Durability of High Volume Fly Ash Concrete

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***Abstract*— Concrete is by far the most widely used construction material worldwide. First, it consumes huge quantities of virgin materials. Second, the principal binder in concrete is cement, by these production the greenhouse gas is increased which causes effects the global warming and climatic changes. Many structures suffer from lack of durability which has an adverse effect on the resource productivity of the industry. The supplementary cementing materials like natural materials, by-products or industrial wastes are used. The cement is replaced with high volumes of fly ash(> 40%) for M_{30} & M_{40} grades with percent variation of fly ash used in this grades and also finding the durability of this concrete(HVFC). The Compressive strength test to be conducted to justify the strength properties of HVFC. Few durability properties like Resistance to 2% and 5% sulfuric acids and Resistance to 2% and 5% Hydrochloric acids, Resistance to 5% Magnesium sulfate solution and Resistance to 5% Sodium chloride solution were studied. The mass variation of the specimens are also to be studied for M_{30} & M_{40} grades of concrete for HVFC when immersed in acids,the strength tests of the specimens that are immersed in acid solutions to be finded.The deterioration effect of sulphuric acid and hydrochloric acid are to be compared. The strength parameters of fly ash replacing will be compared with the nominal mix of HVFC.**

Key words: HVFC, Fly ash, Durability,

I. INTRODUCTION

Energy conservation in the building industry is a world-wide concern, by taking this into consideration the engineers and scientists have taken this as challenge and exploring the ways of producing building materials with minimum energy unit. containing a fly ash content

Fly ash

Fly ash is a by-product of coal-fired from thermal power plants, it is approximately 80 million tons each year, and its percentage utilization is less than 10% during last few years [1]. Any concrete that is greater than 50 percent by mass of the total cementitious materials is considered as HVFA.The production of Portland cement is not only costly and energy-intensive, but it also produces large amounts of carbon dioxide. Fly ash is commonly used in concrete in replacements ranging from 0 to 30 percent by mass of the total cementitious material. However, research has shown that using a 50 percent or greater replacement of fly ash can have a wide range of benefits. Fly ash exits in a number of different chemistries and classes, but it is primarily the particle size that is important. The average particle size of fly ash is about 20 microns, which is similar to the average particle size of Portland cement. Particles below 10 microns provide the early strength needed in concrete, while particles between 10 and 45 microns react more slowly. Depending on the lime content, fly ash is categorized as low lime fly ash (Cao<10%) and high lime fly ash(Cao>10%). Low lime fly ash corresponding to class 'C' and high lime fly ash corresponding to class 'F' Fly ash properties are hollow spherical glassy particles of size between 1 to 150 microns in diameter and also passes through the 45 microns sieve. Fly ash used supplementary cementitious materials in the concrete. The specific gravity of fly ash particles ranges between 2.0 to 2.4 depending on the source of coal. The fineness of fly ash is typically in the range of 250 to 600 m^2/kg.

Fly ash is a by-product and therefore less expensive than portland cement; it is also known to improve workability and reduce internal temperatures.(2002_brouch)With large quantities of fly ash available around the world at low costs, the use of HVFA seems to offer the best short term solution to rising cement demands. It improves the durability when used as replacement of cement, as an admixture in concrete and increases the strength of the concrete [2].There is advantage in adding fly ash to concrete products cured at normal atmospheric conditions or in the autoclave at high temperatures and pressures. Recently, fly ash has been increasingly used in the concrete industry. In some cases, large volume of (>40%) fly ash is used to achieve desired concrete properties and lower the cost of concrete production. This limits the wide use of high-volume fly ash concrete by engineers. As fly ash is more complex than silica, however, and contains CaO, $A1_20_3$, Fe_20_3 and other impurities, its composition is dependent on the source and operational conditions at each power plan. Different approaches are used to accelerate the pozzolanic reaction, these approaches include (i) mechanical treatment (grinding), (ii) accelerated curing and autoclaving, and (iii) chemical activating. Chemical activating involved using alkali activation and sulfate activation. However, alkali activation used in concrete may lead to alkali–silica reaction, and sulfate activation may decrease the durability of concrete due to the large ettringite contents. If the materials show high pozzolanic activity, the heat produced during hydration is higher

Water-tightness and durability :

In general, the resistance of a reinforced-concrete structure to corrosion, alkali aggregate expansion, sulfate and other forms of chemical attack depends on the water-tightness of the concrete.

The water-tightness is greatly influenced by the amount of mixing-water, type and amount of supplementary cementing materials, curing, and cracking resistance of concrete.High-volume fly ash concrete mixtures when properly cured, are able to provide excellent water-tightness and durability.

The inferior durability characteristics of concrete may be caused by the environment that the concrete is exposed to. The following environmental condition can affect the concrete durability: Temperature, Moisture, Physical factors, Chemical factors, and Biological factors.

These factors may be due to weathering conditions (temperature, and moisture changes), or to abrasion, attack by natural or industrial liquids and gases, or biological agents. Durability problems related to environmental causes include the following: steel corrosion, delamination, cracking, carbonation, sulfate attack, chemical attack, scaling, spalling, abrasion and cavitation.

II. EXPERIMENTAL PROGRAM

(1) Materials

The 53 grade ordinary Portland cement and HVFA (brought from VTPS,IBM) were used as binder materials in the production of concrete mixes. The chemical compositions and physical characteristics of binders are given in Table 1. The fine aggregate was natural river sand. Limestone gravel a nominal maximum size of 20 mm was used as coarse aggregate..

Table 1: Chemical composition of binders

COMPOSITION	CEMENT(%)	FLY-ASH(%)
SiO_2	21.06	45.31
Al_2O_3	5.15	28.73
Fe_2O_3	2.8	3.89
CaO	64.17	6.25
Mgo	1.46	1.26
K_2O	0.42	0.73
Na_2O	0.28	0.97

(2) Pozzolanic reaction

A pozzolanic reaction occurs when a siliceous or aluminous material get in touch with calcium hydroxide in the presence of humidity to form compounds exhibiting cementitious properties . In the cement hydration development, the calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$, or CH) are released within the hydration of two main components of cement namely tricalcium silicate (C3S) and dicalcium silicate (C2S) where C, S represent CaO and SiO_2. Hydration of C3S, C2S also C3A and C4AF (A and F symbolize Al2O3 and Fe2O3) respectively, is important. Upon wetting, the following reactions occur

$$2(3CaO\text{-}SiO_2) + 6H_20 \rightarrow 3CaO.2SiO_2.3H_20 + 3Ca(OH)_2 \quad (1)$$

$$2(2CaO.SiO_2) + 4H_20 \rightarrow 3CaO.2SiO_2.3H_20 + Ca(OH)_2 \quad (2)$$

$$3CaO.A1_203 + 31H_20 + 3CASO_4 \rightarrow 3CaO.\ A1_203.\ 3CaSO_4.\ 31\ H_20 \quad (3)$$

$$4CaO.A1_20_3.Fe_20_3 + 10H_20 + 2Ca(OH)_2 \rightarrow 6CaO.\ AI_20_3.\ Fe_20_3.\ 12\ H_20 \quad (4)$$

(3) Tests on Hardened concrete

Determination of comperessive strength: Determination of comperessive strength: The compression test on cubes was carried out according to the procedure given in IS:516-1959. The cubes were cured under water for 28days ,then placed in acids for 7 and 28 days later they were tested for compression strength.

Non Destructive Tests: Rebound hammer test and ultrasonic pulse velocity test are conducted as per IS: 13311 (Part 2) – 1992 and IS: 13311 (Part 1) – 1992 to find out the compressive strength and assess the quality of concrete

Acid attack study:

The chemical resistance of the concrete was studied through chemical attack by immersing them in an acid solution. After 28 days period of curing twelve specimens each of two grades M30 and M40, the initial mass, body diagonal dimensions, Ultrasonic pulse velocity, Rebound hammer value were measured. Six specimens of each grade of concrete were immersed in 2%, 5% H_2SO_4 solution and 2%, 5% Hydrochloric acid solutions. For preparing 2% acid solution 2 litres of concentrated acid is mixed in 98 litres water and 5% acid solution is prepared by mixing 5 litres concentrated acid in 95 litres of water.

Sulfate attack and chloride attack study:

The chemical resistance of the concretes was studied through chemical attack by immersing them in 2% & 5 % Magnesium sulfate solution and 2% & 5% Sodium chloride solution. 5% magnesium sulfate solution and 5% sodium chloride solution are prepared by mixing 5 Kgs of magnesium sulfate salt in 100 litres of water and 5 Kgs of sodium chloride salt in 100 litres of water. After 28 days period of curing six specimens each of two grades M30 and M40, the initial mass, Ultrasonic pulse velocity, Rebound hammer value were measured. Three specimens of each grade of concrete were immersed in 5% Magnesium sulfate solution and 5% Sodium chloride solution. After 7 and 28 days of immersion, change in mass, change in UPV and change in Rebound number are recorded. After 28 days of immersion change in average compressive strength is also observed

III. RESULTS & DISCUSSIONS

(1) Compressive strength

The compressive strength of fly ash concrete mixes with 20%, 30%, 40%, and 50% fine aggregate replacement with fly ash, was higher than the control mix at all ages. Compressive strength of all mixes continued to increase with the increase in age.However, the rate of increase of strength decreases with the increase in fly ash content.This trend is more obvious between 40% and 50% replacement level.However,maximum strength at all ages occurs with 50% fine aggregate replacement.This increase in strength due to the replacement of fine aggregate with fly ash is attributed to the pozzolanic action of fly ash. In the beginning (early age), fly ash reacts slowly with calcium hydroxide liberated during hydration of cement and does not contribute significantly to the densification of the concrete matrix at early ages. Concrete with fly ash shows higher strength at early ages because inclusion of fly ash as partial replacement of sand starts pozzolanic action and densification of the concrete matrix, and due to this strength of fly ash concrete is higher than the strength of control mix even at early ages.

Fig:1Compressive strength of M30 grade of concrete (% vs C.S)

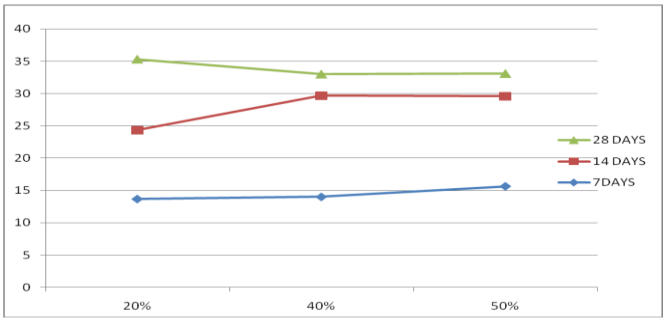
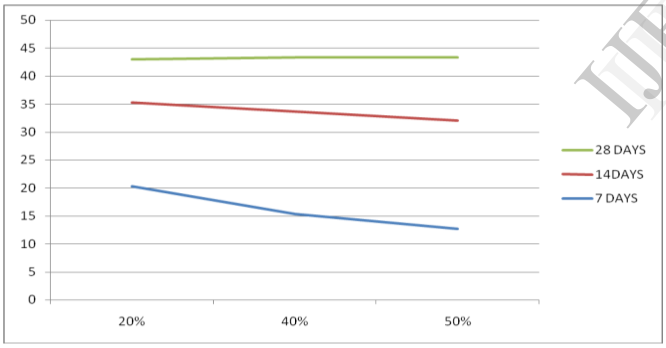


Fig:2Compressive strength of M40 grade of concrete (% vs C.S)



(2) Acid attack test:

B.1. Visual appearance:

It has been observed that in specimens immersed in 5% sulfuric acid, after 28 days of immersion the cement mortar from the surface was badly eaten up and aggregates are clearly visible. The specimens in 2% sulfuric acid solution were not that much damaged when compared to those of 5% sulfuric acid. In both the solutions even after 7 days immersion time only efflorescence was observed.

B.2. Mass loss

The change in the mass of the specimens were observed and the results are shown in the Table 2

Table 2 Percentage mass losses when immersed in acid Solutions

No of days of immersion	Percentage mass loss %			
	2% H_2SO_4		5% H_2SO_4	
Grade of concrete	M40	M30	M40	M30
0	0	0	0	0
7	1.89	5.12	5.01	6.4
28	4.6	5.71	10.93	11.89

It can be observed that the mass loss in M40 and M30 grade HVFC after 28 days immersion in 2% sulfuric acid are 4.6 % and 5.71%.similarly in 5% sulfuric acid the values are 10.93% and 11.89% respectively. It was observed that in all the acid solutions,the mass loss is more in M30 grade HVFC when compared to that of M40 grade HVFC. This might be because of higher content of pozzolanic material in M40 grade HVFC than M30.

Fig: 3 compressive strength for 5% & 2% H2SO4 for 20% fly ash for 7&28 days

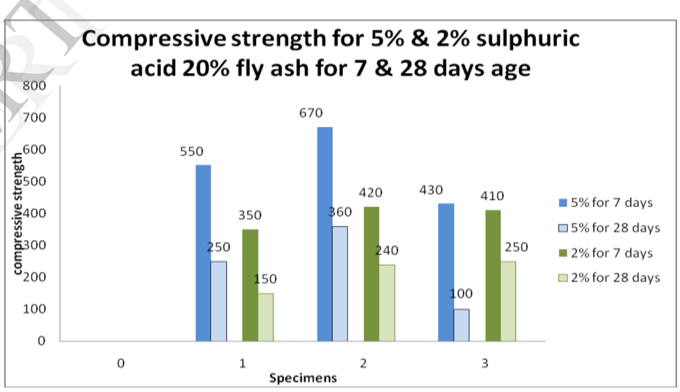


Fig: 4 compressive strength for 5% & 2% H2SO4 for 40% fly ash for 7&28 days

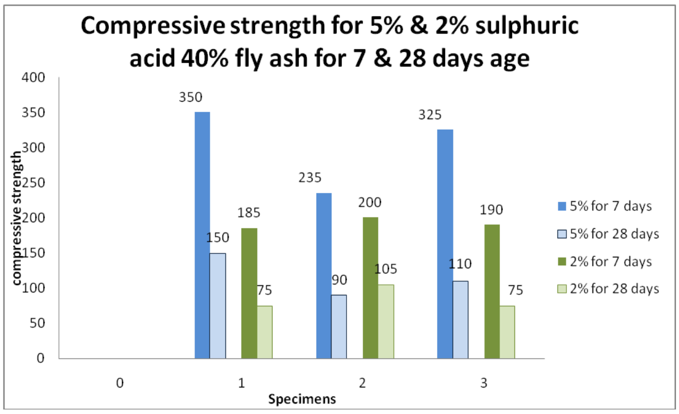


Fig: 5 compressive strength for 5% & 2% H2SO4 for 50% fly ash for 7&28 days

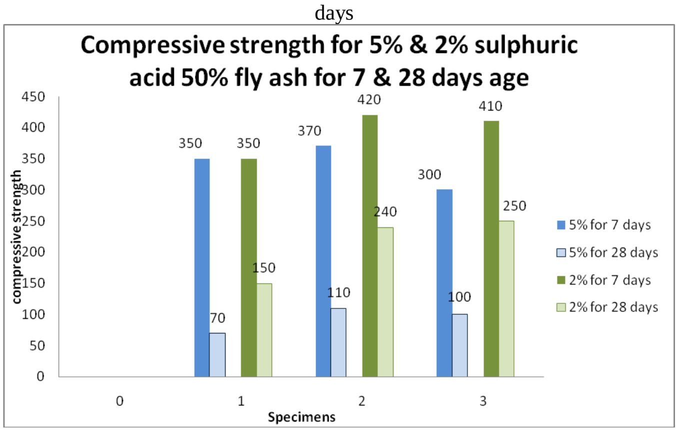
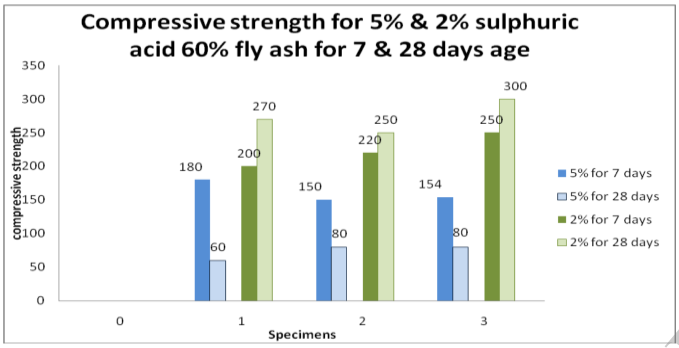


Fig: 6 compressive strength for 5% & 2% H2SO4 for 60% fly ash for 7&28 days



(3) Magnesium sulphate attack

C.1.Vissual observation

There was no change in the dimensions of the specimens but efflorscense was observed on the surface of the specimens and it increased with increase in the immersion time.

C.2.Mass loss

It was observed that there was no change in the mass of the specimens even after 28 days immersion in 2% & 5% magnesium sulfate solution.

C.3.Average compressive strength

Change in the Average compressive strengths were studied after 28 days immersion in 2% & 5% Magnesium sulfate solution.There was only minor change in the compressive strength for 0 & 7 days. It was observed that there is 6% decrease in the compressive strength after 28 days immersion in both the grades of concrete. Table 3 shows the values of compressive strength after immersion in acid at the end of 28 days.

Table 3:Average compressive strength when immersed in MgSo4

No of days	Avg.compressive strength in MPa	
of immersion	M40	M30
0	85.69	56.68
28	81.21	53.41
% loss in strength	6%	6%

(4) Sodium chloride attack

In Sodium chloride attack there was no considerable difference in the mass loss,NDT values and Average compressive strength was observed

IV. CONCLUSION

After the analysis of the results of the experimental program the following conclusions were arrived..

(1) Early age strength of concrete i.e for 7 days & 14 days is decreasing with increase in percentage replacement of fly ash28 days strength of concrete increasing with increase in percentage replacement of fly ash upto 50%.
(2) Flexural strength of concrete is decreasing with increase of % replacement of flyash
(3) The visual appearance, mass change,Average compressive strength variation after certain exposure periods were studied to assess the deterioration of HVFC when subjected to 2%, 5% Sulfuric acid and Hydrochloric acid solutions.
(4) The surface of the specimens was badly damaged and cement mortar was completely eaten up and coarse aggregates were clearly visible in case of Sulfuric acid attack.
(5) The mass loss is more in M30 grade HVFC when compared to that of M40 grade HVFC when immersed in acids due to higher content of pozzolanic material in M40 than in M30 grades HVFC
(6) The decrease in the average compressive strength and rate of decrease is more in M40 grade HVFC than that of in M30 grade when immersed in acid solutions .
(7) The deterioration effect of sulfuric acid was found more severe
(8) When HVFC is subjected to 5% magnesium sulfate attack, the mass variation was not observed and the average compressive strength decreased by 6% after 28 days of immersion.
(9) When HVFC is subjected to 5% Sodium chloride attack, there was no change in mass and average compressive strength even after 28 days of immersion.

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