



Research of Building the Reasonable Mixing Ratio between Waste Rock and Fly Ash as Backfill Material in Mongduong-Cocsau Area, Quang Ninh, Vietnam

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Abstract

The coal mining industry in Quang Ninh province is primarily focused on serving thermal power plants which has resulted in a substantial amount of waste rock and ash. This way has not only narrowed the used land but also had a negative impact on the environment. However, the economic development plan for the province until 2030 emphasizes the development of a greener economy. Therefore, balancing between economic growth and environmental protection is one of the significant challenges of this province.

To solve the problem of waste rock and ash dumps, some methods have been proposed. It tends to use waste materials for backfilling the underground mines, this can help to minimize the bad impact on the environment. Additionally, Another solution is to handle the waste in abandoned mining areas, or use them as construction materials. These ways are expected to partially reduce the bad effects of waste rock and ash dumps on the environment.

In the world, there are many studies on filling using waste rock and fly ash, but in Vietnam this issue is quite new. In order to turn waste rock and fly ash into filling materials, the article researches on a laboratory scale, the ability of transportation in hydraulic pipelines, level of the water separation and shrinkage of mixtures of rock and fly ash in the Mong Duong – Coc Sau area with the different proportions. The results of the experiments show that the area has appropriate mixing ratio as 70–73% of waste rock and 30–27% of fly ash, this ratio satisfies the transportation conditions in the pipeline and the shrinkage rate of 8, 8–12.3%. The indicators in experiments show that it is able to take waste rock into mined underground area to fill, which prevents displacement of strata from mining, protects the underground water flow, and also reduces negative impact of waste rock on environment.

Keywords: waste rock, fly ash, shrinkage rate, pipeline transportation capacity

1. INTRODUCTION

In recent years, many different mining methods have been applied to control the displacement of stratigraphy, such as leaving a strip of minerals (earth and rock), pillar-room mining, and mining combined with filling. The mining method of leaving the mineral strip and pillar-room can achieve the imposed mining capacity but results in a high mineral loss rate, which is a significant waste of non-renewable resources (B.D. Thompson et al. 2012; Changxiang Wang et al. 2019; Guo et al. 2014; J Mgumbwa et al. 2014). Hydraulic filling technology has been developed for over 30 years. It was first used in Europe in 1978, in the United States in 1980, in South Africa in 1984, in Canada in 1984, and in Australia in the 1990s. Extensive research carried out in Canadian mines in the early 1990s brought steady progress in the preparation and paste-fill transportation. Accepting the backfill factories, especially bulk mining, has become popular since then. The first backfill factory was built to process mineral tail ore in 1999, and then more than 30 paste-fill installations were operated or in stages of designing or construction around the world (A Bascetin et al. 2016; F.P. Hassani et al.; Jean Béket Dalcé et al. 2019; Kambiz Tahzibil et al. 2016).

The feature of the hydraulic fill method is to combine solid materials with water in order to form a pastefill mixture that can be transported in a pipeline. When this mixture is transported into the fill area, the water will gradually separate in order to form the fill blocks in the Gob area (Huang et al. 2011; Nagaratnam Sivakugan et al. 2015; SD Widisinghe et al. 2014). The fill materials are cement, combined with sand, tailings, waste rock, etc. Most of these materials are waste prod-

ucts that are placed in different areas. However, the disadvantages of the mixture of cement and other solid materials are to harden easily in pipelines and to have high cost (Chaoqun Dai et al. 2019; Jixiong Zhang et al. 2019; Milena Kostović 2019; R. Cooke 2001). Recently, some studies have replaced cement with thermoelectric fly ash. Fly ash is both a conductor in the mixture of filler materials, which reduces blockage of pipelines due to stagnation of heavy material at the bottom of the pipe, and a binding agent in the solid-liquid phase of the fill materials (Fabrice Kazambua Beya et al. 2019; Krzysztof Skrzypkowski 2018; Pengfei Zhang et al. 2019). The binding agent is described as a condensed viscous gel but not like mud and it is difficult to separate in transportation. This mixture is like wet concrete that has nearly the same specifications as concrete (Khaldoun Abdelhadi et al. 2018; Morteza Sheshpari 2015; Ning Jiang et al. 2017; Pengyu, Y. and Li, L. 2015).

The displacement of stratigraphy is the consequence of losing balance when coal mining forms space in the ground. Therefore, wall rocks and pillar rocks, under the impact of gravity, tend to move into that space, which causes the collapse of the rock layers. This creates a new pressure balance again. Mining methods combined with fire break are unable to control the overload of the upper rock-soil layers, which causes the stratigraphic displacement and then leads to subsidence and tilting of structures on the surface (Peng Huang, 2018; Qingliang Chang et al., 2014; R. Rankine et al., 2007). On the other hand, the collapse of the rock layers above the coal seam can cause the loss of groundwater (Bai E et al., 2018; Erhu Bai et al., 2019; F.P. Hassani et al.).



Fig. 1. The waste dump site at Mong Duong-Coc Sau mine: a. Foot of the waste dump site, b. The slope of waste dump site



Fig. 2. The fly ash of Mong Duong thermal plant: a. a whole scenery of the area containing fly ash at the Mong Duong thermal plant [21], b. Slag ash at the Mong Duong thermal plant [18]

The fill method is considered a green mining solution that can control the displacement of stratigraphy more thoroughly than other methods (Changxiang Wang et al., 2019; Liang Cui and Mamadou Fall, 1976; Von M.Eng. and Manoon Masniyom, 2009).

The filling rate is closely related to the shrinkage, and is an important indicator that affects the support of the suspended soil and rock parts on the wall of the coal seam. It has a direct effect on controlling the overload of pressure from the upper rock, preventing surface subsidence, and protecting the ecological environment and groundwater system (Dónal O'Sullivan and Alexandra Newman, 2014; Guo et al., 2014; Khaldoun Abdelhadi et al., 2018; Milena Kostović, 2019).

Under the same backfill condition, a higher backfill ratio leaves a smaller empty space, resulting in less bending strain at the top and better control of stratigraphic displacement. Conversely, a low backfill rate creates more spaces in the soil-rock area of the Gob, increasing the risk of breaking the original structure of the rock layers on the wall and reducing the efficiency of controlling stratigraphic displacement (Nagaratnam Sivakugan et al., 2015; Pengfei Zhang et al., 2019; R. Rankine et al., 2007).

One of the main issues promoting the support efficiency of fill materials in preventing the displacement of the upper stratigraphy is the shrinkage of the materials. During the process, a mixture of fill material and water is pumped into the underground mining space. When the heavy material settles, excess water drains or loses through seepage. Yanchun Yin and colleagues (2020) used tailings with the main component of dry sand that has chemical elements of Na, Mg, Al, Si, and others. The mixing ratios of cement and tailings were 1:4, 1:6, 1:8, 1:10, 1:12, and 1:15. Based on their experience, the researchers chose a ratio of 2/8 (i.e., 80% of tailings) and achieved the highest efficiency (Yanchun Yin et al., 2019).

Using the hydraulic transportation method with high water pressure, a mixture of material A, mainly including aluminate or additives, and material B, including gypsum, lime, and clay, is transported. Both materials A and B are added to a certain amount of water to make mortar. After mixing at the ratio of 1:1, the solidification time of the material can last from 8 to 90 minutes depending on the different content of additives. Compressive strength can also vary according to the different amount of water. For example, when the volume

of water changes in the range of 1.5 MPa (Bai E et al. 2018; Changxiang Wang et al. 2019). The slurry is formed by A or B maintaining for 30 to 40 hours without solidifying, while a mixture of A and B hardens rapidly (Erhu Bai et al. 2019; Guo et al. 2014).

The fill method with a mixture of soil-rock and water was used in 1991. This method was effective in preventing the subsidence of underground mines, especially when mining structures started to collapse. One of the limitations of this method is its expense, mainly due to the high cost of Portland cement. In 1995, a trial research about mortar determined that fly ash existing and available from specific sources in North Dakota could be used to partially replace cement in mortar mixture. This research created a cheaper mortar formula that had better handling properties and safety (Von M.Eng and Manoon Masniyom, 2009). Fly ash has about 80–90% glass that is made of molten clay, shale, limestone, and dolomite. These small spherical particles combine with calcium hydroxide to form calcium silicate hydrate as the main pastefill of cement. Fly ash is classified according to pastefill parameters by the American Society for Testing and Materials (ASTM). Fly ash is a pozzolan that forms cement-like compounds after mixing with lime and water (Changxiang Wang et al., 2019; Kambiz Tahzibi1 et al., 2016; Krzysztof Skrzykowski, 2018).

Specifications of fly ash include compressive strength, flowability, stability, force-resistance, lateral pressure, solidification time, bleeding and shrinkage, density, and permeability. The largest influence on the effectiveness of fly ash in a filling mixture is the spherical particle shape and the pozzolanic activity of fly ash with Portland cement. The development of strength in the filling mixture directly relates to the cement and water composition. Most mixtures with high fly ash content require only 3 to 5% Portland cement, depending on the dry amount of fly ash, to develop compressive strength from 500 to 1,000 kPa in 28 days, while mixtures with low fly ash content may not require Portland cement. When the amount of water increases in producing a more flowable mixture, the development of compressive strength can decrease (Changxiang Wang et al. 2019; Yanlong Zhou et al. 2020; Yue Zhao et al. 2019).

Using raw ash as a cementitious material and coal as a core material, an orthogonal experiment of the pastefill was performed in this study. The ratio of the original pastefill

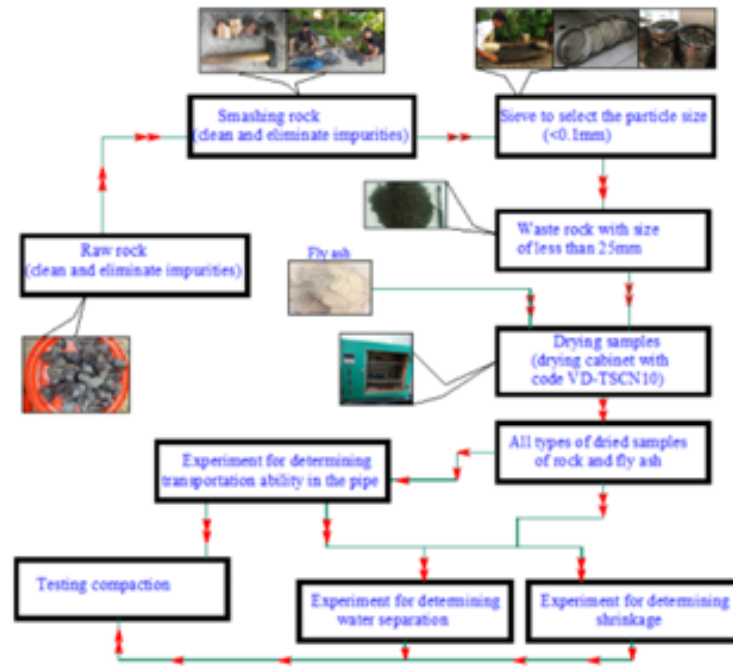


Fig. 3. The process of the sample preparation and experiment

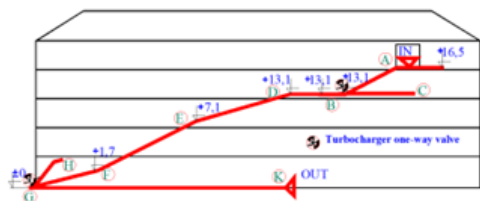


Fig. 4. Diagram of self-flowing generality transportation of backfill material



Fig. 5. Diagram of layout the points changing the flowing direction



Fig. 6. The area for the experiment of backfill materials transportation

(coarse ash) and coal particles (Factor A), the proportion of coal particles less than 5 mm (Factor B), and the amount of the pastefill (Factor C) are the three main factors. Factor A ranges from 1:1 to 1:3; Factor B ranges from 30% to 50%; Factor C belongs to the interval of 74% to 78% (Bai E et al. 2018; Yanchun Yin et al. 2019; Yue Zhao et al. 2019).

The development of flowable fill mixture directly relates to the composition of the fly ash and water. Flow can be measured by using a standard concrete slump cone, and the slump varies from 150 mm to 200 mm. For the flowable backfill mixture with a high amount of fly ash, the slump is at least 25

to 50 millimeters higher than the mixture with low fly ash at equivalent moisture. Additives, such as dehydrating agents, are hardly used in flowable buffer blocks (Yanchun Yin et al. 2019; Yanlong Zhou et al. 2020).

On the other hand, when the proportion of hard rock in the pipeline is too big, the hydraulic transportation can cause the pipeline to become clogged. Instead, the fill material transported into the gob area is mainly mud. This type of mud is difficult to fix and flow around, which reduces the efficiency of support for the upper roof. (Guo et al. 2014; Milena Kostović. 2019; Peng Huang et al. 2018). Therefore, if the fill

Tab. 1. List the parameters from the transport experiment

N°	Ratio		Minimum amount of water, %	Solvent density of fly ash and water after saturating, tons/m ³	Volume ratio of rock in the mixture, %
	a%	b%			
1	99	1	40.57	1.014	48.63
2	98	2	39.72	1.028	48.63
3	97	3	38.86	1.042	48.63
4	96	4	38.01	1.056	48.63
5	95	5	37.15	1.071	48.63
6	94	6	36.30	1.086	48.63
7	93	7	35.44	1.102	48.63
8	92	8	34.58	1.117	48.63
9	91	9	33.73	1.133	48.63
10	90	10	32.87	1.150	48.63
11	89	11	32.02	1.167	48.63
12	88	12	31.16	1.184	48.63
13	87	13	30.31	1.202	48.63
14	86	14	29.45	1.220	48.63
15	85	15	28.60	1.238	48.63
16	84	16	27.74	1.257	48.63
17	83	17	26.88	1.276	48.63
18	82	18	26.54	1.29	48.25
19	81	19	28.01	1.29	46.60
20	80	20	29.49	1.29	45.02
21	79	21	30.96	1.29	43.51
22	78	22	32.44	1.29	42.06
23	77	23	33.91	1.29	40.66
24	76	24	35.39	1.29	39.33
25	75	25	36.86	1.29	38.05
26	74	26	38.33	1.29	36.81
27	73	27	39.81	1.29	35.63
28	72	28	41.28	1.29	34.49



Fig. 7. Results of transport experiment in the pipeline: a. ratio of fly ash 18% < b < 30%, b. b < 18% và b > 30%

method is used, some indicators need to be established appropriately for (1) the ability of transportation in the pipeline, (2) the ability of separating water from the fill, and (3) the shrinkage of the fill.

2. SAMPLING AREA AND THE PROCESS OF SAMPLE PREPARATION

2.1 Introduction of the area for sampling waste rock

The waste dump at Mong Duong coal mine is planned in an area of 66,780 m². This is the place where collects waste rock from coal mining activities. The main ingredients are sandstone, siltstone, and pebbles (Fig. 1). The distribution about the size of rocks in the waste dump site is hardly similar. The surface is mainly dust, small-sized gravel and larger rocks are distributed along the slope

Results of analyzing the main mineral components are as follows: SiO₂ = 77.12%; Fe₂O₃ = 4.47%; MnO = 4.42%; Al₂O₃ = 9.4%; TiO₂ = 0.26%; K₂O = 1.67%; Na₂O = 0.16%; CaO = 0.84%; MgO = 0.80%; SO₃ = 0.02%. Other components, including stone and wood mulch, account for 1.27%.

2.2 Introduction of the area for sampling fly ash

Mong Duong Thermal Power Plant, which uses local coal as its source, annually consumes about 3.5 million tons of coal and generates approximately 1.3 million tons of slag ash. Of this, the bottom slag from the longwall amounts to 525,000 tons, or 40%, while the fly ash accounts for 787,500 tons, or 60%. A small portion of the slag ash is utilized as backfill material, while the rest is dumped in a designated disposal site.

Basic features of fly ash: The structure is a glass spherical molecule; Molecular size: 1.0 ~ 120/μm (Average input size: 20 ~ 30/μm); Fineness: 2400 ~ 4000 cm²/g; Main ingredients: SiO₂,

Al₂O₃, Fe₂O₃, these components are mainly soil and rock left due to no fire, existing in the components of coal before burning. The total amount of ash, slag, and gypsum stored at waste dumps 1 and 2 of the plant is 3,694,148 tons. The ash, slag, and gypsum are transported to the waste dump using the wet waste method. The size of wet slag is large, so it cannot be transported by pipeline and waste slag pumping system. Instead, the plant transports it by truck with a closed basket.

2.3 The process of the sample preparation

* Instruments preparation

- Set of sieving (the bottom compartment) with the size of hole: 100; 80; 60; 40; 20; 10; 5; 2; 1; 0.5; 0.25 and 0.1 millimeters;
- Types of scale:
 - + Scale for the volume up to 10 kg, accuracy of 5 g;
 - + Scales for volume of 5 kg, accuracy of 1 g;
 - + Scales for volume of 1 kg, accuracy of 0.1 g;
 - + the one for volume of 200 g and 500 g, accuracy of 0.01 g;
- Drying oven with temperature control part from 50 degree Celsius to 110 degree Celsius;
- Vibrating sieve machine;
- Thermometer with the measured value up to 50 degree Celsius, accuracy of 0.5 degree Celsius;
- Desiccator with anhydrous silicagel desiccant;
- Ground grinding equipment: porcelain mortar and pestle (the top of the pestle is covered with rubber);
- Soil trays with different sizes; enamel or porcelain bowl;
- Clean water (tap water) or distilled water;
- ray sprayers or pear-shaped rubber suction bottle (called rubber pears);
- Instrument for moisture determination

Tab. 2. The experimental results of determining water separation

N°	Ratio		water separation, cm ³ /(cm ² /s)	The height of the initial backfill block, mm	The height of the backfill block after experimenting, mm	percentage of shrinkage, %
	a% Percentage of waste rock	b% Percentage of fly ash				
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	99	1	0,017	92,89	64,88	30,15395
2	98	2	0,0159	92,88	64,56	30,49096
3	97	3	0,0148	92,85	63,89	31,19009
4	96	4	0,0136	90,65	62,65	30,88803
5	95	5	0,0122	91,88	64,88	29,38616
6	94	6	0,0113	90,58	65,58	27,59991
7	93	7	0,0102	89,69	65,69	26,75884
8	92	8	0,0093	91,14	70,14	23,04147
9	91	9	0,008	92,94	71,94	22,59522
10	90	10	0,0078	92,89	74,89	19,37776
11	89	11	0,0069	89,78	73,78	17,82134
12	88	12	0,0062	88,24	74,24	15,86582
13	87	13	0,0059	90,32	79,32	12,17892
14	86	14	0,0056	88,64	82,64	6,768953
15	85	15	0,0053	90,06	86,06	4,441483
16	84	16	0,005	88,6	84,6	4,514673
17	83	17	0,0047	91,09	85,09	6,586892
18	82	18	0,0044	93	86	7,526882
19	81	19	0,0042	89,89	82,89	7,787296
20	80	20	0,0039	90,75	82,75	8,815427
21	79	21	0,0036	92,33	83,33	9,747644
22	78	22	0,0033	92,31	83,31	9,749756
23	77	23	0,003	91,83	82,83	9,800719
24	76	24	0,0027	89,17	80,17	10,09308
25	75	25	0,0024	90,52	82,52	8,837826
26	74	26	0,0022	90,33	80,33	11,07052
27	73	27	0,0019	92	83	9,782609
28	72	28	0,0016	88,24	77,24	12,466
29	71	29	0,0013	89,37	78,37	12,30838
30	70	30	0,001	91,96	80,96	11,96172
31	69	31	0,0007	92,24	81,24	11,92541
32	68	32	0,0004	90,55	79,55	12,14798



Fig. 8. Experiment for determining the water separation of backfill materials

* Experimental sample preparation

The experiment was carried out at the laboratory of the Mining Department – Hanoi University of Mining and Geology, Vietnam, using fly ash, bottom ash from the Mong Duong thermal plant, and waste rock from Mong Duong and Coc Sau mines. The steps included cleaning the waste rock with water, then crushing it and classifying it with a sieve to choose particles with a size less than 25mm. If deployed in real mining operations in Quang Ninh, this particle size will allow the use of a jaw crusher machine in combination with a vibrating sieve to create products, and the cost for this production will be lower than using a ball mill. Samples of waste rock material after crushing and fly ash are taken into the drying oven to dry, respectively (Figure 3). The crushed waste rock is separated from the fly ash for ease of mixing in experiments.

Samples of rock and fly ash were mixed in ratios from 1/99 to 99/1 for the purpose of testing: (1) the ability of transportation in the pipeline, (2) the ability of separating water from the backfill, and (3) shrinkage of the backfill. In which the rock plays the role of the main fill material, bearing the

main pressure, the fly ash plays the role of a conductor (with water) in the pipeline, and the fly ash is used for filling into the space between the stones in order to improve compaction of the backfill before it is given to the fill area.

Thus, it is necessary to do three experiments with mixing ratios of rock (a) and fly ash (b) to find the appropriate a/b ratio that satisfies all 3 conditions (1), (2), and (3). Do 3 experiments simultaneously.

3. EXPERIMENT 1. DETERMINING THE TRANSPORTATION ABILITY OF THE FILL MATERIALS IN THE PIPELINE

Target: Determine the transportation ability of the mixture of rock, fly ash, and water in the pipeline. Prepare test samples with different mixing ratios and allow them to hydrate to saturation. Set up the pipeline with three sections of changing direction from a height of 16.5m to a height of 0m (see Figures 7 and 9). Install 3-pronged elbows and one-way valves at the places of direction change. The one-way valve will add pressure if the flow gets stuck at the place of direction change (see Figures 8 and 9).

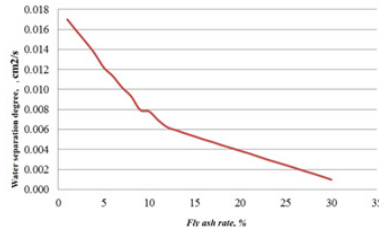


Fig. 9. Relationship between water separation and ratio of fly ash in the mixture

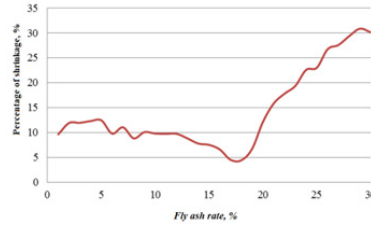


Fig. 10. Relationship between shrinkage and ratio of fly ash

In the implementation process, it shows that when the amount of fly ash is less than 18%, most of the samples cause pipe blockage. When water is added into the top of the pipe, the blockage happens at point B (elevation of 13.1m). Pressure is continually added by opening valve No. 1, the output is a suspension mixture (mainly water and fly ash, Fig. 4). Further experimenting with the ratios of fly ash from 18 to 30%, it shows that the mixture does not get stuck and the results are obtained as shown in Fig. 7a. When the amount of fly ash increases and the percentage of rock reduces, the mixture mainly consists of suspended ash and water with only a small amount of rock.

From the experiment, it is realized that when the ratio of a/b equals 82/18 and the minimum amount of water is used, the density of the mixture of water and fly ash reaches saturation of 1.29 tons/m³. However, when the natural height difference is 16.5 m, the tube gets stuck at turning point (B). This is due to insufficient pressure and the high density of a/b, which causes the heavy rock to sink quickly into the pipeline. Testing by adding water pressure at bends (D), (E), and (F) prevents pipe blockage, but the resulting product is a mixture of mud and water (Fig. 7b).

Case 1: The volume of fly ash is larger than the porosity of the rock ($b \geq 18\%$):

$$m \cdot \gamma_n = V_{\text{void}} = V_t^{vl} - V_s^{vl} = V_t^{\text{ash}} + V_s^{\text{rock}} - (V_s^{\text{rock}} + V_s^{\text{ash}}) = V_t^{\text{ash}} - V_s^{\text{ash}} = b \left(\frac{1}{\gamma_v^{\text{ash}}} - \frac{1}{\gamma_f^{\text{ash}}} \right) \quad (1)$$

$$\Leftrightarrow \frac{m}{\gamma_n} \geq b \left(\frac{1}{\gamma_v^{\text{ash}}} - \frac{1}{\gamma_f^{\text{ash}}} \right), \quad (2)$$

With “m” is ratio of water (according to weight) for transporting one material unit

Case 2: The volume of fly ash is smaller than the porosity of the rock ($b \leq 18\%$):

$$V_{\text{void}} = V_t^{\text{rock}} - V_s^{\text{rock}} - V_s^{\text{ash}} = a \left(\frac{1}{\gamma_v^{\text{rock}}} - \frac{1}{\gamma_f^{\text{rock}}} \right) - \frac{b}{\gamma_f^{\text{ash}}} \quad (3)$$

$$\Leftrightarrow \frac{m}{\gamma_n} \geq a \left(\frac{1}{\gamma_v^{\text{rock}}} - \frac{1}{\gamma_f^{\text{rock}}} \right) - \frac{b}{\gamma_f^{\text{ash}}}$$

Note: Choose $\gamma_n = 1$; $\gamma_v^{\text{rock}} = 1.24$; $\gamma_f^{\text{rock}} = 2.55$; $\gamma_v^{\text{ash}} = 0.522$; $\gamma_f^{\text{ro}} = 2.266$, tons/m³ (4)

When the mixture is saturated, the factors affecting the transportation process are the solvent density and the volume ratio of the rock.

- Solvent density: the higher the density of the fly ash water suspension is, the more it prevents the deposition of rock;

$$\gamma_{\text{solvents}} = (b+m)(b/(\gamma_r^{\text{ash}}) + m)$$

- The volume ratio of rock in the mixture: The smaller the volume ratio of rock is, the more beneficial transportation is:

$$+ \text{ Case of } b \leq 18\%: V_{\text{rock}}^{\%} = \frac{\gamma_v^{\text{rock}}}{\gamma_f^{\text{rock}}}$$

$$+ \text{ Case of } b \geq 18\%: V_{\text{rock}}^{\%} = \frac{a}{\gamma_f^{\text{rock}}} : \left(\frac{a}{\gamma_f^{\text{rock}}} + \frac{b}{\gamma_v^{\text{ash}}} \right)$$

Results of Experiment 1 determined that the ratio of $82/18 < a/b < 70/30$ is the effective transportation ratio both in terms of moving in the pipeline and the obtained mixture at the end of the pipe. Experimenting again at different ratios $a/b = 73/27-70/27$, i.e., the percentage of fly ash increased to 27–30%, the time of material transportation is about 95 seconds, the weight of the material that can be loaded is 0.02 m³, equivalent to a speed of 0.75 m/s and requiring 34 liters of additional water. The following experiments will confirm this ratio, no exceed 36 samples.

4. DETERMINATION OF THE SHRINKAGE RATIO AND WATER SEPARATION RATIO

4.1 Experiment 2. Determining the water separation ability of the mixture of rock and fly ash according to the mixing ratios

Target: Determining the water separation ability of the mixture of rock and fly ash and water with different a/b mixing ratios.

Prepare 36 samples for the experiment with ratios shown in table 2. Weigh the dry samples. Let the samples hydrate until saturation. Place these samples into PVC pipes with the same type and volume. Continuously pour an equal amount of water into the pipes (figure...), measure the time of draining from point 1 to point 2 (figure 8).

The experiment reached sample 32th, where it was found that when the mixing ratio a/b equals 68/32, the water separation gradually decreased to zero. The experiment was stopped because a larger fly ash ratio will be inappropriate to use in production reality. The water-filled block has poor water separation ability and the materials are easily transported to another place. Experiment results are shown in Table 1, column (4), and Figure 9. When the ratio of rock (a) is high, the water separation ability is better, and vice versa. If the proportion of rock is too high, then heavy materials will sink to the bottom of the pipe, causing blockage and making transportation difficult.

4.2 Experiment 3. Determining the shrinkage of the mixture of rock and fly ash after separating water

Target: Determining the volumetric shrinkage of the mixture of rock, fly ash, and water after water separation.

Prepare 100 samples of mixture of rock, fly ash, and water. Use the same type of PVC pipe with a height of 1 meter and a water filter at the bottom. Pour each sample into the PVC pipe and measure the height of the material in the pipe using a ruler with an accuracy of 0.1 mm. Then, pour water into the pipe as shown in Figure 4. Use a ruler to measure the subsidence of the backfill in the PVC pipe. The experimental results are shown in Table 2, columns (4), (5), (6) and Figure 10.

The experiment reached sample 36, which showed that when the mixing ratio a/b equals 64/36, the water separation gradually decreased to zero. The experiment was stopped because this ratio is not suitable with production reality. The water-containing backfill has poor water separation, making it easy for the material to flow to other places. When the ratio of rock (a) is high, the water separation is better, and vice versa. If the proportion of rock is too high, heavy materials sink to the bottom of the pipe, it will cause blockages and make transportation difficult.

The relationship for shrinkage ratio can be expressed as:

$$\text{shrinkage ratio (\%)} = \text{weight of water} / (\text{weight of solid} + \text{weight of water}) \quad (1)$$

When the proportion of fly ash is lower than the void in rock, the unfilled rock tends to be crushed by pressure, resulting in smaller particles and a reduced volume of the backfill. The optimal ratio is that the small particles fill all voids between the large particles. Volume of voids in rock:

$$V_{\text{void}} = \frac{a}{\gamma_v^{\text{rock}}} - \frac{a}{\gamma_r^{\text{rock}}} \quad (5)$$

The volume of fly ash in void:

$$b = 100 - a = \gamma_v^{\text{ash}} \times V_{\text{void}} \Rightarrow b = 100 \left(1 - \frac{1}{1 + \gamma_v^{\text{ash}} \times \left(\frac{1}{\gamma_v^{\text{rock}}} - \frac{1}{\gamma_r^{\text{rock}}} \right)} \right) \quad (6)$$

The relationship of shrinkage ratio is determined as follows: ratio of shrinkage (%) = weight of water / (weight of solid + weight of water) (1). If the proportion of fly ash has less volume than the void in rock, the unfilled rock tends to be crushed by pressure to create smaller particles and reduce the volume of the backfill. The right ratio means that the small particles fill all voids in the large particles.

Where a and b are respectively the ratio of rock and the ratio of fly ash (a+b = 100); $\gamma_v^{\text{rock}} = 1.20 \div 1.34 \text{ tons/m}^3$, $\gamma_v^{\text{rock}} =$

2.45 to 2.63 tons/m³, and $\gamma_v^{\text{ash}} = 0.52$ to 0.56 tons/m³ are the volumetric weight, private weight of rock, and volumetric weight of fly ash. Different proportions of rock (a%) and fly ash (b%) will have different shrinkage, as shown in Table 2. Formulas (2), (3), and Tables 2 and 6 show that when the ratio of fly ash is high, the deformation of the backfill does not change much. The fly ash particles are too fine, so there is no space to fill, and the volume of the backfill is stable. The disturbance of the backfill from sample 6 to sample 19 hardly has a clear rule between the mixing ratio a/b and the volumetric change in the presence of water. The reason is due to water that washes away the fly ash particles. In reality, with higher water pressure, if the fly ash ratio is too high, it will be difficult to form backfills due to being swept away by water in the process of water separation from the backfill.

5. RESULTS AND DISCUSS

The results of the water separation test show that the higher the ratio of rock to fly ash (a/b) is, the greater the water separation of the backfill is. When this ratio (a/b) equals 7/3, the mixture of fly ash and rock becomes viscous. The results of the shrinkage test show that the peak shrinkage occurs in case of that the ratio of fly ash accounts for 27% and the ratio of rock accounts for 73%. Therefore, in order to achieve optimal shrinkage, the suitable mixing ratio is between 27–30% of fly ash and 73–70% of waste rock.

The testing of transportation in the pipeline showed that when the height difference is 16.5 m without the addition of pressure, and the ratio of rock to fly ash (a/b) is 82/18, the tube is blocked in the first bend at a height difference of 13.1 m. After adding a pressure difference to the water, the obtained backfill material at the output is mainly a mixture of mud and water. When the percentage of fly ash increases 27–30%, the material transportation time is about 95 seconds, the volume of the loaded material is 0.02 m³, equivalent to a speed of 0.75 m/s, and requires over 34 liters of water (0.034 m³ of water). Thus, in the production reality, it is necessary to pay attention to adding pressure or pressurized water in the bends or calculate the capacity of the pump appropriately to avoid the blockage of pipes.

6. CONCLUSIONS

The chemical compositions of the waste rock and fly ash used as fill materials in Mong Duong, Cam Pha, Quang Ninh, Vietnam are safe and do not contaminate groundwater in the longwall. The optimal mixing ratio of materials that is suitable with transportation conditions in the pipeline is from 70/30 to 80/20. This mixing ratio helps to create a safe conductor in order to transport into the longwall without the risk of tube blockage. However, it is still necessary to add pressure at the turning bends during the transportation process.

When the optimal mixing ratio (70/30 to 80/20) is used for waste rock and fly ash in Mong Duong, Cam Pha, Quang Ninh, Vietnam, the shrinkage ranges is from 8.8% to 12.3%. After 48 hours, additional fill materials should be pumped into the longwall to achieve a higher anti-subsidence effect. It is also important to consider the mechanical and physical characteristics of the wall rock when calculating the backfill materials and determining the appropriate pump capacity and timing to maximize the effectiveness of the fill materials in preventing collapse of the wall rock.

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