International Journal of Emerging Trends in Science and Technology
11 (2) December 2025, 23-34
www.publishingindia.com/ijetst

Experimental Study on the Strength and Properties of High-Volume Fly Ash Concrete

Vetturayasudharsanan Ramasamy
Assistant Professor, Department of Civil Engineering, M.Kumarasamy College of Engineering, Karur, Tamil Nadu, India. Email: vetturayasudharsananr.civil@mkce.ac.in

Abstract: Construction industry plays a major role in building up nation's economy. The annual consumption of concrete is about 10 million tonnes in India. At present abundant quantity of fly ash from thermal power plants are being thrown out as waste which creates severe ecological problems and requires large storage area. Various researches have been made to utilize these materials in the production of concrete with the use of appropriate technology. The present study was investigated about the various percentage replacements of high volume fly ash (HVFA) by cement. The fundamental properties of HVFA concrete at various percentage of replacement of cement by fly ash is important to study how the concrete is able to withstand compressive load and tensile load. The replacement of fly ash for cement was 0%, 40%, 50% & 60% respectively. Preliminary tests were conducted to study the properties of materials, whereas the investigations such as compressive strength, flexural strength, split tensile strength and young's modulus of the concrete were done by casting several cubes, beams and cylinders. The experimental result shows good results when compared to the nominal concrete in terms of strength and economical value.

Keywords: Coarse aggregate, Crusher sand, Fly ash, High volume.

I. Introduction

Concrete is a construction material made by combining different ingredients, such as cement, aggregates, water, and additives. When these components mix, a chemical process occurs that gives concrete strength and cohesion. This process involves the reaction between the binding agent and water, as well as interactions with other materials added to the mixture [1]. The result is strong and durable building material. The strength and durability of concrete come from the chemical reactions that occur between its components. When the binding agent reacts with water, it forms a strong bond that holds the aggregates together. Additional materials can be added to the mixture to enhance its properties and performance [16]. Concrete is widely used in construction due to its strength, durability, and versatility [2]. It's a fundamental material in building design and construction, and its properties can be tailored to meet specific needs and applications.

Fly ash can be used to partially replace cement in concrete, offering several benefits. It can be added directly to the concrete mixture or blended with cement to create a specialized product. Typically, fly ash makes up 15-25% of the total cementing materials, although it can be used in higher proportions for specific applications. When used correctly, fly ash can improve concrete's performance in several ways [6]. It can increase long-term strength, reduce permeability, and enhance durability. Additionally, fly ash can help mitigate certain durability issues, such as damage from sulphates and alkali-silica reactions. By incorporating fly ash into concrete, builders can create structures that are more resilient and long-lasting [18]. With proper design and execution, fly ash concrete can exhibit superior performance and durability.

A specialized type of concrete, known as high-volume fly ash concrete, utilizes a significant amount of fly ash to reduce cement content [5]. This approach leads to improved workability, durability, and environmental sustainability. By optimizing the mixture and selecting the right materials, high-volume fly ash concrete can achieve superior performance while minimizing its ecological footprint [14].

The proportion of cement replacement by fly ash can vary significantly in high-volume fly ash concrete. In many cases, replacement levels of 50% or more have been successfully used [4]. To achieve workability at low water-to-cement ratios, specialized additives are often necessary of the HVFAC made with cement and fly ash from numerous sources and covering a wide range of physical properties and chemical compositions [17]. It was found from those investigations and field applications that properly designed and cured, HVFAC can demonstrate excellent performance, both in mechanical as well as in durability aspects, and this when it is made with a wide range of materials [8].

A. Fly Ash: Composition and Properties

Fly ash is a fine powder recovered from the gases of burning coal. It consists primarily of silica, alumina, and iron, and can be used as a mineral admixture in concrete [3]. Fly ash is classified into two main categories: Class C and Class F, based on its chemical composition.

B. Characteristics of Fly Ash

The quality of fly ash is affected by various factors, including the type of coal used, combustion processes, and flue gas cleaning methods [7]. Key characteristics of fly ash include loss on ignition, fineness, chemical composition, and uniformity.

C. Importance of Fly Ash Quality

The quality of fly ash is crucial for its use in concrete. Loss on ignition, fineness, and chemical composition can impact the performance and durability of concrete [12]. High-quality fly ash can improve the strength and resistance of concrete.

D. Mechanism of Fly Ash in Concrete

When fly ash is used in concrete, it can improve the microstructure and reduce heterogeneities. The pozzolanic reaction of fly ash can lead to a more durable and crack-resistant concrete [20].

E. Benefits of High-Volume Fly Ash Concrete

High-volume fly ash concrete has been shown to exhibit excellent structural and durability characteristics. Its use can lead to improved sustainability, reduced environmental impact, and cost savings [10].

F. Objectives of the Study

The study aims to investigate the properties of high-volume fly ash concrete with crusher sand as fine aggregate. The objectives include:

- Evaluating the compressive strength of high-volume fly ash concrete at different ages.
- Assessing the split tensile strength and flexural strength of high-volume fly ash concrete.
- Investigating the stress-strain behavior of high-volume fly ash concrete with crusher sand.

II. Material and Its Properties

A. Cement Properties

The study used Ordinary Portland Cement (OPC) 53 grade to manufacture high-volume fly ash concrete [9]. The physical and chemical properties of the cement were evaluated.

Fig. 1: Cement

B. Physical Properties of Cement

The specific gravity of cement was determined using a density bottle. The test involved measuring the weight of the empty bottle, the bottle with cement, and the bottle with cement and kerosene. The specific gravity was calculated using the formula:

Specific Gravity = (W2-W1) / (W2-W1) - (W3-W4)

The consistency test was conducted to determine the amount of water required to produce a paste of normal consistency [19]. The test involved mixing cement with varying amounts of water and measuring the depth of penetration of a Vicat plunger.

Table I: Physical Properties of Cement

Test Conducted	Observed Values
Specific gravity of cement	3.15
Consistency	35%
Initial setting time	28 min
Final setting time	60 min

C. Setting Time of Cement

The initial and final setting times of cement were determined using a Vicat apparatus. The test involved measuring the time it takes for the needle to penetrate the test block to a depth of 33-35 mm from the top [11].

D. Chemical Properties of Cement

The chemical composition of cement was analyzed, and the results are presented in the following tables:

- Calcium oxide: 62.68%
- Silica: 20.36%
- Alumina: 6.87%
- Iron oxide: 3.67%
- Magnesia: 1.77%

- Sulphuric anhydride: 2.24%
- Tri calcium silicate: 42.57%
- Di calcium silicate: 26.33%
- Tri calcium aluminate: 12%
- Tetra calcium alumino ferrite: 2.24%

TABLE II: CHEMICAL PROPERTIES OF CEMENT

Test Conducted	Observed Values (%)
Calcium oxide	62.68
Silica	20.36
Alumina	6.87
Iron oxide	3.67
Magnesia	1.77
Sulphuric anhydride	2.24
Tri calcium silicate	42.57
Di calcium silicate	26.33
Tri calcium aluminate	12
Tetra calcium alumino ferrite	2.24

E. Fly Ash Properties

Class F fly ash from Mettur Thermal Power Plant was used in the study. The specific gravity of fly ash was 2.2, and its chemical properties were evaluated.

F. Fly Ash

Class F fly ash of high volume was used and it is obtained from Mettur Thermal Power Plant. The fly ash is in conformity with the general requirements of pozzolana. The specific gravity of fly ash is 2.2 chemical properties are presented in Table III.

Fig. 2: Fly Ash

TABLE III: CHEMICAL PROPERTIES OF FLY ASH

Test Conducted	Observed Values (%)
Los on ignition	3.74
Silica as SiO_2	35.87
Iron as Fe_2O_3	4.00
Alumina as Al_2O_3	34.14
Calcium as CaO	14.25
Magnesium as MgO	3.64
Sulphate as SO_3	3.4
Sodium as Na_2O	0.90
Potassium as K_2O	0.06
Chloride	-

G. Crusher Sand

Crusher sand was obtained from ARR Ltd., Mettur [13]. The properties of the artificial sand were studied in accordance with BIS 2386-1963, and the results are given in Table IV and V.

Fig. 3: Crusher Sand

TABLE IV: PHYSICAL PROPERTIES OF CRUSHER SAND

Sr. No.	Test Conducted	Observed Values
1	Specific gravity	2.74
2	Water absorption	1.8%
3	Bulk density	1.64 gm/cc
4	Percentage of voids	40%
5	Fineness modulus	2.49

Table V: Chemical Properties of Crusher Sand

Sr. No.	Test Conducted	Observed Values (%)
1	SiO_2	34.06
2	Al_2O_3	18.8
3	Fe_2O_3	0.70
4	CaO	32.40
5	MgO	10.75
6	SO_3	0.85
7	S	0.65
8	MnO	0.49
9	Na_2O	0.31
10	K_2O	0.98
11	Cl	0.008

H. Coarse Aggregate

Coarse aggregate of hard blue granite of size 20 mm aggregates were used to manufacture the concrete. The aggregates are in angular shape. The physical properties are given Table VI.

Fig. 4: Coarse Aggregate

I. Specific Gravity

To calculate the specific gravity of coarse aggregate, a pycnometer was employed. The process involved the following steps:

- Weigh the empty, dry pycnometer (W1).
- Fill the pycnometer 2/3 full with coarse aggregate and record the weight (W2).
- Add water to the pycnometer with the coarse aggregate and weigh it (W3).
- Fill the pycnometer to the top with water and record the weight (W4).

The specific gravity of the coarse aggregate is then calculated using the formula:

Specific Gravity = (W2 - W1) / (W2 - W1) - (W3 - W4)

Where:

- W1 = weight of empty pycnometer

- W2 = weight of pycnometer with coarse aggregate

- W3 = weight of pycnometer with coarse aggregate and water

- W4 = weight of pycnometer filled with water

This calculation provides the specific gravity of the coarse aggregate, a crucial parameter in determining its properties and behavior in concrete.

J. Bulk Density

Bulk density is the weight of a material in a given volume. It is expressed in Kg/m^3. A cylindrical measure of nominal diameter 250 mm and height 300 mm was used. The cylinder has the capacity of 15 liters with the thickness of 4 mm. The cylindrical measure was filled about 1/3 each time with thoroughly mixed aggregate and tampered with 25 strokes. The measure was carefully struck off level using tamping rod as straight edge. The net weight of aggregate in the measure was determined. Bulk density was calculated as follows:

Bulk density = (Net weight of coarse aggregate in Kg)/(Volume)

K. Surface Moisture

100 g of coarse aggregate was taken and their weight was determined, say W_1. The sample was then kept in the oven for 24 hours. It was then taken out and the dry weight is determined, says W_2. The difference between W_1 and W_2 gives the surface moisture of the sample.

L. Water Absorption

100 g of nominal coarse aggregate was taken and their weight was determined, say W_1. The sample was then immersed in water for 24 hours. It was then taken out, drained and its weight was determined, say W_2. The difference between W_1 and W_2 gives the water absorption of the sample.

M. Fineness Modulus

To calculate the fineness modulus, a sample was prepared and sieved for 10 minutes. The weight of aggregate retained on each sieve was measured, and the cumulative percentage weight retained was calculated. The fineness modulus is the ratio of the sum of these cumulative percentages to 100, providing insight into the aggregate’s size distribution and properties.

N. Sieve Analysis

Coarse aggregate is composed of natural stones that are crushed, uncrushed, or broken. To be suitable for use, coarse aggregate should possess certain characteristics, including:

- Hardness and strength.
- Density and durability.
- Cleanliness, with no lumps of clay or vegetable matter.
- A roughly cubical shape, avoiding flaky pieces.
- Low water absorption (not exceeding 10% of its weight after 24 hours of immersion).

Angular and cubical particles are preferred for optimal performance. These characteristics ensure the coarse aggregate meets the required standards for construction applications.

Table VI: Physical Properties of Coarse Aggregate

Sr. No.	Parameter	Result	Limits IS : 456-2000
1	PH	6.92	6.5 -8.5
2	Chloride	52 mg/l	2000 mg/l(PCC) 500 mg/l(RCC)
3	Alkalinity	7 ml	<25 ml
4	Sulphate	128 mg/l	400 mg/l
5	Fluorides	0.04 mg/l	1.5 mg/l
6	Organic solids	56 mg/l	200 mg/l
7	Inorganic solids	129 mg/l	3000 mg/l

O. Water

Potable tap water available in laboratory with pH value of 7.0 ± 1 and conforming to the requirement of IS 456-2000 was used for mixing concrete and curing the specimen as well.

Fig. 5: Water

The water used for making concrete should be free from undesirable salts that may react with cement and admixture and reduce their efficiency. Silts and suspended particles and undesirable as they interfere with setting, hardening and bond characteristics [15]. Algae in mixing water may cause a marked reduction in strength of concrete either by combining with cement to reduce the bond or by causing large amount of air entrainment in concrete.

Although the pH of pure water is 7, drinking water and natural water exhibits a pH range because it contains dissolved minerals and gases. Surface waters typically range from pH 6.5 to 8.5 while groundwater ranges from pH 6 to 8.5.

Water with a pH less than 6.5 is considered acidic. This water typically is corrosive and soft. It may contain metal ions, such as copper, iron, lead, manganese and zinc. The metal ions may be toxic, may produce a metallic taste, and can stain fixtures and fabrics. The low pH can damage metal pipes and fixtures.

Table VII: Physical Properties of Water

Test Conducted	Observed Values
Specific gravity	2.75
Water absorption	0.9%
Moisture Content	10%
Bulk density	1.66 g/cc
Fineness modulus	3.20

P. Super Plasticizers

Conplast SP-430 was used in this study to increase the workability of fresh fly ash concrete. Conplast SP-430 is a high range super plasticizing admixture. It compliance with IS 9103:1999. It speeds up construction, increase workability and cohesion, aids pumping by reducing line friction and dry packing. Low porosity resulting in sustainability improved water penetration resistance.

Fig. 6: Conplast SP-430

Table VIII: Properties of Super Plasticizer

Test Conducted	Observed Values
Specific gravity	1.20
Ph	7.71
Solid content (%)	34.50
Appearance	Brown Liquid

III. Experimental Investigations and Methodology

A. Methodology

The study involved several key steps:

- *Material Procurement:* Sourcing cement, coarse and fine aggregates, fly ash, and superplasticizer.
- *Material Characterization:* Studying the properties and characteristics of HVFAC materials.

- *Mix Design Optimization:* Using IS/DOE methods to optimize the mix proportioning of HVFAC.
- *Specimen Preparation:* Preparing cubes and cylinders for testing.

The experimental investigation focused on evaluating the workability and mechanical properties of HVFAC, including:

- *Workability Tests:* Slump test and compaction test.
- *Mechanical Properties Tests:* Compressive strength and split tensile test.

The study used a specified mix design procedure and conducted trial mixes with varying percentages of fly ash replacement (0%, 40%, 50%, and 60%) to determine the optimum proportions. A minimum of three specimens were tested for each trial mix, and all tests were conducted according to specifications.

B. Mix Proportions

The process of determining the optimal proportions of concrete ingredients is crucial to achieving the desired workability, strength, and durability. For this study, the mix proportions for M40 grade concrete were determined using the DOE method of mix design, based on trial mixes. The resulting mix proportions are presented in Table IX, and these mixtures were used consistently throughout the investigation.

Table IX: Mix Proportions for M_{40} Grade Concrete

% Fly Ash	Cement kg/m^3	Fly Ash kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	w/c Ratio kg/m^3
0	360	0	764	1146	180
40	222.7	148.66	758	1136	160
50	198.93	198.93	741.28	1111.926	155
60	172.26	258	685.61	1118.41	150

C. Specimen Casting Details

A total of 144 specimens were cast to evaluate the mechanical properties of the mixture, consisting of:

- 36 cube specimens (150 mm x 150 mm x 150 mm) for compressive strength testing.
- 36 cylinder specimens (150 mm diameter x 300 mm height) for splitting tensile strength testing.
- 36 prism specimens (100 mm x 100 mm x 500 mm) for flexural strength testing.
- 36 cylinder specimens (150 mm diameter x 300 mm height) for determining Young's modulus of elasticity.

After casting, the specimens were demolded after 48 hours and then cured in a water tank until testing.

D. Casting

The test specimens were cast in steel moulds, which were lubricated with oil to ensure easy demolding. A concrete mixer was used throughout the experimental work. The casting process involved:

- Weighing and mixing cement and fly ash.
- Adding coarse aggregate and crusher sand to the mixture and mixing thoroughly.
- Preparing a solution of superplasticizer and water, which was then added to the concrete mixture.
- Placing the concrete mixture in the moulds in three equal layers.
- Compacting the concrete using a table vibrator to eliminate air pockets.

The cast specimens were then prepared for further testing and evaluation.

Fig. 7: HVFC Casted in Mould

E. Testing of Specimens

i. Compressive Strength of Concrete

The strength of concrete is influenced by several factors, including:

- Properties and proportions of constituent materials (cement, fine aggregate, coarse aggregate).
- Degree of hydration.
- Rate of loading.
- Method of testing.
- Specimen geometry.

The quality of the aggregate, cement paste, and paste-aggregate bond also play a significant role in determining concrete strength. Additionally, the strength can be affected by the specimen's moisture condition, with saturated specimens potentially exhibiting 15-20% lower strength than dry specimens.

Testing Procedure Compressive strength testing was conducted using a hydraulic digital compression testing machine with a capacity of 2000 kN and a pace rate of 2.5 kN/sec. The testing procedure took into account the differences in strength between cube and cylindrical specimens, as well as the potential impact of specimen size on test results.

Fig. 8: Testing of Cube Specimen for Compressive Strength

ii. Split Tensile Strength of Concrete

The split tensile strength is the indirect measurement of the tensile strength by placing a cylindrical specimen horizontally between the loading surfaces. This method consists of applying a diametric compressive force along the length of a cylindrical specimen. This loading induces tensile stresses on the plane containing the applied load. Tensile failure occurs rather than compressive failure. Plywood strips are used so that the load is applied uniformly along the length of the cylinder and the load is applied until failure of the cylinder, along the vertical diameter shown in Fig. 10. The maximum load is divided by appropriate geometrical factors to obtain the splitting tensile strength of concrete are the ASTM C 496 splitting tension test and the ASTM C 78 third-point flexural loading test. The test setup was shown in Fig. 9.

$$\text{split Tensile strength (T)} = \frac{2P}{\pi LD}$$

Where

P-Compressive load on the cylinder in N,

L-Length of the cylinder in mm,

D-Diameter of the cylinder in mm,

Fig. 9: Testing of Cylindrical Specimen for Split Tensile Strength

iii. Flexural Strength of Concrete

Flexural strength is the ability of a beam or slab to resist failure in bending. It is measured by loading un-reinforced concrete beam of size 500 x 100 x 100 mm. Flexural MR is about 12 to 20 percent of compressive strength. Hydraulic Flexural testing machine was used for the test and with a capacity of 10 tones. The bearing surfaces of the supporting, loading rollers are wiped clean and make contact with the rollers. The specimen is then placed in the machine is such a manner that the load is applied to the uppermost surface as cast in the mould, along two lines spaced 20 cm apart. The load was applied gradually until the specimen fails and the maximum load applied to the specimen during the test is noted. The flexural strength of the specimen is expressed as the modulus of rupture f_b and the formula used to calculate the flexural strength depends on the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen. Since the failure distance 'a' is greater than 13.3 cm the formula used shown below:

$$\text{Flexural Strength (fb)} = \frac{\text{Pl}}{\text{bd2}}$$

Where

P = Load (Kg);

l = Length of the specimen;

b = Breadth of the Specimen;

d = Depth of the Specimen

Beam Specimen subjected to flexural strength is presented in Fig. 10.

Fig. 10: Beam Specimen Subjected to Flexural Strength

IV. Result and Discussion

A. Compressive Strength of HVFAC with Crusher Sand

Compressive strength of HVFAC with crusher sand was found at the age of 7, 14 and 28 days. Test results are summarized in Table X. Compressive strength variation at different curing period is also illustrated in Fig. 11 to 13. Comparison of compressive strength of HVFC with crusher sand with conventional concrete is also shown in Fig. 14.

At the age of 7 days, compressive strength of HVFAC with crusher sand was less compared to conventional concrete at the 40%, 50% and 60% replacement of fly ash. Similar condition was observed even at the age of 14 days. But at the age of 28 days compressive strength of HVFAC with crusher sand is comparable with conventional concrete. However, compressive strength of HVFAC with crusher sand at the age of 28 days achieved the target strength at all fly ash replacement level.

Table X: Test Results of High Volume Fly Ash Concrete with Crusher Sand Fine

Properties	Age at Testing	Conventional Concrete	40% Fly Ash Replacement	50% Fly Ash Replacement	60% Fly Ash Replacement
Compressive strength test (MPa)	7 days	16.6	12.6	10.47	9.38
	14 days	29.38	25.78	19.40	18.97
	28 days	44.85	41.70	41.67	40.94
Flexural strength test (MPa)	7 days	3.05	2.82	2.65	1.98
	14 days	3.12	2.92	2.81	2.58
	28 days	6.8	5.18	4.54	4.00
Split tensile strength test (MPa)	7 days	2.05	1.45	1.33	1.22
	14 days	2.16	1.80	1.65	1.45
	28 days	2.37	2.91	2.76	2.581

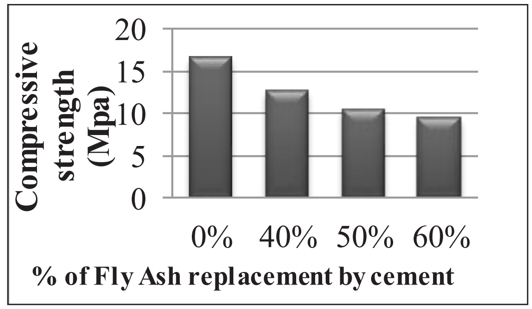

Fig. 11: 7 Days Compressive Strength of HVFAC with Crusher Sand

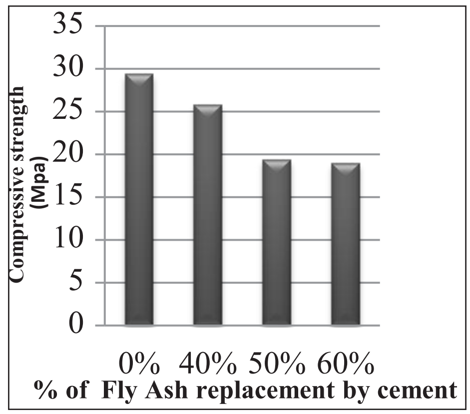

Fig. 12: 14 days Compressive Strength of HVFAC with Crusher Sand

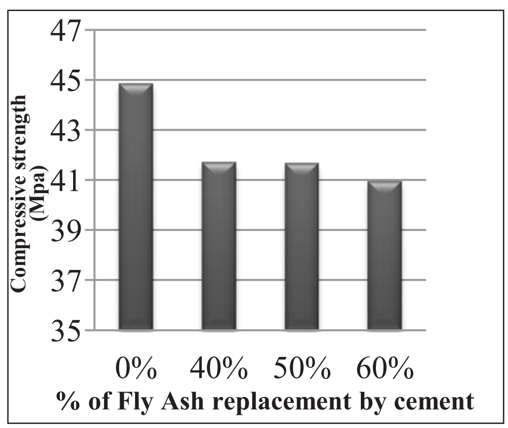

Fig. 13: 28 Days Compressive Strength of HVFAC with Crusher Sand

B. Flexural Strength of HVFAC with Crusher Sand

Flexural strength of HVFAC with crusher sand was found at the age of 7, 14 and 28 days. Test results are summarized in Table X. Flexural strength variation at different curing period is also illustrated in Fig. 15 to 17. Comparison of flexural strength of HVFC with crusher sand with conventional concrete is also shown in Fig. 18.

At all age flexural strength of HVFAC with crusher sand was comparable with conventional concrete except at 60% fly ash replacement level. At the age of 7 days it is ranged from 2.82 to 1.98 MPa for 40% to 60% fly ash replacement level. At the age of 14 days it is varied from 2.92 MPa to 2.58 MPa. And at the age of 28 days it is in the range of 5.18 MPa to 4.00 MPa. Flexural strength was found to decrease with increased fly ash content.

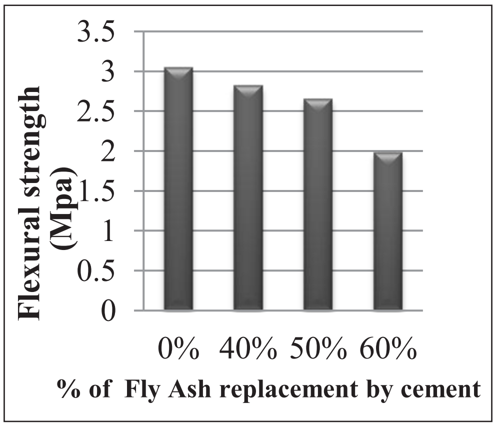

Fig. 14: 7 Days Flexural Strength of HVFAC with Crusher Sand

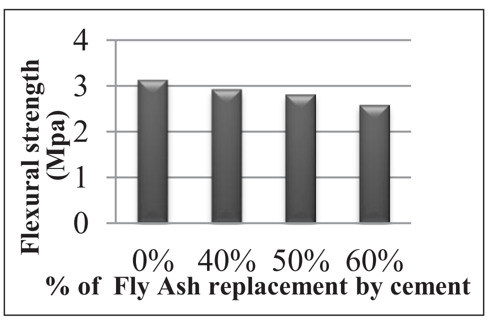

Fig. 15: 14 Days Flexural Strength of HVFAC with Crusher Sand

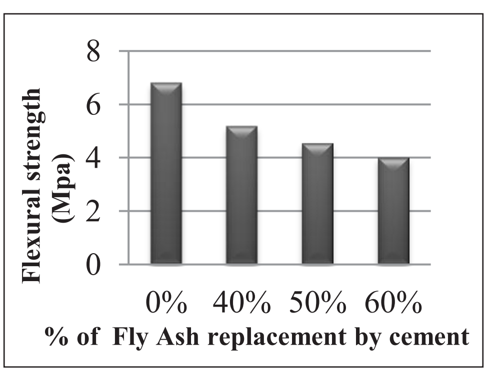

Fig. 16: 28 Days Flexural Strength of HVFAC with Crusher Sand

C. Split Tensile Strength of HVFAC with Crusher Sand

Split tensile strength of HVFAC with crusher sand was found at the age of 7, 14 and 28 days. Test results are summarized in Table X. Split tensile strength variation at different curing period is also illustrated in Fig. 19 to 21. Comparison of split tensile strength of HVFAC with crusher sand with conventional concrete is also shown in Fig. 22.

At initial age split tensile strength of HVFAC with crusher sand was less compared to conventional concrete. At the age of 28 days it is found to increase with fly ash content. At the age of 7 days it is in the range of 1.45 MPa to 1.22 MPa. At the age of 14 days is ranged from 1.8 MPa to 1.45 MPa. And at the age of 28 days is varied from 2.91 MPa to 2.58 MPa.

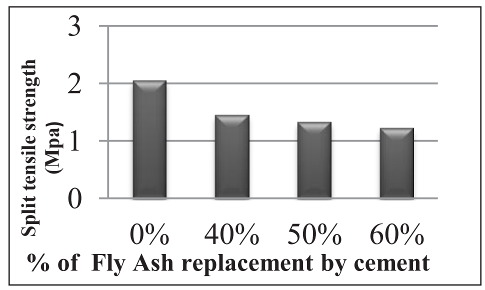

Fig. 17: 7 Days Split Tensile Strength of HVFAC with Crusher Sand

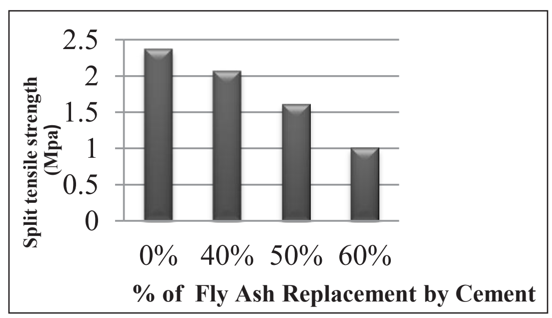

Fig. 18: 14 Days Split Tensile Strength of HVFAC with Crusher Sand

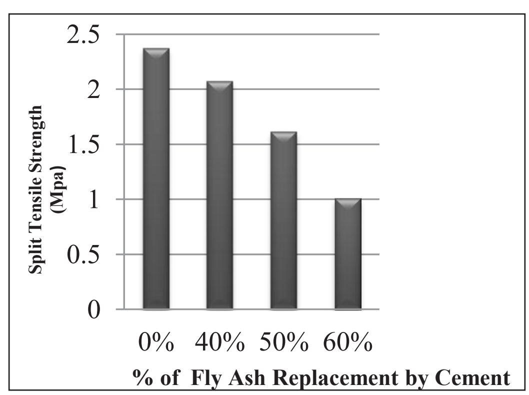

Fig. 19: 28 Days Split Tensile Strength of HVFAC with Crusher Sand

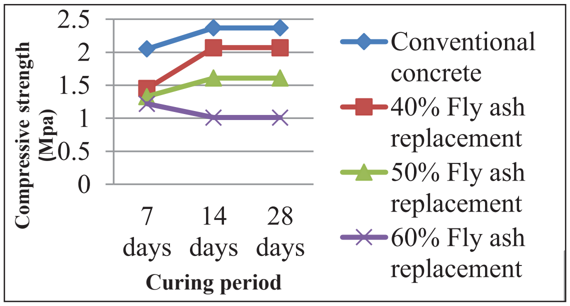

Fig. 20: Comparison of Split Tensile of HVFAC with Crusher Sand

D. Test Results for Young's Modulus of Elasticity

The concrete samples with various percentages of fly ash have been prepared as per mix design and tested in compressometer to determine young's modulus of elasticity by plotting stress Vs strain curves at 28 days. The test results are presented in Table X. The stress strain variation of HVFC with crusher sand as fine aggregate is illustrated in Fig. Fig. 21 and 22. The young's modulus of elasticity of HVFC with crusher sand as fine aggregate is given in Table XI.. The values are in the range of 23530 MPa to 23530 MPa for HVHC with crusher sand which is comparable with conventional concrete.

Table XI: Stress and Strain Values of HVFC with Crusher Sand as Fine Aggregate

Load (Kg)	Stress (N/mm^2)	Strain x 10-5 (% Fly Ash in Concrete)			
		0%	40%	50%	60%
500	0.2775	0	0	0	0
1000	0.5550	0	1	1	0
1500	0.832	2	2	3	2
2000	1.110	5	5	8	7
2500	1.387	8	11	12	9
3000	1.665	13	18	20	24
3500	1.945	20	32	25	45
4000	2.220	45	72	85	90
4500	2.498	75	115	119	130

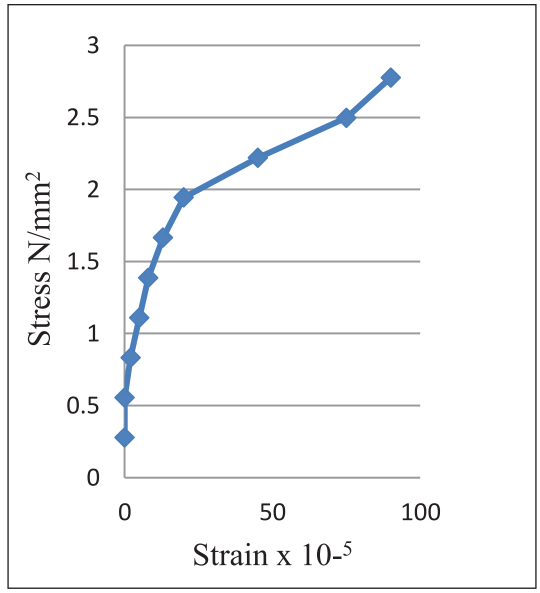

Fig. 21: Stress Vs Strain Curve for Conventional Concrete

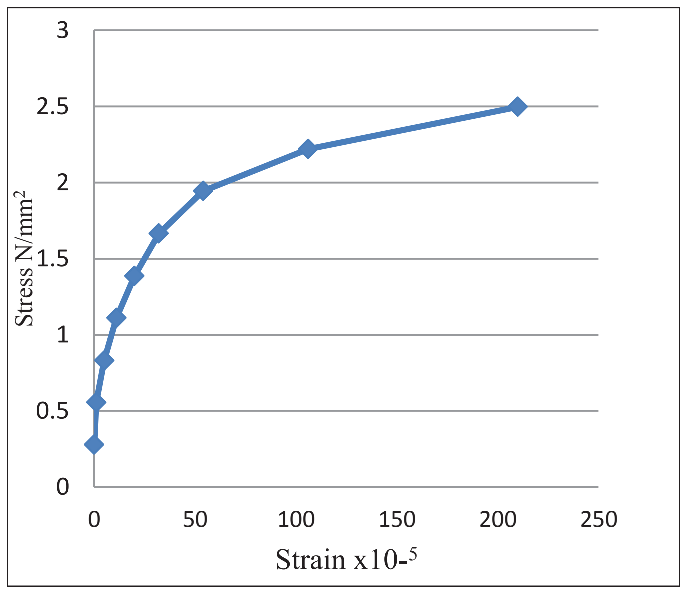

Fig. 22: Stress Vs Strain Curve for 40% Fly Ash Concrete

V. Discussions

- Workability normal concrete measures are 45 mm, which is well in the design range of 30 to 60 mm.
- Workability of fresh concretes increased by adding super plasticizer to attain the design slump value.

- 7 days compressive of fly ash concretes are much less than the normal concrete especially beyond 40% replacement of fly ash.
- At 28 days fly ash concrete up to 50% replacement attains the target mean strength of 48.25 N/mm^2.
- Flexural strength of fly ash concrete at 28 days is determination and its around 4.86 N/mm^2. As per IS 456-2000 the flexural strength of concrete = $0.7\ (fck)^{0.5}$

$$= 0.7\ (40)^{0.5}$$

$$= 4.5\ N/mm^2$$

- The Young's modulus of elasticity (Ec) for concrete can be calculated using the formula:

  Ec = 5000 × (fck)^0.5

  For M40 grade concrete, with a characteristic compressive strength (fck) of 40 MPa:

  Ec = 5000 × (40)^0.5 = 31,622.77 N/mm^2

However, for fly ash concrete, the modulus of elasticity tends to decrease compared to normal concrete. According to IS 456-2000, the modulus of elasticity for normal M40 grade concrete is approximately 24,785 N/mm^2.

VI. Conclusion

The experimental investigation on high-volume fly ash (HVFA) concrete yielded several key findings. Initially, HVFA concrete exhibited lower mechanical properties due to the presence of water-soluble alkalies and organic matter in the fly ash. However, with the addition of superplasticizers, HVFA concrete demonstrated good workability and retarded setting time. The study suggests that up to 40% replacement of cement with fly ash can be used for structural concreting, while 50% can be used for minor concreting works.

The results showed that workability decreased with increasing fly ash content, but increased with the addition of superplasticizers. Compressive strength development was slower in the initial days, but fly ash concrete gained strength over time, surpassing normal concrete after 28 days. Up to 40% fly ash replacement showed no significant strength loss, while beyond 40% and up to 60% replacement resulted in a sudden decrease in strength.

Future studies should focus on developing a suitable mix design for HVFA concrete, investigating the structural behavior of reinforced HVFA concrete, and examining other concrete properties such as drying shrinkage, pore size distribution, and long-term durability. A detailed study on the transition zone characteristics of HVFA-based concrete mixtures is also essential.

References

[1] C. D. Atis, "Aabrasion resistance of high volume fly ash concrete: Digest 2000 of Turkigh chamber of civil engineers," 2000.

[2] J. P. Behera, B. D. Sarangj, and H. S. Ray, "Investigation"on the development of blended cement using activated fly ash," *Indian Concrete Journal,* pp. 260-263, May 2000.

[3] B. Fourier, D. Lu, J. P. Charland, and J. Li, "Indian fly ashes for use in HVFA concrete," *ICJ*, vol. 78, no.11, Nov. 2004.

[4] A. Camoes, B. Aquiar, and S. Jalai, "Durability of low cost high performance fly ash concrete," in *Proceedings of IAUS International Ash Utilization Symposium,* 2003.

[5] V. M. Malhotra, "Role of supplementary cementing materials in reducing greenhouse emission," Canmet, Ottawa, Canada, Mar. 1998.

[6] P. Kumar, Mohd. Ajaful Haq, and S. K. Kaushik, "Early strength of SSC with large volumes of fly ash," *ICJ,* Jun. 2004.

[7] S. Qian, D. Qu, G. P. Gu, and N. Bouzoubaa, "Reinforcing steel corrosion in HVFA concrete," *ICJ,* vol. 78, no. 11, Nov. 2004.

[8] A. K. Saxena, and P. K. Kaku, "The associated cement companies ltd. Madukkarai cement works, usage of fly ash in cement industry," n.d.

[9] P. Srinivasan, A. K. Tiwari, and A. Banchhor, "Suitability of HVFA concrete for pavements," *ICJ,* vol. 78, no. 11, Nov. 2004.

[10] E. E. Berry, and V. M. Malhotra, "Fly ash for use in concrete," *Proceedings of ACI Journal*, 1980.

[11] A. Bilodeau, and V. Malhotra, "High volume fly ash system: Concrete solution for sustainable development," *ACI Material Journal,* vol. 97, no. 1, Jan.- Feb. 2000.

[12] M. Haque, B. Langan, and M. Ward, "High fly ash content," *ACI Material Journal,* 1984.

[13] T. Naik, B. Ramne, R. Krauj, and R. Siddque, "Long–term performance of high volume fly ash concrete pavements," *ACI Materials Journal,* vol. 100, no. 2, 2003.

[14] A. Peled, M. F. Cyr, and S. P. Shap, "High content of fly ash (class F) in extruded cementitious composities," *ACI Material Journal*, vol. 97, n.d.

[15] M. Reiner, and K. Rens, "High volume fly ash concrete: Analysis and applications," *Practice Periodical on Structural Design and Construction*, vol. 11, no. 16, 2006.

[16] V. Sivasunfaran, G. C. Curette, and V. M. Malhotra, "Long term strength development of high volume fly ash concrete," *Cement and Concrete Composites*, vol. 12, no. 4, pp. 263-270, 1990.

[17] V. M. Malhotra, and P. K. Mehta, "*High Performance High Volume Fly Ash Concrete: Materials, Mixture Proportioning, Properties Construction Practices and Case Histories*. 2002.

[18] M. S. Shetty, *Concrete Technology.* n.d.

[19] N. Krishnaraju, *Concrete Mix Design*. n.d.

[20] IS-3812-1981, *Specifications for Fly Ash for Use as Pozzolonic and Admixtures*. BIS: New Delhi.