

Experimental study on use fly ash in underground construction concrete



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ABSTRACT

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Fly ash utilization in concrete as partial replacement of cement is gaining importance day by day. In Vietnam, fly ash has been used to as roller compacted concrete of Son La hydroelectricity, rural road concrete and unburnt bricks. However, they have not been used in the rock/soil support of underground coal mines. Now, concrete insert plates with steel arches are the biggest proportion of the type of current structural support in underground mining (about 70÷80%). Concrete insert plates is one part of the concrete insert plates are responsible for closing the gap between the SVP steel frames in drift and the dug evenly distributing the pressure of rock and soil on SVP steel frames, preventing roof landslides and sidewalls. This paper studies the use of fly ash in concrete, cement is replaced partially by fly ash in underground construction concrete. In this experimental work concrete mix prepared with replacement of fly ash by 0%, and 20%. Effect of fly ash on compressive strength and flexural strength of underground construction concrete are studied. To study the impact of partial replacement of cement by fly ash on making concrete insert plate of SVP steel frame in underground mines.

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1. Introduction

The use of concrete has recently gained popularity as a resource-efficient, durable and cost effective. A concrete mixture with fly ash can provide environmental and economical benefits.

Fly ash concrete enhances the workability, compressive strength, flexural strength and also increases its pumpability, durability and concrete finishing. It also reduces corrosion, alkali silica reaction, sulphate reaction shrinkage as it decreases its permeability and bleeding in concrete. Sample of fly ash is presented on Figure 1. The disposal of fly ash is a seriously environmental problem. In India, 110 million of fly ash is produced and 2÷30% is used and rest

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occupies vast tracks of valuable land as a pond (Dang Van kien et al 2019).

The fly ash used in concrete industry by partly replacement it with cement and also in embankment for filling the material. Leaving the waste materials to the environment directly can cause environmental problem. Hence the reuse of waste material has been emphasized. These industrial wastes are dumped in the nearby land and the natural fertility of the soil is spoiled. Concrete with fly ash reduces the permeability of concrete and dense calcium silicate hydrate (C-S-H). Past research shows that adding fly ash to concrete, as a partial replacement of cement (less than 35%), will benefit both the fresh and hardened states. While in the fresh state, the fly ash improves workability. This is due to the smooth, spherical shape of the fly ash particle. The tiny spheres act as a form of ball bearing that aids the flow of the concrete. This improved workability allows for lower water-to-cement ratios, which later leads to higher compressive strengths. In the hardened state, fly ash contributes in a number of ways, including strength and durability. While fly ash tends to increase the setting time of the concrete. The pozzolanic reaction removing the excess calcium hydroxide, produced by the cement reaction, and forming a harder CSH.

The fly ash were used in many purposes of underground construction as lining tunnel and other supports (Dang Van Kien et al, 2019). The new St. Clair River Tunnel was constructed in 1993-1994 between Sarnia in Ontario and Port Huron in Michigan (Figure 2). The groundwater contained chlorides (4000 ppm) and sulfates (155 ppm), and this environment, combined with hydrostatic heads of up to 35 m (115 ft) led to the inclusion of both chloride diffusion and permeability limits in the concrete specification for the precast tunnel lining segments. The requirements for the concrete were (Hart, 1997) (Michael Thomas, 2007):

- Cementitious content from 400 to 550 kg/m; w/cm \geq 0.36;
- Compressive strength \geq 60 MPa (8700 psi) at 28 days;
- Chloride diffusion coefficient, $a \geq 600 \times 10^{-15} \text{ m}^2/\text{s}$ at 120 days;

- Water permeability, $k \leq 25 \times 10^{-15} \text{ m/s}$ at 40 days.

The concrete was produced at a local ready-mixed concrete plant and delivered in a transit mixer to the precast plant. The concrete mixture used at the start of the production process contained 6% silica fume and 30% Class C fly ash with w/cm ranging from 0.29 to 0.32. This mix met specification including the chloride diffusion coefficient at 120 days.

Advantages of fly ash in cement concrete (Kosalram et al, 2015), (Rajamane et al, 2001), (Amit Ahirwar et al, 2015):

1. Reduction in heat of hydration and thus the reduction of thermal cracks and improves soundness of concrete mass.
2. Improved workability and pumpability of concrete.
3. Converting the excess lime into binding material through hydration process.
4. Improved impermeability.
5. Reduced cement requirement for the same strength and reduced cost of concrete.

Effect of quality of fly ash on concrete properties.

The characteristics of fly ash depend on the coal burnt, degree of pulverised coal, rate and temperature of combustion. The important things which affect the performance of fly ash concrete are:

1. Loss of ignition(LOI);
2. Fineness;
3. CaO content.



Figure 1. Sample of fly ash.



Figure 2. St. Clair river tunnel precast tunnel lining segments (Courtesy Hatch Mott MacDonald) (Dang Van Kien et al, 2019).

A various numbers of research have been conducted to examine the effects of use of fly ash as additive in cement, admixture in concrete and as replacement of cement in concrete. The compressive strength of concrete was checked by replacing different proportions of cement with suitable quantities of fly ash and the results have been found most effective and applicable. Incidentally most of the research works have been conducted only for a limited percentage of cement replacement that too for a lower grade of concrete. It is, therefore, necessary to conduct an extensive research on compressive strength of different qualities of concrete as well as different proportions of fly ash at different curing periods. Here in below the various methods of using the fly ash as a cement replacement in concrete is discussed vividly. This paper presents the effect of fly ash replacement on compressive strength and flexural strength of concrete along with the slump and other fresh and hardened properties. A comparative cost investigation with making concrete insert plate of SVP steel frame in underground mines has presented.

2. Methodology & eperimental program

The test was carried out in the Construction Laboratory of Hanoi University of Mining and Geology (HUMG) by advantest 9 (control- Italy) system (Figure 3). Materials used in the experiments are as under:

Cement: Ordinary Portland cement (Ambuja Cements of 53 grades) was used having specific



Figure 3. Advantest 9 (control- Italy) system of HUMG.



Figure 4. Specimen prepared for test.



Figure 5. Testing of concrete cube in Advantest 9 (control- Italy) system of HUMG.

Table 1. Details of specimens prepared for test at Construction laboratory of HUMG.

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

gravity: 3.10÷31.5 % consistency and compressive strength 53 MPa.

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 Kolaghat thermal power station, dried and subsequently used.

Fine aggregate: Natural sand with maximum size of 4.75 mm was used with specific gravity 2.55 and fineness modulus 2.61.

Coarse aggregate: Natural aggregates with maximum size of 40 mm were used with specific gravity of 2.68 and fine modulus 7.5.

Water: Drinking water from Seacom Engineering College and Howrah Dhulagarh was used for the preparation of concrete. The quality was uniform and the water samples were potable.

The concrete mixture was designed for M20 grade and the mixture design was done as per IS 10262-1982 and IS 456-2000, TCVN 10302:2014: Activity admixture – Fly ash for concrete, mortar and cement. The properties of constituents of concrete was taken into account for mix design of concrete. Different concrete mixes with varying fly ash content percentage were produced, replacing 0% (reference concrete), 20%, cement in terms of weight (Table 1). For compressive strength tests cube specimens of 150 mm size were casted. The cubes were casted in stainless steel moulds and wet cured at standard temperature until the time of test. The cubes were cured for a time period of 28 day. Three samples from each set of the mix were tested at the age of 28 days for compressive strength 28 days for flexural strength. Preparation of Specimen: All concrete mixes were prepared using a motorized mixer of mix design proportion, 1:1.27:2.83 with constant water cement ratio of 0.42. Cube specimens are prepared of size 150 mm×150

mm×150 mm and beam specimen of 100 mm×100 mm×500 mm (Figure 4). The specimens were cured in a curing room at 30°C temperature and 90% relative humidity. Fly ash mix concretes were tested at 28 days of age to get compressive strength and 28 days for flexural strength values. Servo-hydraulic system for static and low frequency dynamic tests on building materials under control of Load/Stress, Displacement Strain (Figure 3) in the Construction Laboratory of HUMG. Ideal both for traditional tests, such as compression and flexure on concrete, cement, mortar, blocks etc. and cyclic tests for the determination of elastic modulus (E) according to all relevant international standards, and also for measuring, for example, the ductility and fracture energy of concrete reinforced with fibres (FRC) and lined with polymers (FRP), or the toughness of sprayed concrete slabs (shotcrete) under concentrated load tests is can be carried by this system. The console is connectable to up to four test frames.

Features of advantest 9 (control - Italy) system are:

- Performance: user defined test procedures which can be easily performed under load, specific load, displacement and strain control.
- Flexibility: possibility to connect up to 4 different testing frames from 15 to 5000 kN load capacity, easily selectable by the user friendly software.
- Accuracy and reliability: long life system due, essentially, to the advanced electronic, efficiency of closed loop system;
- Interactive software: To perform:
 - Remote control of the system;
 - Monitoring and display of all test data and parameter either in graphic or numerical format.

Table 2. Flexural strength of samples in 28th day.

Fly ash concrete	Grade20	Size of sample	Distance of two beam abutments	Characteristics of the sample		Flexural strength				Average
				Width	Height	Max load	Tension trength during flexural	Average	Tension trength along axial	
										MPa
Fly ash - 20%	20	15x15 x60	45.00	15.00	15.00	23.6	3.15	2.95	1.83	1.71
		15x15 x60	45.00	15.00	15.00	20.63	2.75		1.60	

Table 3. Compressive strength of samples in 28th day.

Fly ash concrete	Grade20	Dimension	Time		Result of tests			Note
			Create the sample	Date Test	Load	Sample	Avergate	
								MPa
Fly Ash - 20%	20	15x15	09/12/2019	06/01/2020	450.664	20.03		
	20	15x30	09/12/2019	06/01/2020	275.334	18.7	19.81	28 age
	20	15x30	09/12/2019	06/01/2020	304.608	20.7		
				28 th day compressive strength is equal to 99.1% of concrete design strength				

- File management by building materials, tests, specifications, clients etc.

- Print of standard or customised test certificate.

- Real time variation of the setting including the control method (load, displacement or strain).

- User-friendly interface.

• Extra channels: in addition to the four channels used for the connection of up to four separate test frames, an extra four channels are provided for connection to the displacement transducers, pressure transducers, load cells,

strain gauges or similar sensors, which can be configured by the user conforming to the test requirement on a case by case basis.

The of compressive strength limits of concrete are determinated by TCVN 3118-1993 standard. To determine compressive strength of concrete is prented by following formula.

$$R_n = \frac{P}{F} \quad (1)$$

Where: P- destructive load of samples (N); F - cross section area of sample (mm²);



Figure 6. Compressive strength test at HUMG.

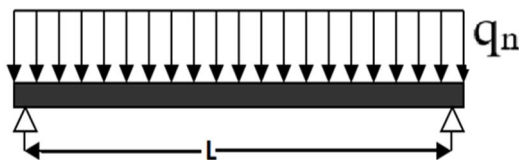


Figure 7. Diagram of the concrete insert.

3. The result of experimental study on use fly ash

The result of experimental study on use fly ash present on Table 2 (flexural strength) and Table 3, Figure 5 and Figure 6 (Compressive strength).

Testing of the hardened concrete were conducted as per the following codes in the Construction Laboratory of HUMG. The compressive strength on cubes were tested after 28 days of curing as per TCVN 3118-1993 standard. For compressive strength test, cubes of specimen size 150 mm x 150 mm x 150 mm were cast and for M20 grade concrete. The mixtures were having the different proportions of fly ash varying of 0% and 20%. Table vibration is given to the moulds. The specimens were levelled and finished on the top surface of the concrete. After 24 hours of casting the specimens were do moulded and kept for moist curing for 28 days (Kosalram et al, 2015).

The compressive strength of the concrete cubes had been tested at the interval of 28 days. It seems that the strength goes on increasing with

the increase in fly ash but after the replacement of 20% fly ash with cement, the strength decreases.

The flexural strength of concrete sample is tested at the interval of 28 days. It seemed that flexural strength goes on increasing up to 20% replacement. The strength variation is more on compressive as compared to flexural strength.

4. Method of fly ash concrete mixing

To obtain the best result, the fly ash concrete should be prepared by the following mixing method: About 3/4 quantity of the mixing water is taken in the concrete mixer. The amount of the required quantity of fly ash is weighted then added to it and mixed for 30 sec. To the slurry of fly ash so obtained, weighted quantities of coarse aggregate, fine aggregate, cement and remaining quantity of the mixing water be added and mixed for 90 sec. However, if this is not convenient normal mixing method may be adopted i.e. Weighted quantities of coarse aggregate, fine aggregate cement and fly ash should be put together in the concrete mixer and mixed dry for 30 sec. The required quantity of the mixing water then added and the mixing continued for 90 sec. The superplasticizer by added just before discharge of the mixture from mixer.

5. Research on the usage of fly ash for making concrete insert plate of SVP steel frame in underground mines

Now, concrete insert plates with steel arches (SVP steel frame, I frame, ...) are the biggest proportion of the type of current structural support in underground mining (about 70÷80%) (Dang et al., 2018), (Nhu et al., 2020). Concrete insert plates is one part of rock/soil support of SVP steel frame in underground mines. They are responsible for closing the gap between the SVP steel frames in drift and the dug evenly distributing the pressure of rock and soil on SVP steel frames, preventing roof landslides and sidewalls. Selecting concrete insert plates with dimensions: $b \times h = 150 \times 50$ (mm) with the length equal to the distance of SVP steel frames: $L = 0.7$ m; $L = 0.9$ m; $L = 1.0$ m depending on the characteristic of mine pressure where the drift

Table 4. Compare mixtures of M200 concrete in making concrete insert plate of SVP steel frame in underground mines between two methods.

Parameters	Concrete mix using fly ash	Ordinary concrete mix
Cement (kg)	193,83	312
Coarse aggregate(kg)	1216	1251
Fine aggregate (kg)	568,7	540
Water (liter)	195	195
Fly ash (kg)	83,07	0
Plasticizer additives (kg)	3,87	0
Total: Cement + Coarse aggregate + Fine aggregate + Fly ash; (kg)	2065,22	2103

thought rock mass. The calculation of the selection of the concrete insert plates is made by treating the inserts as beams on 2 supports, the distance of 2 supports equals to the distance of SVP steel frames, the distance of SVP steel frames is located in the middle of the roof, subject to the uniformly distributed load of arches destroyed as Figure 7.

According to the results of this study, the determine the aggregate content for 1 m³ of concrete M200 used for manufacturing concrete insert plates as Table 4. When calculating mortar concrete mix for M200 concrete insert plates using fly ash instead of a part of cement in concrete gradation of this study has compared results of two alternatives as Table 4. 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 37.78 kg lighter than the normal concrete grade and save 118.17 kg of cement (Table 4).

6. Conclusions

- The workability of concrete decreases with the increase in fly ash, the particles of fly ash reduces 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 improve with the increase of fly ash in concrete up to 20% replacement with cement unconventional mix.

- Mixing of fly ash in concrete conventional mix has resulted in considerable variation in the

properties of fresh concrete. Integration of fly ash in concrete increased the cohesiveness of the mix, prohibited segregation and resulted in reduced bleeding.

- Higher percentages of fly ash can cause a change in color of the mix. Incorporation of fly ash in concrete can save the coal & thermal industry disposal costs and produce a "greener" concrete for underground construction.

- 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.

- We can realize that the usage of fly ash to replace a part of cement will be 37.78kg lighter than the normal concrete grade. It also saves 118.17 kg of cement in 1 m³ of concrete for making concrete insert plate of SVP steel frame in underground mines.

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