) was 100 MPa·s. The curing speed can be accelerated with the addition of a curing agent and an accelerant. The ratio of the curing agent and accelerant can be adjusted within 0.25%~4%. The polymerization reaction time of the mixture can be adjusted between 2 min and 200 min, and the curing time can be adjusted between 10 min and 250 min. The main characteristics of the chemical grouting material are shown in Table 2.

A two-component (resin component A and catalyst component B) epoxy resin grout and a chemical additive were prepared with a ratio of 1.5 : 1. A certain amount of sand with moisture content being 1.85% and particle size being 0.2~0.5 mm was selected and put into a plastic pot. The prepared chemical grout was poured into the pot and sufficiently mixed with the sand before standing for four hours. And then, a cured mass of the resin grout was formed. An autocore drilling machine and a cutting machine were used to process the resin grout mass to the standard cylindrical specimen (i.e., the specimen diameter is 50 mm and the length is 100 mm). The universal compression testing was conducted by using the rock mechanic system (MTS Corporation, USA), and the physical and mechanical properties and the stress-strain curve of the cured material were obtained according to the international rock mechanic test standard. The stress-strain curve is shown in Figure 1; the main rock mechanical properties of the cured material are determined and listed in Table 3.

The test results show that the resin grout and sand are cemented into a compact structure after being cured. The macroscopic structure is featured by a stronger bearing capacity, and the compressive strength reaches 10.3~13.1 MPa. The product generated by the resin grout and sand has a stronger plastic deformation capacity and an evident Poisson's ratio effect.

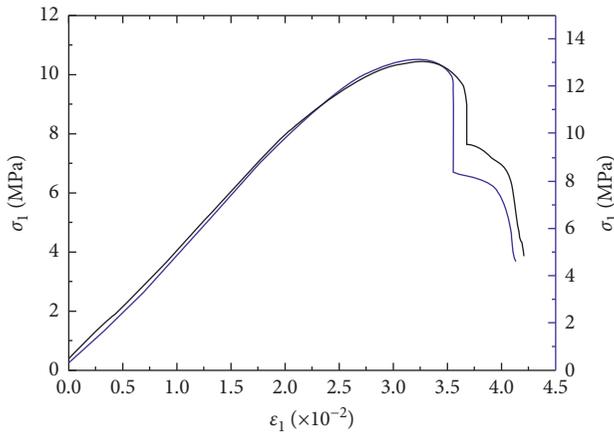


FIGURE 1: Stress-strain curves of the solidification material.

TABLE 3: Main properties of the cured material.

Category	Mechanical characteristics
Density	1.6938 g/cm ³
Compressive strength	10.38~13.09 MPa
Strength of extension	0.32~0.53 MPa
Elasticity modulus	401.37~490.64 MPa
Poisson's ratio	0.447~0.846
Cohesion	0.866 MPa
Internal friction angle	49.38°

3. Engineering Application of Chemical Pregrouting

3.1. Project Overview. Songxinzhuang mine is a newly constructed mine, with a production capacity of 1.2 million t/a and a designed service life of 59 years. The geologic data and geologic report indicate that the vice inclined shaft is 630 m long and passes through the quaternary stratum and tertiary stratum. The quaternary stratum mainly has wind-borne sand and floury soil with a thickness of about 1.6~3.75 m. Half-agglutinating clay and argillaceous substance contain a large quantity of silt and fine sand. The engineering geological conditions are poor. Moreover, hydrogeological conditions in this mining area are complicated. The shaft construction process is frequently under water burst influence from the confined aquifers of the Jurassic Zhiluo rock mass group and Yan'an rock mass group.

The section of the vice inclined shaft passage is a vertical-wall semicircular arch with a net width of 4400 mm, a net height of 3800 mm, and a net section area of 14.6 m². The preliminary support pattern at the drift-sand segment adopts reinforced concrete support, lay rubble mortar, and reinforced concrete-hardened baseboard. The vertical-wall semicircular arch was adopted reinforced support with the concrete thickness being 400 mm and the strength grade of the concrete being C30. Flagstone mortar metal net concrete pouring of the roadway baseboard is conducted with a bedding thickness of 600 mm and a flagstone strength not less than MU30. The upper concrete thickness is 200 mm, and the total bedding is

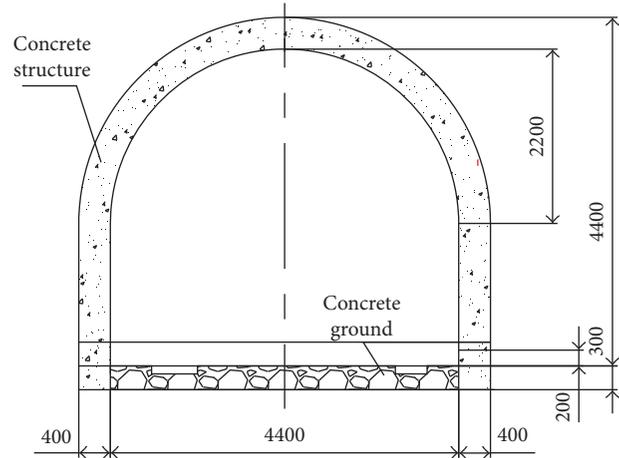


FIGURE 2: Preliminary supporting section.

800 mm. The strength grade of the bedding concrete is C20. A reinforcing steel bar adopts a Φ 20 mm deformed steel bar. Two adjacent reinforcing steel bars are lapped by welding. The preliminary support section is shown in Figure 2.

The drift-sand layer of the vice inclined shaft project first appeared on September 15, 2010, at the location 58.3 m. The sandstone layer is quite soft and loose and will easily drop down when meeting water. This sand layer contains loess, which forms liquid yellow mud. The delaminating and wall caving phenomena are seen after layer tunneling, which is accompanied by a water inflow of 25 m³/h. This results in wall caving, roof caving, and the sinking and deformation of permanent support. And the average excavation footage per day is 0.82 m because of the construction conditions of sinking and driving engineering.

3.2. Multistep Grouting Construction Technology. Considering the above specific engineering geological conditions, the multistep pregrouting and rapid construction technology is used for construction of the shaft according to the experience of water prevention and control in nearby mines.

The shaft construction reveals that the seepage channels of surrounding rocks are mainly holes with weak permeability. The alkaline water has a negative influence on the reaction of the grout and the durability of curing materials.

The compound chemical grouting materials (i.e., sand curing material MGS and water plugging material Midwest213) with lower viscosity and controllable curing time are selected. The sand curing material MGS also has other advantages such as higher safety without aldehyde, acid and alkali resistance, and fire resistance; thus, MGS is applicable in an aquifer of sandstone, which is rich in soluble salts, drift-sand layer curing, and water inflow plugging. The relevant technical parameters of chemical grouting materials were shown in Tables 4 and 5.

3.3. Multistep Pregrouting Design Scheme

3.3.1. Distributed Grouting and Plugging at Water Bursting Positions of the Shaft. A concrete wall was first constructed

TABLE 4: Main technical parameters of construction chemical grouting.

Category	Two-component ratio	Width of the smallest crack (mm)	Setting time (min)	Resin viscosity (MPa·s)	Catalyst viscosity (MPa·s)
MGS	1:1~1:2	0.01	10~250	150	50~80

TABLE 5: Main technical parameters of water plugging chemical grouting.

Category	Two-component ratio	Solid content (%)	Dilatation coefficient	Setting time (min)	Resin viscosity (MPa·s)	Catalyst viscosity (MPa·s)
Midwest213	1.5:1	100	8~10	2~900	350	150~180

at the driving face in the shaft passing over the drift-sand layer with a thickness of 600 mm. A relief hole was set in the middle bottom of the wall with a hole diameter of 80~100 mm.

In order to leave the grout enough time for reaction and curing before flowing to the relief hole, the grouting holes were drilled using the common electric coal drill from the bottom to the top. A specific method was used for water plugging and drilling at the location where the sealing wall was far away from the water exit along the roadway border, and the chemical grouting material Midwest213 was used for water plugging. And then, the water flow in the drift-sand layer inside the sealing wall was relatively stable.

According to the situation, the grouting drilling depth was preliminarily set as 850 mm. A six-decimeter galvanized pipe was adopted to seal the end. Some 5 mm diameter holes were drilled every other 150~200 mm along the galvanized pipe. The length of the grouting pipe was 950 mm. About 100 mm from the pipe orifice was left outside the concrete wall. Cotton yarn and grout or accelerated cement was used to seal the seam between the grouting pipe and the concrete wall. The layout of the water plugging well location is shown in Figure 3.

Feed pipes of components A and B were plugged into a bucket. When the normal construction was being conducted, it was mixed according to the matching ratio of the grout. During the process of grouting into grouting holes, the best practice was to use low-pressure grouting because the underground water pressure is 0.5 MPa. The grouting pressure was then set within 1~2 MPa, which was same or twice as water pressure, and should be gradually increased. The pressure gauge of the pump and situation of the working face must be given attention. Grouting should be stopped when the value indicated on the pressure gauge of the pump reaches above 2 MPa or grout spillover occurs.

3.3.2. Rapid Curing of Rock Mass Grouting at the Drift-Sand Layer. The sealing wall was used as a grouting pad at the jointing part between the vertical wall and the concrete shaft at the middle lower part of the sealing wall. The drills were constructed by the common hand drill, and the chemical material MGS was grouted. The location of the one-way valve was confirmed based on the on-site fracture development. The exposure part should not be more than 50 mm. Grouting can be started after confirming that preparation

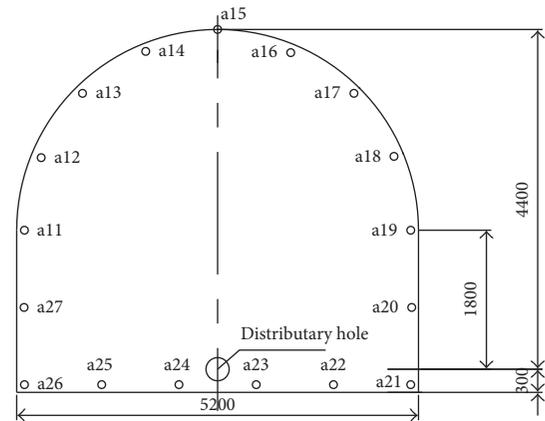


FIGURE 3: Layout of the water plugging well location.

has been made. The layout of the construction well location is shown in Figure 4.

3.3.3. Grout Sealing of Major Jointing Parts of Shaft Secondary Support Concrete. After the multistep chemical grouting, curing, and water plugging of the shaft were completed, “short excavation and short supporting” construction technology was adopted for shaft excavation. Pipe shed, plank, and meshes were used as the temporary support, and the single reinforced concrete was used as the permanent support.

The supporting template or footage of the monolayer-reinforced concrete of the shaft is generally 0.9 m. Jointing parts between the concrete templates are the weakest parts of the shaft, which usually are the flow channel of groundwater. The grouting technology with shallow holes and high pressure is adopted to seal the jointing parts of the shaft permanent support.

4. Result Evaluation and Discussion

The slant angle of the vice inclined shaft is 6° , and the drift-sand layer thickness is 1.4 m. And the slant length is 13.9 m in the project of the Songxinshuang coal mine at first. The comprehensive construction method of self-closing, highest-priority water plugging, and secondary sand curing at the drift-sand layer is confirmed. Two liquid compound chemical

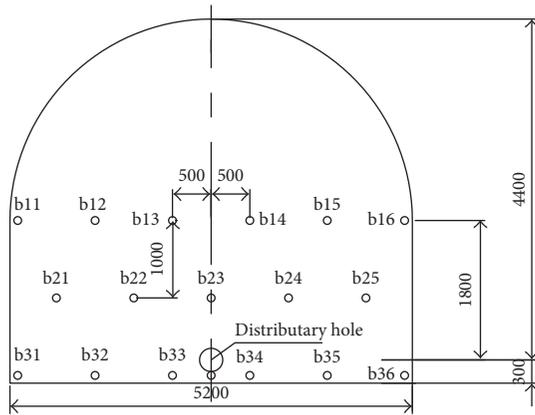


FIGURE 4: Layout of the construction well location.

grouting materials with lower viscosity and controllable curing time are applied on the sand curing, water plugging, and grouting for shaft passing through the drift-sand layer.

Twelve water plugging and grouting drill holes were set on the sealing wall. The amount of the chemical grout Midwest213 used was 1900 kg. The grouting material quantity for each hole was 158.3 kg. The water inflow of roadway became 1.5 m³/h upon completion. Water flow at the drift-sand layer inside the sealing wall of the shaft was relatively stable. The sealing wall was used as a grouting pad. About 28 holes with a depth of 350 mm were drilled for sand curing construction. The amount of the chemical grouting material MGS used was 3000 kg. The grouting material quantity for each hole was 107.1 kg. A rock sample was drilled after grouting construction was finished to evaluate the grouting effect. No water burst and sand drifting phenomenon and the solidified bodied strength were stronger after the sealing wall was broken. Sand curing and water plugging effects are prominent. Thus, the water burst passing over the drift-sand layer under complicated conditions is effectively controlled, and the normal excavation speed of the shaft is guaranteed.

5. Conclusion

- (1) The new vinyl epoxy resin materials are two-component polymer chemical grouting materials with lower viscosity, polymerization reaction, accurate and controllable curing time, and better grout ability. Lower viscosity guarantees the sufficient permeation and diffusion of the grout in rock mass. After curing and expansion, the resin grout is cemented with sand particles into a compact structure. This compact structure is featured by a stronger bearing capacity. Thus, the new chemical grouting materials have a broad application prospect in coal mining.
- (2) According to the characteristics of the vice shaft surrounding rock mass in the Songxinzhuang coal mine, the new vinyl epoxy resin of sand consolidation and the water plugging material are specially developed. The comprehensive grouting scheme of initiative self-closing, highest-priority water plugging, and secondary sand curing and rapid construction method are put

forward to achieve effective control of water burst at the drift-sand layer under complicated conditions.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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