



DATA ACQUISITION SYSTEM BASED ON VIRTUAL INSTRUMENTS FOR PRE-STRESS CHARACTERISTICS OF EXPANDABLE BACKFILL MATERIALS AND COMPUTATIONAL SIMULATION

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ABSTRACT

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The applying proportion of filling mining method is increasing considerably in mines as it meets the demands of building "two-oriented" society. However, due to the influence of various factors, the backfill materials fail to contact the roof of goaf completely, causing the backfill materials can't play its role fully. In the paper, the over burnt calcium oxide is injected into goaf as cementations materials together with the tailings. Those mixed backfill material will swell in a relatively short period of time and fill the goaf thoroughly. When the volume expansion is constrained by the boundry of the goaf, the backfill materials will exert stress on the surrounding rock. Firstly, stress data acquisition system based on virtual instruments was established when pre-stress measurement experiment was conducted, the goaf model was filled up with the expandable backfill materials (cement-sand ratio is 1:3 and concentration is 75%), which exerted 0.76MPa and 0.42MPa pre-stress on the roof and bottom of the stope respectively after its volume expansion was limited and stopped. Moreover, the computational simulation was carried out for mutual verification and the results show that: keeping the initial filling rate 0.85, the largest displacement and maximum stress in vertical direction of stope roof are 44.2mm and 17.3MPa respectively when using the ordinary portland cement as backfill materials, however, the corresponding figures are only 4.6mm and 12.1MPa when using the expandable backfill materials. In conclusion, the pre-stress measurement experiment facilitated by self-designed data acquisition system and computational simulation has proved that the expandable backfill materials are effective in controlling displacement and improving the stress distribution in surrounding rock.

1. INTRODUCTION

The applying proportion of filling mining method is increasing considerably in mines as it meets the demands of building "two-oriented" society. In China, the filling mining has gone through dry filling, water filling, cemented filling stage^[1]. Currently, the most widely used filling method is cemented filling whose filling aggregate mainly is stone, gangue, and tailings and cementitious materials is often ordinary Portland cement. Due to the high cost of cement, mines that have their conditions replace cement with fly ash, red mud, slag, blast furnace slag and other cementitious materials partly or completely, and achieve better economic results^[2]. But the filling body is affected by many factors, often failing to fully meet the roof^[3-5]. There is usually clearance left from a few meters to several tens of centimeters between the roof and the backfill, resulting in the fail of filling body in playing its due role. Engineering and technical personnel improve the rate of filling body contacting the roof by improving the filling process and other means^[6-9], but they can't fundamentally resolve the problem of filling body fully contacting the roof.

The main component of static expansion agent is overburnt calcium oxide. Calcium oxide reacts with water to produce calcium hydroxide and releases a lot of heat. When calcium hydroxide is doing its crystal development, its volume will expand. When the volume expansion is constrained by the boundary of the goaf, the backfill materials will exert stress on the surrounding rock. Blasting workers used this characteristics of over burnt calcium oxide to burst rock and concrete and other brittle material^[10-11]. Now static expansion agent as a cementitious material is injected into goaf with tailings, forming expandable backfill. Expandable backfill body will expand in a certain period of time, filling the whole empty area, making backfill body touch surrounding rock very tightly, forming a mutual coupling integrity, making the best use of the advantage of backfill in the aspect of improving the surrounding rock stress distribution and controlling surrounding rock deformation. What's more,

when the volume expansion of swelling backfill is constrained, the expandable backfill body can exert a certain amount of pressure on the surrounding country rock, changing from the original passive force into the active support of surrounding rock.

In order to figure out the effect of expandable backfill body in the aspect of improving the surrounding rock stress distribution and controlling surrounding rock deformation, firstly, we preliminarily chose the concentration range of expandable backfill mortar through segregation experiment; Secondly, we got the expansion coefficient of swelling backfill in the free stage by measuring the volume value of expandable backfill mortar with different ratio in different periods in the free state. Thirdly, we collected the surrounding rock pressure when the expansion of expandable backfill mortar is limited by using pressure sensors and data acquisition system through similar experiment. Finally we compare and analyzed the effect of expandable backfill body and ordinary cemented backfill body in the aspect of improving the surrounding rock stress distribution and controlling surrounding rock deformation by using numerical simulation method.

2. Segregation Experiment

The purpose of the experiment is to preliminarily choose the concentration range of expandable backfill mortar. When the concentration of expandable backfill mortar is too low, the filling aggregate and the mortar will separate due to the lack of cohesion between the mortar and filling aggregate, not only reducing the mortar transmission capacity but also affecting the integral structure of backfill, which decrease the strength of the backfill greatly^[12]. When the concentration of expandable backfill mortar is too high, the mortar transmission capacity is very weak, and can't be transported.

The ratio of static expansion agent and tailings ranged from 1:1 to 1:6 and

the concentration of expandable backfill mortar varied from 50%~80% in the experiment (Table 1). The backfill mortar with different ratio after being stirred sufficiently was left in a transparent container to stand for a period time to observe whether the layered segregation phenomenon will appear. The indoor temperature is 23 °C, humidity is 70% when the expandable backfill mortar was made.

Ratio	1 : 1	1 : 2	1 : 3	1 : 4	1 : 5	1 : 6
Concentration range(%)	60~80	65~80	70~80	70~80	70~80	70~80

Table 1: The concentration range of expandable backfill mortar

Table 1 shows that with the ratio decreasing, the concentration range of expandable backfill mortar without segregation phenomenon is narrowing and the lowest concentration increases from 60% to 70% gradually, but the highest concentration does not change.

3. Determination of coefficient of expansion of expandable backfill mortar in free stage

The purpose of the experiment is to preliminarily know the expansibility of expandable backfill mortar. The backfill mortar with different ratio after being stirred sufficiently was left in a cylindrical plastic cup with a certain characteristic of expansion to stand for a period of time. The expanded volume of expandable backfill mortar was calculated by the diameter of cylindrical cup and the height of expandable backfill mortar after fully expanding using vernier caliper to measure in the plastic cup. The coefficient of expansion is the ratio of volume value after expandable backfill mortar fully expanding and initial volume value. The observation period was 30 days. The coefficient of expansion is shown in Figure.1.

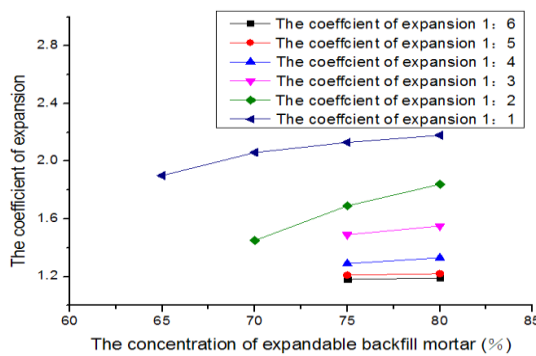


Fig.1 The expansion coefficient of expandable backfill mortar

As the Fig.1 shows, expandable backfill mortar has good expansibility. The value of expansion coefficient is closely related to the ratio of static expansion agent and tailings and the concentration of expandable backfill mortar. When the ratio of static expansion agent and tailings is higher, the concentration of expandable backfill mortar is higher and the expansion of expandable backfill mortar is better. When the ratio of expandable backfill mortar is 1:3 and the concentration of expandable backfill mortar is 75%, the value of expansion coefficient can reach 1.49. When the filling rate reaches 0.9, the expandable backfill mortar with the ratio of 1:6 and the concentration of 75% after expanding can fill the whole empty area.

4. Pre-stress measurement experiment of expandable backfill

4.1 Experiment purpose

To measure pre-stress on the surrounding rock exerted by expandable backfill with the different ratio of static expansion agent and tailings when the volume expand is constrained.

4.2 Experiment facilities

A small scale model of goaf was made. The internal of goaf model is cube and the inner side is 10cm. The four micro pressure sensors were placed in the upper part, the lower part, the left and the right part in the internal model. After the backfill mortar production was completed, the mortar was injected into the goaf model. Then the model was placed on the tray of the hydraulic machine and the hydraulic machine limited displacement of roof by putting pressure on the roof. And the data of pressure sensors was collected by data acquisition system.

4.3 Pressure measurement equipment

The pressure measuring instrument is LY-350 micro pressure box, the measuring range is 5MPa, Sensitive coefficient of Strain gauge is 2.0.

4.4 Data acquisition system

The data acquisition system was developed based on Lab view software, which is a data acquisition and virtual instrument control software of a standard. Designed by graphical programming language, the acquisition system can achieve the real-time data communication between PC and sensors, accurately describes the stress status of the monitored site.

Specifically, on one hand, Virtual Instrument – VI is a pivotal applications which represent the virtual reality (Virtual Reality) in the instrumentation application and a modular hardware with high performance. On the other hand, Lab VIEW (Laboratory Virtual Instrument Engineering Workbench) has introduced a virtual instrument software development environment with a lot of built-in capabilities[13]. Easily, it is able to realize simulation, data acquisition, instrument control, measurement analysis and data display functions. Furthermore, with user friendly interface, designers can take advantage of LabVIEW software to facilitate the realization of all the traditional functions of electronic measuring instruments. Wang Yawei[14] designed a mine fans performance testing system based on Lab VIEW. Lv JunLin[15] utilized the Lab VIEW virtual instrument to realize the real-time monitoring of gob for the sake of gob mining disaster analysis. The front panel of data acquisition system on PC terminal is displayed in Fig.2.

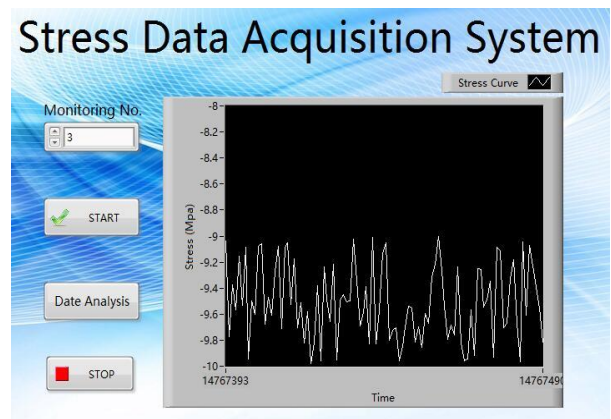


Fig.2 Front panel of data acquisition system

When the micro pressure box is pressured by the force, the inside resistance of the micro pressure box changes due to the deformation of resistance strain gauges. Measuring circuit outputs the change of resistance in the form of voltage signal. After collecting the voltage signal outputted by the micro pressure box, NI data acquisition card connect the database by DSN. The stored procedure of the database create a new table with the headers of serial number, date, channel coding in which the data will be put and saved. Block diagram is shown in Fig.3.

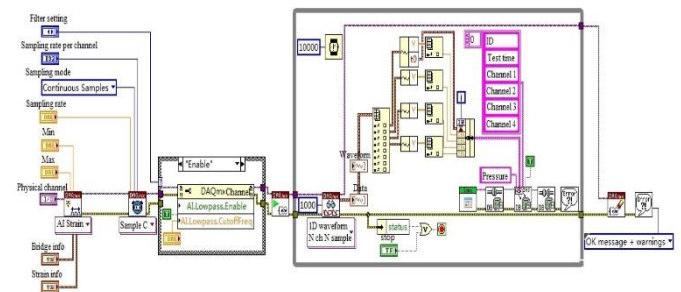


Fig.3 The program diagram of pre-stress data acquisition system

4.5 Experimental procedure

Based on segregation experiment and the result of determination of coefficient of expansion of expandable backfill mortar in free stage, the expandable backfill mortar with the concentration of 75% and the ratio of 1:1、1:3、1:5 respectively, was injected into the goaf model after being fully stirred. One of the height of the backfill mortar injected into the model with different ratio of static expansion agent and tailings was 10cm, the other was 8.5cm, that is one of the initial filling rate was 1 and the other

was 0.85. The expandable backfill mortar would expand in a certain time. When volume expansion was limited, the backfill put pre-stress on the model around. The roof couldn't produce displacement due to the pressure put on by hydraulic press. So when the expansion of the backfill mortar was limited, the coefficient of expansion was 1 and 1.2. The pre-stress in the different directions put by different groups with different coefficient of expansion was acquired by the stress sensor and data acquisition system. The data was acquired after the expandable backfill mortar was injected within 15 days.

4.6 The experimental results

The experiment result shows that the value of pre-stress of the expandable backfill in the different directions did not change in 8 days later, so the data collected in the first 8 days was analyzed. The analysis revealed the pre-stress changing curve of each group was similar. The change of pre-stress in the different directions of the backfill mortar with the ratio of 1:1 and the coefficient of 75% is shown in fig.4. The fig.4 shows that the variety characteristic of pre-stress of the expandable backfill over time. The final pre-stress of expandable backfill in the different directions is shown in Table 2.

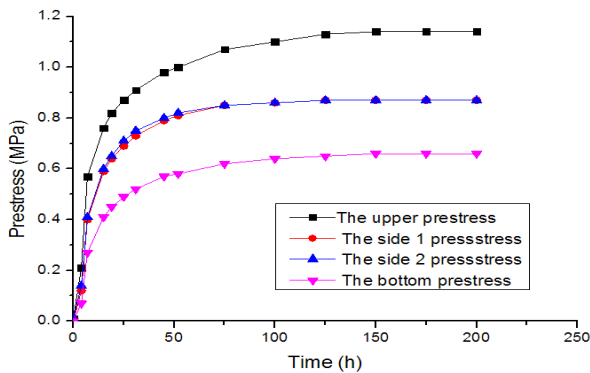


Fig.4 The graph of changing pre-stress of expandable backfill body from different direction

As the fig.4 shows, the expandable backfill has two following characteristics when it was limited. 1) Pre-stress grew rapidly in the first 3 days. The value of pre-stress of the first day was 76% of the total value. The value of pre-stress of the second day was 86%, the value of pre-stress of the third day was 94%. After 3 days, the curve of the pre-stress changed slowly. The value of pre-stress that the backfill put on the upper part of the modal was bigger than the other parts'. And the values of pre-stress of the left and the right were all bigger than the bottom's. It is because that the filling aggregate of the expandable backfill mortar slowly sank due to the heavier density after the expandable backfill being stirred fully and stood for a certain while, resulting in the increase of the content of the tailings of the modal from the upper to the bottom and the reduction of the cementitious materials (over burnt calcium oxide) from the upper to the bottom.

	Expansion coe 1.0			1.2		
	Ratio 1:1	1:3	1:5	1:1	1:3	1:5
The upper	1.14	0.76	0.34	0.67	0.20	0.06
Side 1	0.87	0.57	0.29	0.40	0.10	0.04
Side 2	0.87	0.56	0.29	0.41	0.10	0.04
The bottom	0.66	0.42	0.24	0.22	0.08	0.02

Table 2: The pre-stress of expandable backfill body from different direction

As the Table 2 shows that at the same of expand coefficient, when the ratio of the cementitious materials of the mortar is higher, the pre-stress that the expandable backfill put on the modal was greater. At the same of the ratio, when the volume of the expandable backfill mortar was limited more serious, the pre-stress that the expandable backfill mortar put on the modal was greater.

From the analysis of fig.4 and Table 2, it can be found that when the volume expansion is limited, the pre-stress that the expandable backfill mortar put on the modal has positive correlation with the content of overburnt

calcium oxide. When the content of calcium oxide is larger, the pre-stress of the expandable backfill mortar is greater. So when the volume expansion of the expandable backfill mortar is limited, the expandable backfill can put stress on the surrounding rock in a short time, supporting the surrounding rock and blocking the further deformation of surrounding rock.

5. Computational simulation

5.1 Overview

Taking the stope of western of a mine 360 meters below sea level as an example, the average buried depth of the stop is 360 m. The roof, floor and surrounding rock are skarn. The ore body is magnetite, having good stability. The open stope filling method is applied and the stops were arranged along the direction of ore. Room parameters: length of 60 m, width of 20m, height of 8m. The FLAC3D was used to simulate the excavation and filling of the goaf. The expandable backfill was analyzed in the effect of stress distribution, the displacement of the surrounding rock control.

5.2 Modal establishment

The numerical analysis model was three-dimensional. The direction of ore body was X direction, the direction of the width of the goaf was Y direction and the direction of gravity is Z direction. Considering the boundary effect and the simplification of the calculation, the each end of model in the X direction is the 2 times as long as the length of mined-out area and the total length of the X direction was 180m. The each end of model in the Y direction is the 3 times as wide as the width of the mine-out area and the total length of the Y direction was 100m. The top boundary of modal was 40m beyond the upper of the room and the lower boundary of the modal was 20m lower than the floor of the goaf. The length of the Z direction was 68m. The model has 168759 nodes, 159000 units after meshing. The modal was applied with displacement boundary

conditions. In three-dimensional numerical analysis, the displacement in the X direction of the left and right 2 sides of the modal was constrained, the displacement in the Y direction of the front and back 2 sides of the modal was constrained and the displacement in the Z direction of the bottom was constrained. The numerical calculation model used Moore - coulomb criterion.

The simulation of the exploiting of room was carried out by the empty cell command of the FLAC3D and the simulation of the filling was realized by the method of the reassignment of the material. The physical and mechanical parameters of the empty area and surrounding rock came from the literature [16]. Cementitious materials of the original backfill mortar was portland cement and the filling aggregate was tailings. Its ratio of cementitious materials and tailings is 1:8 and the concentration was 65%. Its physical and mechanical parameters came from the literature [17]. The ratio of static expansion agent and tailings of the expandable backfill mortar was 1:3 and the concentration was 75% and the physical and mechanical parameters came from the literature [18]. The physical and mechanical parameters were shown in the Table 3. Vertical stress $\sigma_y = -9.5$ MPa, horizontal stress $\sigma_x = -12.5$ MPa coming from the literature [17]. The different filling rates were expressed by the different heights. The supporting force put by the backfill was expressed by applying surface force. The value of the supporting force corresponded to the value of the final expansion force produced by the expandable backfill when the expansion of the backfill was limited in the pre-stress measurement experiment of expandable backfill.

Table 3: Physical and mechanical parameters of the experimental materials

Material	Bulk densit y / (kg-m ⁻³)	The bulk modul us /GPa	Shear modul us /GPa	Cohesi on /MPa	Intern al frictio n angle / (°)	Tensile streng th /MPa
Magnetite	4120	13.21	5.69	8.32	33.6	5.55
Skarn	3020	6.93	4.56	4.07	38.4	3.96
Cemented backfill	1800	0.38	0.17	0.14	22	0.36
Expandable backfill	1250	4.2	2.1	0.85	28	1.55

5.3 Simulation Content

When the room became the empty area after excavation, the empty area was filled with original cemented backfill and expandable backfill respectively. When the filling rate was 0.85, the height of the cemented backfill body was 6.8 m and the height of the expandable backfill body was 8 m after the volume expansion. When the filling rate was 1, the heights were both 8 m. It was studied that the improvement in stress distribution and the effect of controlling the displacement of the surrounding rock in the different filling rate of the two backfill body.

5.4 Simulation results and analysis

The geometric center was taken as the 0 point. And a vertical axis across the 0 point of the direction of the rooms in the plane of the roof was chosen. The range of the axis was outward 10 m from the width of the room, that was from -20 m to 20 m. It was studied that the variations of the displacement and stress in the vertical direction of the roof of the room in the vertical axis.

5.4.1 Simulation analysis of controlling surrounding rock displacement of expandable backfill material

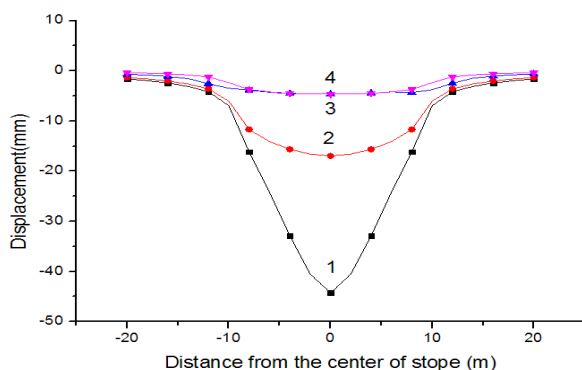


Fig.4 The displacement curve of slope roof from vertical direction

In the fig.5, the curve 1 shows the displacement in the vertical direction of the roof of the room with the filling rate of the ordinary backfill of 0.85. The amount of subsidence across the center point in the vertical direction of the roof of the room was largest, 44.2mm by the stress of the surrounding rock in the upper part because the roof lack in support due to the space between the roof and backfill. The amount of the subsidence gradually reduced from the center to sides and the final amount was 0. The curve 2 shows the displacement in the vertical direction of the roof of the room with the filling rate of the ordinary backfill of 1., the amount of the subsidence in the vertical direction of the roof reduced considerably compared with curve 1 and the largest amount was 17.0mm because the backfill connected to the roof and the roof was supported by the backfill. The curve 3 and curve 4 expressed the displacement in the vertical direction of the roof of the room with the filling rate of the expandable backfill of 0.85 and 1 respectively. The empty area was filled with the expandable backfill and the roof and backfill connected tightly, forming a whole due to the coupling effect so curve 3 and curve 4 were largely similar and the amount of subsidence was minimal. The filling body changed active support from passive force. The effect of the controlling of the subsidence of the roof was obvious.

5.4.2 Simulation analysis of improving surrounding rock stress distribution of expandable backfill material

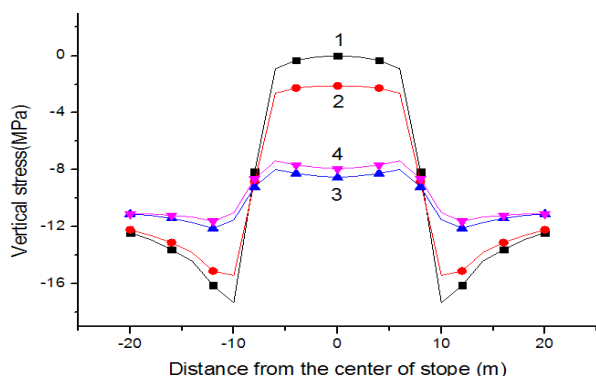


Fig.6 The stress distribution curve of slope roof from vertical direction

In fig.6 the Curve 1 expresses the stress distribution in the vertical direction of the roof of the room with the filling rate of the ordinary backfill of 0.85. The stress in the center of roof transferred to the both sides. The center of the room did not bear pressure and the maximum stress in the vertical direction of the room appeared on the side of the room, the largest value was 17.3MPa. The place of the maximum stress of the room would form the stress concentrated zone causing shear failure of the room. Curve 2 expressed the stress distribution in the vertical direction of the roof of the room with the filling rate of 1 of the ordinary backfill. The backfill played the role of transferring the stress. The largest value of the stress in the vertical direction of the roof of the room became smaller and the largest value was 15.4MPa, appearing still on the side of the room. The Curve 3 and Curve 4 express the stress distribution in the vertical direction of the roof of the room with the filling rate of expandable backfill body of 0.85 and 1 respectively. At this time, The largest value of the stress in the vertical direction of the roof of the room reduced greatly. The largest value was 12.1MPa with the filling rate of 0.85 and the largest value was 11.6MPa with the filling rate of 1. When the ordinary cemented material was used to fill the empty area, the change of stress gradient was larger. When the expandable backfill mortar was used to fill the empty area, the change of stress gradient was gentler. It's obvious that when the expandable backfill mortar is used to fill the empty area, the mortar can play a fully role in improving the stress distribution of the roof, strengthening the stability of the roof.

6. Conclusion

(1) A stress data acquisition system based on virtual instrument was designed utilizing graphical programming language, which can accurately and dynamically collect the stress status of monitoring spots. At the same time, computational simulation was carried out for mutual authentication for the pre-stress characteristics of the expansible backfill material.

(2) The expandable backfill mortar has excellent expansibility and the volume can expand in a short time. The value of the expansion coefficient is closely related with concentration and the ratio of the static expansion agent and tailings. The pre-stress that the expandable backfill mortar produces is closely related with the amount of the cementitious materials and they have a positive correlation when the expansion volume is limited.

(3) The expandable backfill mortar can solve the roof-contacted filling problem fundamentally. The expandable backfill mortar injected into the goaf with filling rate of 0.9, the concentration of 75% and the ratio of the static expansion agent and tailings of 1:6 can fully fill the empty area after volume expansion.

(4) After connecting the roof, the expandable backfill body can fully play its role in controlling the displacement of the room and improving the stress distribution of the surrounding rock, strengthening the stability, ensuring safety in production. Mine can adjust the filling rate and the concentration and the ration of the static expansion agent and tailings to balance the safety in production and cost of filling to achieve the best balance point.

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