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Research Paper

Research on the use fly ash and bottom ash from coal-fired power plants for making concrete lagging at underground mines

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ABSTRACT

Vietnam currently has 26 coal-fired power plants in operation, emitting a total amount of coal ash about 16 million tons/year of Fly Ash (FA) and Coal Bottom Ash (CBA). FA and CBA increase the costs of landfill space, and negatively affect the environment. Now, concrete lagging with steel arches is the biggest proportion of the type of current structural support in underground mining (about 70÷80%) in Quang Ninh coal area, Vietnam. The main objective of this research is to propose an optimized proportion of the FA and CBA of thermal power plants used in concrete mixture on making concrete lagging in SVP steel arches. This paper also presents the results of an experimental study using FA and CBA for making concrete lagging with the optimized proportion as cement and sand by the Advantest 9 (Control- Italy) system at the Laboratory of Underground and Mining Construction of Hanoi University of Mining and Geology (HUMG). The study result can be concluded that cement and sand replacement by FA and CBA are 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 in contributing to the environment protection.

1 Introduction

The development of coal-fired power plants to ensure energy security and electricity consumption is a matter for the Vietnam economy. However, the huge amount of ash discharged is a major environmental challenge. While the quantity of coal-fired power plants is rising, the ash content will increase year by year if the ash doesn't treat well. In Vietnam, 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 [1, 2]. Coal ash consists of CBA and FA of which fly ash accounts for 80% to 85%; it also contains heavy metals which can be damaged for land quality. In Quang Ninh coal area of Vietnam, for instance, the burst of streams ash dump in Cam Pha and the broken wall of ash pond in Quang Ninh coal area leaked the thousands of m^3 of coal waste to the residential areas. As the result, the soil was polluted with Arsenic ranging from 17-21 mg/kg, exceeding 1.13-1.4 times of QCVN 03:

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2008/BTNMT standards. In Quang Ninh coal area, Ha Long Bay is a UNESCO World Heritage Site, and Bai Tu Long Bay are suffering from the 7 million tons of ash produced by the coal-fired power plants, as shown in Fig. 1. There are 7 coal-fired power plants in Quang Ninh coal area with a total capacity of 4.150 MW electricity (16% of the country's total electricity). There are 2 more coal-fired power plants that will be built in 2020 as planned. The dumping ground for coal ash is currently overloading. For example, the Cam Pha's Power Plant has two electricity generation units with total capacity of 600 MW and spends 34 hectares dumping ground with the coal ash of 1 million tons/year. After 7 years of operation, the dumping ground has become nearly occupied.

Vietnam government launched a program to use coal combustion residuals (CCR), a waste product from thermal power plants to make building materials. The program demanded that at least 25% of CCR must be recycled by 2015. However, only 18% of CCR was recycled at the end of 2015, according to a survey of the Building Materials Institute. If there are no effective treatment methods, the current 21 coal-fired power plants will produce 61 million tons by 2018, rises to 109 million tons by 2020, and 442 million tons by 2030 of the CCR (Fig. 2). The difficulties of coal-fired power plants are the problem of ash handling, some plants are at risk of closure because there is not enough dump capacity to storage. Therefore, Vietnam is in need of urgent measures to treat a large amount of waste from coal-fired power plants. However, some of the factors that make utilization of FA and CBA is not increasing at desired rate are the lack of awareness of coal ash properties, non-availability of dry FA and bottom ash, the lack of proper coordination, easy availability of topsoil and variations in the quality of CBA.

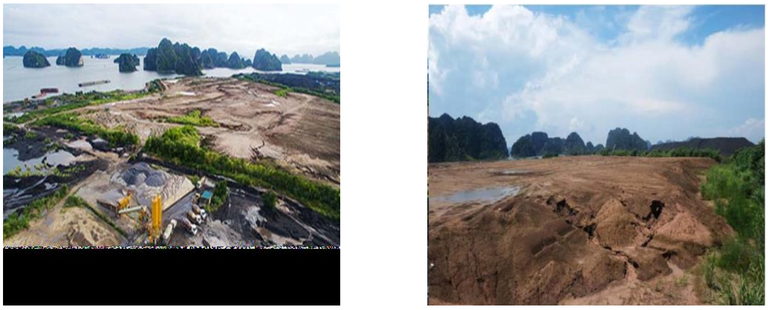


Fig. 1 – A dumping site just besides Ha Long Bay, a UNESCO World Heritage

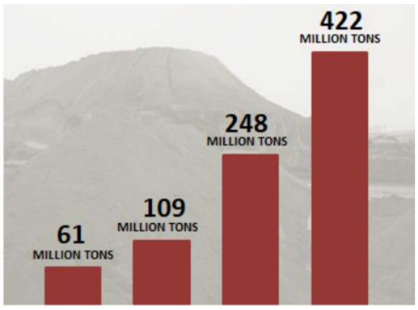
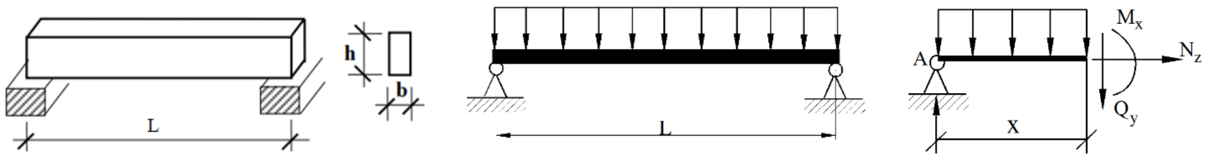


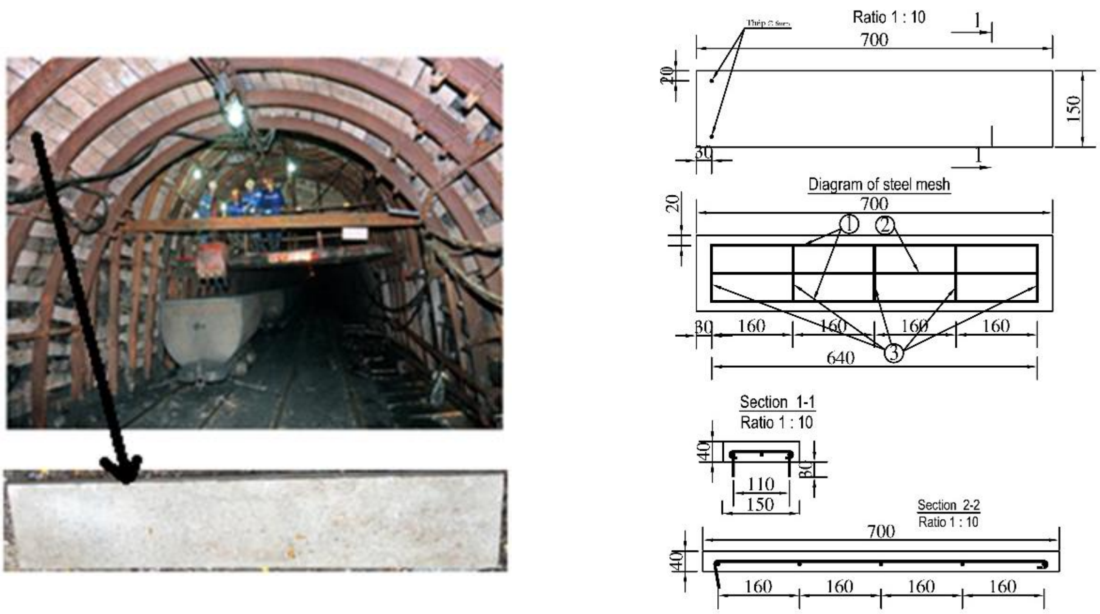
Fig. 2 – The plan of coal ash will be discharged from coal-fired power plants [3]

In addition, Quang Ninh is the biggest area coal of Vietnam but FA and CBA still have not been studied using for making the rock/soil support of underground coal mines. Now, Vietnam national coal - mineral industries holding corporation limited - Vinacomin (TKV), concrete lagging with steel arches (SVP steel arches, I-arches, U- shaped steel arches…) are the biggest proportion of the type of current structural support (about 70-80% of support systems in underground mines). Concrete lagging is one part of SVP steel arches in underground mines [6] (Fig 3). 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: bxh = 150 × 50 (mm) and the length equal to the distance of SVP steel arches: L = 0.7 m; L = 0.9m; L = 1.0m depending on the characteristic of mine pressure where the drift thought rock mass [3, 4]. A concrete mix of lagging is 20Mpa in compressive strength. The calculation of the dimension of the cross-section of the concrete lagging is made by treating the lagging 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 at the middle of the roof, subject to the uniformly distributed load of arches destroyed [4-6] (see Fig.3). The typical structure of the concrete lagging is shown in Fig. 4. CBA forms up to 25% of the total ash while the FA forms the remaining 75%. One of the most common uses for CBA is structural fill. According to Vietnam Electricity (EVN), by the end of 2020, the total volume of ash and slag in the Group's coal-fired power plants is more than 8.5 million tons, of which more than 7.1 million tons, fly ash and nearly 1.4 million tons of furnace slag, 120 thousand tons of gypsum.



a) b)

Fig. 3 – The calculation diagram of the concrete lagging using in SVP steel arches. a) The calculation model of concrete lagging in SVP steel arches; b) Load diagram



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

Fig. 4 – For example, structure of concrete lagging with length L = 0.7m in Ha Lam coal mine in Quangninh coal area

In Viet Nam, CBA only using as backfill material [7]. The study results in [8] showed that the optimum percentage of CBA as a fine aggregate replacement is range of 40% - 70%. Singh et al., 2015 concluded that up to 50% replacement level, CBA can be used as fine aggregate in concrete [9]. CBA is the potential viable material to be used as fine aggregate to produce durable concrete. However, there is not much research on using FA and CBA for making rock/soil structures of underground mines. In this study, the effect of FA partial replacement of cement and CBA partial replacement of sand on properties of concrete is carried out by experimental study. By the optimum percentage of CBA as sand, the concrete lagging is made to mechanical test.

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 Fig.7) for concrete samples with 20 MPa in compressive strength. Materials used in tests are as under:

Cement: Using ordinary Portland cement (PCB 30 Nghi Son) with FA and ordinary Portland cement (PCB 40 Nghi Son) with CBA. Cement has specific gravity: 3.10, 31.5% consistency, and compressive strength 30Mpa and 40 MPa, respectively.

Fly ash: From the combustion of pulverized coal and transported by the flue gases of boilers by pulverized coal, Fly Ash is produced. It was obtained from Pha Lai, Quang Ninh coal area, Vietnam thermal power station, dried and subsequently used. The properties of FA are given in Table 1.

Coal Bottom Ash: CBA is a hazardous by-product from coal- based Pha Lai, Quang Ninh coal area (Fig. 5). Properties of CBA ares given in Table 2.

Table 1 – Physical properties of Fly Ash [10]

Specific gravity	2.146 to 2.42
Wet sieve analysis (% retained on No. 325 BS sieve)	51.00 (Dry)
Specific surface (cm2/g)	2800 to 3250
Lime reactivity (kg/cm2)	56.25 to 70.3

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) (IBST, 2006).

a) Sample of Fly Ash b) CBA sample in Pha Lai, Quangninh coal area

Fig. 5 – Sample FA and CBA in Pha Lai, Quang Ninh coal area

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

Table 2 – Physical Properties of CBA [11]

N°	**Properties of CBA**	**Values**
1	Specific gravity	2.12
2	Bulk density (gam/cc)	0.642-0.747
3	Fines modules	6.28
4	Maximum dry density (kN/m3)	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

Water: Drinking water from HUMG was used for the preparation of concrete. The quality was uniform and the water samples were potable. The concrete mix was designed for M200 grade and the mix design was done [12] (TCVN 10302:2014)]: Activity admixture - FA for concrete, mortar, and cement

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) [12]. 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 was 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.

Table 3 – Details of specimens prepared for test (FA replacement with cement)

S. Nº	Details of Cube Specimen			Details of Beam Specimen			SlumpValue (%)
	Name of Cube Sample	FA (%)	Weight of FlyAsh in Mix (gam)	Name Of Beam Sample	FA (%)	Weight of FA 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

Table 4 – Details of cube specimens prepared for compressive test (CBA replacement with sand)

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) [13] . Cube specimens are prepared of size 150mm×150mm×150mm and beam specimen of 100mm×100mm×600mm (see on Fig.6). 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 3, Table 4 and Table 5. A three-point load method was used to measure the flexural strength of bottom ash aggregate concrete (TCVN 3118 : 1993) [13].

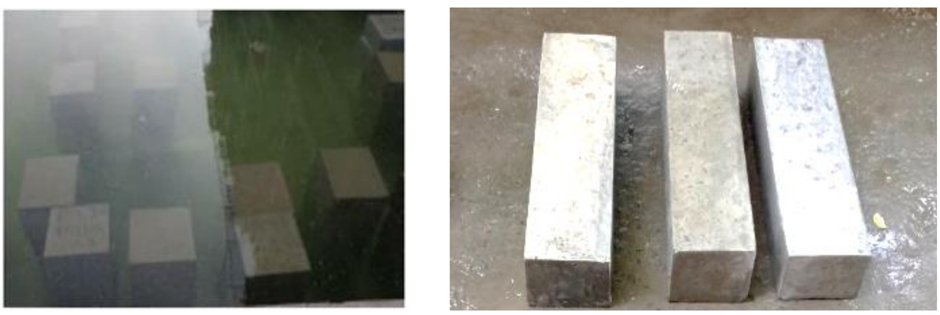
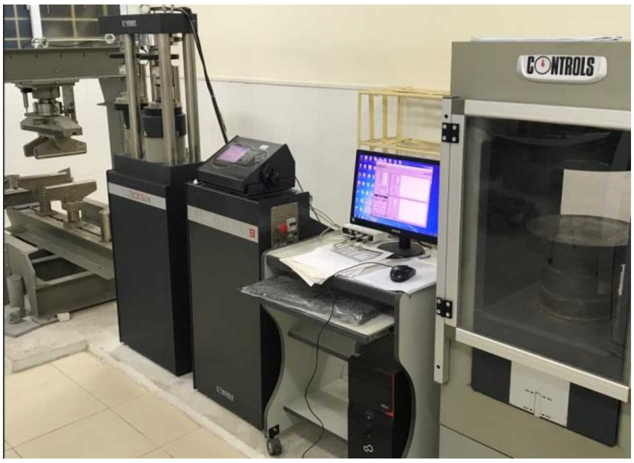
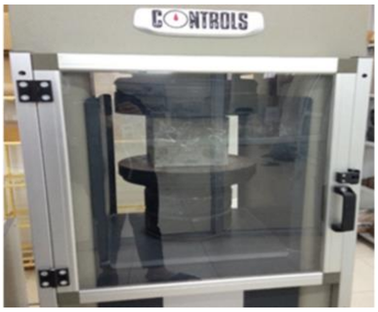


Fig. 6 – Specimen prepared for compressive and flexural tests



a)



b)

Fig. 7 – Compressive strength test on the cube sample by Advantest 9 (Control- Italy) system in HUMG

Table 5 – Details of beam specimens prepared for flexural test (CBA replacement with sand)

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

Table 6 – Test results of compressive and flexural strength (FA replacement with cement)

S.No	Cube Sample Name	FA %	28 Days Strength N/mm^2 (Average of three samples)	Beam Sample Name	28 days Strength N/mm^2 (Average of three samples)
1	C 0	0	40.15	B 0	6.17
2	C 10	10	39.60	B 10	6.20
3	C 20	20	41.15	B 20	6.33
4	C 30	30	43.19	B 30	6.42
5	C 40	40	40.28	B 40	6.16

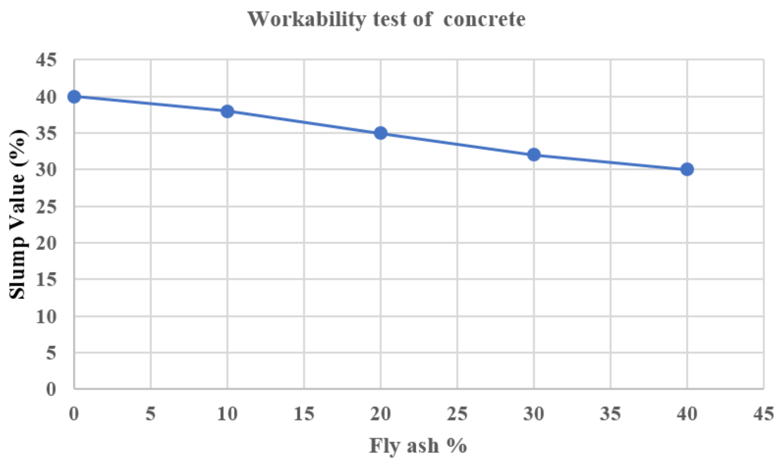


Fig. 8 – Workability test of concrete mix with different percentage of FA

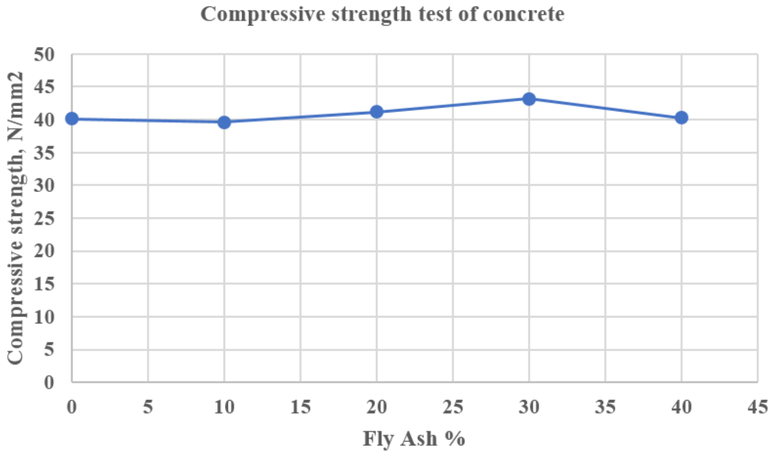


Fig. 9 – Compressive strength test of concrete mix with different percentage of FA

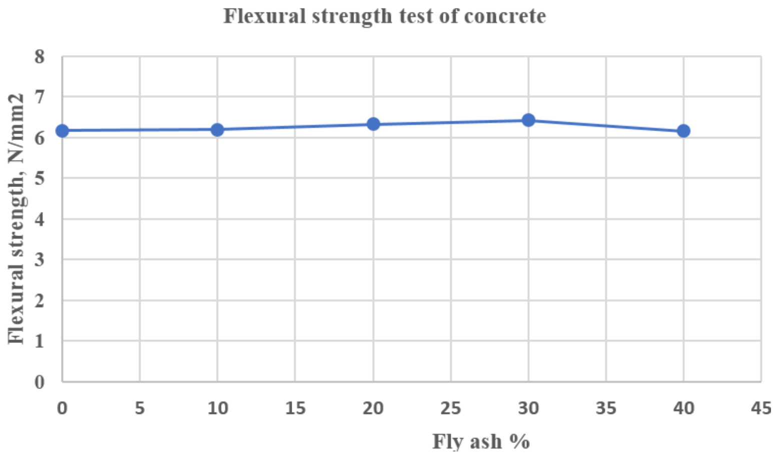


Fig. 10 – Flexural strength test of concrete mix with different percentage of FA

The results in Fig. 12 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 shown in Fig. 13 and Fig. 14. The result 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.

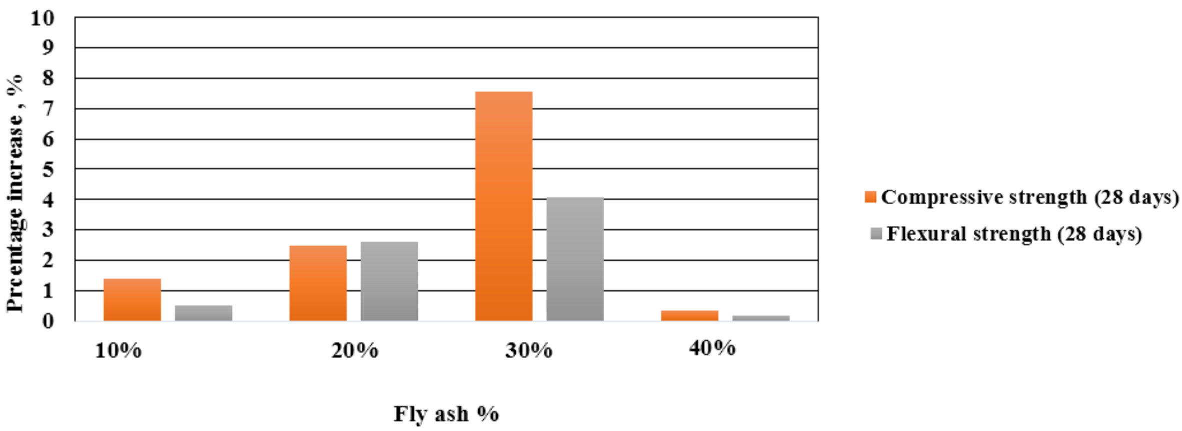


Fig. 11 – 28 Days percentage increase of strength with different percentage of FA

Table 7 – Compressive Strength of Concrete (CBA replacement with sand)

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	4.35	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 8 – Flexural strength at different ages (CBA replacement with sand)

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

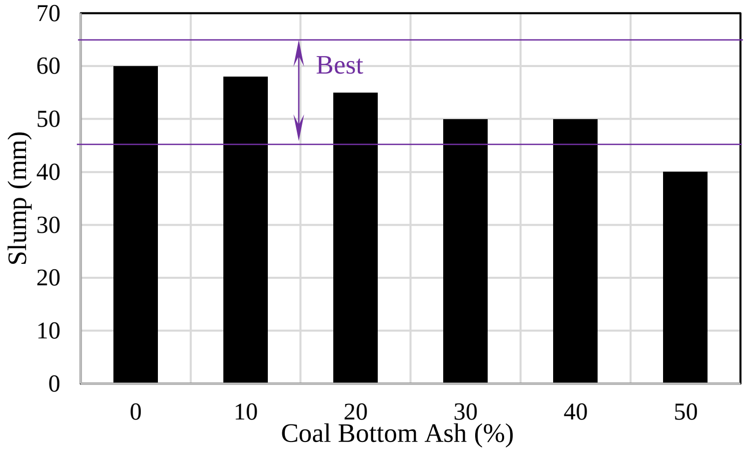


Fig. 12 – Workability test of concrete mix with different percentages of CBA

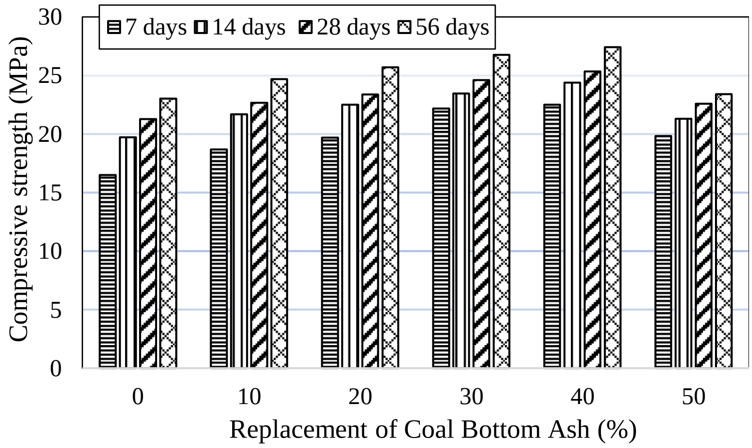


Fig. 13 – Compressive strength test of concrete with different percentages of CBA

For flexural test beams of 150×150×60 (TCVN 3118:2022)[13] 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 (Fig. 15). The result in Fig. 13 and Fig.15 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 Fig.14 and Fig. 16). The 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 a 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 thermal power plants.

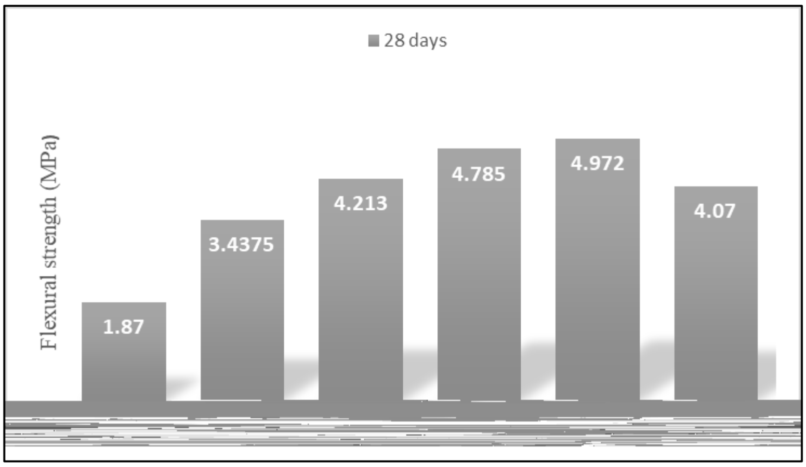


Fig. 14 – Flexural strength test of concrete with different percentages of CBA

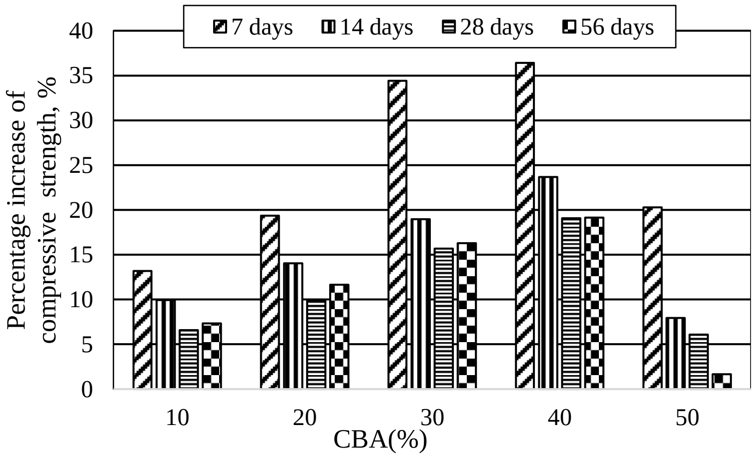


Fig. 15 – Percentage increase of compressive strength with different percentages of CBA at 28 days

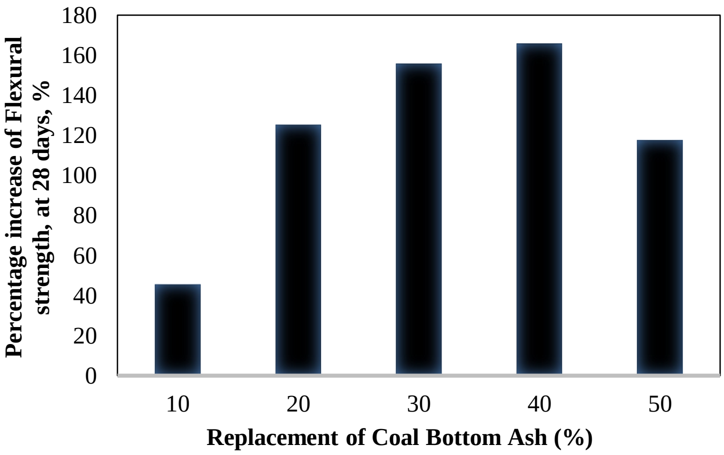
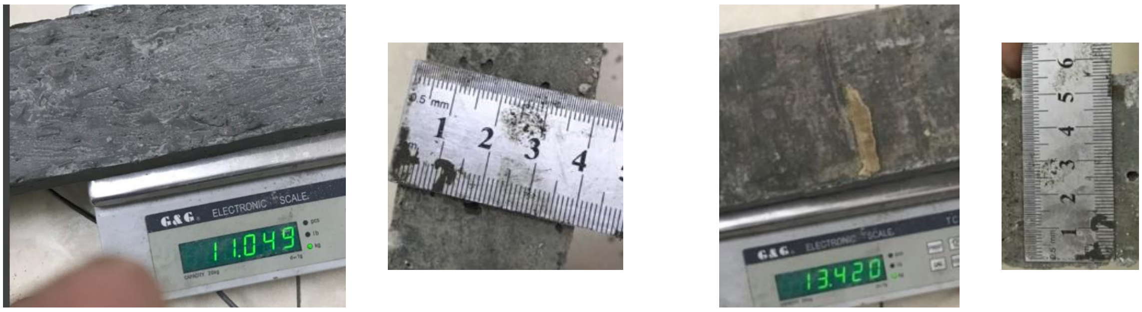


Fig. 16 – Percentage increase of flexural strength with different percentages of CBA at 28 days

2.3. Test results of experimental study on concrete lagging

According to the above research results the aggregate content for 1m^3 of M200 concrete mix used for manufacturing concrete lagging. When calculating mortar concrete mix for M200 concrete lagging using 30% replacement with cement and 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 = 150x50mm and bxh = 150x50mm respectively. The length of CBA concrete lagging in this study is 700 mm (Fig. 17). In this section, a concrete lagging plate is carried out experimental study the load capacity, expansion crack by Advantest 9 (Control- Italy) by a three-point load method (Fig.19). 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 (Fig. 18).

Fig 17 – Manufacturing concrete laggings in HUMG



a) CBA concrete lagging b) Control concrete lagging

Fig 18 – Compare weight and thickness between CBA concrete lagging and control concrete lagging

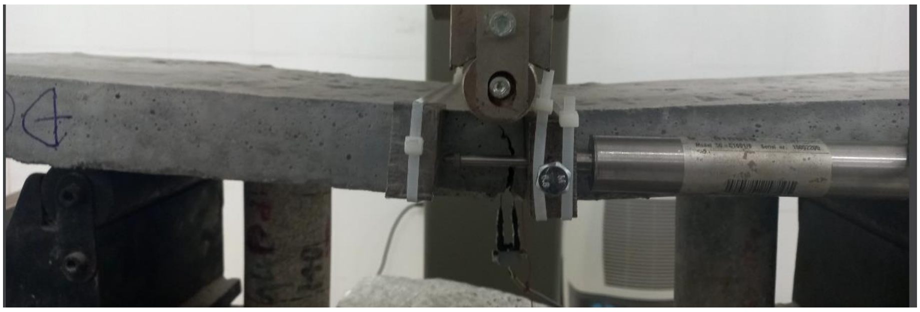


Fig 19 – The three-point load method for concrete lagging

It makes sense to transport a large amount of concrete lagging into great depth in underground mines in Quang Ninh coal area. The expansion cracks of concrete lagging versus maximum load are present in Fig 20, Fig 21, and Fig 22. 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 Fig. 22. 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 causes higher crack expansion and greater deformation. It is quite consistent with the characteristic of increasing the load of stability drifts located at great depth in Quang Ninh coal area.

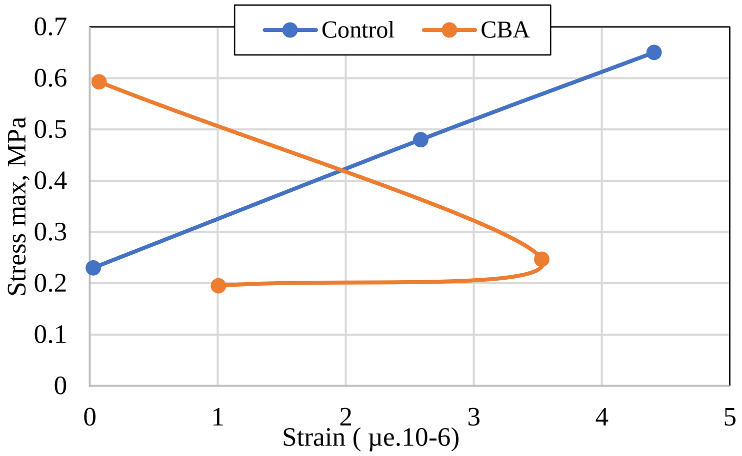
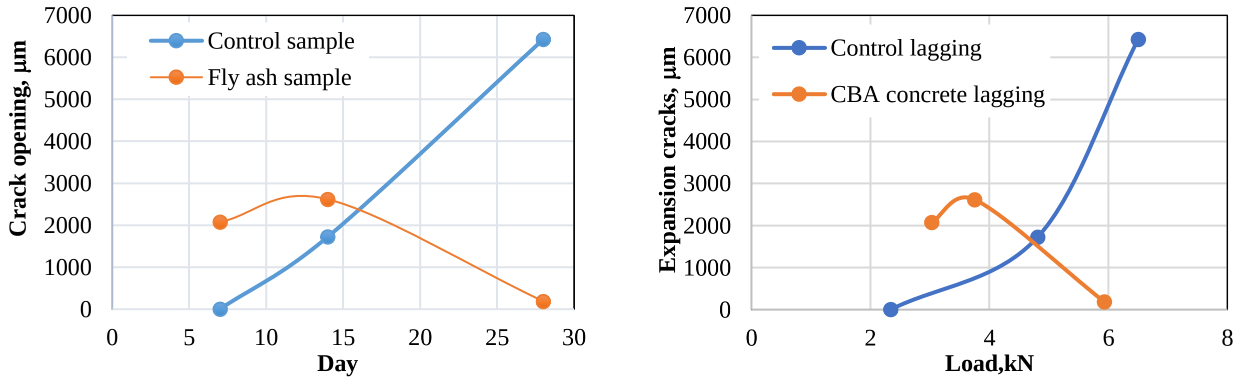
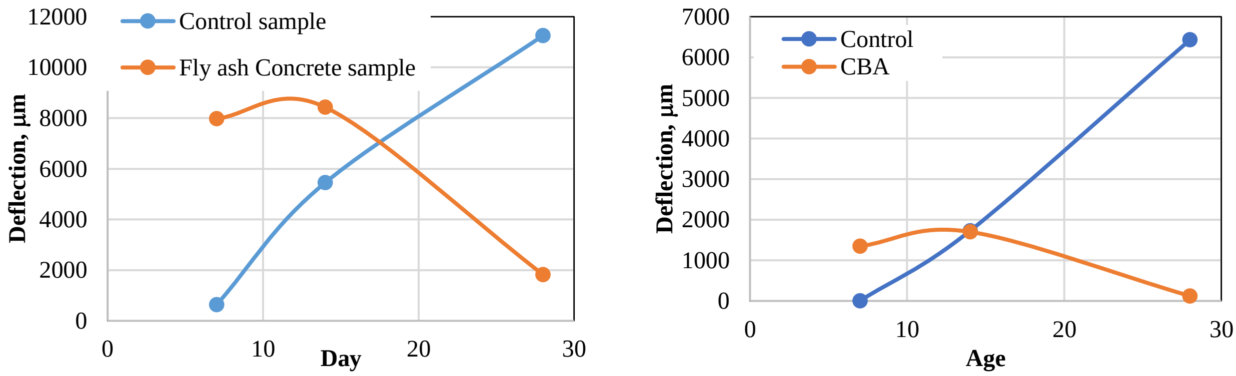


Fig 20 – Max stress in concrete lagging versus strain



(a) (b)

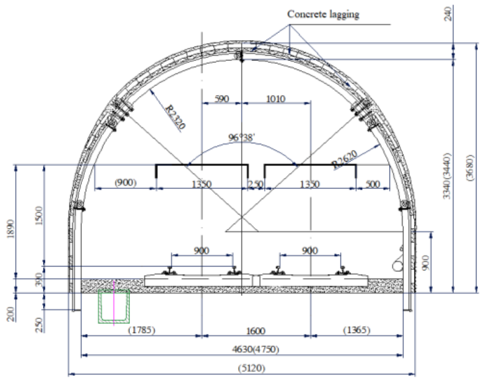
Fig 21 – The expansion cracks of concrete lagging versus time and maximum load



(a) (b)

Fig 22 – Deflection of concrete lagging versus time

a) The finished concrete lagging to use in undergaround mining



b) Using concrete lagging as a rock/soil support in Mao Khe Coal Company

Fig 23 – Making concrete lagging as a rock/soil support in Mao Khe Coal Company [6]

3 Effects of environmental protection due to using fa and cba to make concrete lagging

FA and CBA can be defined as a waste residue that is released from coal combustion process in electric power stations. FA and CBA are the unburned residue that are carried away from the burning zone in the boiler by the flue gases and then collected by either mechanical or electrostatic separators.

Table 9 – Statistics of FA and CBA in thermal power plants in Vietnam [2]

N^0	Coal fired power plants	Allotted ash and slag disposal area, ha	Volume of ash, slag discharged million tons /year	Total volume contained, million tons	Enough years to contain, year
11	Phalai	27.7	0.802	0	25.0
22	Uongbi RM	29.0	0.337	0.75	4.5
33	Quangninh coal area	15.0	0.945	4.80	7.0
44	Haiphong	56.0	0.949	1.0	3.0
55	Nghi Son 1	74.7	0.359	0.85	6.3
66	Vinh Tan 2	38.37	1.371	3.90	2.9
77	Vinh Tan 4	-	0.544	-	-
88	Duyen Hai 1	31.0	1.006	1.73	1.4
99	Duyen Hai 3	29.0	1.112	0.065	9.6
110	Mong Duong 1	24.0	1.125	1.70	0.8
111	Na Duong 1	57.6	0.485	2.002	15.0
112	Cao Ngan	4.4	0.260	1.806	10.0
113	Son Dong	2.2	0.605	2.020	4.0
114	Dong Trieu	24.0	1.048	1.255	7.0
115	Cam Pha 1+2	47.0	1.530	5.535	6.0
116	Nong Son	10.7	0.052	0.108	25.0
	Total	-	12.530	27.521	-

Vietnam has started the development of coal fired power plants 20 year ago. Now, there are 26 coal fired power plants in Vietnam. They produce about 16 million tons/year of coal ash (see Table 8). According to statistics, the production rate of FA and CBA clearly exceeds the consumption rate, attributed to the increasing operation levels of coal-fired power plants, resulting in the generation of more FA and CBA. FA and CBA contain silica, alumina, ferric oxide, and other oxide materials, which could potentially render them hazardous. This hazardous material is a contributing factor in air, water and soil pollution that lead to human health problems and various geo-environmental issues. These bad situations will interrupt the entire ecological cycle if not properly disposed. Therefore, good waste management practice need to sustain a healthy environment [14]. Emissions of FA and CBA from coal combustion units exhibit a wide range of compositions, including elements with atomic numbers below 92, and are considered a significant source of air pollution. The ultrafine particle of FA and CBA will behave like cumulative poisons after remaining for long periods of time when reaches the respiratory region. As a result, several physiological disorders and other related health problems such as respiratory problems, cancer, anaemia, hepatic disorder, gastroenteritis and dermatitis will arise. Several studies on the present ground showed that wet disposal of this waste causes migration of metal into the soil. The populations located near the FA and CBA dumping area, facing surface water pollution and underground water pollution. However, surface water pollution is more critical than underground water pollution. The surface water pollution decreases the fish population and other aquatic organisms due to heavy metal material and organic matter content contained in the water. The surface water contamination also causes skin diseases diarrhoea and death due to bathing and drinking of water from the contamination river [14]. Waste treatment is a vital issue of thermal power plants and society of Vietnam. It is really big problem. If treated and used thoroughly, it will solve many goals such as: Saving land area used as a waste dump, minimizing environmental pollution, creating more revenue from treated products, increasing investment efficiency of projects including pit mining, underground mining projects. In addition, it contributes to saving foreign currencies, reducing the burden of trade deficit for the economy, because recycling will create a source of raw materials to replace the raw materials that are still imported to add additives for cement production, making concrete, treating soil. At the same time, to form a market for buying and selling waste that has been treated for use as raw materials for construction materials.

4 Conclusions

In this study, some interesting conclusions arising from the experimental study are given in the following points: The Vietnam electricity has grown rapidly, reflecting the country's economic development. It is supposed to increase two to three times over the next two decades; The increase in FA and CBA makes the workability of concrete reduced. The particles of FA and CBA reduce the amount of water required to produce a given slump. The circular shape of the fly ash particles and its dispersive ability provide water reducing characteristics. The compressive strength and flexural strength increase with the increase of FA in concrete up to 30% replacement with cement, CBA in concrete up to 40% replacement with sand unconventional mix; The use of CBA to replace a part of sand in the concrete mix makes the weight of concrete lagging 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 coal area 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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