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An experimental study on the use of fly ash for making concrete lagging of SVP steel arches in underground coal mines in Quang Ninh area

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ABSTRACT

In 2020, Vietnam has 25 thermal power plants in operation, emitting a total amount of fly ash and coal bottom ash of about 13 million tons/year. It makes increasing the costs of landfill space, and negatively affect the environment. The major goal of this study is to recommend an optimal amount of thermal power plant fly ash to be added to the concrete mix to create concrete lagging for the SVP steel arches of the underground coal mine in the Quang Ninh region. In order to lower the cost of drift support and improve the efficiency of environmental protection, fly ash is used in this study to make concrete lagging in place of cement to the extent of 30%. This study also demonstrates a recent development in the use of novel materials to construct rock/soil supports for underground mines in Vietnam. use of fly ash in concrete as a partial replacement for cement is more important today. The comparison of strength properties of concrete laggings by experimental study at the Laboratory of underground construction between two concrete lagging types at Hanoi University of Mining and Geology (HUMG) will show the benefits in terms of the strength of concrete lagging using fly ash. The paper also presents the results of an experimental study on using fly ash for making concrete lagging at the Laboratory. The comparison of the drift support using concrete laggings in SVP steel arches fly ash-made products and conventional underground mining support will aid in demonstrating the benefits of employing fly ash. From the study's findings, it can be inferred that fly ash can substitute cement in lower classes of construction concrete such as M200.

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1. Introduction

In Viet Nam, for Son La hydroelectricity, fly ash was used as roller-compacted concrete for unburned bricks and rural roads (Nguyen, 2007). However, they are still not being utilized in the underground coal mines' rock and soil support. Currently, concrete lagging with steel arches (SVP steel arches, I arches, U-shaped steel arches, etc.) are the largest proportion of the type of current structural support used in underground mining at Viet Nam National Coal - Mineral Industries Holding Corporation Limited (Vinacomin) (about 70÷80%). Concrete lagging is one part of rock/soil support of SVP steel arches in underground mines (Dang et al., 2019). They are responsible for closing the gap between the SVP steel arches in drift and the dug evenly distributing the pressure of rock and soil on SVP steel arches, preventing roof landslides and sidewalls. Selecting concrete lagging with a dimension of section: b.h = 150 × 50 (mm) with the length equal to the distance of SVP steel arches: L = 0.7 m; L = 0.9 m; L = 1.0 m depending on the characteristic of mine pressure where the drift thought rock mass (Dang et al., 2020). The calculation of the dimension of the cross-section of the concrete lagging is made by treating the as a beam on two supports in which the distance between two supports equals the distance of SVP steel arches. The SVP steel arches are located in the middle of the roof, subject to the uniformly distributed load of arches destroyed (Figure 1) (Pham et al., 2020). The typical structure of the concrete lagging is shown in Figure 2.

2. Methodology

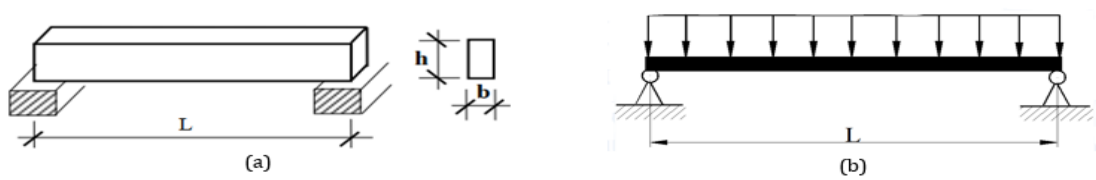


Figure 1. The calculation diagram of the concrete lagging in SVP steel arches. (a)The calculation model of concrete lagging in SVP steel arches; (b) Load diagram.

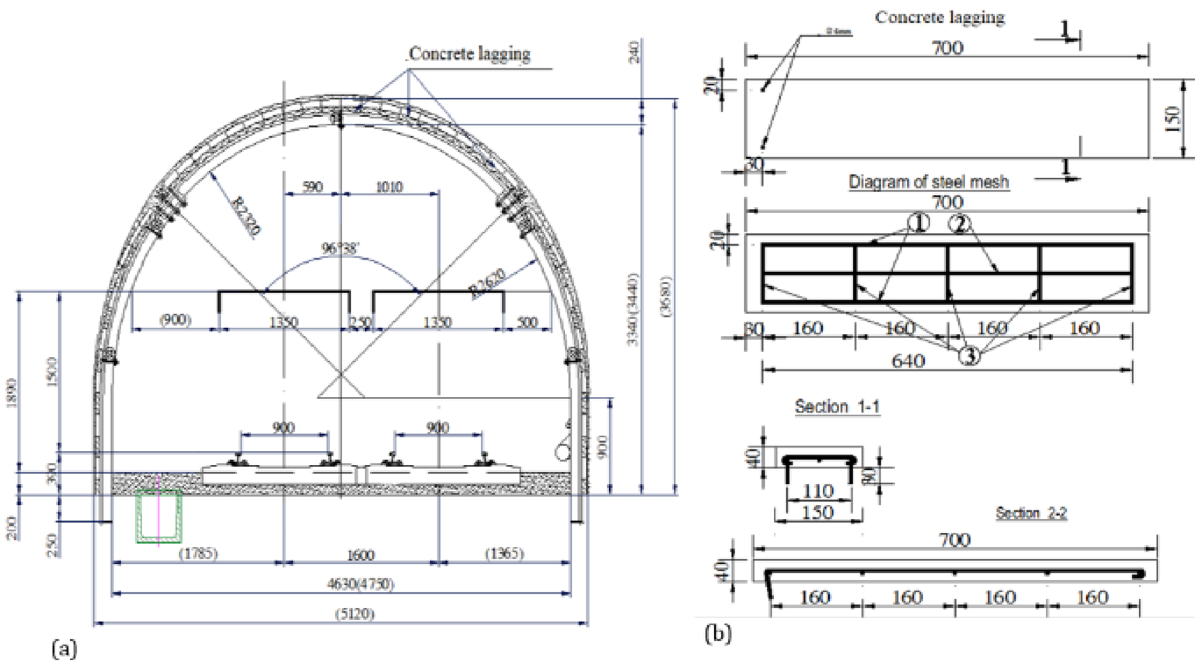


Figure 2. Structure of concrete lagging with length L = 0.7 m in Ha Lam coal mine, Quang Ninh. (a) The concrete lagging in SVP steel arches at a drift; (b) The structure of concrete lagging.

2.1. Material

Advantest 9 (Control- Italy) system tests were conducted in the construction laboratory at the Ha Noi University of Mining and Geology (HUMG) (Figure 3). The following materials are utilized in experiments**:**

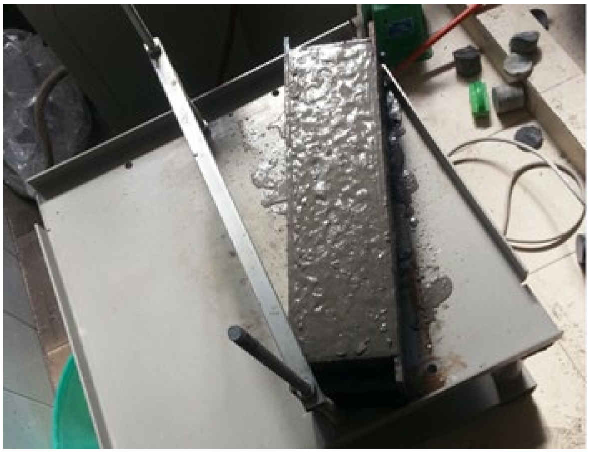


Figure 3. Specimen ready for tests on flexural strength values.

Cement: Regular Portland cement (PCB 40 Nghi Son) with a specific gravity of 3.10, a consistency of 31.5 percent, and a compressive strength of 40 MPa was utilized.

Fly ash: Fly Ash is created during the burning of pulverized coal and is transferred through boiler flue gases. It was acquired from the Pha Lai thermal power plant in Quang Ninh, Vietnam, dried, and then used.

Fine Aggregate: Natural sand with a maximum grain size of 4.75 mm and specific gravities of 2.55 and 2.61 was employed (by standard TCVN 7572-2006).

Coarse Aggregate: At the rock mine in Hoa Thach, Quoc Oai, and Ha Noi, natural aggregates with a maximum size of 20 mm and specific gravities of 2.68 and 7.5 were employed;

Water: Concrete was prepared using drinking water from HUMG. The consistency of the quality and the potability of the water samples.

Activity additive - Fly ash for concrete, mortar, and cement was used in the concrete mix design, which was completed in accordance with TCVN 10302:2014. (IS 3812-2003).

2.2. Mix Design

In this study, the chosen characteristic strength of 30 N/mm^2 at 28 days was applied. According to TCVN 10302:2014, the concrete mix was created for the M200 grade. For this study, 5 sets of 45 cubes and 30 beams in total were constructed. All sets were created using a control mixture with a 0.42 water-to-cement ratio (see Table 1). At ages 7, 14, and 28 days, three samples from each batch of the mix were examined for compressive strength, and at ages 7 and 28 days, for flexural strength (Tipraj et al., 2019; Rajamane et al., 200; Dwivedi and Jain, 2014; Tipraj et al., 2019; Patil, 2017; Tiwari., 2016).

Preparation of Specimen: A motorized mixer with a mix design ratio of 1:1.27:2.83 and a consistent water-cement ratio of 0.42 was used to prepare all concrete mixtures (TCVN 3118: 1993). Cube specimens measuring 150x150x150 mm and beam specimens measuring 100x100x500 mm are created (Figures 3 and 4). At a temperature of 30^{0}C and relative humidity of 90%, the specimens were cured. Concretes made with a fly ash mix were evaluated at 28 days old to determine their compressive strength for 28 days. Table 2 gives specifics on the specimens that were made for the test. Tests were conducted at HUMG using the Advantest 9 (Control- Italy) system (Figure 5). Tables 3 and 4 provide details on the compressive strength and flexural strength test findings. Figure 6 is findings demonstrate that when fly ash content rises, concrete's workability declines because less water is needed to achieve a given slump thanks to the fly ash's particle size. Fly ash particles have features that reduce water absorption due to their circular shape and dispersiveness. Figure 7 depicts the results of a compressive strength test on a concrete mixture containing various amounts of fly ash. The results in Figures 7 and 8 also demonstrate that compressive strength and flexural strength both increase as fly ash content is increased in concrete up to a 30% replacement of cement in the conventional mix; however, the percentage increase of compressive strength is greater than the percentage increase of flexural strength at about 2,8% at this level of cement replacement (Figure 9). The characteristics of fresh concrete have significantly varied as a result of the addition of fly ash to the traditional concrete mix.

Table 1. Compare the two approaches for using M200 concrete mixtures to create concrete lagging for SVP steel arches in underground mines.

Materials	Traditional concrete mixture	Fly ash is added to a concrete mix to create concrete lagging.
Cement PCB 40 (kg)	312.0	193.83
Coarse aggregate (kg)	1251.0	1216.0
Fine aggregate (kg)	540.0	568.7
Water (liter)	195.0	195.0
Fly ash (kg)	0.0	83.07
Plasticizer additives (kg)	0.0	3.87
Total: Fly ash plus coarse aggregate plus fine aggregate plus cement; (kg)	2298.0	2260.47
Cement savings: 312-193.83 = 118.17 kg/m^3 also, the weight is lower: 37.3 kg/m^3;		

Table 2. Specifications of the samples prepared for testing at the HUMG construction laboratory.

No	Information on the Cube Specimen			Information on the Beam Specimen			Slump Value (%)
	Name of Cube Sample	Fly Ash (%)	Weight of Fly Ash in Mix (gam)	Name of Beam Sample	Fly Ash (%)	Weight of Fly Ash in Mix (gam)	
1	C 0	0	0	B 0	0	0	40
2	C 10	10	156	B 10	10	235	38
3	C 20	20	312	B 20	20	470	35
4	C 30	30	468	B 30	30	705	32
5	C 40	40	624	B 40	40	940	30

Figure 4. Curing of concrete cube.

Table 3. Results of compression strength tests

N^o	Name of Cube Sample	Fly Ash (%)	28 Days Strength, N/mm^2 (Three samples' average)
1	B 0	0	40.15
2	B 10	10	39.60
3	B 20	20	41.15
4	B 30	30	43.19
5	B 40	40	40.28

Table 4. Results of the flexural strength test.

N^0	Name of Beam Sample	Fly Ash (%)	28 days Strength, N/mm^2 (Three samples' average)
1	B 0	0	6.17
2	B 10	10	6.20
3	B 20	20	6.33
4	B 30	30	6.42
5	B 40	40	6.16

(a) (b)

Figure 5. Compressive strength test on a cube sample performed at HUMG using the Advantest 9 (Control-Italy) instrument..

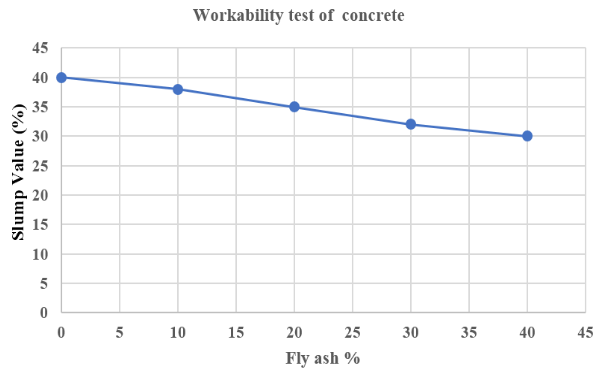


Figure 6. Workability evaluation of concrete with various levels of fly ash.

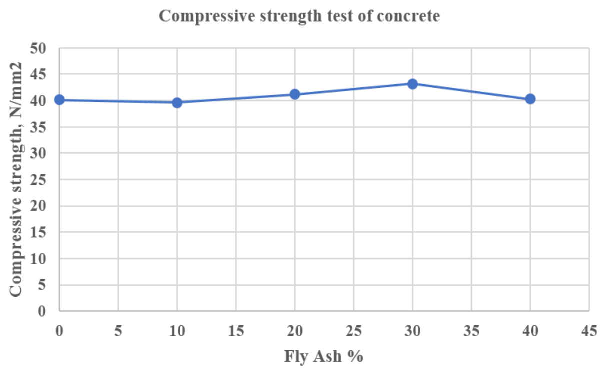


Figure 7. Concrete mixtures with varying amounts of fly ash were tested for their compressive strength..

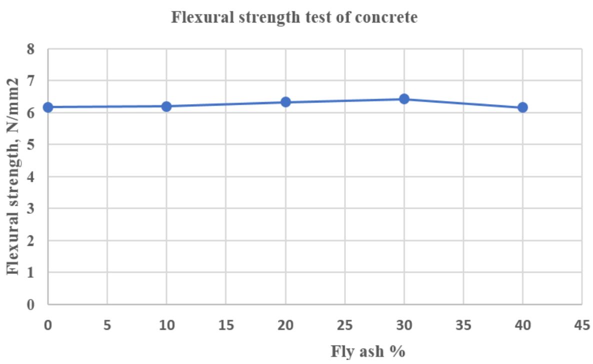


Figure 8. Flexural testing of concrete mixes with various amounts of fly ash.

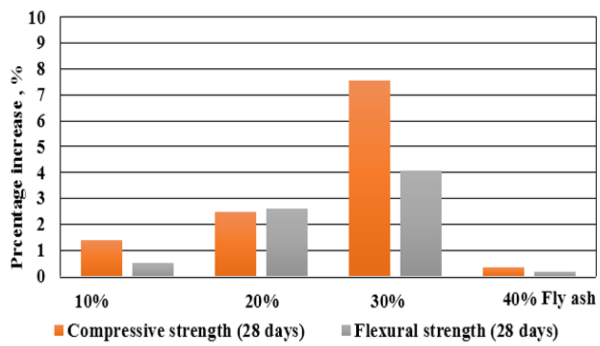


Figure 9. Using varied Fly Ash percentages, I increased my strength over the course of 28 days.

concrete. The addition of fly ash to concrete improved the mix's cohesion, prevented segregation, and reduced bleeding. The color of the mixture may alter if fly ash is added at higher concentrations. Fly ash can reduce disposal costs for the coal and thermal industries and provide green concrete for underground construction. The outcome in Figures 8 and 9 demonstrates that the concrete cubes' compressive strength had been evaluated at a 28-day interval. The strength appears to rise as fly ash content rises, but once cement replaced 30% of the fly ash, the strength appears to fall. Concrete's flexural strength is assessed every 28 days, and it appears that the strength is growing, maybe reaching 30% replacement. In terms of strength variation, compressive strength predominates over flexural strength.

3. Experimental study on concrete lagging

Determine the aggregate composition for 1 m^3 of concrete M200 used to make concrete lagging based on the research results mentioned above (Table 1). When calculating mortar concrete mix for M200 concrete lagging using fly ash instead of a part of cement in concrete gradation the research team has compared the results of two alternatives. Thus, from the total weight between the two methods of concrete mix, we can realize that the use of fly ash to replace a part of cement will be saved in cement 312-193.83 = 118.17 kg/m^3 and 37.3 kg lighter than normal concrete grade. Control concrete lagging is marked in dimension b x h = 150 x 50 mm. The fly ash concrete lagging is made in dimension b x h = 150x40 mm (Table 5 and Figure 10).

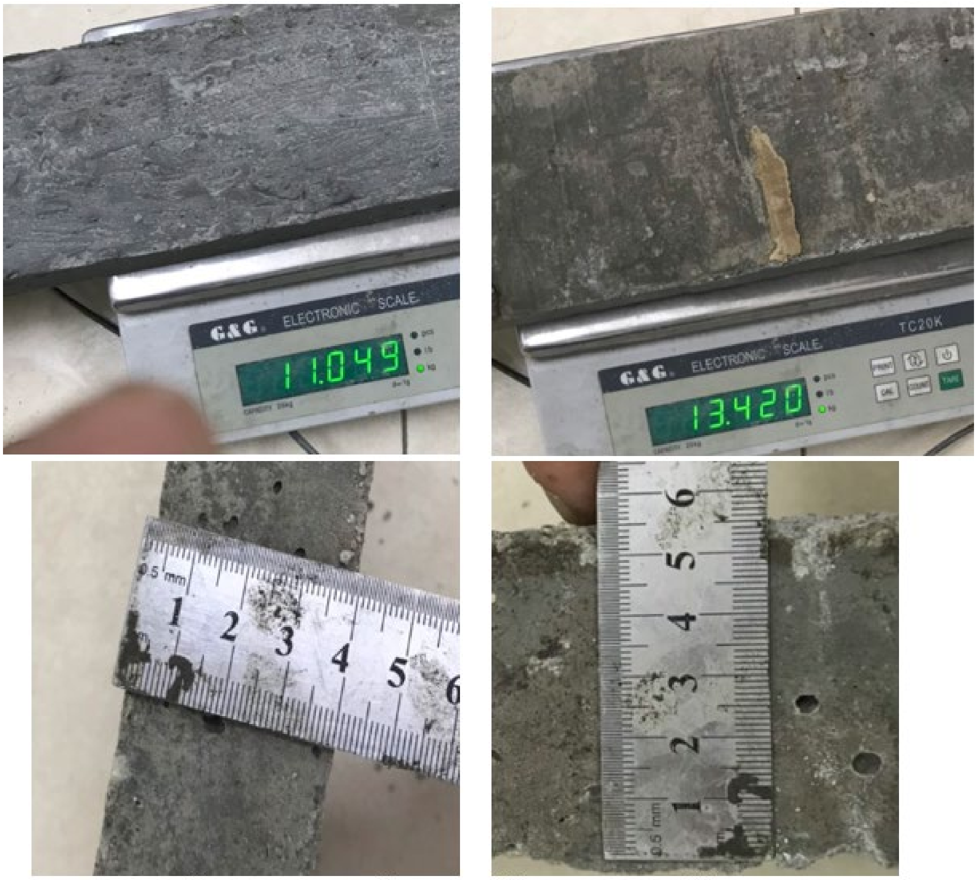
The final fly ash concrete lagging weighs roughly 2 kg less than the control lagging in the same M200 (Figure 11). Transporting a lot of concrete lagging into deep underground mines in Quang Ninh makes sense. In this section, an experimental examination of the load capacity, expansion cracks, etc. on a concrete lagging plate is conducted by Advantest 9 (Control- Italy) in the construction laboratory (HUMG) (Figure 12). Figures 13÷15 show the expansion fractures of concrete lagging versus maximum load. Fly ash concrete lagging has greater expansion fractures in 5÷7 days than standard concrete lagging with the same M200 grade. Fly ash concrete's crack expansion accelerated in the range of 5÷7 days but slowed down from 7÷28 days. When compared to the control concrete lagging after 14 days, the fly ash concrete lagging's expansion cracks shrank, but the overall value of the concrete lagging increased. Figure 16 shows the progression of concrete lagging displacement over time.

In 5÷7 days, fly ash concrete lagging displaces more than standard concrete lagging with the same M200. Fly ash concrete displacement is somewhat raised between 5 and 7 days, however it is lowered between 7 and 28 days. After 14 days, the fly ash concrete lagging's displacement significantly decreased as compared to the control concrete lagging, and this value of concrete lagging generally increased.

Table 5. Summing of main material for a concrete lagging with L= 0.7 m, bxh = 150x40 mm.

No	Details of Cube Specimen			Details of Beam Specimen			Slump Value (%)
	Name of Cube Sample	Fly Ash (%)	Weight of Fly Ash in Mix (gam)	Name of Beam Sample	Fly Ash (%)	Weight of Fly Ash in Mix (gam)	
1	C 0	0	0	B 0	0	0	40
2	C 20	20	312	B 20	20	470	35

Figure 10. Concrete lagging.



(a) Concrete control lagging (b) Concrete control lagging

Figure 11. Dimension of concrete lagging.

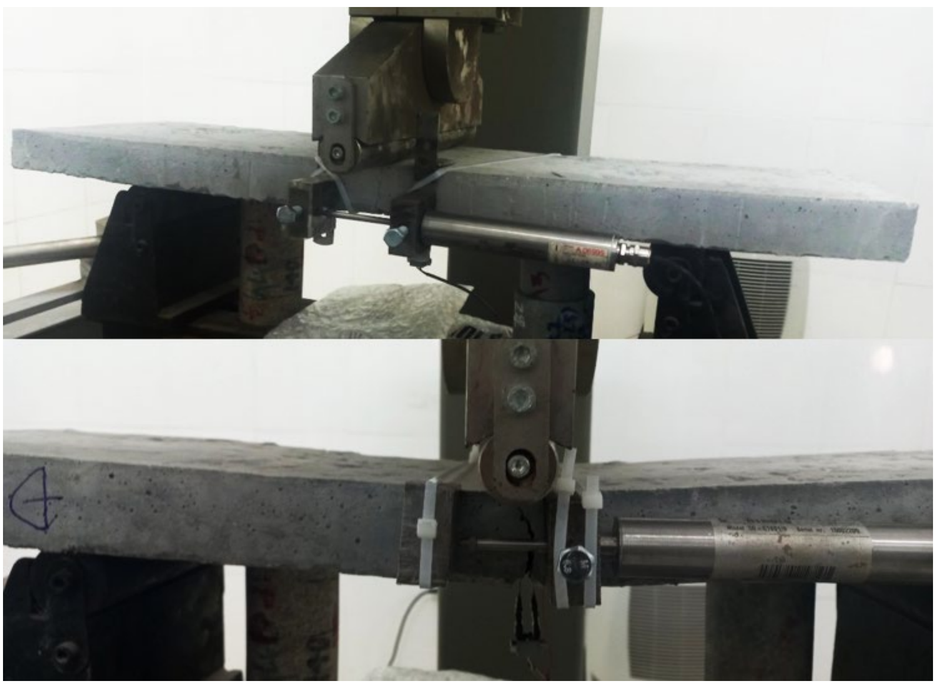


Figure 12.Test concrete lagging.

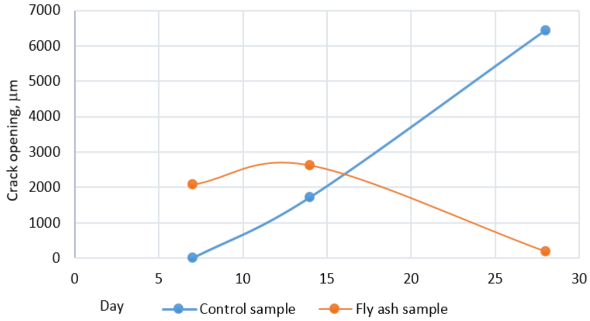


Figure 13. Expansion cracks of concrete lagging versus time.

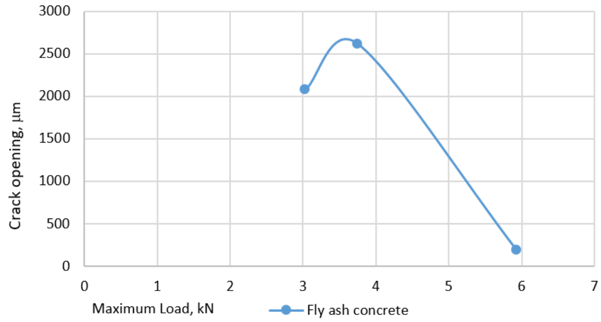


Figure 14. The expansion cracks of concrete lagging versus maximum load in control samples.

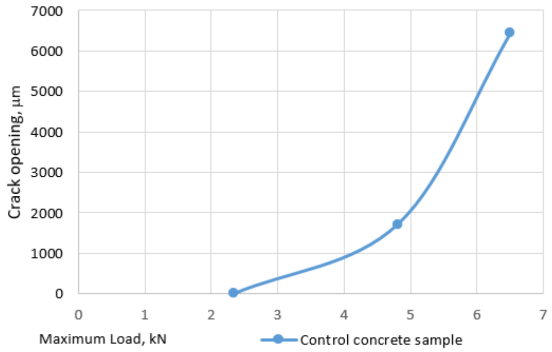


Figure 15. The expansion cracks of concrete lagging versus maximum load in Fly ash concrete.

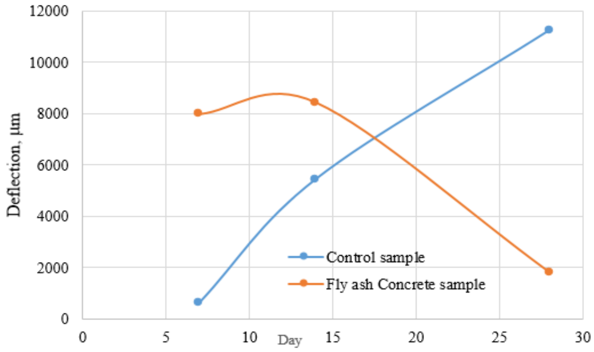


Figure 16. Displacement of concrete lagging versus time.

The above results can be explained by the fact that fly ash concrete has a lower cement content, so the early workability is worse than that of normal concrete of the same strength. It also makes to the extent that the expansion cracks are higher and the deformation capacity is greater. It is quite consistent with the characteristic of increasing the load of stability drifts located at great depth in Quang Ninh

4. Conclusions

In this study, an experimental study on concrete lagging at Construction Laboratory (HUMG) is carried out. Some interesting conclusions arising from the experimental study are given in the following points:

- By replacing up to 30% of the cement with an unusual cement mix, fly ash increases the concrete's compressive and flexural strengths.

- We can see that using fly ash in place of some cement can make concrete lagging for SVP steel arches in underground mines 37.78 kg lighter than standard concrete grade and save 118.17 kg of cement, etc.

- The concrete lagging is lighter than the control concrete lagging in the same grade. It really makes sense to transport a large amount of concrete lagging into great depth in underground mines in Quang Ninh.

- The expansion cracks and displacement of fly ash concrete lagging are higher than that of regular concrete lagging with the same M200 grade during 7÷14 first days but it is decreased from 7÷28 days. The above results can be explained by the fact that fly ash concrete has a lower cement content, so the early workability is worse than that of normal concrete of the same strength.

- Higher grades of concrete or the incorporation of such waste materials could be the subjects of future study to improve strength.

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Author Contributions

Kien Van Dang - collecting documents and writing the manuscript, experimental study; Hung Trong Vo - collecting documents, editing manuscript; Hao Doan Ngo - collecting documents; Huy Xuan Tran - collecting documents and writing the manuscript.

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