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Innovative Geosciences, Circular Economy and Sustainability

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RESEARCH ON THE USE COAL BOTTOM ASH FROM THERMAL POWER PLANTS FOR MAKING CONCRETE LAGGING AT UNDERGROUND MINES IN QUANG NINH COAL AREA

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Abstract: In 2020, Vietnam has 25 thermal power plants in operation, emitting a total amount of Fly Ash (FA) and Coal Bottom Ash (CBA) about 13 million tons/year, of which fly ash accounts for 80% to 85%. FA and CBA increase costs of landfill space, and negatively affect the environment. The main objective of this research is to propose an optimized proportion of the CBA of thermal power plants used in concrete mixture on making concrete lagging in SVP steel arches of the underground mine in Quang Ninh coal area. In our above study, FA has used 30% replacement of cement in fresh concrete and in making concrete lagging. This study also shows that the new trend study in using new material to make rock/soil support in the underground mines in Quang Ninh in Viet nam. The mechanical test was conducted on CBA concrete. Before starting the mechanical test, cubic and cylindrical specimens with dimensions measuring 150x150x150 mm and 150x150x600 mm were produced based on the percentage of CBA in this study which is 0% as the control specimen. Mean while 10%, 20%, 30%, 40%, 50% of CBA were used to replace the sand in the mix and curing for 7 days, 14 days, 28 days, and 56 days respectively to maintain the rate of hydration and moisture. After the test work was done, it can be concluded that the optimum percentage of CBA as sand is 40%. This paper also presents results on an experimental study using CBA for making concrete lagging with 40% as sand at Construction Laboratory at HUMG. From the result of this study, it can be concluded that sand replacement by CBA is useful in lower grades of concrete such as M200 in making laggings of SVP steel arches of the underground mines in Quang Ninh coal area and protecting the environment.

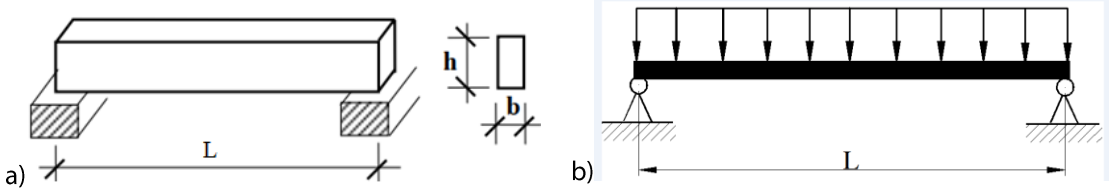
Keywords: Coal bottom ash; Concrete lagging; Drift; SVP steel arches; Experimental study.

1. INTRODUCTION

In Viet Nam, the ash will be increased from 61 million tons in 2018 to 109 million tons in 2020, 248 million tons in 2025 and 422 million tons in 2030 (Nguyen Quang Chieu, 2011); (Hong Ha Thi Vu, and Ji Whan Ahn, 2018). Some of the factors that make utilization of FA and CBA is not increasing at desired rate are he lack of awareness of coal ash properties; non-availability of dry fly ash and bottom ash, the lack of proper coordination, easy availability of top soil and ariations in the quality of CBA.

In addition, FA and CBA still have not been used for making the rock/soil support of underground coal mines. Now, in Vietnam national coal - mineral industries holding corporation limited - Vinacomin, concrete lagging with steel arches (SVP steel arches, I arches, U- shaped steel arches, etc.) are the biggest proportion of the type of current structural support (about 70-80% of all support type). Concrete lagging is one part of rock/soil support of SVP steel arches in underground mines (Dang Van Kien et al., 2019) (Figure 2). 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 the dimension of section:

b.h = 150 × 50 (mm) and 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 Van Kien et al., 2020); (Pham Tuan Anh 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 adjacent 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 (see Figure.1) (Dang Van Kien et al., 2019); (Van Kien Dang et al., 2020); (T.H. Vo, et al., 2020). The typical structure of the concrete lagging is shown in Figure 2. Bottom ash forms up to 25% of the total ash while the fly ash forms the remaining 75%. One of the most common uses for bottom ash is as structural fill. In Viet Nam, CBA just used to use as backfill material (TCVN12249:2018). The study results in (Ahmad Maliki et al., 2017) showed that the optimum percentage of CBA as a fine aggregate replacement is range of 40% - 70%. Singh, M., and Siddique, R. (2015) concluded that up to 50% replacement level, coal bottom ash can be used as fine aggregate in concrete. CBA is the potential viable material to be used as fine aggregate to produce durable concrete. However, there are not much researchs on using CBA for making rock/soil structures in underground mines. In this study, effect of coal bottom ash as partial replacement of sand on properties of concrete is carried out by experimental study. By the the optimum percentage of CBA as sand, the concrete lagging is made to mechanical test.



a)The calculation model of concrete lagging in SVP steel arches; b) Load diagram

Figure.1. The calculation diagram of the concrete lagging in SVP steel arches.

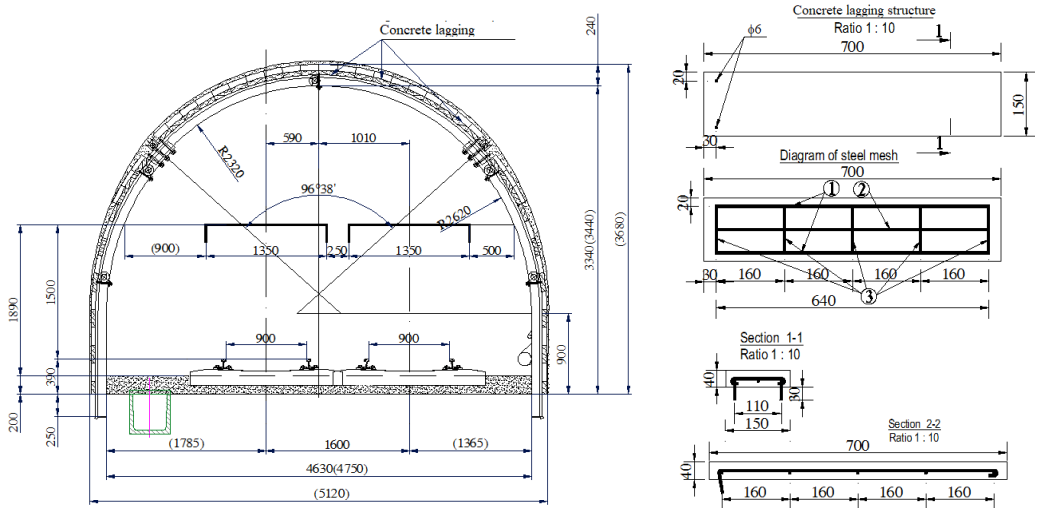
2. MATERIALS AND METHODS

2.1. Material

The test was carried out in the Construction Laboratory of Ha Noi University of Mining and Geology (HUMG) by Advantest 9 (Control- Italy) system (see on Figure.6). Materials used in tests are as under:

Cement: Ordinary Portland cement (PCB 40 Nghi Son) was used having specific gravity: 3.10, 31.5% Consistency, and compressive strength 40 MPa.

Coal Bottom Ash: CBA is a hazardous by-product from coal-based Pha Lai, Quang Ninh, Vietnam thermal power plants. The properties of bottom ash are given in Table 1.



a) The concrete lagging in SVP steel arches at a drift; b) The structure of concrete lagging

Figure 2. Structure of concrete lagging with length L = 0.7 m in Ha Lam coal mine in Quang Ninh.

Table 1. Physical Properties of CBA (Viet Hung Le, el al., 2020)

N0	Properties of CBA	Values
1	Specific gravity	2.12
2	Bulk density (g/cc)	0.642-0.747
3	Fines modules	6.28
4	Maximum dry density (kN/m^3)	7.20
5	Water absorption (%)	14.10
6	Sizes produced (mm)	3.40-4.75
7	Aggregate impact value (%)	18.25
8	Aggregate crushing strength (%)	19.30
9	Aggregate abrasion value (%)	30.12

Fine Aggregate (Sand): Natural sand with a maximum size of 4.75 mm was used with specific gravity 2.55 and fineness modulus 2.61 (by standard TCVN 7572-2006) as Table .2.

Coarse Aggregate: Natural aggregates with a maximum size of 20 mm at Hoa Thach - Quoc Oai - Ha Noi city rock mine were used with a specific gravity of 2.68 and fine modulus of 7.5;

Water: Drinking water from HUMG was used for the preparation of concrete. The quality was uniform and the water samples were potable.



Figure 3. CBA in Pha Lai, Quang Ninh province.

The concrete mix was designed for M200 grade and the mix design was done (TCVN 10302:2014): Activity admixture - FA for concrete, mortar, and cement.

Table 2. Physical Properties of sand

No	Physical Property	Test Result
1	Fineness modulus	2.40
2	Specific Gravity	2.65
3	Bulk Density(g/cc)	1.53-1.58
4	Water Absorption (%)	0.72

2.2. Mix Design

The preferred characteristic strength of 20 MPa at 28 days was used in this study. The concrete mix was designed for M200 grade and the mix design was done as per (TCVN 10302:2014). A total of 45 cubes and 15 beams were prepared for this study in 5 sets. Cube of size 150 mm × 150 mm × 150 mm of each concrete mixture were cast for determining the compressive strength. All sets were prepared in a control mix of water-cement ratio 0.45. In this study, three samples from each set of the mix were tested at the age of 7, 14, 28 and 56 days for compressive strength and 28 days for flexural strength.



Figure 4. Specimen prepared for flexural tests.

Table 3. Details of cube specimens prepared for compressive test

Name of Cube Sample	Percent (%)	CBA (kg)	Cement (kg)	Water (kg/L)	Sand (kg)	Coarse aggregate (kg)
C 0	0	0	4.85	2.45	5.94	11.10
C 10	10	0.31	4.85	2.45	5.35	11.10
C 20	20	0.62	4.85	2.45	4.75	11.10
C 30	30	0.93	4.85	2.45	4.16	11.10
C 40	40	1.24	4.85	2.45	3.56	11.10
C 50	50	1.55	4.85	2.45	2.97	11.10

Preparation of Specimen: All concrete mixes were prepared using a motorized mixer of mix design proportion, 1:1.27:2.83 with a constant water-cement ratio of 0.45 (TCVN 3118 : 1993). Cube specimens are prepared of size 150 mm×150 mm×150 mm and beam specimen of 100 mm×100 mm×600 mm (see on Figure.4 and Figure.5). CBA mix concretes were tested at 7, 14, 28, 56 days to get compressive strength for 28 days of age for flexural strength values. Details of specimens prepared for the test is described in Table 2 and Table 3. A three-point load method was used to measure the flexural strength of bottom ash aggregate concrete (TCVN 3118 : 1993).

Table 4. Details of beam specimens prepared for flexural test

Details of Beam Specimen			Slump Value (mm)
Name of Beam Sample	CBA (%)	Weight of CBA in Mix (gam)	
B 0	0	0	60
B 10	10	235	58
B 20	20	470	55
B 30	30	705	50
B 40	40	940	50
B 50	50	1175	40



Figure 5. Curing of Concrete Cube.

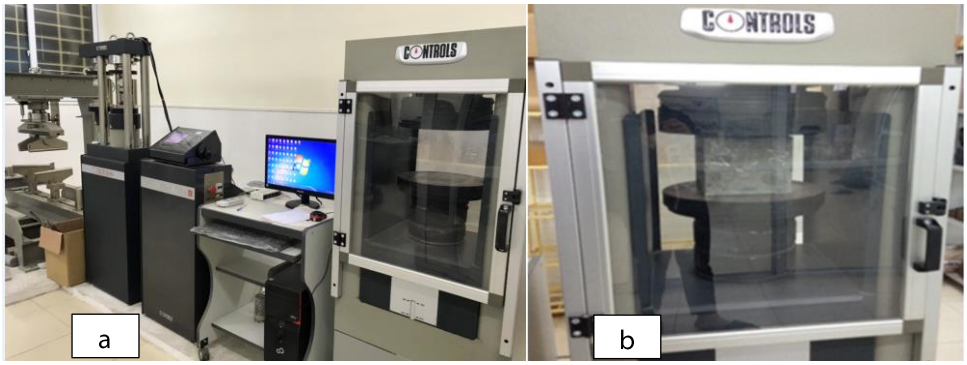


Figure 6. Compressive strength test on the cube sample by Advantest 9 (Control-Italy) system in HUMG.

3. Results and discussion

3.1. Test results of compressive strength and Flexural strength

Test results of compressive strength and Flexural strength are described in Table 4 and Table 5. The results in Figure. 7 show that the workability of concrete decreases with the increase in CBA, the particles of CBA reduce the amount of water required to produce a given slump. The circular shape of the CBA particles and their dispersive ability provide

water-reducing characteristics. Result of compressive strength and flexural strength in tests of concrete mix with different percentages of CBA is shown in Figure 8 and Figure 9. The result in Figure.8 and Figure.10 shows that the compressive strength test of concrete mix with different percentages of CBA on the concrete cubes had been tested at an interval of 7, 14, 28, and 56 days. It seems that the strength goes on the increase with the increase in CBA but after the replacement of 40% CBA with sand the strength decreases.

For flexural test beams of 150×150×60 (TCVN 3118 : 1993) cubic mm size was adopted. The load was applied without shock and was increased until the specimen failed, and the maximum load applied which is on the meter to the prism during the test was recorded. The appearances of the fractured faces of concrete failure were noted. The flexural strength of concrete is tested at the interval at 28 days and it seems that flexural strength goes on increase up to 40% replacement. The strength variation is more compressive as compared to flexural strength (Figure 9).

Table 5. Compressive Strength of Concrete with Coal Bottom Ash

Days	0% CBA (MPa)	10% CBA (MPa)	20% CBA (MPa)	30% CBA (MPa)	40% CBA (MPa)	50% CBA (MPa)
7	16.492	18.69	19.64	22.19	22.48	19.88
14	19.726	21.66	22.48	23.44	24.35	21.24
28	21.28	22.68	23.38	24.619	25.34	22.55
56	23.009	24.66	25.69	26.71	27.42	23.34

Table 6. Flexural strength at different ages (MPa)

Days	0%CBA (MPa)	10% CBA (Mpa)	20% CBA (MPa)	30% CBA (MPa)	40%, CBA (MPa)	50% CBA (MPa)
28	3.40	6.25	7.66	8.70	9.04	7.40

The result in Figure 9 and Figure.11 shows that the flexural strength also increases with the increase of CBA in concrete up to 40% replacement with sand in the conventional mix, however, the percentage increase of flexural strength more than compared to the percentage increase of compressive strength (see Figure.10 and Figure 11). Mixing of CBA in the concrete conventional mix has resulted in considerable variation in the properties of fresh concrete. Integration of CBA in concrete increased the cohesiveness of the mix, prohibited segregation, and resulted in reduced bleeding. Higher percentages of CBA can cause a change in the color of the mix. The incorporation of CBA in concrete can save the coal and thermal industry disposal costs and produce green concrete for underground construction. BCA is the potentially viable material to be used as fine aggregate to produce durable concrete. Its use as fine aggregate in concrete will help in alleviating the potential problem of dwindling natural resources. Its use will also help in protecting the environment surrounding the thermal power plants.

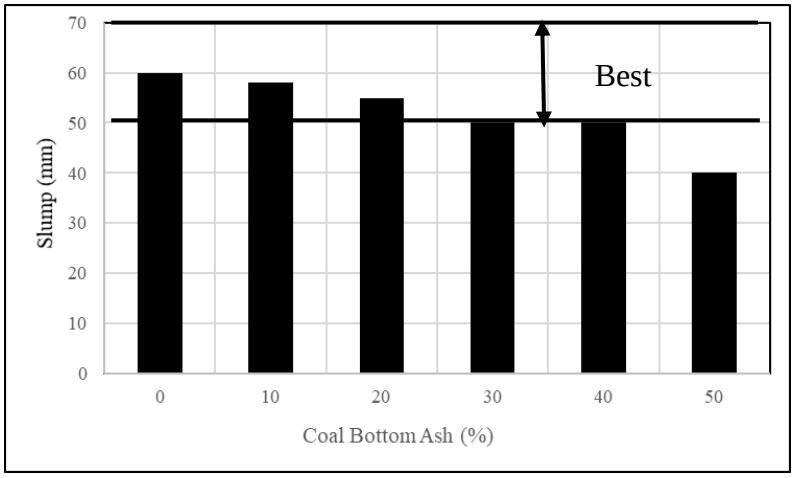


Figure 7. Workability test of concrete mix with different percentages of CBA.

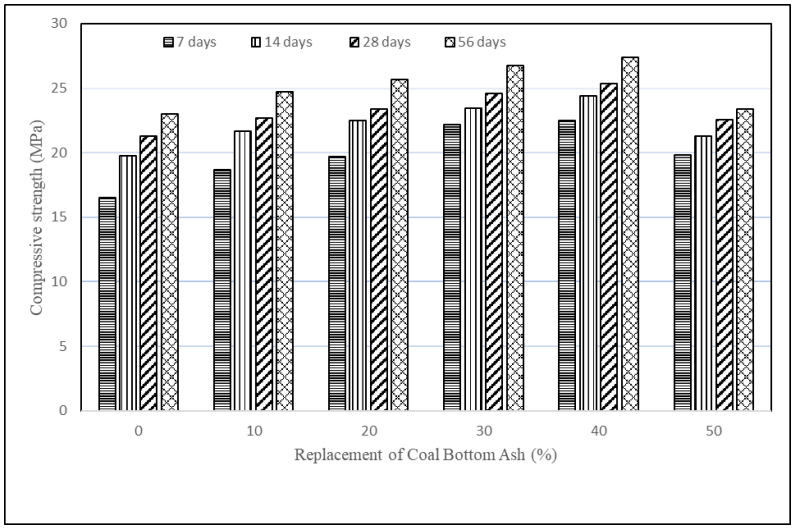


Figure 8. Compressive strength test of concrete with different percentages of CBA.

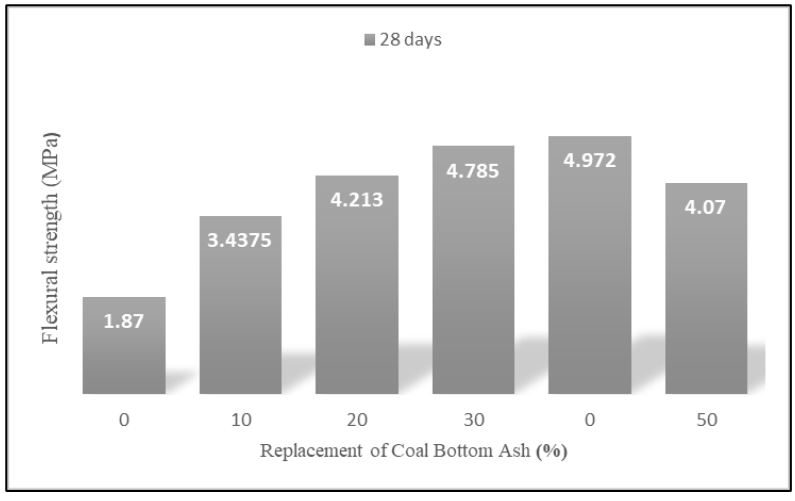


Figure 9. Flexural strength test of concrete with different percentages of CBA.

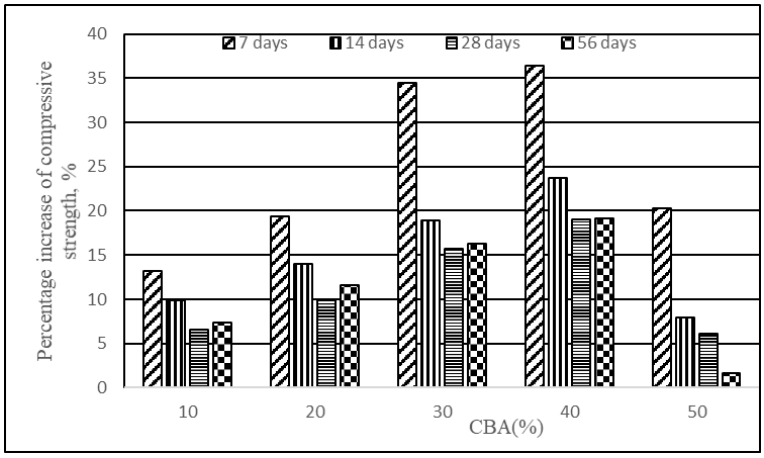


Figure 10. Percentage increase of compressive strength with different percentages of CBA at 28 days.

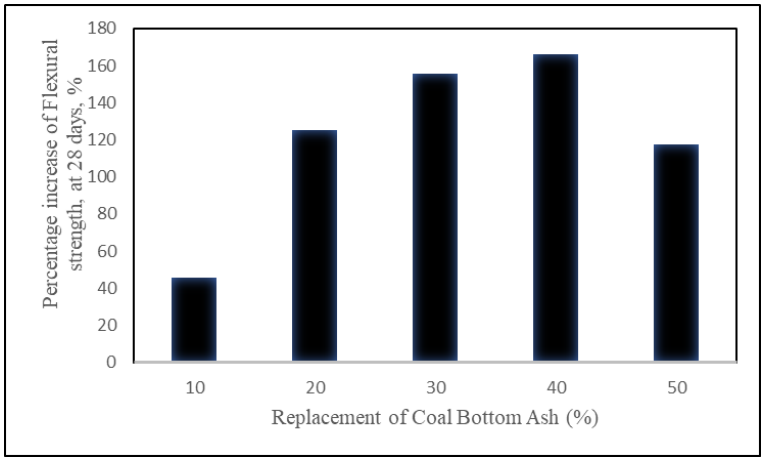


Figure 11. Percentage increase of flexural strength with different percentages of CBA at 28 days.

3.2. Test results of experimental study on concrete lagging

According to the above research results, the determine the aggregate content for 1 m^3 of M200 concere mix used for manufacturing concrete lagging. When calculating mortar concrete mix for M200 concrete lagging using CBA instead of 40% of sand in concrete gradation of 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 CBA to replace 40% of sand will be saved in the sand in the concrete mix. Control concrete lagging, CBA concrete lagging are marked in dimension bxh = 150x50 mm and bxh = 150x50 mm respectively. The length of CBA concrete lagging in this study is 700 mm (Figure. 12). In this section, a concrete lagging plate is carried out experimental study the load capacity, expansion crack by Advantest 9 (Control- Italy) in construction labor (HUMG) by a three-point load method (Figure.14). The specific gravity of CBA (2.21) is lighter than sand (2.65) makes the weight of concrete lagging is reduced about (1÷2) kg

(Figure. 13). It makes sense to transport a large amount of concrete lagging into great depth in underground mines in Quang Ninh. The expansion cracks of concrete lagging versus maximum load are present in Figure15, Figure 16, and Figure 17. The expansion cracks of CBA concrete lagging are higher than that of control concrete lagging with the same M200 grade in 5 -7 days. The crack expansion of CBA concrete is increased in the range of 5-7 days but decreased from 7 to 28 days. After 14 days, the expansion cracks in the CBA concrete lagging decreased strongly compared to the control concrete lagging while this value of concrete lagging increased as a rule. The result of deflection of concrete lagging versus time is present in Figure 17.



Figure 12. Concrete lagging.



a) CBA concrete lagging



b) Control concrete lagging

Figure 13. Weight and dimensions of CBA concrete lagging and control concrete lagging.

The above results can be explained by the fact that CBA concrete has a lower sand content, so the early workability is worse than that of control concrete in 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.



Figure 14. The three-point load method for concrete lagging.

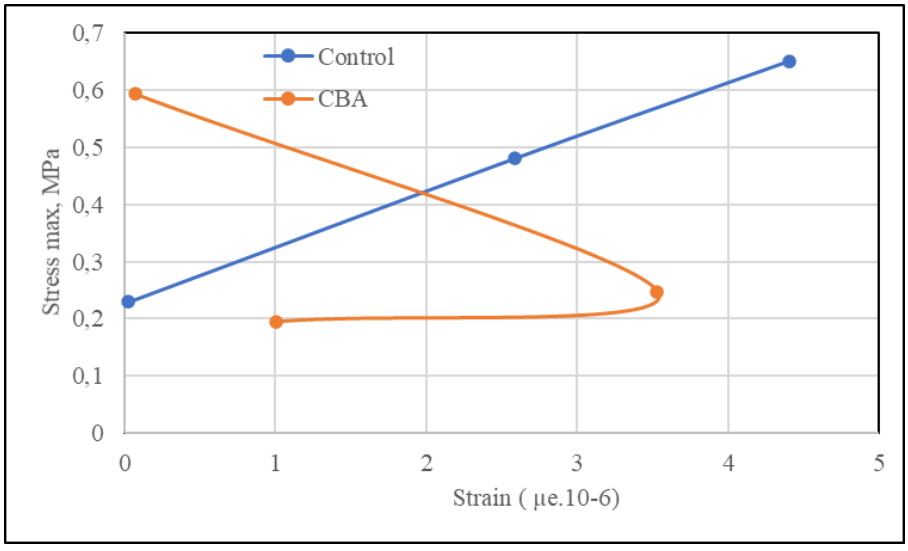


Figure 15. Max stress in concrete lagging versus strain.

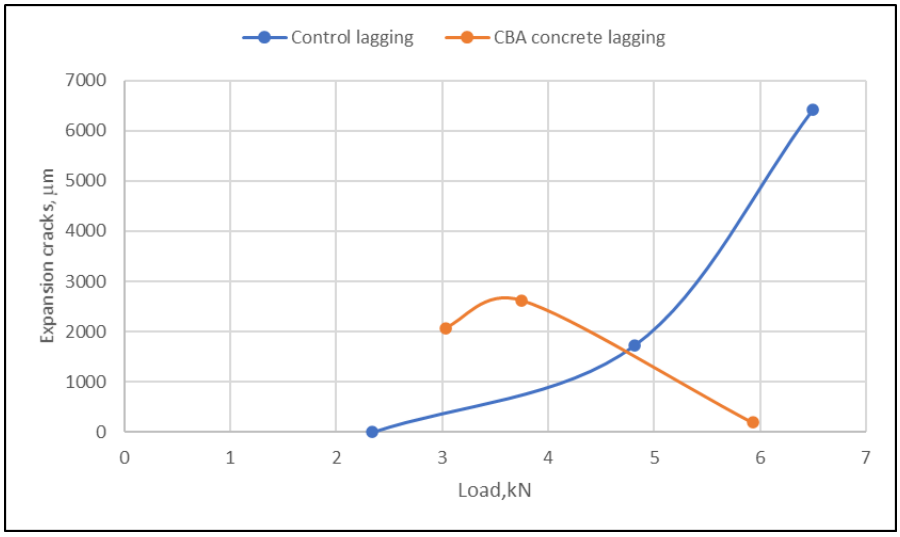


Figure 16. The expansion cracks of concrete lagging versus maximum load in concrete lagging.

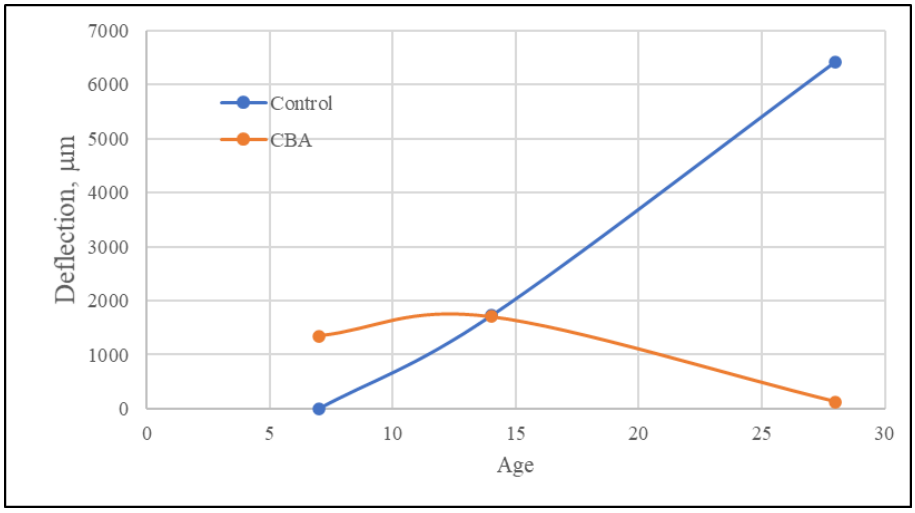


Figure 17. Deflection of concrete lagging versus time.

4. CONCLUSIONS

In this study, some interesting conclusions arising from the experimental study are given in the following points:

- The compressive strength and flexural strength increase with the increase of CBA in concrete up to 40% replacement with cement unconventional mix.

- The use of CBA to replace a part of sand in the concrete mix makes the weight of concrete lagging is reduced. The concrete lagging is lighter than the control concrete lagging in the same grade. It makes sense to transport a large amount of concrete lagging into great depth in underground mines in Quang Ninh with 400-500 m in depth.

- The expansion cracks and displacement of CBA 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 to 28 days. The above results can be explained by the fact that CBA concrete has a lower sand content, so the early workability is worse than that of normal concrete in the same strength.

- The research can be conducted further on higher grades of concrete or integration of such waste material by which more impact can be created improvement of strength, other underground mining such as drift lining…

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