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Influence of Aggressive Chemical Environment on High Volume Fly Ash Concrete

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Abstract

The benefits of using fly ash in cement concrete construction are well recognized in terms of cost reduction and management of environmental pollution. The advantages offered by the use of fly ash in concrete have impelled engineers to further extend the use of this waste product in the form of 'High Volume Fly Ash Concrete' (HVFAC). In the present paper, results of a study concerning the effect of acidic environment on the compressive strength of HVFAC have been reported. On the basis of results obtained; it has been concluded that HVFAC may be a promising material under such types of aggressive environmental conditions.

Keywords: Fly ash, concrete, HVFAC, acidic environment, compressive strength.

1. Introduction

Recently there has been a growing trend towards the use of supplementary cementitious materials, whether natural, waste or by-products, in the production of concrete because of ecological, economical and diversified product quality reasons. Fly ash which is a by-product of combustion of pulverized coal in the thermal power plants, is used for these reasons. Fly ash is removed from the effluent gases of these power plants by electrostatic precipitators. Fly ash, along-with coal dust, is also collected from the furnaces of the thermal power plants. The intrusion of fly ash in concrete affects all aspects of concrete properties. The main objective in using the fly ash in concrete is to achieve a reduced cement content to reduce costs, reduced heat of hydration and attainment of required levels of ultimate strength of concrete with the help of pozzolanic reactions. In this study an attempt has been made to explore the possibility of maximum use of fly ash in concrete.

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Shukla et al [1] have reported that use of waste materials such as fly ash and stone dust in concrete making is beneficial. It has been reported that the compressive strength of concrete increases up to about 40% replacement of sand by stone dust. Regourd [2] has carried out the strength tests on cubes subjected to sea water curing condition and found the loss in strength of cubes due to chemical environment. Building Research Establishment digest [3] discussed the factors responsible for sulphate attack on concrete below the ground level and recommended that suitable selection of cement type and concrete quality are important factors in resisting attack by naturally occurring sulphates.

Mehta [4] has studied the mechanism of sulphate attack on ordinary Portland cement. Wond and Poole [5] have studied the effect of pozzolana and slags on sulphate resistance of hydraulic cement mortar and found them to be beneficial for concrete. Lawrence [6] has observed the types of disruption during sulphate attack on mortars and concretes and explained the chemical processes involved. It was concluded that partial replacement of ordinary Portland by various latent hydraulic binders can lead to improved sulphate resistance.

Tikalsky and Carrasquillo [7] have carried out the experiments to observe the influence of fly ash on the sulphate resistance of concrete and explained the dilution effect and pozzolanic effect of fly ash in cement. The fly ashes with a low amount of calcium hydroxide and amorphous calcium aluminate decrease the susceptibility of concrete to sulphate attack. Several aspects related with the utilization of fly ash in concrete in sulfate aggressive environments have been examined by Torii and Kawamura [8]. Wang [9] has carried out the experiments on hardened cement paste specimens made with different cement types and varying water-cement ratios. These specimens were immersed in 5% sodium sulphate solution maintained at constant pH value of 6. The mechanism of sulphate attack is evaluated with the help of XRD analysis in regard to leaching of $Ca(OH)_2$ and formation of gypsum and Ettringite.

O.S.B. Al-Amoudi et al [10] have observed the effect of magnesium sulphate and sodium sulphate on durability performance of plain and blended cements. It was observed that the deterioration of blended cement exposed to sodium sulphate environment is less. This is attributed to reduced quantity of calcium hydroxide which significantly mitigates the sulphate attack in these cements. Naik et al [11] have carried out the experiments on fly ash blended cement concrete and reported the improvements in mechanical properties of concrete. Mosszza [12] has studied the chemistry of pozzolanic action of fly ash mixed cement and explained the mechanism of this action. Cohen and Bentur [13] have described the effect of sulfates on concrete as complex. In most of the practical situations the concentration of sulphates in ground waters and soils is upto the order of 1000 ppm while that of sea water and industrial effluents is more than this extent. Rasheeduzzafar et al [14] have reported the influence of cement composition on the corrosion of reinforcement and sulphate resistance of concrete.

The C_3S/C_2S ratio of cement has been shown to have a significant effect on sulphate resistance of the cement. Bureau of Indian standards [15] provides necessary guidelines for maintaining quality control on concrete materials to improve durability of concrete in aggressive conditions of exposure. Miyagawa [16] has observed the corrosion effect of chlorides on reinforcing steel and suggested a durable design and repair of concrete structures. Kumar and Rao [17,18,] have observed the effect of aggressive chemical environment on the setting time of cement and strength of concrete. They have reported that the setting times increase with the concentration of sulphate ions. This may be due to reduction in solubility of cement paste ions in presence of strong anions in solution (i.e., SO_4^{--}). The loss in compressive strength of concrete cubes cured under different types of sulphates was observed with the passage of time.

O.S.B. Al-Amoudi [19] has discussed the mechanism of sulphate attack in cement blended with fly ash. Concrete used for underground construction is generally subjected to aggressive soil and sub-soil conditions. Studies have reported replacement of 30% cement by fly ash in such cases.

In the case of road construction about 70% cement has been replaced by fly ash. Kumar and Rao [20,21,22] presented the results of experimental investigation showing the effect of sulphates on the strength of concrete under the conditions simulating cast in situ and precast situations. It was concluded that the use of precasting in place of cast in situ is preferable in situations exposed to sulphate environments. The compressive strength tests on cubes exposed to time varying sulphate environment have been reported by them and cumulative damage to concrete due to such aggressive environmental conditions was considered by them.

Garvin et al [23] have reported the effect of contaminated land on the performance of concrete. They observed the loss in strength of concrete due to the contaminated soil environment in which the concrete cubes were buried for a long duration of time. Aziz and Koe [24] have observed the durability of concrete sewers in aggressive sub-soil and ground water conditions. Berke et al [25] have considered several aspects of concrete protection in such conditions and pozzolanic materials have been recommended to be beneficial. Camps et al [26] have observed the influence of surface absorption on sulphate attack and reported the sorptivity of mortar to be sensitive to the condition of cure and type of mortar skin in contact with the fluid. The influence of cure has a dominant effect on the capillarity of mortar which was reflected in the variation of porosity and strength.

Nagele [27] has suggested new and powerful method for evaluation of multi-parameter corrosion test. Mehta [28] has carried out a laboratory investigation involving sixteen fly ash samples of varying calcium content with the objective of clarifying the relationship between fly ash composition and sulphate resistance. The results show that rather than the chemical composition it is the mineralogical composition of cement fly ash interaction product that controls the sulphate resistance.

On the basis of the literature survey it was proposed to study the strength and durability aspect of HVFAC with the following objectives.

1. To observe the development of compressive strength in concrete of M35 grade and HVFAC, of the similar grade (in which 50% cement is replaced by fly ash of fineness lower than that of cement), cured in ordinary water for different curing times.
2. To observe the loss in compressive strength of these mixes of concrete which were exposed to sulphuric acid of different concentrations for various time periods.

2. Experimental Program

The cement used for investigation was 43 grade ordinary Portland cement with specific gravity 3.15, fineness 3250 cm^2/gm (by Blaine's apparatus) and ignition loss 1.6%. Blaine's method was used to determine, as per ASTM C 204-92 [29], specific surface area of cement by passing a known volume of air through a bed of cement of known porosity and thickness under a prescribed average pressure. In this method the rate of flow of air through the cement bed diminishes continuously and time, taken for the flow of air, is measured. Considering these parameters, specific surface area of cement indicating fineness of cement was calculated. The initial and final setting times of cement were 45 and 300 minutes respectively. The 3, 7 and 28 days compressive strength of cement were 24.6, 36.2 and 49.1 N/mm^2 respectively. The sand used was confirming to grading zone-II as per IS:383-1970 [30]. The properties of sand were – specific gravity 2.63, water absorption 3.68 % and fineness modulus 3.05. Fineness modulus is a dimensionless index defining average size of a material which has various sizes mixed in different quantities. The coarse aggregate was crushed granite of maximum size 20 mm. The physical properties of coarse aggregate were – angular shape, rough texture, specific gravity 2.65, water absorption 0.5% and fineness modulus 7.4. Potable tap water, free from impurities, was used for making concrete.

Sodium Naphthalene Formaldehyde, a naphthalene based non-air-type superplasticizer, was used in the mix for imparting workability to the concrete mix. The fly ash used in the study had an average fineness 4270 cm^2/gm (by Blain's apparatus), loss of ignition 0.45% and conformed to IS: 3812-2003 (Part 1) [31]. The fly ash was collected from the thermal power plant, of an Indian public sector undertaking namely, National Thermal Power Corporation, located at Dadri. Dadri is located in Gautam Budh district of the state of Uttar Pradesh in India.

In order to observe the effect of sulphuric acid on concrete specimens, one tank with ordinary water and two tanks of sulphuric acid solutions having concentrations of 0.1 N and 0.2 N respectively were prepared. 60 samples of 150 mm size concrete cubes were cast for each type of concrete using table vibrator. The mix design was carried out for M 35 grade of concrete as per Indian standard guidelines and the compositions of these mixes were as given in Table 1. The water cementitious ratio of the mixes was maintained at 0.42. After one day of hardening, the moulds were stripped off and 20 samples of different types of mix were immersed in each type of curing tanks. After 7, 28, 90 and 180 days curing, 5 samples in each case were tested for compressive strength of cubes.

Table 1: Composition of Mixes

Type Of Concrete	**Quantities Of Mix Constituents (Kg/ m^3)**					
	Cement	CA 20 mm	CA 10 mm	FA	Fly Ash	Admixture (Liters/ m^3)
Plain Concrete	400	670	436	705	Zero	3.9
HVFAC	227	709	478	564	223	5.9

CA – Coarse aggregate, FA – Fine aggregate

3. Results

The results, obtained from the study, for the development of compressive strengths and losses in compressive strengths in both the types of mixes are summarized in Table 2.

Table 2: Variations of Compressive Strengths and Losses in Different Mixes

Time (Days)	**Concrete Mix Type**	**For Curing in Water**	**For Curing in 0.1 N Sulphuric Acid**		**For Curing in 0.2 N Sulphuric Acid**	
		Compressive Strength (N/mm^2)	Compressive Strength (N/mm^2)	Loss (%)	Compressive Strength (N/mm^2)	Loss (%)
7	PLAIN	28.60	28.50	0.35	26.90	5.94
	HVFAC	26.80	25.90	3.36	24.80	7.50
28	PLAIN	51.27	47.90	6.60	43.80	14.50
	HVFAC	49.28	46.60	5.40	44.20	10.31
90	PLAIN	63.30	55.70	12.00	50.40	20.40
	HVFAC	55.58	50.00	10.00	46.40	16.52
180	PLAIN	66.92	54.70	18.26	50.70	24.24
	HVFAC	63.42	54.40	14.22	51.00	19.58

4. Discussion of Results

Figure1 shows the development of compressive strength in plain concrete and HVFAC with time in the entire duration of 180 days. Since the mixes were designed for approximately the same strength levels, both the mixes attain strength in the same manner in the initial stage of hardening. But with time the rate of development of strength in HVFAC increases at a faster pace due to the pozzolanic reactions of fly ash.

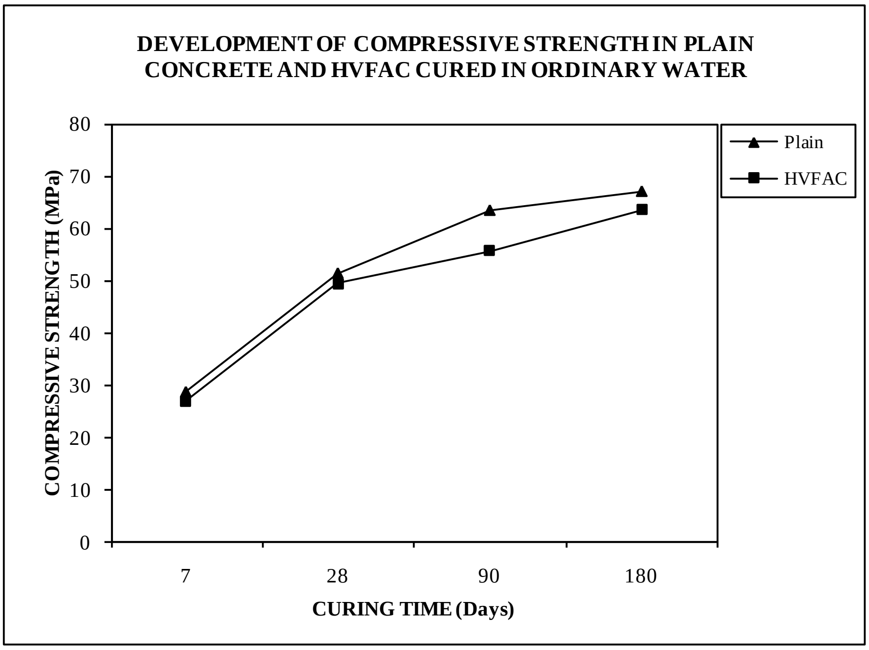

Figure 1: Development of compressive strength in plain concrete and HVFAC with time

Figure 2 shows the variations in loss of compressive strength in both of such mixes due to chemical aggressive environment of the order of 0.1 N and 0.2 N sulphuric acid.

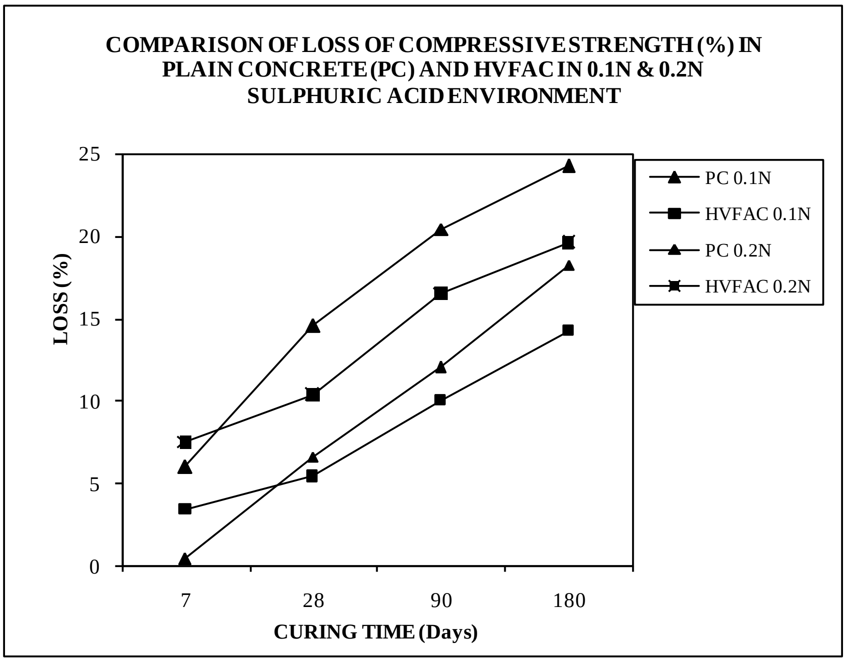

Figure 2: Variations in loss of compressive strength

In both the mixes the patterns of losses taking place show a similar trend. The losses in compressive strength increase with the time of exposure. But the percentage of losses in compressive strength in HVFAC in both the environments has been observed to be less than those in plain concrete except in the initial period of 7 day. The residual strength of HVFAC is found to be more than that of plain concrete at any stage of exposure. In the advanced stages of exposure time, the rate of increase in losses in the case of HVFAC is found to be less than that in the case of plain concrete. It gives indication of likely improved behaviour of HVFAC under aggressive environment conditions for a long time of exposure.

5. Conclusion

On the basis of the experimental results regarding the plain concrete and HVFAC subjected to aggressive acidic environment, it has been concluded that the utilization of fly ash reduces the loss in compressive strength in concrete. Therefore, fly ash has been proved as an effective material which can be used for making concrete in aggressive environmental conditions.

REFERENCES

[1] Shukla, M., Sahu, A.K. and Sachan, A.K., "Performance of Stone dust as fine aggregate replacing sand in concrete and mortar", National Seminar on Advances in Special concretes, Indian Concrete Institute, Bangalore, 1998, pp. 241-248.

[2] Regourd, M., "Resistance of Concrete to Chemical Attacks Sea Water Attack on Concrete and Precautionary Measures", Material & Structures, Vol. 18, 1985, pp. 223-226

[3] "Concrete in Sulphate-Bearing Soils and Ground Waters", Building Research Establishment Digest 250, H.M. Stationary office, London, 1986.

[4] Mehta, P.K., "Mechanism of Sulphate Attack on Portland cement concrete – another look", Cement and Concrete Research, Vol. 13, No. 3, May 1983, pp. 401-406.

[5] Wond, G. and Poole, T., "Effect of Pozzolans and Stags on the Sulfate Resistance of Hardraulic cement Mortars", Concrete Durability - Katharine and Bryant Mather International Conference, A.C.I. SP-100, 1987

[6] Lawrence, C.D., "Sulphate Attack on Concrete", Magazine of Concrete Research, Vol. No. 153, 1990, pp.249-264.

[7] Tikalsky, P.J. and Carras-quillo, R. L, "Influence of Fly Ash on the Sulfate Resistance of Concrete", A.C.I. Materials Journal, Vol. 89, No.1, 1992, pp. 69-75.

[8] Torii, M. and Kawamura, M., "Effects of Fly Ash on Silica Fume on the Resistance of Mortar to Sulfuric Acid and Sulfate Attack", Cement and Concrete Research, Vol. 24, No. 2, 1994, pp. 361-370.

[9] Wang, J.G., "Sulfate Attack on Hardened Cement Paste", Cement and Concrete Research, Vol. 24, No. 4, 1994, pp. 735–742.

[10] Al–Amoudi, O.S.B. et al, "Effects of Magnesium Sulfate and Sodium Sulfate on the Durability Performance of Plain and Blended Cements", A.C.I. Materials Journal, Vol. 92, No.1, 1995, pp. 15-24.

[11] Naik, T.R. et al, "Enhancement in Mechanical Properties of Concrete due to Blended Ash", Cement and Concrete Research, Vol. 26, No. 1, 1996, pp. 49-54.

[12] Mossazza, F., "Chemistry of Pozzolanic Addition and Mixed Cement", Principal paper, 6th International Congress on the Chemistry of Cement, Moscow, 1974, pp. 3–38.

[13] Cohen, M.D. and Bentur, A., "Durability of Portland Cement Silicon Fume Paste in Magnesium Sulfate and Sodium Sulfate Solutions", A.C.I. Materials Journal, Vol. 85, No. 3, 1988, pp. 148–157.
[14] Rasheeduzzafar et al, "Influence of Cement Composition on the Corrosion of Reinforcement and Sulfate Resistance of Concrete", A.C.I. Materials Journal, Vol. 87, No. 2, 1990, pp. 114-122.
[15] "Code of Practice for Plain and Reinforced Concrete", IS:456-2000, Bureau of Indian Standards, New Delhi.
[16] Miyagawa, T., "Durability Design and Repair of Concrete Structures: Chloride Corrosion of Reinforcing Steel and Alkali-Aggregate Reaction", Magazine of Concrete Research, Vol. 43, No. 156, 1991, pp. 155-170.
[17] Kumar, S. and Rao, C.V.S.K., "Sulfate Attack on Concrete in Simulated Cast–In Situ and Precast Situations", Cement and Concrete Research, Vol. 25, No. 01, 1995, pp. 1-8.
[18] Kumar, S., "Influence of Water Quality on the Strength of Plain and Blended Cement Concrete in Marine Environments", Cement and Concrete Research, Vol.30 (2000), pp. 345-350
[19] Al-Amoundi, O.S.B., "Mechanisms of Sulfate Attack in Plain and Blended Cements: A Review", "Extending Performance of Concrete Structures", Edited by Dhir, R.K. and Tittle, P.A.J., 1999, pp. 201-210.
[20] Kumar, S. and Rao, C.V.S.K., "Effect of Sulfates on the Setting Time of Cement and Strength of concrete", Cement and Concrete Research, Vol. 24, No. 7, 1994, pp. 1237–1244.
[21] Kumar, S. and Rao, C.V.S.K., "Durability of Materials under Random Exposure Conditions", Proceedings of International Seminar on "Civil Engineering Practices in the Twenty First Century", Roorkee, 1996, pp. 751–756.
[22] S. Kumar and C.V.S.K. Rao, "Strength Loss in Concrete due to varying Sulfate Exposure", Cement and concrete Research Vol. 25, No. 1, 1995, pp. 57-62
[23] Garvin, S.L., Ridal, J.P. and Halliwell, M., "Performance of Concrete in Contaminated Land", "Extending Performance of Concrete Structures", Edited by Dhir, R.K. and Tittle, P.A.J., 1999, pp. 201-210.
[24] Aziz, M.A. and Koe, L.C.C., "Durability of Concrete Sewers in Aggressive Subsoils and Ground Water Conditions", Geotechnical Aspects of Restoration Works, Edited by Balasubraman et al, Roterdam, 1990, pp 299-310.
[25] Berke, N.S., Pfeifer, D.W. and Weil, T.G., "Protection Against Chloride Induced Corrosion", Concrete International, Vol. 10, No. 12, 1988, pp.44-55
[26] Camps, J.P., Jauberthie, R. and Rendell, F., "The Influence of Surface Absorption on Sulphate Attack", "Concrete Durability and Repair Technology", Edited by Dhir, R.K. and McCarthy, M.J., pp 197-207.
[27] Nagele, E., "New and Powerful Method for the Evaluation of Multi Parameter Corrosion Tests", Cement and Concrete Research, Vol. 25, No. 6, 1995, pp.1209-1217.
[28] Mehta, P.K., "Effect of Fly Ash Composition on Sulfate Resistance of Cement", A .C.I. Materials Journal, Vol. 83, No. 6, 1986, pp. 994-1000.
[29] ASTM C 204-92, Test for fineness of Portland cement by Air Permeability Apparatus.
[30] IS:383-1970, "Specification for coarse and fine aggregates from natural sources for concrete", Bureau of Indian Standards, New Delhi.
[31] IS:3812-2003 (Part1), "Specification for Fly Ash for use as pozzolana and admixture", Bureau of Indian Standards, New Delhi.