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Acid, Alkali and Chloride Resistance of High Volume Fly Ash Concrete

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Abstract

Objectives: To find variation in compressive strength and mass of high volume fly ash concrete samples subjected to different chemical solutions of sodium chloride, sodium sulphate and sulphuric acid. **Methods:** A total of 900 numbers of cubes were cast and cured with four levels of curing period of 28, 56, 90 and 120 days. After certain duration of curing period, specific numbers (60) of cubes were submerged each in 5 percent sodium sulphate solution (Na_2SO_4), 5 percent sodium chloride solution (NaCl) and 1percent of sulphuric acid solution (H_2SO_4) separately in chemical exposure containers for an exposure period of 30, 60, 90 and 120 days. **Findings:** Investigations with respect to acid, alkali and chloride resistance were carried out on high volume fly ash concrete, HFC (40 percent replacement with cement), low volume fly ash concrete, LFC (25 percent replacement with cement) and their performances against control concrete (NC) is presented in this paper. Their performance was measured with respect to the loss in compressive strength and weight of the concrete cubes over the period of exposure time. It is found that the resistance of control concrete to all the three chemical attack is better only up to 28 days of water curing. At 56 days of water curing LFC shows better resistance against the control and HFC. However, with prolonged water curing of cubes of 90 days and more, HFC has consistently shown highest resistance; whereas the control concrete faced a great loss in strength.

Keywords: Concrete, Compressive Strength, Durability, Fly Ash

1. Introduction

Use of fly ash concrete has been investigated from different perspectives such as strength, durability, microstructures, permeability etc. Compressive strength is a primary requirement from utility point of view. Several researchers[1–6] have detected enhancement in compressive strength in fly ash concrete in longer duration. Durability refers to resistance of concrete to adverse conditions. Adverse conditions include the corrosive, erosive and abrasive factors which are expected to reduce the strength and hamper microstructure that may limit the possibility of usage in construction sector. It is well established that coastal construction sites are more exposed to air and water with higher salt concentration. The sites near industries are more susceptible to sulphate attack, since soil near these areas does have more sulphate contents. Similar locations also experience water contents which tend to be slightly acidic. In this context it is pertinent that utility of fly ash concrete under such environment is studied extensively. This present research aims at exploring the durability of fly ash concrete in corrosive environment. Researchers usually consider loss in compressive strength, ion permeability and weight loss, freezing and thawing resistance, etc. in concrete specimens as durability measurement indices. After subjecting the specimens to different periods in alkali or acidic or saline environments these parameters are measured to indicate measure of durability.

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The durability of fly ash concrete considering chloride ion penetration, compressive strength and weight loss as durability indicators have been investigated[7]. High fly ash concrete was observed to be more durable in Salt, acidic and sulphate prone environment.

In experimental investigations to detect the acid resistance of ternary (cement, fly ash, silica fume) blended concrete to compare with the binary (cement, fly ash) blended concrete and control concrete the researchers have used the sulphuric acid and hydrochloric acid as acidic medium. They have considered mass loss and strength deterioration as durability measures. They concluded that ternary blended concrete having 20percent fly ash and 8percent silica fume gives the highest resistance to acid[8].

The acid resistivity of three different grades of fly ash concrete immersed in 5 percent H_2SO_4 solution for 7 and 28 days have been measured in terms of compressive strength loss and weight loss. They reported that, at 7 days the weight loss observed was very less and with 40percent fly ash replacement concrete has given better performance[9].

The response of four different concrete mixes to the sulphuric acid attack was studied by measuring the change in weight and thickness as durability indicator and was reported that the deterioration of concrete starts at the surface first, then progress inwards[10].

The sulphate resistance of fly ash concrete was studied[11–13] comparing the compressive strength of fly ash concrete (0-20%) cured in water and H_2SO_4 for a period of 28, 60, 90. In acidic environment, the strength decreases with age of concrete and increase percent of fly ash replacement. Optimum strength of concrete was observed at 10 percent fly ash replacement. With varying percentage of fly ash replacement in different grade of concrete, the compressive strength was observed to be decreasing rapidly in case of normal concrete than fly ash concrete when exposed to sulphate solution for 28 days. Regardless of the fly ash type, the addition of the fly ash in concrete enhances the durability properties.

The sulphate and chloride resistance of high volume fly ash concrete considering the durability indicator aswater permeability, resistance to freezing and thawing, resistance to de-icing salt scaling and chloride ion penetration, carbonation, sulphate attack etc. were studied. High volume fly ash concrete was found as less permeable, more durable and environmental friendly[14]. Similarly the resistance to acid and sulphateof concrete with additive as pulverised fly ash and palm oil fuel ash, dipped in $MgSO_4$ solution for curing period of 3, 7, 28, 56, 90 was studied[15], considering the weight loss, length change and residual strength as durability indicatorslight increase in mass and decrease in strength was noticed.

The durability properties like permeability, resistance to sulphate and acid attack, carbonation, alkali silica reaction, fire, abrasion, chloride ion penetration, etc. of pozzolanic concrete with addition of mineral admixtures such as fly ash, silica fume, metakaolin and rice husk ash were reviewed[16]. Researchers reported that the use of mineral admixture in concrete reduces the environmental damage along with improving concrete durability.

Chemical resistance of geopolymer concrete and control concrete against acid, salt and sulphate solution for 30, 60 and 90 days of exposure were investigated[17]. They reported that the loss in weight was observed in all specimens and the acid and sulphate resistance of geopolymer concrete is significantly better than that of control concrete. Geopolymer concrete specimens were immersed in 10 percent sulphuric acid and tested the samples for acid resistance at 7, 28, 56 days of immersion[18]. They confirmed that geopolymerconcrete is highly resistant to sulphuric acid in terms of very low mass loss less than 3 percent. The corrosion current and cracking behaviour of geopolymer concrete was investigated and it was observed that geo-polymer concrete immersed partially in sea water for 21 days after 28 days water curing, shows excellent resistance to chloride attack and longer time to corrosion cracking compared to control concrete[19].

The objectives of the research have been framed to find variation in compressive strength and mass of concrete samples subjected to different chemical solutions of sodium chloride, sodium sulphate and sulphuric acid. The mass loss and the deterioration in compressive strength for different types of concrete under these aggressive media are determined and further discussion is presented in detail in this paper.

2. Experimental Program

2.1 Materials

Commercially available ordinary Portland cement (43 grades) and class F fly ash collected from National Thermal Power Corporation (NTPC), Kaniha are used in this study.

The physical properties of cement have been tested as per the methods prescribed in the Indian standard and the results are presented in Table 1.

Table 1. Physical properties of Portland cement

Parameters	Test Result	Requirement as per IS 8112-1989
Fineness (retained on 90 micron sieve)	7.6	10 max
Normal consistency(%)	32	
Vicat time of setting (minimum) - Initial Vicat time of setting (minimum) - final	35 160	30 min 600min
Specific gravity	3.1	
Cube compressive strength (KN/mm²) 1. 3 days 2. 7 days 3. 28 days	25.3 34.6 46.5	23 33 43

Mastercizer-2000 has been used in the experiment to measure the particle size distribution of cement and fly ash by a laser scattering technique. The weight % distribution over the particle size range for cement and fly ash are furnished in Figure 1 and Figure 2, respectively.

The chemical composition of cement and fly ash has been determined by X-Ray Fluorescence (XRF) spectrophotometer and the results are presented in Table 2.

The mineralogical characterization of fly ash sample has been carried out for the X-Ray diffraction analysis which has been shown in Figure 3.

Crushed granite were used as coarse aggregate with a nominal maximum size of 20 mm and river sand was used as fine aggregate conforming to zone-III of nominal maximum size of 4.75 mm in this concrete mixtures. Their physical properties and sieve analysis are given in Table 3 and Table 4, respectively. Both aggregates were tested as per Indian standard specifications IS: 383-1970.

Normal tap water was used as the mixing water. A commercially available poly carboxylic based super plasticizer was used to get a high degree of workability of

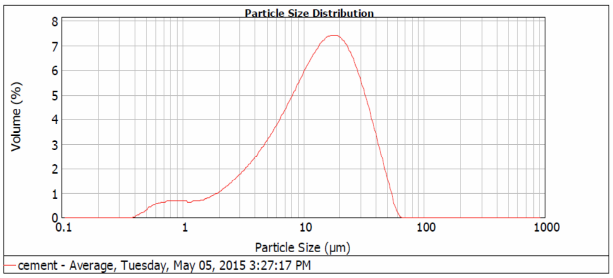


Figure 1. Particle size distribution of cement.

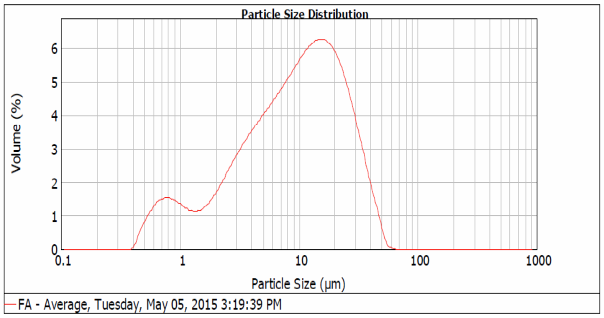


Figure 2. Particle size distribution of fly ash.

Table 2. Oxide composition of cement and fly ash

Component %	Cement	Fly ash
SiO_2	20.7	55.4
Fe_2O_3	4.41	7.84
Al_2O_3	11	28.4
CaO	57.7	1.59
MgO	1.24	2.86
Na_2O	0.23	0.59
K_2O	2.11	2.09
SO_3	1.96	0.09
Loss ignition	0.65	1.14

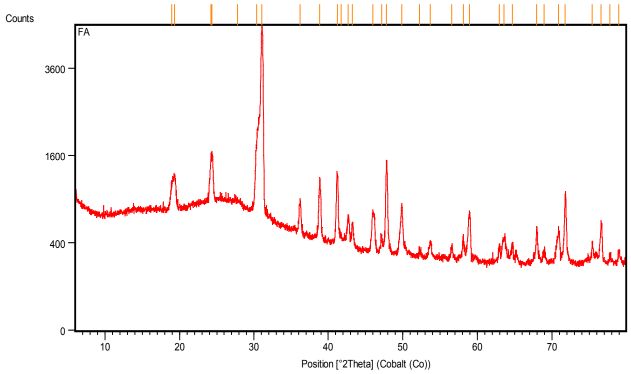


Figure 3. X-ray diffraction of fly ash.

Table 3. Physical properties of aggregates

Property	Fine aggregates	Coarse aggregates
Specific gravity	2.58	2.73
Fineness modulus	2.23	6.58
Water absorption (%)	0.6	0.8
Unit weight (kg/m³)	1676	1622

Table 4. Sieve analysis results

Results from Sieve analysis of fine aggregates			Results from Sieve analysis of coarse aggregates					
Sieve Number	% Passing	Requirement (IS: 383-1970)	IS sieve Size	coarse aggregate types		% of different fractions		
				I	II	I (60%)	II (40%)	Combined
4.75 mm	99.6	90-100	**20 mm**	100	100	60	40	100
2.36 mm	99.2	85-100	**10 mm**	0	71.20	0	28.5	28.5
1.18 mm	89.07	75-100	**4.75 mm**		9.40		3.7	3.7
600 micron	67.2	60-79	**2.36mm**		0			95 to 100
300 micron	15.2	12-40	Conforming to Table-2 of IS: 383-1970					
150 micron	6.39	0-10						

concrete. Pure sodium chloride and sodium sulphate salts were used in the experimental programme to make the solutions. The concentrated sulphuric acid of 98percent purity and density of 1.84 g/cc was utilized to prepare the sulphuric acid solution.

2.2 Mixture Proportion

Seven trial mixes have been prepared with varying w/c ratio and super plasticizer amount to get the optimized mixture proportion. The absolute volume method was adopted for calculation of mixture proportions. The water cement ratio has been varied as 0.4, 0.38, 0.35 and 0.34 with the amount of super plasticizer varying as 0.2% and 0.3% of cement. All the mixtures were prepared and casted to check the slump value and compressive strength of concrete cubes for 3, 7 and 28 days. The trial mix No-4 (1: 2.18: 3.16, w/c = 0.38, super plasticizer content = 0.2%) has been chosen as the optimized mixture proportion as it has satisfied the required slump with the required target mean design strength. The details of the mix proportion ratios, slump values and cube compressive strength at 3, 7, 28 days of seven trial mixes have been given in the Table 5, 6 and 7, respectively.

Table 5. Slump value of trial mixes

Trials	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Slump (mm)	30	50	45	95	0	120	55

Table 6. Compressive strength (MPa) test results of trial mixes

Trials		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Compressive Strength (MPa)	3 days	29.49	35.95	36.04	31.11	27.96	38.02	30.18
	7 days	34.89	44.5	42.34	40.36	33.51	47.32	38.64
	28 days	40.79	47.86	50.33	46.6	38.09	54.8	44.8

Table 7. Mix proportions of trial mixes

Mix Proportions	Mass of constituents (kg/m³)				
	C	F.A	C.A	W	S.P
Trial Mix-1 (1:1.92:2.92) at w/c =0.4 and S.P = 0.2%	394	756.5	1150.5	157.6	0.788
Trial Mix-2 (1:2:2.98) at w/c=0.35 and S.P = 0.2%	394	788	1174	137.9	0.788
Trial Mix-3 (1:2.34:3.4) at w/c=0.38 and S.P = 0.3%	350	822	1193	133	0.7
Trial Mix-4 (1:2.18:3.16) at w/c=0.38 and S.P = 0.2%	370	807.34	1171.5	140.6	0.74
Trial Mix-5 (1:2.34:3.49) at w/c=0.35 and S.P = 0.2%	350	819	1221.5	122.5	0.7
Trial Mix-6 (1:2.18:3.24) at w/c=0.35 and S.P = 0.3%	370	806.6	1199	129.5	0.74
Trial Mix-7 (1:2.08:3.02) at w/c=0.34 and S.P = 0.2%	385	802	1165	130.8	0.77

C-cement, F.A.-fine aggregate, C.A.-coarse aggregate, W-water, S.P.-super plasticizer

Further, three types of concrete mixtures were prepared in the laboratory with the optimised mix proportion ratio (based on trial mix-4). Control mixture (Type-1) was designed as per Indian Standard Specifications IS: 10262-1982 and named as Normal concrete and the other two concrete mixtures namely Type-2 and Type-3were prepared by replacing cement with 25 percent and 40 percent of class-F fly ash and named as Low Fly ash Concrete (LFC) and High Fly ash Concrete (HFC). A constant water/binder ratio of 0.38 was considered for all the concrete mixture keeping all other parameters constant. The concrete mixtures were mixed to give a slump range of 100mm.

2.3 Fresh Properties of Concrete and Testing of Specimens

Fresh concrete properties like slump, air content, temperature and unit weight were determined as per Indian Standard specifications IS: 1199-1159. The mixture proportions and fresh concrete properties of the three types of concrete are presented in the Table 8.

2.4 Casting and Curingand Testing of Specimens

Concrete cubes of 150 mm size were cast for compressive strength of sample as a measure of strength parameter. All the samples were prepared in accordance with Indian Standard specifications IS: 516-1959. A total number of 900 concrete cubes of size 150mmx150mmx150mm were casted from the three types of concrete. Specimens were cast and allowed to be in room temperature for 24 h with approximate relative humidity of 95 percent. Then they were then remoulded and were cured in normal water for a curing period of 28, 56, 90, 180 days in a curing chamber having controlled temperature and humidity until the time of the exposure to chemicals. After the required water curing period, the samples were taken out of the curing chamber and were allowed to dry till it reaches to saturated

Table 8. Mixture proportions and fresh concrete properties

Constituents	Type I	Type 2	Type 3
Fly ash (%)	0	25	40
Cement, C (kg/m^3)	370	296	222
Fly ash, FA (kg/m^3)	0	74	148
Water, W (kg/m^3)	140.6	140.6	140.6
Fine aggregate (kg/m^3)	807.34	807.34	807.34
Coarse aggregates (kg/m^3)	1171.5	1171.5	1171.5
Super plasticizer (l/m^3)	0.68	0.68	0.68
w/b	0.38	0.38	0.38
Slump (mm)	95	107	121
Concrete temperature	29	28	26
Concrete density (kg/m^3)	2422	2404	2393

surface dry condition. They were then weighed in a weighing balance to record the weight of each sample before exposure to chemical solution curing. From each type of concrete, sixty (60) numbers of cube were immersed in 5 percent sodium sulphate solution (Na_2SO_4), 5percent sodium chloride solution (NaCl) and 1percent of sulphuric acid solution (H_2SO_4) separately in chemical exposure containers for an exposure period of 30, 60, 90 and 120 days. Tests were carried out at room temperature in laboratory environment for the desired period of chemical exposure in all the three chemicals. Other set of samples were taken for the compressive strength testing to record their compressive strength for a certain degree of water curing.

After the required chemical exposure period, the specimens were taken out of the container and placed in the ambient until reaches to the saturated surface dry conditions. The compressive strength of the specimens of each type of concrete was tested in an automatic compressive testing machine of 2000KN capacity at the loading rate of 0.2-0.4 N/mm^2/s. For each weight and strength measurement, three similar specimens were considered. Mean of three strengths and weights has been considered for computation and related analysis. Structural strength tests have been carried out as per provision in IS: 516-1959. The sample photographs of casting, curing and tests undertaken are given in Figure 4.

3. Results and Discussions

3.1 Effect of Chemical Exposureon Compressive Strength of Concrete

Figure 5 represents the compressive strength of control concrete, Low volume Fly ash Concrete (LFC) and high

Figure 4. Specimen preparation stages (**a**) Mixing, (**b**) casting, (**c**) vibrating, (**d**) water curing, (**e**) chemicals, (**f**), (**g**) chemical exposure, (**h**) compressive strength testing.

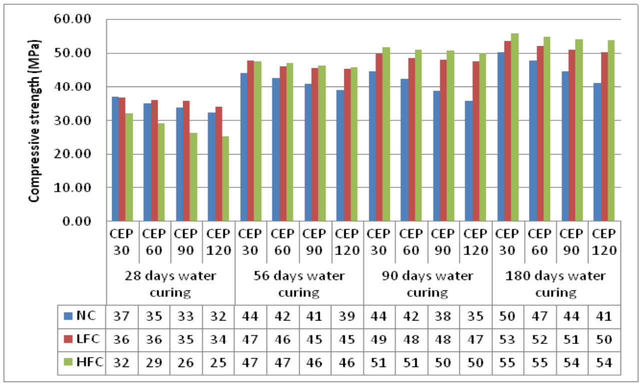


Figure 5. Compressive strength of concrete submerged in sodium chloride (NaCl) solution after different periods of water curing.

volume fly ash concrete (HFC) against salt (NaCl) attack subjected to different chemical exposure ages after different water curing periods. Similarly, Figure 6 and 7 depict for sulphate (Na_2SO_4) and acid attack (H_2SO_4), respectively. The Y axis represents the compressive strength encountered when the concrete specimens are immersed in a particular chemical solution for varying chemical exposure period and the X axis represents the chemical exposure period for different water curing ages. It is to be noted that three chemical solutions considered are 5 percent sodium chloride solution, 5 percent sodium sulphate solution and 1 percent sulphuric acid solution.

It is to be noted that CEP corresponds to the Chemical Exposure Period (either in H_2SO_4, Na_2SO_4or NaCl) after certain duration of normal curing in water.

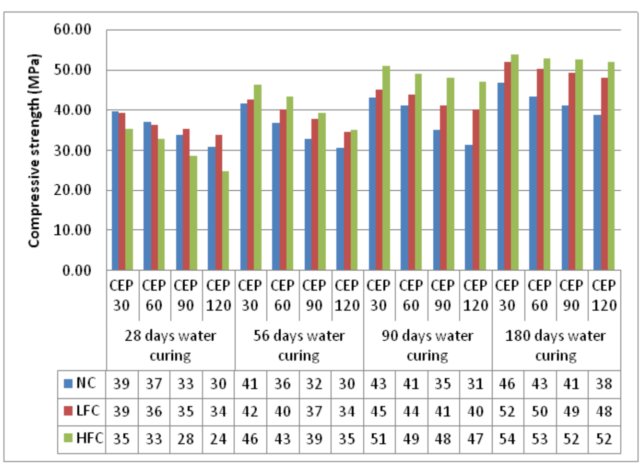


Figure 6. Compressive strength of concrete submerged in sodium sulphate (Na_2SO_4) solution after different periods of water curing.

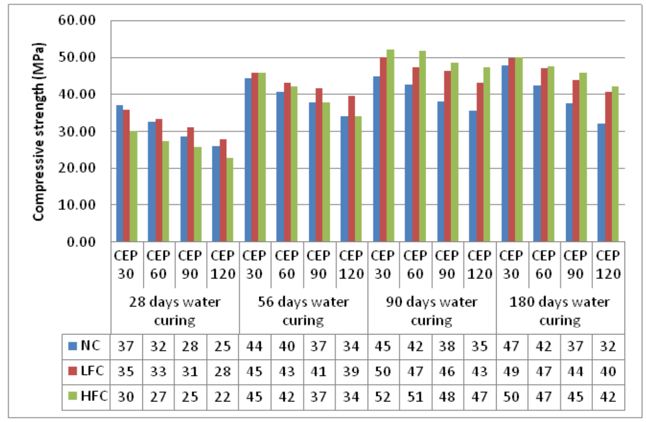


Figure 7. Compressive strength of concrete submerged in hydrochloric acid (H_2SO_4) solution after different periods of water curing.

From the Figures 5, 6, 7 the following inferences can be drawn.

3.1.1 Concrete Cubes Submerged in Sodium Chloride Solution

1. For the 28 days water cured sample normal concrete has shown the highest resistance to salt attack than LFC and followed by HFC, with exposure time is restricted to 30 days.
2. Irrespective of water curing age, all concretes display strength loss with increase in chemical exposure period. Rate of loss appears to be high, when water curing period use to be low. The reduction in strength is maximum for high fly ash concrete and minimum for low fly ash concrete in this early age of water curing.
3. After 90 days of water curing, HFC has shown consistently much high resistance than that of low fly ash concrete and control concrete.

3.1.2 Concrete Cubes Submerged in Sodium Sulphate Solution

- All the types of concrete has suffered strength loss with sulphate attack during all the chemical exposure period for different water curing periods.
- For 28 days water cured sample, normal concrete shown the highest resistance at the early chemical exposure period, but after 90 days of chemical exposure its strength starts decreasing in comparison to that of LFC. The strength loss rate is almost similar

in all three concrete types at lower water curing period.

- At 56 days of water curing HFC has shown the highest resistance against sulphate attack than that of LFC and normal concrete.
- With water curing age the strength reduction rate of fly ash concrete goes down to a great extent, but the case is observed to be just reverse in the case with normal concrete.
- For longer water curing ages and with increase in chemical exposure period, the resistance of HFC to strength loss improves as compared to control concrete and LFC.

3.1.3 Concrete Cubes Submerged in Sulphuric Acid Solution

- For all the concrete the rate of strength loss is very high in acid solution; however in the longer water curing period, rate of strength loss comes down.
- For 28 days of water curing control concrete has the highest resistance only up to 30 day chemical exposure, then after up to 120 days of chemical exposure LFC has the highest resistance than that of HFC and normal concrete.
- After 90 days of water curing HFC has consistently shown highest resistance to acid, whereas the control concrete faced a great loss in strength with subsequent water curing period.

At early age of water curing, control concrete shows good strength related behavior is well established[18–20]. Since the pozzolanic reactions of fly ash are slow the behavior of fly ash concrete in strength and durability aspects vastly improves with longer water curing age[1,2]. The superior resistance of the concrete mix against sulphate attack can be brought in by the pore refinement process and densification of transition zone occurring due to conversion of lime forming from the hydration of cement in to additional binding material through pozzolanic activity[21]. Strength loss in concrete may be attributed to three reasons. Free lime of cement in control concrete reacts with sulphate to form gypsum. The volume of gypsum being higher it causes expansion internally and results in crack propagation there by reducing the strength of concrete[22]. The sulphates also react with the aluminate of concrete forming ettringite which also helps in crack formation and propagation because of similar reason. Calcium silicate hydrate degrades, when control concrete is subject to sulphate attack[23]. Mechanism of strength reduction subject to chloride attack is different.

Chloride attack, from the immersion in salt solution, results in scaling in surface and reduction in binding strength inside the concrete. Chlorides interact with Calcium Silicate Hydrate (CSH) at three different levels as either chemisorbed layer on CSH, in the CSH inter layer spaces or be intimately bound in the CSH lattice[24]. Chlorides are also known to promote the leaching of $Ca(OH)_2$ and promote the formation of porous

CSH involving complex reactions[25]. The decalcification effects of NaCl, the formation of porous CSH and the leaching of calcium hydroxide all take their toll on concrete. In fly ash concrete, the microstructure is dense. Dense microstructure results owing to small size and spherical nature of the fly ash. Owing to low inter-particulate friction the fly ash particles permeate through concrete pores thereby decreasing voids resulting in denser microstructure. Also fly ash addition consumes the hydrates of Calcium and develops secondary hydration products like C-S-H gel. This is also responsible in reducing micro-pores of concrete making it dense[26,27]. Dense impermeable concrete mass increases resistance against chemical attack.

The strength reduction subject to acid attack may be considered as this. The acid diffuses into concrete structure destroys the cement gel binder and forming soft and soluble gypsum (calcium sulphate hydrate), which reacts with C_4A to form ettringite. The formation of secondary ettringite results in a substantial expansion of PCC specimens and leads to increase the degree of acid attack[28].

Figure 8 to 11 represents the percentage strength loss in normal concrete, low fly ash concrete and high fly ash concrete immersed in different chemicals with different

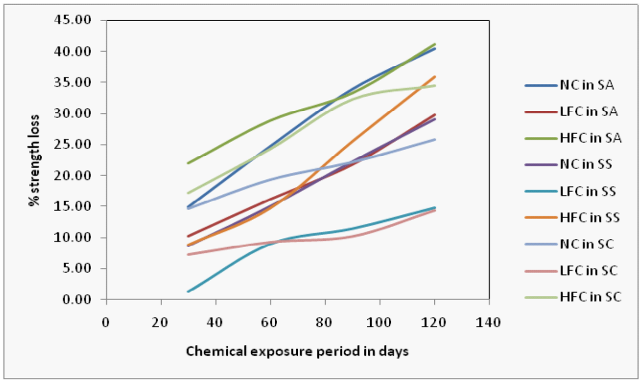


Figure 8. Percentage (%) strength loss of concretes over chemical exposure period for 28 days water curing.

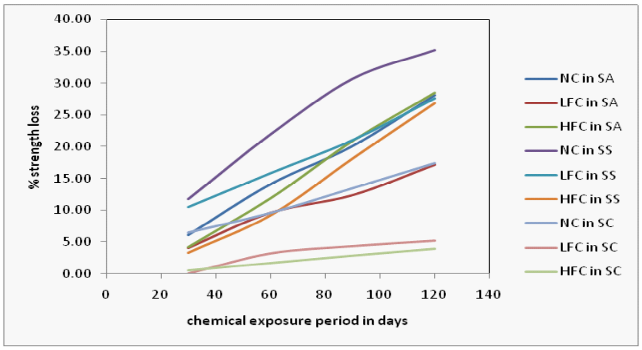


Figure 9. Percentage (%) strength loss of concretes over chemical exposure period for 56 days water curing.

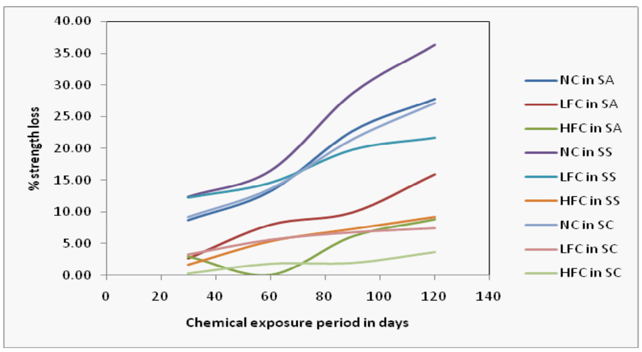


Figure 10. Percentage (%) strength loss of concretes over chemical exposure period for 90 days water curing.

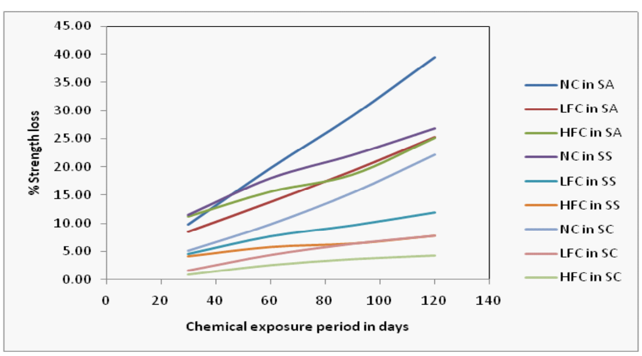


Figure 11. Percentage (%)strength loss of concretes over chemical exposure period for 180 days water curing.

chemical exposure periods after a water curing age of 28, 56, 90 and 180 days.

From the Figure 8, it can be observed that for the 28 days water cured samples the strength loss percentage of High Fly ash Concrete (HFC) in sulfuric acid, sodium sulphate and sodium chloride solution is the highest than the control concrete and Low Fly ash Concrete (LFC). It can be understood that HFC needs a longer duration of curing for getting internally stabilized.

It can be observed from the Figures 9, 10 and 11 that control concrete has the highest strength loss in all the chemicals with respect to Low Fly ash (LFC) and High Fly ash Concrete (HFC). For all the concrete, highest strength loss has been occurred in sulphuric acid and the lowest loss observed to be in sodium chloride solution. Further, it is to be noted that both LFC and HFC have shown better resistance against all types of aggressive media than normal concrete, however, High Fly Ash Concrete (HFC) has shown the greatest resistance and hence the least compressive strength reduction as compared to other types.

3.2 Effect of Chemical Exposure on Weight Loss of Sample

Weight loss is one of the important performance measuring characteristics of durability. Weight loss may happen due to results of new compound formation or physical deterioration. The Y axis represents the % weight loss encountered when the concrete specimens are immersed in different chemical solutions for different Chemical Exposure Period (CEP).

Figure 12 to Figure 14 represent the weight loss % in normal concrete, Low Fly Ash Concrete and High Fly Ash

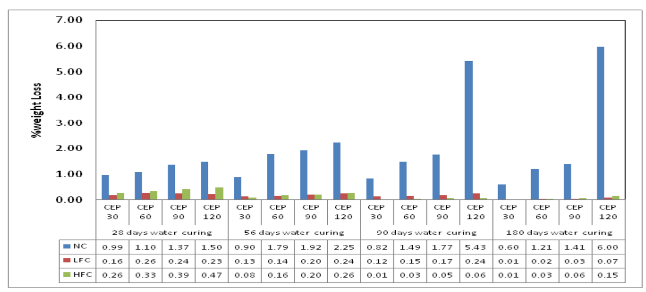


Figure 12. Percentage (%) weight loss of concrete submerged in sodium chloride (NaCl) solution after different periods of water curing.

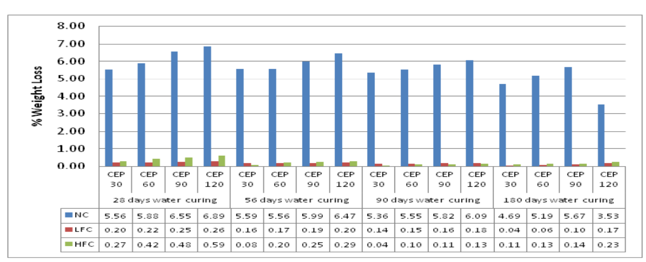
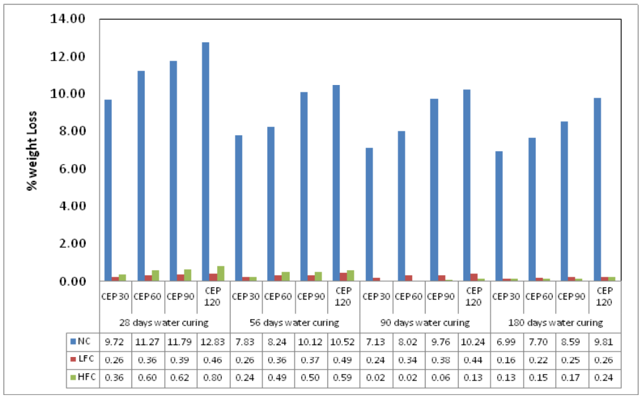


Figure 13. Percentage (%) weight loss of concrete submerged in sodium sulphate (Na_2SO_4) solution after different periods of water curing.

Concrete subject to different chemical exposure. Figure 15 to 18 depicts the weight loss for concrete specimens at 28, 56, 90 and 180 days of water curing.

Following inferences may be drawn from observation of the Figures 12 to 18.



	28 days water curing				56 days water curing				90 days water curing				180 days water curing			
	CEP 30	CEP 60	CEP 90	CEP 120	CEP 30	CEP 60	CEP 90	CEP 120	CEP 30	CEP 60	CEP 90	CEP 120	CEP 30	CEP 60	CEP 90	CEP 120
NC	9.72	11.27	11.79	12.83	7.83	8.24	10.12	10.52	7.13	8.02	9.76	10.24	6.99	7.70	8.59	9.81
LFC	0.26	0.36	0.39	0.46	0.26	0.36	0.37	0.49	0.24	0.34	0.38	0.44	0.16	0.22	0.25	0.26
HFC	0.36	0.60	0.62	0.80	0.24	0.49	0.50	0.59	0.02	0.02	0.06	0.13	0.13	0.15	0.17	0.24

Figure 14. Percentage (%) weight loss of concrete submerged in hydrochloric acid (H_2SO_4) solution after different periods of water curing.

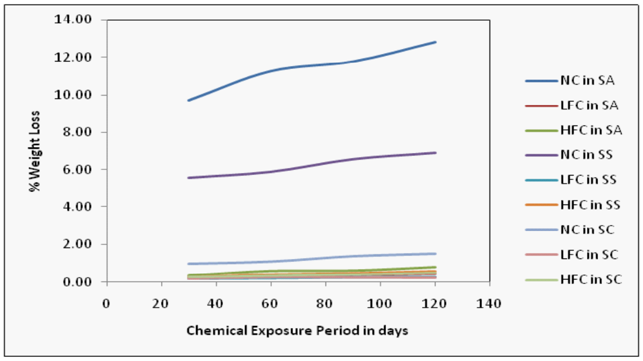


Figure 15. Percentage (%) weight loss of concrete over chemical exposure period for 28 days water curing.

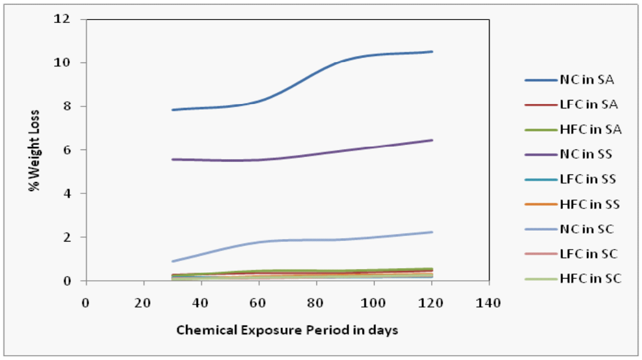


Figure 16. Percentage (%) weight loss of concrete over chemical exposure period for 56 days water curing.

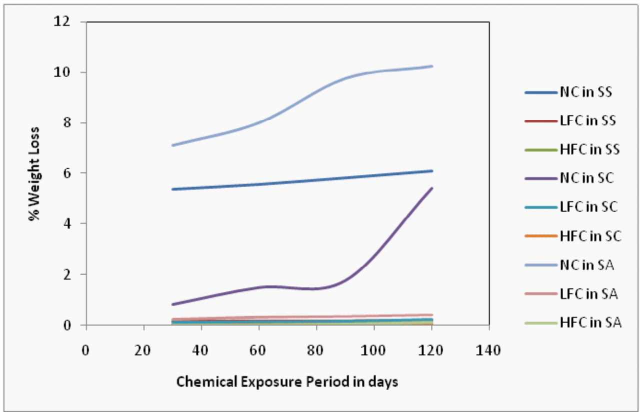


Figure 17. Percentage (%) weight loss of concrete over chemical exposure period for 90 days water curing.

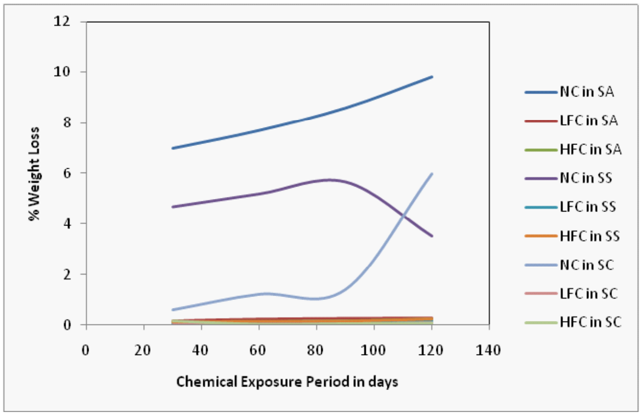


Figure 18. Percentage (%) weight loss of concrete over chemical exposure period for 180 days water curing.

- Maximum weight loss occurs when the specimen immersion is in solution of sulphuric acid. However, the minimum % weight reduction obtained when the specimens are immersed in sodium chloride solution.
- The % weight reduction increases when the chemical exposure period increases. The rate of weight loss is more, when water curing is the least.
- Chloride attack, sulphate attack and acid attack are most common representations of corrosive environment for concrete. Concrete structures exposed to sea water suffer deterioration due to attack of dissolved chemicals on products of hydrations. Presence of chlorides retard concrete swelling and owing to chemical reaction some part of lime is removed due to leaching action[29]. Near industrial sites, water is contaminated with sulphate ions in varied concentrations. In case, a porous concrete structure is in contact with saturated ground, sulphate ions may be readily carried

into concrete body. Sulphate ions migrate to concrete body through diffusion, which is a slow process[30-32]. Sulphuric Acid is a strong reactant on constituents of concrete. A combinatorial attack that is from acid attack as well as sulphate attack can be observed under impact of sulphuric acid. It attacks on Calcium hydroxide and forms Calcium Sulphate which can be leached out easily. The Calcium sulphates formed act with calcium Aluminate phase to form voluminous Calcium sulpho aluminate or ettringite, which promotes weight loss and disintegration of concrete. Calcium Silicate hydrate reacts with Sulphuric acid to form Silica gel, which may be destroyed easily by physical forces[22,23].

- Increase in curing period provides more exposure and time for ion formation and penetration. The mechanism of ionic penetration is through diffusion of ions. Though in initial period the effect is less visible in terms of deterioration, in longer duration enough ions pass into the structure and deterioration becomes faster. So it is expected that with increase in chemical exposure period weight loss will be higher, which is clearly visible during experimental findings. It is well established that effects of sulphate ions and sulphuric acid are more deteriorating compared to that of chloride ions in that order. The experiments reveal the same effect.
- Among three specimens, control concrete is most prone to chloride, sulphate and acid attack. As evident from the experimental results weight loss in control concrete with any of the attacking agents is much high compared to low fly ash concrete and high fly ash concrete. This trend remains at higher water curing and chemical exposure too. Effective diffusivity of chloride ions comes down when fly ash is blended in ordinary Portland cement. Pore blocking and increase in chloride binding capacity due to fly ash addition are two possible phenomena which are responsible for lower chloride diffusivity and reduced weight loss in fly ash concrete. In case of sulphate attack and acid attack the deterioration is higher owing to formation of soluble salts. Blending fly ash reduces permeability and brings the diffusion rate down. The deterioration which during initial period remains on surface proceeds inward at a very slow rate thus indicating low weight loss in fly ash concretes.

Further, significance test through ANOVA has been carried out in this study for all the specimens under different water curing period. The test results have been summarized in Table 9. A value of F higher than that of F critical indicates the significant influence of the parameter on output variable. As observed from the test, chemical solution category is a significant factor in weight loss when control concrete is subject to chemical attack. In case of control concrete chemical exposure period does not have

Table 9. Summary of ANOVA test

Specimen	Water curing age	Factor	F value	F critical
CC	28	Chemical Solutions	206.473	5.14325
		Chemical exposure period	4.44424	4.75706
LFC	28	Chemical Solutions	29.4384	5.14325
		Chemical exposure period	7.61581	4.75706
HFC	28	Chemical Solutions	23.6068	5.14325
		Chemical exposure period	23.3932	4.75706
CC	56	Chemical Solutions	177.179	5.14325
		Chemical exposure period	5.31365	4.75706
LFC	56	Chemical Solutions	31.6364	5.14325
		Chemical exposure period	5.37043	4.75706
HFC	56	Chemical Solutions	50.7822	5.14325
		Chemical exposure period	16.7788	4.75706
CC	90	Chemical Solutions	39.4834	5.14325
		Chemical exposure period	4.27458	4.75706
LFC	90	Chemical Solutions	38.066	5.14325
		Chemical exposure period	6.21861	4.75706
HFC	90	Chemical Solutions	7.0478	5.14325
		Chemical exposure period	7.37563	4.75706
CC	180	Chemical Solutions	200.386	5.14325
		Chemical exposure period	13.804	4.75706
LFC	180	Chemical Solutions	84.0832	5.14325
		Chemical exposure period	10.2525	4.75706
HFC	180	Chemical Solutions	170.278	5.14325
		Chemical exposure period	103.636	4.75706

a significant influence on the weight loss. In low fly ash concrete and high fly ash concrete both the parameters chemical solution type and the chemical exposure period contribute significantly to the weight loss in specimens subject to immersion. Because of higher permeability in control concrete compared to fly ash concrete, the rate of diffusion is higher and the chemical exposure period does not have a significant contribution. However, in fly ash blended concretes the diffusion is a slow process and therefore under prolonged chemical exposure the weight loss is affected in a significant manner.

4. Conclusions

Irrespective of water curing, all the concrete suffered strength loss in all the three chemicals attack, however the strength loss percentage in acid solution was the highest and that in the salt solution was the lowest. The resistance of control concrete to all the three chemical attack is better only up to 56 days of water curing. At 90 days of water curing the low fly ash concrete has shown the best resistance to all the chemicals attack and the resistance of high fly ash concrete to salt, acid and sulphate solution is more than normal concrete. However, for 180 days of water cured concrete subjected to the aggressive media, the rate of percentage strength loss is very high for normal concrete and that for the high fly ash concrete is the least.

5. References

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