Revista Ingeniería de Construcción RIC
Vol 38 Nº1 2023 www.ricuc.cl
DOI: 10.7764/RIC.00052.21

ENGLISH VERSION..

High Strength Green (HSG) Concrete with Coal Fly Ash

Hormigón verde de alta resistencia con cenizas volantes de carbón

I. Raham *[1], S. Sahid*, S. Ali *

* *National University of Computer and Emerging Sciences (NUCES), Peshawar, PAKISTAN*

Fecha de Recepción: 02/02/2022
Fecha de Aceptación: 20/06/2022
Fecha de Publicación: 02/04/2023
PAG: 60-79

Abstract
The use of fly ash in concrete can lessen the burden of its dumping in landfills to protect the environment and soil degradation. We investigated the concrete mixtures incorporating various percentages of fly ash and studied the mechanical properties of high strength green (HSG) concrete. 0.32 w/c ratio was used. Six mixtures were investigated with varying percentages of fly ash (0%, 4%, 8%, 12%, 16%, 20%) with HRWR (high range water reducer) ranges (0%, 0.4%, 0.7%, 1.0%, 1.3%, 1.6%). The compressive strength of the mixture with a dosage of fly ash from 4 -12%, showed satisfactory results. The peak value of split tensile strength was 4.9 MPa with 12% fly ash dosage. Flexural strength in control mixture was observed at 3.73 MPa in 28 days and there was a slight increase in the trend of flexural strength. The compressive strength was achieved till 12% volume of fly ash for 14 and 28 days. It was due to more adherence between the fly ash and aggregate. Fly ash is very suitable to be used in concrete to produce high strength green (HSG) concrete. If we use fly ash in concrete, it can help us cleaning the environment from contaminating materials.

Keywords: *Fly ash; Workability; HRWR (high range water reducer agent); Compressive strength; Split tensile strength; Flexural strength; Green concrete; High strength concrete (HSC)*

Resumen:
El uso de cenizas volantes en el hormigón puede disminuir la carga de su vertido en vertederos para proteger el medio ambiente y la degradación del suelo. Investigamos las mezclas de hormigón que incorporan varios porcentajes de cenizas volantes y estudiamos las propiedades mecánicas del hormigón verde de alta resistencia (HSG). Se utilizó una relación a/c de 0,32. Se investigaron seis mezclas con porcentajes variables de cenizas volantes (0 %, 4 %, 8 %, 12 %, 16 %, 20 %) con rangos de HRWR (reductor de agua de alto rango) (0 %, 0,4 %, 0,7 %, 1,0 % , 1,3%, 1,6%). La resistencia a la compresión de la mezcla con una dosificación de cenizas volantes del 4 al 12%, mostró resultados satisfactorios. El valor máximo de la resistencia a la tracción dividida fue de 4,9 MPa con una dosis de cenizas volantes del 12 %. La resistencia a la flexión en la mezcla de control se observó a 3,73 MPa en 28 días y hubo un ligero aumento en la tendencia de la resistencia a la flexión. La resistencia a la compresión se logró hasta el 12% del volumen de cenizas volantes durante 14 y 28 días. Se debió a una mayor adherencia entre la ceniza volante y el agregado. Las cenizas volantes son muy adecuadas para usarse en la produción de Hormigón verde de alta resistencia (HSG). Si usamos cenizas volantes en el hormigón, nos puede ayudar a limpiar el medio ambiente de materiales contaminantes.

Palabras Clave: Ceniza volante; trabajabilidad; HRWR (agente redactor de agua); resistencia a la compression; resistencia al endimiento; resistencia a la flexion; hormigón Verde; Hormigón de Alta Resitencia (HSC)

[1] ***Corresponding author:***
National University of Computer and Emerging Sciences (NUCES), FAST Lahore Campus, PAKISTAN
E-mail: drshahidsaman@gmail.com

DOI: 10.7764/RIC.00052.21

1. Introduction

Properties like adaptability, strength and permanency make the concrete the most extensively used construction material. Concrete is the main constituent used in the infrastructure of the buildings. The concrete structures of the dams, bridges and high rise buildings are however, considered vulnerable against severe and dangerous loadings such as earthquakes, blasting, and detonations. Due to the variable loadings, different types of failure can occur, such as compression failure or tension failure. Concrete has three major characteristics such as workability, strength, and durability. Workability depends on water-cement (w/c) ratio. More water cement ratio, more will be the workability but it can decrease the strength. The strength of concrete also depends on the size and shape of its constituents. The ability of concrete to resist chemical attack, abrasion, and weathering action called durability. In this research, we incorporated the varying percentages of high fineness fly ash in a high-strength concrete to check that how it can affect the mechanical properties of concrete (compressive strength, tensile strength and flexure strength). Very low water-to-cement binder ratio is used with high range water reducing admixture. The behavior of concrete depends on the mixing properties and quality of the materials to be used, but these features cannot be changed after the hardening of concrete (Deb and Sarker, 2017). Fly ash is a byproduct of power plants, which uses the coal as a primary fuel. It has been widely used as a fractional substitute for regular cement in the concrete. Although, the use of fly ash in concrete has been raised from the last two decades. According to the literature, the 25% doses of low volume fly ash are considered for a high strength concrete (Lavasani and Werner, 2012). Fly ash is a pozzolanic cementitious material and it also acts as a filler material. Fly ash is not being used just as a filler material, it also enhances the quality of fresh and hardened concretes, which includes flowability of concrete, strength properties and durability (Haque and Keyali, 1998). When cement reacts with water, hydration process occurs, and concrete settles in a hardened form. During the hydration process, lime reacts with hydroxide ions of water to form calcium silicate hydrate (CSH) and calcium hydrate (CH). Now the CSH bond is stronger bond and the CH bond is weaker bond. Actually, the concrete strength relies on the CSH bond and corrosion of concrete is just because of the CH bond. The role of fly ash starts from here, showing its pozzolanic and cementitious properties. It readily reacts with CH bond and converts it into CSH-the stronger bond. This makes concrete stronger (Huang et al., 2013). The cement which we manufacture in Pakistan is ordinary Portland cement. It is hydraulic cement. Other constituents of concrete are fine and coarse aggregates. In normal concrete, we use high water-cement ratio, normally ranges from 0.45 or above. High strength concrete (HSC) is a special type of concrete, as it possesses distinctive properties of its own kind, when compared to normal strength concrete. It can resist high compressive pressure per unit volume as compared to normal strength concrete. Increased compressive strength is the primary advantage of high strength concrete (Nelson et al., 1992). High strength concrete is a type of concrete which can bear loads more than normal concrete. It is specially designed to give higher compressive strength of not less than 40 MPa. (Wang and Ponk, 2015) suggested that a high strength concrete can be formed by reducing the water cement ratio to 0.35 or lower.

Normal concrete is more vulnerable than high strength concrete due to the aggressive chemical conditions and the application of different types of varying loads. In the recent years, the normal concretes are replaced with high strength concretes in the construction industry worldwide. The basic purpose of the high strength concrete is to improve the safe life of a structure against heavy stresses. The mix design of high strength concrete includes some admixture that required for a fresh and hardened concrete. These admixtures include fly ash, silica fumes, superplasticizers and HRWR (high range water reducing admixtures) (Samad and Shah, 2017). For the past few years, concrete mixture proportioning is a serious problem when incorporating with pozzolanic materials. Because, the pozzolanic materials have a very fine particle size, which requires more water, but in high strength concretes, we use very low water-cement binder ratio. Therefore, we use some high range water reducing agents to improve the workability of concrete for the desired results. All the fly ash is produced in coal power plants is useless and it is dumped into the landfills, which can reduce the fertility of the soil. Moreover, because of increasing power demand, more fly ash is produced from the coal power plants and hence more it will be dumped, which will also negatively impact the environment. The discarding of fly ash may cause severe ecological complications including groundwater pollution, infertility of soil and causing large-scale adulteration (Copeland et al., 2001). Therefore, the use of fly ash in concrete must be encouraged in order to avoid its dumping in the landfills (Naik et al., 1995).

In this era, it has become necessary to explore the innovative steps and methods to minimize the cost of concrete material while improving its properties. The core focus of this research was to study experimentally, *the use of fly ash in high strength concrete by varying percentages of fly ash (0 to 20 percent) and high range water reducing admixture (0.5 to 1.7 percent), according to the ACI (American Concrete Institute) codes. This study explored the strength properties of concrete with the low water-cement ratio, fly ash and high range water reducing admixture. Through current study, we explored the benefits of using fly ash in high strength concrete and examined the influence of various dosages of fly ash on the mechanical properties of high strength concrete. The use of fly ash in concretes, can lessen the burden of its dumping and deposition in the open landfills to protect the environment in terms of soil degradation. We identified and selected the desired type and quality of green material (fly ash) that are appropriate to use for the mixture composition of high strength concrete. For this purpose, we carried out laboratory investigations for defining the mechanical properties (at 14 and 28 days) of high strength concrete like compressive, tensile and flexure strength. The Pozzolanic materials are just like normal Portland cement. Pozzolanic materials have good binding properties and give high compressive strengths. Pozzolanic materials are silica fumes, fly ash, slag, metakaolin etc. These Pozzolanic materials have been studied for last two decades. Previous researches showed that they have amazing properties. Silica fume and fly ash are amongst the best in giving good compressive strength (Poon et al., 2000); (Poon et al., 1999). Different type of admixtures like silica fume, fly ash and workable agents like super-plasticizers are also used to yield workable high strength concrete with normal ingredients. To upsurge the durability and strength of concrete some admixtures are used. The compressive strength is determined to optimize the use of mineral admixtures like fly ash in different percentages: 0%, 4%, 8%, 12%, 16% and 20% at 7 days and 28 days of curing. Concrete must have an ability to endure varying high-level stresses without no damage, cracks, and deterioration. High strength concrete will have far more strength, durability, and will have a longer lifespan than normal concrete (Copeland et al., 2001). Fly ash is a Pozzolanic cementitious material, it has binding properties like cement. It increases the strength properties of concrete. Normally, a high strength concrete with fly ash is used in the first two to three floors of high rise buildings and areas which are likely to be affected by the earthquake. Other major applications are road pavements where are specifically used roller compacted concrete and in the construction of dams or barrages (Haque and Keyali, 1998). Fly ash is a waste by-product of coal combustion in power plants or other factories, so it is available freely in Pakistan. On the other hand, cement is an expansive construction material. If we use fly ash in concrete as a replacement of cement, then it will definitely reduce the overall cost of concrete, making the concrete very economical. During hydration, concrete is used to be in fresh state where we check workability, heat of hydration, etc., and after it becomes solid means hardened state, we check its different strength properties. Fly ash's doses not only affects the concrete in fresh state, but also the hardened properties like mechanical and drying shrinkage (Naik et al., 1995).*

2. Material and Methods

In this section, we will discuss about the material which was used for making high strength concrete specimen along with the complete experimental procedure. We first designed the concrete mixture proportion for high strength concrete with fly ash. There were basically two types of concrete mixes. The control mixes, which were without fly ash. Second mixes were with the increasing percentages of fly ash such as: 4%, 8%, 12%, 16%, and 20%, in replacement of cement by weight. Materials, mixture design, casting, curing, test methods and procedures for categorizing fresh and hardened properties of mixtures incorporating fly ash, are explained below.

2.1 Materials

Locally available materials were used for concrete casting.

2.2 Cement, Aggregates and Water

*Locally available Portland cement was used (**Figure 1a**). For aggregates, a Sargodha crush was used for concrete mixtures. It was more angular size rather than flaky shape, aggregates are shown in (**Figure 1b**). Lawrencepur*

DOI: 10.7764/RIC.00052.21

*sand was used (**Figure 1c**). Although, it was not very fine, but its particle strength was very good so it was most suitable for high strength concrete. Ordinary tap water was used for mixing concrete ingredients.*

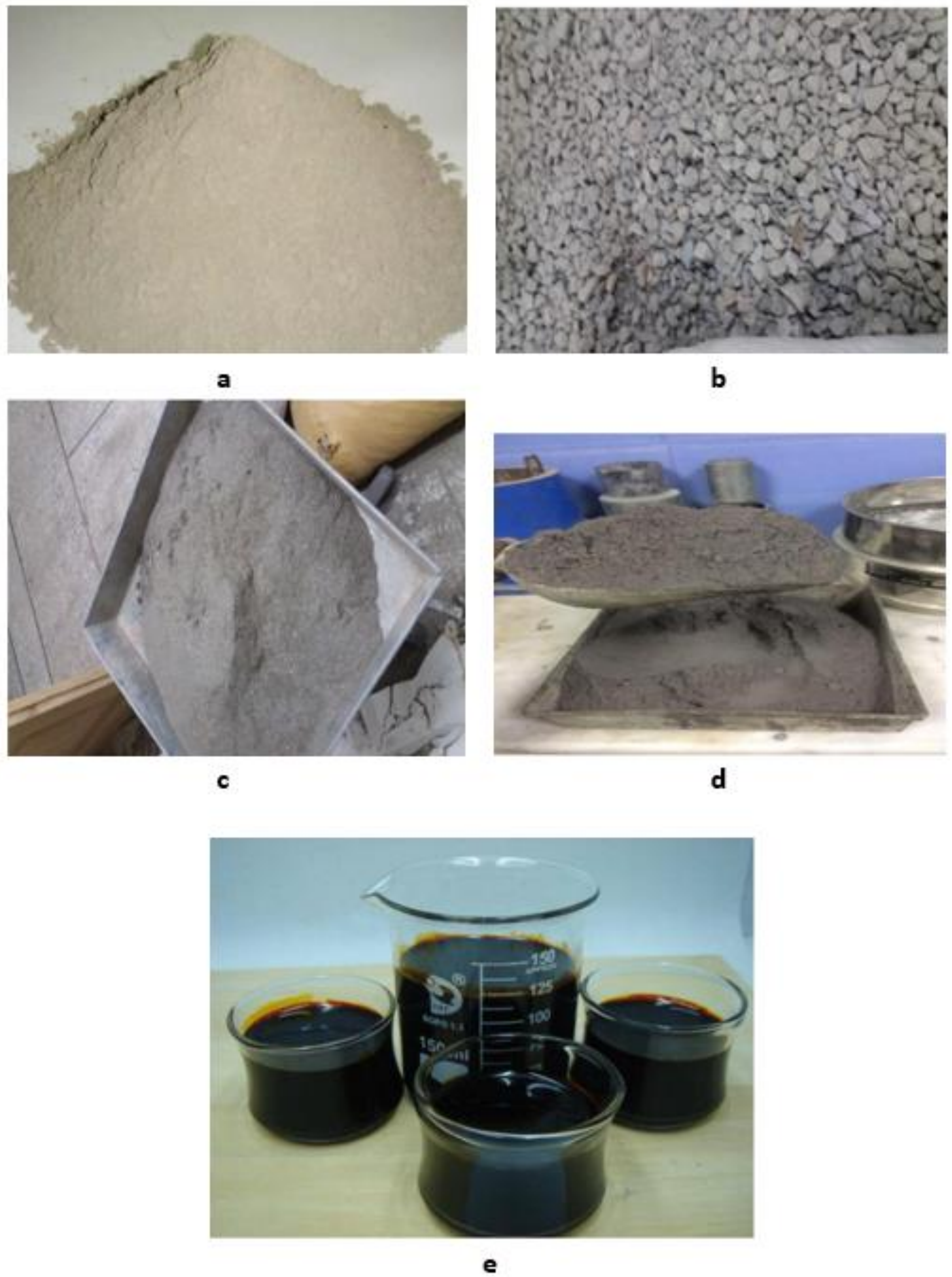


Figure 1. a. *Ordinary Portland Cement **b**. Sargodha Crush **c**. Lawrencepur sand **d**. Fly Ash **e**. High early strength and High range water reducing agent*

2.3 Pozzolanic Material-Fly ash

It is an extremely reactive pozzolanic material. It is a waste product, produced after the burning of coal.

DOI: 10.7764/RIC.00052.21

2.4 Physical properties

Fly ash gains its natural color from carbon and iron. If the fly ash contains high amount of carbon than its color could be grey to black. Moreover, its tin color shade comes from iron. Fineness: Its particle size ranges from 15 microns to 1 mm. Shape: Normally the particles of fly ash are spherical shape. Micro-structure: In coal power plants, when coal is fully burnt, some of the ash deposits at the bottom of combustion area, but, a glass powder form of fly ash flies into the air with other combustion gases. Fly ash used to collect from the chimneys when it's on the way into the air.

2.5 Chemical Properties

Fly ash is normally divided into two categories as per ASTM C618, Class F Fly ash: This type of fly ash comes from the combustion of large and harder bituminous coal. It possesses pozzolanic properties only. Class C fly ash: This type of fly ash comes from combustion of smaller bituminous, softer coal. It also holds cementitious properties. In this research, we have used class the ''F'' fly ash purchased from by Nishat Chunian electric power plant in Chunian (Figure 1d). Fly ash is a diverse material containing mainly Silicon dioxide, Iron trioxide, Aluminum trioxide and most important Calcium oxide. Every type of bituminous coal produces a different type of fly ash with varying properties, varying percentages of its constituents. This is largely being influenced by the chemical composition of lignite or bituminous coal. The pozzolanic activity of fly ash is directly proportional to its fineness, a more finer fly ash more pozzolanic activity it possesses. According to ASTM, it is restricted that fly ash should pass 45-micron sieve and retained percentage calculated should not exceed 34%. Moreover, the main source of fly ash also affects the pozzolanic working of fly ash. It shows cementitious and pozzolanic properties when mixed with cement and water. (Table 1) shows chemical composition and characteristics of fly ash. In this research, we have used locally available class ''F'' fly ash, by Nishat Chunian electric power plant situated in Chunian (Figure 1d).

Table 1. *Chemical composition of Fly Ash*

Composition/ Characteristic	Fly ash (%age)
CaO	14.49
MgO	0.38
SiO_2	60.37
$SO3$	2.50
Al_2O_3	13.48
Fe_2O_3	6.62
Cr_2O_3	0.09
Cl	0.009
K_2O	0.717
Na_2O	0.425
LOI (loss on Ignition)	0.432

2.6 Super-Plasticizer (SP-650)

Super-plasticizer (SP-650) as a high range water reducer (HRWR) was used. It is basically a water reducing admixture.

We added (HRWR) agent to the concrete mixture, to increase flowability. This admixture was basically a chemical, designed to reduce the water demand of concrete. It also gave an earliest high strength in concrete. The HRWR provided a gel like structure between the particles of the mixture so that the particles slide into each other and thus, provided a reasonable flow to the concrete. The Super-plasticizer used was received from the Ozone Chemicals private Ltd. (Figure 1e).

2.7 Mixture Design and Concrete Mixing Procedure

One mixture was prepared for the control samples to compare results with the mixtures incorporated with fly ash. There were six mixtures for the experimental program, which were prepared in two weeks. Each mixture consisted of 17 samples. Protocol of this research study is shown in (Table 2). We studied the ACI committee report 211 in order to compose mix design for high strength concrete (HSC) incorporating fly ash. After conducting a trial mixing of high strength concrete, they were cured for 7 days and then tested. Finally, the trial mixture with 0.32% water to cement ratio (0.32 w/c ratio) provided the optimum results. A high range water reducing agent (HRWR) was used to make concrete workable according to the desired slump value. SP-650 was used to acquire desirable flowability of concrete.

An electric rotary mixer was used for the mixing of concrete. The drum was first cleaned with a dry cloth, then sprayed with the water to wash it and moistened the inner surface of the drum. Before adding material in the mixer, all the concrete constituents were measured according to the desired proportions.

Mixing procedure was very simple. At first, a dry mixing of the aggregates was done and for this, we added coarse and fine aggregates and fly ash, and mixed for 2 minutes. Then added cement and mixed for 1 minute. Also, during mixing, we added water and mixed for 2 minutes. At the end, we added high range water reducing agent (HRWR) and mixed for 4 minutes and poured the mixer into pan. After mixing, the concrete was placed in the wide pan immediately. Slump test was carried out. The concrete was placed in the molds. The top surface of the concrete in molds was planed by trowel

***Table 2**. Protocol of experimental program*

Percentage dosage of fly ash	0%	4%	8%	12%	16%	20%
Number of Compression Test Samples (ASTM C39)	3	3	3	3	3	3
Number of Split Tensile Test Samples (ASTM C78)	3	3	3	3	3	3
Number of Flexural strength Test Samples (ASTM C78)	3	3	3	3	3	3

3. Specimen Preparations

3.1 Cylinders

Cylinder dimension was 300 × 150 mm. All cylinder molds were cleaned and washed. After washing and drying the inner surface of the molds, lubrication was done with oil. After oiling, the mold's nut and bolts were *tightened to ensure the firmness of joints to avoid the leakage of slurry from the joints. After mixing, concrete was placed in the cylinder molds in three layers and externally vibrated with the help of the mechanical vibrator for 30 seconds. After placing concrete, all the specimens were left for 24 hours in the laboratory. (Figure 2) shows specimens preparations.*

Figure 2. *Cylinder specimen*

3.2 Beams

Beams were cast in the size 450 × 150 × 150 mm. All the beams were cleaned and washed. After washing and drying the inner surface of the beams, lubrication was done with the oil. After mixing, the concrete was placed in the beams into three layers and externally vibrated with the help of the mechanical vibrator for 30 seconds. After placing concrete, all the beam specimens were left for 24 hours in the laboratory. (Figure 3a)and (Figure 3b) show beam.

Figure 3a. *Beam specimen*

Figure 3b. *Beams and cylinders after casting*

3.3 Curing

We used a curing tank for curing, which is properly designed according to the standards of American Concrete Institute (ACI). The specimens were placed in the tank for 7 and 28 days. Water used in curing tank was normal tap water and room temperature was 25 to 30º C (Figure 4).

Figure 4. *Specimen in curing tank*

4. Test Methodologies

4.1 Workability

It is a kind of measurement of the flow of fresh concrete paste. If the fresh concrete has pretty good flow then it will be easy to pour or cast in beams or columns. Due to flowability it will properly consolidate in the desired shape, there will less air voids, less water bubbles. It results in densely packed concrete. Fly ash has very fine particles having more surface area. During hydration, first we added cement and gave time to react with the water. After that, we added the fly ash into the mixture during hydration. Fly ash consumes all the available water and decreases the flow ability of the mixture. To increase the workability of mixture, we added high range water reducing (HRWR) agent to the concrete mixture. Mixing of incorporating higher dosage of fly ash content, also increases the need of HRWR. It is obvious that the workability of mortar slightly decreases as the dosage of fly ash content increases. This is due to the high specific surface of fly ash, which requires more water for a perfect hydration (Rao, 2003).

4.2 Slump Test

Before pouring concrete into the molds, the slump test was carried out as per ASTM C143 guidelines. The apparatus which was used for the test is just like a hollow cone shape with a top diameter of 4 inches, base of 8 inches and with a height of 12 inches (Figure 5). In this test, we filled the cone with concrete in three equal layers. A steel rod was used to give 25 blows to each layer to get compact freely. When the cone was filled with concrete, extra material was removed from the top. Now the cone was lifted upwards vertically. Next, the concrete height was observed, and then its height with the cone was measured.

DOI: 10.7764/RIC.00052.21

Figure 5. *Slump test*

4.3 Compressive Strength of Concrete Cylinders

The compressive strength test was performed in accordance with ASTM C39 specification (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens). This test method covered the determination of cylindrical compressive strength of concrete specimen. This test was conducted at the surface dry condition. The cylinder's top surfaces were grinded in order to make them uniform, smooth and parallel surface. The samples were tested at the age of 7 and 28 days of curing, under the Universal Testing Machine having a capacity of 2000 kN. Three test samples were tested for each mixture proportion. (Figure 6) shows the compressive test performance. The test loading rate was 0.50 MPa/sec.

Figure 6. *Compression testing of cylinder*

4.4 Splitting Tensile Strength of Concrete Cylinders

This test was carried out according to the ASTM C496. In this test, we actually found out the splitting tensile strength of concrete samples. This test was conducted at surface dry conditions. The cylinder's external surfaces *were made with a clean dry cloth. The samples were then placed horizontally in the machines and tested. The samples were cured for 7 days and 28 days. A universal tensile testing machine was used, which was having a capacity of 2000 kN. The test loading rate was 0.50 MPa/sec. (Figure 7) shows the testing of the cylinder.*

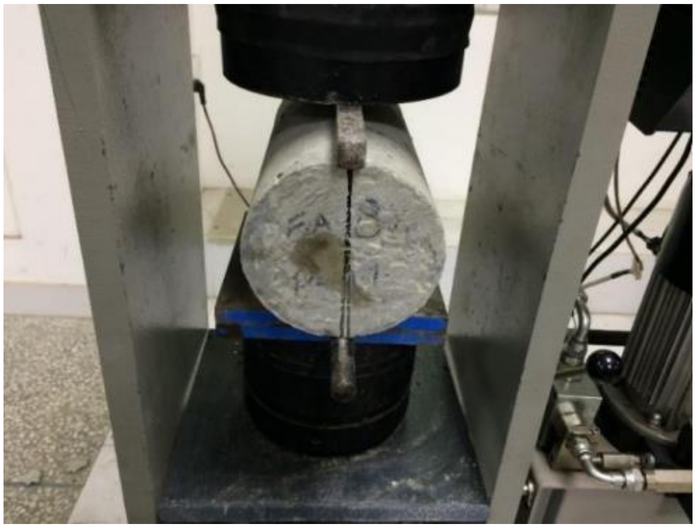


Figure 7. *Splitting Tensile strength of cylinder*

4.5 Flexural Strength of Concrete Beams

This test was carried out according to ASTM C78. In this test, we calculated the flexural strength of concrete by using a third point loading on the center of beams. Third point loading was used according to the ASTM C78 to guarantee that forces, which we are applying should be perpendicular to the beams. (Figure 8) shows the performance and loading assembly of the flexural strength test. The loading rate was 0.04 MPa/sec.

Figure 8. *Flexural testing of beam specimen*

5. Results

5.1 Slump Values and Workability

(Table 3) and (Figure 9) show the effects of fly ash on the workability of fresh concrete. (Figure 10) shows the results of effect of fly ash on slump value. The results portray that by increasing the fly ash, the workability decreased. It was observed, if we increase the volume of fly ash, flow ability of concrete decreases. If we increase the amount of fly ash up to 20% replacement of cement by weight, flow ability also decreases up to 50%. Further, the super-plasticizer (SP-650) contents have been increased with reference to fly ash contents. Therefore, workability decreased.

Figure 9. *Slump test*

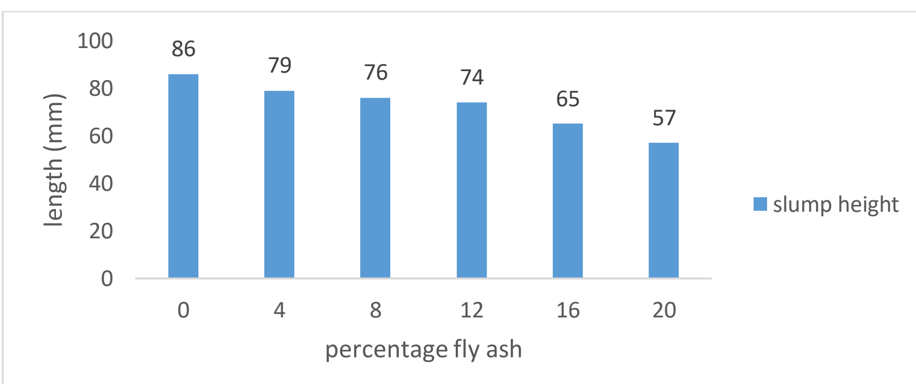


Figure 10. *Results of effect of fly ash on slump value*

***Table 3**. Results of slump with replacement level of fly ash*

Fly ash	0%	4%	8%	12%	16%	20%
HRWR	0%	0.4%	0.7%	1.0%	1.3%	1.6%
Slump (mm)	86	79	76	74	65	57

5.2 Compressive Strength

(Figure 11) shows the trend of how compressive strength varies with the change in volumes of fly ash. (Figure 12a) shows the testing of specimen and (Figure 12b) shows the specimen after rupture. (Table 4) shows the results of compressive strength of cylinders. It was witnessed that the compressive strength increased to a convincing value with the addition of fly ash up to 12%. But, when we increased the volume of fly ash up to 20%, the values of compressive strengths went down. For example, the compressive strength was increased by 70% for a specimen with the admixture of 12% of fly ash and 1.3% high range water reducer (HRWR), as compared to that of the control mixture without fly ash. The compressive strength of the mixture with a dosage of fly ash from 4% to 12%, showed satisfactory results. But at 16% and 20% dosage of fly ash, compressive strength results were very poor. Therefore, we can conclude that we achieved the optimum results till 12% of fly ash. There is a decrease in strength at 16% and 20% of fly ash.

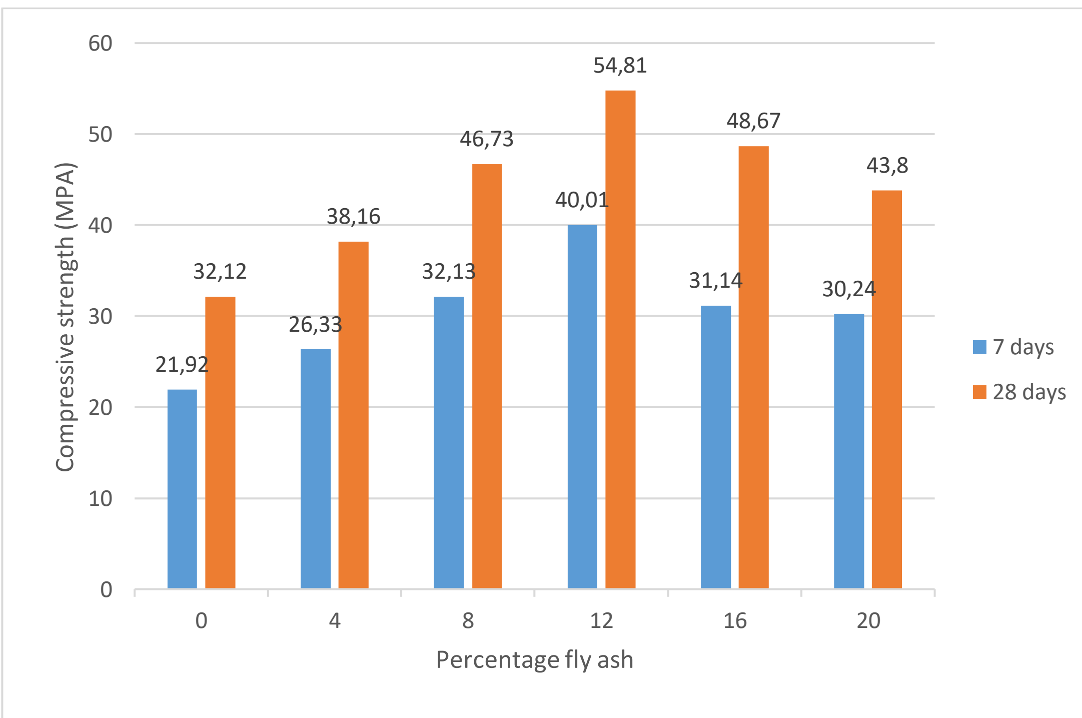


***Figure 11.** Results of effect of fly ash on compressive strength*

DOI: 10.7764/RIC.00052.21

Table 4. *Results of compressive strength of cylinders*

Sample No.	w/b ratio	HRWR	Fly ash	7 days	28 days
HSC1	0.32	0%	0%	21.92	32.12
HSC2	0.32	0.4%	4%	26.33	38.16
HSC3	0.32	0.7%	8%	32.13	46.73
HSC4	0.32	1.0%	12%	40.01	54.81
HSC5	0.32	1.3%	16%	31.14	48.67
HSC6	0.32	1.6%	20%	30.24	43.80

Figure 12a. *cylinder before compression test*

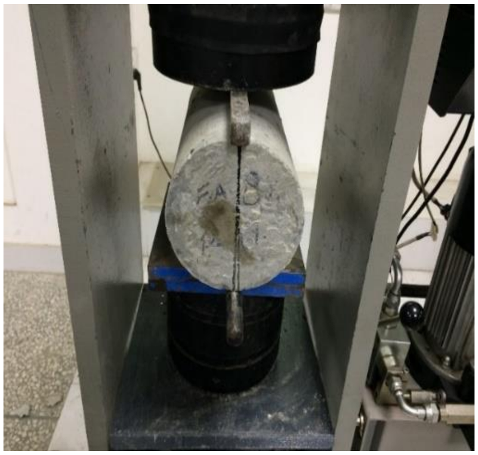
Figure 12b. *Cylinder after compression test*

5.3 Splitting Tensile Strength

(Figure 13a) shows the split tensile strength testing, whereas, the (Figure 13b) and (Figure 13c) represent the top and horizontal views of the post-testing of the specimen. (Figure 14) shows the splitting tensile strength results for varying amount of fly ash. The results showed that with the increased amount of fly ash, it affected the tensile strength of concrete in a very positive way. For example, splitting tensile strength was increased by 4.5% for a specimen with 4% of fly ash as compared to that of the control mixture without fly ash. There was no remarkable increase in split tensile strength of the mixtures with fly ash. The peak value of split tensile strength was 4.9 MPa with 12% fly ash dosage. There was a very minor increase in tensile strength of concrete.

There was a decreasing trend after 12% of fly ash and then 12% is considered the optimum for the pozzolanic reaction of the particles of fly ash and the remaining particles acted as filler material. After that, the volume of fly ash was considered an extra volume for the concrete to digest. (Table 5) shows the split tensile strength of cylinders.

Vol 38 Nº1 2023 www.ricuc.cl
DOI: 10.7764/RIC.00052.21



a

b

c

Figure 13. a. *Splitting tensile strength test of cylinders strength.* ***b.*** *Top view of cylinder after splitting tensile strength.* ***c.*** *Horizontal view of cylinder after splitting tensile strength*

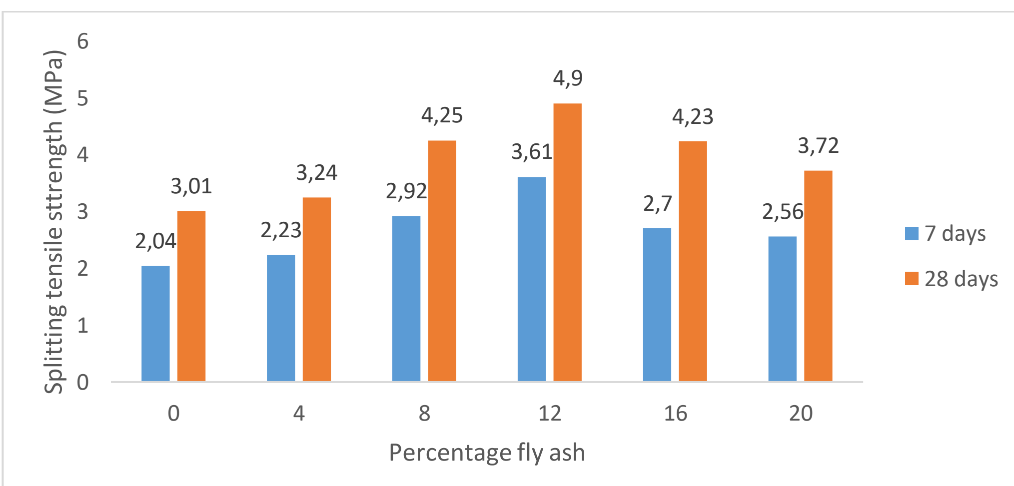


Figure 14. *Results of effect of fly ash on splitting tensile strength*

DOI: 10.7764/RIC.00052.21

Table 5. *Results of Split tensile strength of cylinders*

Sample No.	w/b ratio	HRWR	Fly ash	7 days	28 days
HSC1	0.32	0%	0%	2.04	3.01
HSC2	0.32	0.4%	4%	2.23	3.24
HSC3	0.32	0.7%	8%	2.92	4.25
HSC4	0.32	1.0%	12%	3.61	4.90
HSC5	0.32	1.3%	16%	2.7	4.23
HSC6	0.32	1.6%	20%	2.56	3.72

5.4 Flexural Strength

(Figure 15a) shows the flexural strength test of a beam. (Figure 15b) shows the beam after the flexural strength test. The results are shown in (Table 6). (Figure 12a) shows testing and (Figure 12b) shows after rupture of specimens. Beam specimens without fly ash, had a gradual increase in load carrying capacity before and after peak load was observed. Flexural strength in control mixture was observed at 3.73 MPa in 28 days and there was a slight increase in the trend of flexural strength. A brittle failure was observed in the beams during testing. Fly ash had a very low effect on the flexural strength. (Figure 16) shows the results of effect of fly ash on flexural strength.

a

b

Figure 15a. *Flexural strength test of a beam.* ***15b.*** *Beam after flexural strength test*

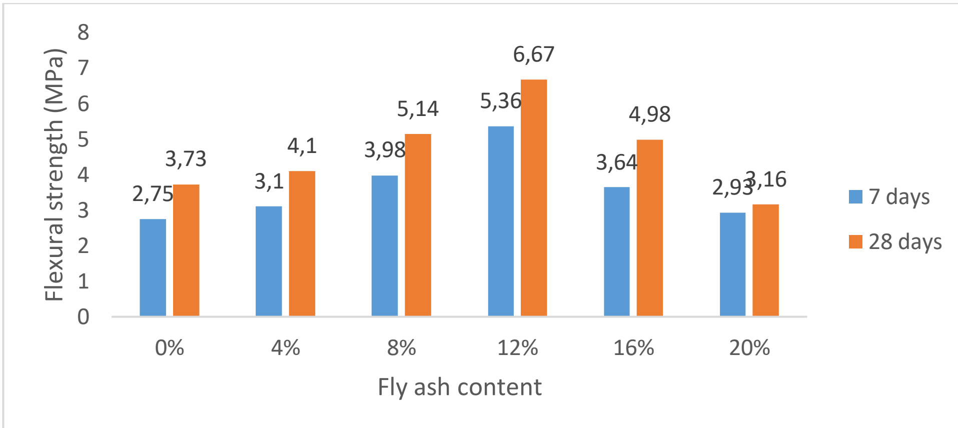


Figure 16. *Result of effect of fly ash on flexural strength*

Table 6. *Results of Flexural strength test of beams*

Sample No.	w/b ratio	HRWR	Fly ash	7 days	28 days
HSC1	0.32	0%	0%	2.75	3.73
HSC2	0.32	0.4%	4%	3.10	4.10
HSC3	0.32	0.7%	8%	3.98	5.14
HSC4	0.32	1.0%	12%	5.36	6.67
HSC5	0.32	1.3%	16%	3.64	4.98
HSC6	0.32	1.6%	20%	2.93	3.16

5. Discussion

Globally, greater than 150 million tons of fly ash as by-product is being generated from the coal combustion power plants. Fly ash is a waste material and its addition in the Portland cement can reduce its content as a waste disposal in the landfills, ponds or lagoons, which can cause serious environmental issues, such as water contamination, infertility of soil and bulk storage contamination (Ugurlu, 2004); (O'Brien et al., 2009). This study not only emphasized the use of fly ash for green-concrete, but also discovered the optimal dose of the fly ash in concrete to enhance the compressive strength of concrete. A high range water reducing agent (HRWR) was used to make concrete workable according to the desired slump value. For the high strength concrete (HSC), the components of the concrete mix proportions are kept very carefully. Highly refined fly ash was used as a cement substitute to enhance the characteristics of a high strength concrete (HSC). Moreover, the concrete is manufactured and used as a construction material in very huge amounts. Due to its extensive use, its mixing constitutes can be depleted and therefore, the research is required on the development of different substitutions. The compressive strength of the mixture with a dosage of fly ash from 4% to 12%, showed satisfactory results. But, at 16% and 20% doses of fly ash, the compressive strength results were very poor. We achieved the optimum results till 12% volume of fly ash and after that, the conditions were not compatible. The strength was increased due to the pozzolanic properties of fly ash. Fly ash reacts with free lime to make calcium silicate hydrate (CSH). The weaker the bond becomes stronger, which results in an overall increase in the compressive strength (Chindaprasirt et al., 2011). This increase in strength is due to the particle size of fly ash. Fly ash has a very fine particle size, so it reacts as a filler material as well. It fills the air voids and pores in concrete, thereby, directly increases its density (Poon et al., 1999). Small particles of fly ash have a larger surface area, which makes a fly ash very effective in terms of the pozzolanic reaction (Mehta, 1998). Because of the small size of fly ash, it produces a uniform paste of concrete, which provides an equal distribution of strength at every inch of the concrete (Chindaprasirt et al., 2005).

We noted that there was a decrease in concrete strength at 16% and 20% of fly ash. Actually, in the start of an increasing trend, all the available free lime was reacting with fly ash particles, providing pozzolanic reaction,

DOI: 10.7764/RIC.00052.21

and remaining fly ash acted as filler material so that's why overall strength was increasing. But when we increased the amount of fly ash to 16% and 20%, these were far more than the required for pozzolanic reaction and filling material, therefore, it exhibited the adverse effects and reduced the strength of concrete. (Atis, 2003) also conducted experiments with high-volume fly ash concrete to observe the strength and shrinkages. He reported that 0.28 – 0.34 water-cement ratios resulted in a good compressive and tensile strengths (at 1 day). He also observed that the 50% replacement of fly ash in the concrete made it a more full of strength as compared to the ordinary Portland cement. Fine high-calcium fly ash in geopolymer mortars were also reported the improvement in the flow, strength and drying shrinkage properties (Chindaprasirt et al., 2011); (Topark-Ngarm et al., 2015). (Sengul and Tasdemir, 2009) reported that high water-binder ratio decreases the concrete strength with pozzolanic materials as compared to Portland cement concrete. Therefore, they recommend the lower water-binder ratios, because less strength reductions were reported. They also concluded that in order to reduce the concrete's chloride permeability, the mixing of the pozzolanic material is more effective than only decreasing the water-cement ratios. In our study, the mixture with 0.32% water to cement ratio (0.32) provided the optimum results.

The results of split tensile strength showed that with the increased volumes of fly ash, it increased the tensile strength as well. Since, the fly ash has very fine particles, and therefore a strong packing of concrete actually increases the strength (Sata et al., 2007). However, we observed that there was a very minor increase in the tensile strength of concrete. There was a decreasing trend after 12% of fly ash and then 12% was considered for the optimum pozzolanic reaction of the particles of fly ash and the remaining particles acted as filler material. But after that, fly ash was considered as an extra amount for the concrete to digest. So, it affected the strength of concrete and reduced it (Poon et al., 2000); (Poon et al., 1999). The flexural strength was slightly increased by adding fly ash in different mixture proportions. The increase in trend was because of fine particles of fly ash. Actually, the closely packed particles in the concrete increases the density of the concrete (Sengul et al., 2005). Fly ash showed a little effect on the flexural strength (Elahi et al., 2010). The experiments showed that by increasing the doses of fly ash, the workability decreased. It was observed, if we increase the volume of fly ash, the flowability of concrete also decreases. The particles of fly ash are finer than cement particles, therefore, with a high surface area, the cohesion between the particles increases. Moreover, due to an increase in the cohesion, the workability decreases (Sengul and Tasdemir, 2009). Further, the super-plasticizer (SP-650) contents increase with the reference to fly ash contents. Therefore, the workability decreases. The high surface area of fly ash increases the demand for water and in order to limit the water content, the addition of super-plasticizer is required in order to maintain a high workability (Lavasani and Werner, 2012). It was noticed that in this situation, the HRWR content can rise up to 2%.

If we use fly ash in concrete, it can help us cleaning the environment from contaminating materials (Kearsley and Wainwright, 2001). The cost of fly ash in a normal market is very low, it is available as the cheapest pozzolanic material in Pakistan. When we use fly ash as a replacement of cement, it reduces the amount of cement to be used in concrete. Major durability issues in concrete occur only because of water, if we can reduce the water content of concrete, we can reduce the durability problems of concrete. And fly ash does this job very well. It reduces the water-cement ratio to extremely low, and it also enhances the texture of mixture composition of concrete (Cerny et al., 2017). Regarding durability and life span of concrete, they primarily rely on the water content. When we use fly ash, it consumes all the available water for hydration and forms CSH bonds (stronger bond) (Wang et al., 2015). In a research, a 11000 psi compressive strength was achieved with 45% fly ash and 0.24 water-cement ratio in 28 days (Poon et al., 2000). We used a class ''F'' fly ash, which lessens permeability more than class ''C'' fly ash. It also diminishes the high temperature of hydration, it also decelerates the access of chloride ion, boosting up the durability problems reducing the handling cost of the concrete mixture. Class F fly ash also accelerates the sulfate confrontation of high strength concrete. It also reduces the bleeding of high strength concrete (Naik et al., 1995).

It is the need of the time that we think of the ways where we can reduce the carbon dioxide emissions by manufacturing sustainable and environment construction materials. The pozzolanic materials require so much attention and significant experience when designing the high concrete mixture compositions. The manufacturing of ordinary cement is escalating every year globally and in the future, the rate of production of Portland cement will increase dramatically because of fast-growing urbanization. Large-scale fossil fuels, gas, coal, and electricity *are required to produce cement, which results in a release of a high amount of Carbon dioxide in the atmosphere (Topark-Ngarm et al. 2015). (Zachar, 2011) has explained the eco-friendliness in terms of carbon dioxide reduction and cost effective or economical solutions by using fly ash in concretes. In the UK, the use of fly ash (50%) yielded from the power plants, is related different industries and construction (McCarthy and Dhir, 1999). In the US, the electrical power plants burn around 95% of the coal received from the manufacturing facilities. The burning of coal emits various coal combustion products and fly ash is the largest part (approximately 60%) of this emission. If this emission into the environment would not be reduced, then serious degradation and impacts will occur, which can result in the increment of greenhouse gases. Therefore, it is recommended to use the fly ash as a partial replacement of cement in the concretes, which will lead to the reduction of concrete's permeability and its enhanced strength. The greenhouse gas emissions, thus can be reduced from the replacement of fly ash with Portland cement (Zachar, 2011); (O'Brien et al., 2009).*

In the current era, the term industrial ecology refers to the use of the Portland cements mixed with fly as obtained from coal power plants or from the blast furnace iron industries for a potential solution to decrease the environmental impacts. Although, the dose percentage from 15-20% (by mass) in cement is cost-effective and good for workability, but this amount might not deal in case of the sulfate attached or any thermal cracking. Therefore, a large amount of mixing fly ash is also recommended (25-35%), but it may be restricted to certain applications such as control of heat (O'Brien et al., 2009); (McCarthy and Dhir, 1999). For a sustainable development in the cement industry, the high-volume concrete mixed with fly ash is considered environment friendly as well as cost-effective, especially for the developing countries (Mehta, 2004). A green cement has been manufactured as per sustainable development goals by using cement kiln dust and Class F fly ash in different proportions by investigating different hydration products and microstructures of binders. These mixes gave satisfactory strength and performance results for new green cementitious products (Shah and Wang, 2004). The industry of concrete considered as a major source of greenhouse gas emission via. manufacturing of Portland cement (Flower and Sanjayan 2007); (Malhotra 2002). This emission is increasing in the developing countries and around half of the produced fly ash is being disposed of as a waste product (Dhir et al., 2006); (Kumar and Patil, 2006); (Malhotra, 2006). In Australia, only 10% of fly ash is used in the construction industry, while the remaining proportion is usually disposed of in landfills or ash dams (Wang and Wu 2006). The disposal of the fly ash is also risky, because there is always danger of leaching of the heavy metals, which can be transported in aquifers and waterways (Bhattacharjee and Kandpal, 2002); (Sushil and Batra, 2006). Coal fly ash is one of the most complex anthropogenic agents, and more degraded environmental impacts would be reported, especially in recoverable resources, if it is not being disposed-off properly (Yao et al., 2015). The environmental effects of the disposed hazardous residue fly ash are related to the contamination of the nearby aquatic environment and water degradation (Ugurlu, 2004). Fly ash's characteristics depends on the type of carbon combusted. Carbon fixation through the recycled application of fly ashes is considered as stable and environmental friendly, though it is a slow process (Uliasz-Bochenczyk et al., 2006). Now we have to take steps in order to reduce the consumption of cement in construction by using alternate pozzolanic materials such as fly ash. Portland cement is very costly and energy exhaustive material with many environmental impacts during all manufacturing stages. Incorporating with fly ash, makes a concrete very economical. We are going through the process of urbanization. New structures are being built. We have less space but demand for the accommodation is high. We cannot make high rise buildings with normal strength concrete. Therefore, we will have to shift towards the option of high strength green (HSG) concrete (Nelson et al., 1992).

6. Conclusion and Recommendations

Through the current research's design, we can identify and select the desired type and quantity of fly ash that is appropriate to use it in the mixture composition of high strength green (HSG) concrete. The compressive strength for 14 and 28 days, showed an increasing trend as the dosage of fly ash increased to 12% by weight, and after that, the trend goes down. It was due to more adherence between the fly ash and aggregate. Fly ash has a very minor effect on split tensile and flexural strength. Workability decreases as we increases the volume of fly *ash. Fly ash has more fine particles leads to the high surface area, cohesion between the particles increases. Due to increase in cohesion, workability decreases. Fly ash is very suitable to be used in concrete to produce high compressive strength. Low water cement ratio in relation with HRWR is key to high compressive strength. Concrete with fly ash gives satisfactory tensile and flexural strength results. Rapid chloride ion penetration test should be further carried out to check permeability of high strength concrete with or without coal fly ash. It is recommended to use the fly ash as a partial replacement of cement in concretes, which will also increase its strength. The greenhouse gas emissions, thus can be reduced from the replacement of fly ash with Portland cement.*

Authors report no conflict of interests. No funding was available for this study.

7. References

ACI committee 211 (1998). *Guide for selecting proportions for high strength concrete with Portland cement and fly ash, ACI 211.4R, ACI Mater J 93, 1-13.*

Atiş, C.D. (2003). *High-volume fly ash concrete with high strength and low drying shrinkage. Journal of materials in civil engineering. 15(2),153-6.*

Bhattacharjee, U.; Kandpal, T.C. (2002). *Potential of fly ash utilisation in India. Energy. 27(2),151-66.*

Cerny, V.; Kocianova, M.; Drochytka, R. (2017). *Possibilities of lightweight high strength concrete production from sintered fly ash aggregate. Procedia engineering. 195,9-16.*

Chindaprasirt, P.; Chareerat, T.; Hatanaka, S.; Cao, T. (2011). *High-strength geopolymer using fine high-calcium fly ash. Journal of Materials in Civil Engineering. 23(3),264-70.*

Chindaprasirt, P.; Jaturapitakkul, C.; Sinsiri T. (2005). *Effect of fly ash fineness on compressive strength and pore size of blended cement paste. Cement and Concrete Composites. 27(4),425-8.*

Copeland, K.D.; Obla, K.H.; Hill, R.L.; Thomas, M. D. (2001). *Ultra Fine Fly Ash for High Performance Concrete. Construction and Materials Issues. 166-75.*

Deb, P.S.; Sarker, P.K. (2017). *Effects of ultrafine fly ash on setting, strength, and porosity of geopolymers cured at room temperature. Journal of Materials in Civil Engineering. 2017;29(2):06016021.*

Dhir, R.; Dyer, T.; Paine, K. (2006). *Appropriate use of sustainable construction materials. Concrete (London).40(9):20-4.*

Elahi, A.; Basheer, P.; Nanukuttan, S.; Khan, Q. (2010). *Mechanical and durability properties of high performance concretes containing supplementary cementitious materials. Construction and Building Materials. 2010;24(3):292-9.*

Flower, D.J.; Sanjayan, J.G. (2007). *Green house gas emissions due to concrete manufacture. The international Journal of life cycle assessment. 2007;12(5):282.*

Haque, M.; Kayali, O. (1998). *Properties of high-strength concrete using a fine fly ash. Cement and Concrete Research. 1998;28(10):1445-52.*

Huang, C-H.; Lin, S-K; Chang, C-S; Chen, H-J. (2013). *Mix proportions and mechanical properties of concrete containing very high-volume of Class F fly ash. Construction and Building Materials. 2013;46:71-8.*

Kearsley, E.; Wainwright P. (2001). *The effect of high fly ash content on the compressive strength of foamed concrete. Cement and concrete research. 31(1),105-12.*

Kumar, S.; Patil, C. (2006). *Estimation of resource savings due to fly ash utilization in road construction. Resources, conservation and recycling. 48(2),125-40.*

Lavasani, H.; Werner, A. editors. (2012). *Practicality and Sustainability of using HVFA for Concrete Sidewalks. Construction Research Congress 2012: Construction Challenges in a Flat World.*

Malhotra, V. (2002). *Introduction: sustainable development and concrete technology. Concrete International. 24(7)*

Malhotra, V.M. (2006). *Reducing CO2 emissions. Concrete international. 28(9),42-5.*

McCarthy, M.; Dhir, R. (1999). *Towards maximising the use of fly ash as a binder. Fuel. 78(2),121-32.*

Mehta, P.K.; editor (2004). *High-performance, high-volume fly ash concrete for sustainable development. Proceedings of the international workshop on sustainable development and concrete technology; Iowa State University Ames, IA, USA.*

Mehta, P.K. (1998). *Role of pozzolanic and cementious material in sustainable development of the concrete industry. Special Publication. 178,1-20.*

DOI: 10.7764/RIC.00052.21

Naik, T.R.; Ramme, B.W.; Tews, J.H. (1995). *Pavement construction with high-volume class C and class F fly ash concrete. Materials Journal. 92(2),200-10.*

Nelson, P.; Sirivivatnanon, V.; Khatri, R. editors. (1992). *Development of high volume fly ash concrete for pavements. Proceedings, 16th arrb conference, 9-13 november 1992, perth, western australia; volume 16, part 2.*

O'Brien, K.R.; Ménaché, J.; O'Moore, L.M. (2009). *Impact of fly ash content and fly ash transportation distance on embodied greenhouse gas emissions and water consumption in concrete. The International Journal of Life Cycle Assessment. 14(7),621-9.*

Poon, C.; Lam, L.; Wong, Y. (2000). *A study on high strength concrete prepared with large volumes of low calcium fly ash. Cement and concrete research. 30(3),447-55.*

Poon, C.S.; Lam, L.; Wong, Y.L.(1999). *Effects of fly ash and silica fume on interfacial porosity of concrete. Journal of materials in civil engineering. 1999;11(3):197-205.*

Rao, G.A. (2003). *Investigations on the performance of silica fume-incorporated cement pastes and mortars. Cement and Concrete Research. 33(11),1765-70.*

Samad, S.; Shah, A. (2017). *Role of binary cement including Supplementary Cementitious Material (SCM), in production of environmentally sustainable concrete: A critical review. International journal of Sustainable built environment. 6(2),663-74.*

Sata, V.; Jaturapitakkul, C.; Kiattikomol, K. (2007). *Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete. Construction and Building Materials. 21(7),1589-98.*

Sengul, O.; Tasdemir, C.; Tasdemir, M.A. (2005). *Mechanical properties and rapid chloride permeability of concretes with ground fly ash. ACI materials journal. 102(6),414.*

Sengul, O.; Tasdemir, M.A. (2009). *Compressive strength and rapid chloride permeability of concretes with ground fly ash and slag. Journal of materials in civil engineering. 21(9),494-501.*

Shah, S.P.; Wang, K. editors. (2004). *Development of 'green' cement for sustainable concrete using cement kiln dust and fly ash. Proceedings of the International Workshop on Sustainable Development and Concrete Technology.*

Sumer, M. (2021). *Compressive strength and sulfate resistance properties of concretes containing Class F and Class C fly ashes. Construction and Building Materials. 34,531-6.*

Sushil, S.; Batra, V.S. (2006). *Analysis of fly ash heavy metal content and disposal in three thermal power plants in India. Fuel. 85(17-18):2676-9.*

Topark-Ngarm, P.; Chindaprasirt, P.; Sata, V. (2015). *Setting time, strength, and bond of high-calcium fly ash geopolymer concrete. Journal of Materials in Civil Engineering. 27(7),04014198.*

Ugurlu, A. (2004) *Leaching characteristics of fly ash. Environmental Geology. 46(6-7),890-5.*

Uliasz-Bochenczyk, A.; Mokrzycki, E.; Mazurkiewicz, M.; Piotrowski Z. (2006). *Utilization of carbon dioxide in fly ash and water mixtures. Chemical Engineering Research and Design. 84(9),843-6.*

Wang, S.; Wu, H. (2006). *Environmental-benign utilisation of fly ash as low-cost adsorbents. Journal of hazardous materials. 136(3),482-501.*

Wang, X-Y.; Park, K-B. (2015). *Analysis of compressive strength development of concrete containing high volume fly ash. Construction and Building Materials. 98,810-9.*

Yao, Z.; Ji, X.; Sarker, P.; Tang, J.; Ge, L.; Xia, M. et al. (2015). *A comprehensive review on the applications of coal fly ash. Earth-Science Reviews. 141,105-21.*

Zachar, J. (2011). *Sustainable and economical precast and prestressed concrete using fly ash as a cement replacement. Journal of materials in civil engineering. 23(6),789-92.*