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DURABILITY OF HIGH VOLUME FLY ASH CONCRETE EXPOSED TO H_2SO_4 ENVIRONMENT

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Abstract: This paper discusses on some experimental investigations on performance of concrete incorporated with fly ash as cement replacement material. The fly ash content was varied from 0.0% to 60.0% by weight of cement. Different concrete mixes were proportioned at constant binder content with different water-binder ratios. The influence of these parameters on the ability of concrete to withstand the impact of aggressive H_2SO_4 concentration in water solution. Three different concentrations of 1.0, 3.0 and 5.0% of H_2SO_4 in solution have been adopted to investigate the loss in strength and weight of concrete. Concrete immersed in concentrated H_2SO_4 solution showed significant deterioration and color change. The strength of concrete decreases with increase in H_2SO_4 concentration. As the concentration of H_2SO_4 increases the loss of weight of concrete increases. At low replacements of cement by fly ash, the losses in strength and weight have been observed to be significantly high. As the percentage of fly ash in cement increases, there has been significant improvement in the resistance of concrete against H_2SO_4 influence. The losses in strength and weight of concrete decrease high volume fly ash concrete mixes. With different combinations of cementitious material (cement plus fly ash = binder), water-binder ratio and concentration of H_2SO_4, the concretes produced using high volume fly ash improve their durability. High volume fly ash concrete seems to be an efficient material for developing high performing durable concretes.

1. INTRODUCTION

Its versatile, durable, and economical benefits made concrete as the most widely used building material. Basic constituents of concrete are cement, sand, coarse aggregate and water. In order to conserve natural resources and maintaining sustainability under different environmental conditions, such concretes for mitigating several complex problems different industrial by-products are also incorporated.

In the recent times, one of the main challenges confronting the concrete industry is to meet the demand for infrastructure needs due to rapid industrialization and urbanization in addition to producing ample quantity of harmful carbon dioxide (CO_2). This contributes to increase greenhouse gases leading to global warming and climate change. A partial replacement of cement by mineral admixtures such as fly ash, slag, silica fume can significantly reduce CO_2 emission due to manufacturing of cement. Fly ash is a pozzalonic mineral admixture used in concrete, obtained as a waste from the thermal power plants. Several structural advantages of fly ash, proved by several research efforts, can be encountered in concrete applications. Fly ash a finer residue collected from coal burning power plants, transported by flue gases and collected by the electrostatic precipitators. It may possess little or no cementitious property, however in the finer form, in presence of moisture, chemically reacts with calcium hydroxide at ordinary temperature to form cementitious compounds. Generally, concrete industry uses fly ash up to 15-20% by the mass of total cementitious material for commercial purpose.

The shape of fly ash particle is spherical, which can fill the pores to reduce the gap between aggregate particles. As a cement replacement material, fly ash reduces the permeability and improves the durability of concrete. Addition of fly ash in concrete also reduces its deterioration due to sulphate attack and alkaline silica reaction. Fly ash containing high calcium (CaO) content greater than 20% is classified as Class-C fly ash, whereas class-F fly ash contains less calcium content. ACI committee reported that fly ash can be used up to 35% as a cement replacement material. High volume fly ash concrete can use fly ash up to 60% as cement replacement material to produce high performance concretes. In order to understand the performance of high volume fly ash concrete, an effort has been made to study its durability in H_2SO_4 environment. High volume fly ash concrete is characterized by replacement of cement by higher volume of fly ash in excess of 30%. Codes allow the replacement of cement by fly ash up to 35% for plain and reinforced concrete as a binding material. Fly ash in concretes is encouraged to mitigate the environmental pollution and disposal problems. Fly ash particles are spherical in shape, which improves workability of concrete and decreases the water content for achieving a given consistency of concrete. Concrete exposed to conditions like marine, coastal and hot environments, durability and life of structure seems to be a concern. The addition of fly ash in concrete is beneficial to improve the durability with increasing age of concrete structures when compared to conventional concrete.

2. LITERATURE REVIEW

El Aziz et al. [1] reported studies on hydration and durability of sulphate-resisting and slag cement pastes and mortars. The aggressive ions of sulphate and chloride caused severe damage to concrete. Mixes made up of sulphate-resisting cement (SRPC) with different proportions of slag were cured in potable water for 3, 7, 28 and 90 days. The durability of cement mortars after curing for 28 days in potable water (taken as zero time), were then immersed in Caron’s Lake water for 1, 3, 6, 9 and 12 months. The compressive strength, free lime, evaporable and non-evaporable water, total chloride and total sulphate contents in mortar at each curing time were observed. The increase in replacement of SRPC up to 30% by blast furnace slag (BFS) slightly increases the total pore volume. The free lime content decreases rapidly in the initial stages of immersion and gradually up to 1 year. The blended cement pastes made up of SRPC with BFS up to 30% by mass exhibited lesser total chlorides and sulphates, while the mortars containing only SRPC exhibited low compressive strength compared with the blended cement mortars at all ages of immersion under Caron’s Lake water. Mortars with 70% SRPC with 30% slag produce very high durable products. *Prasad et al.* [2] investigated influence of sulphate ions on deterioration of concrete. The influence of deteriorating parameters on sulphate resistant blended cement concrete and mortar has been described. The strength and stability of structures seem to be satisfactory but their longevity is a matter of concern. Environment becoming chemically more aggressive due to higher percentage of Sulfur Dioxide, Carbon Dioxide and Chlorides. Oxides of Sulfur are injurious to concrete while Chlorides are harmful to reinforcing steel. Hence, the life span of reinforced concrete structures has been compromised significantly from its originally estimated life of about ninety years. *Pandurangan, et al.* [3] studied the performance of five high volume fly ash concretes with zero and 55, 62, 75, and 85% of fly ash. The water-cement ratio was constant. The compressive strength, flexural strength, impact strength, and rapid chloride permeability in all mixes were determined. The high volume fly ash concrete exhibited good performance in terms of long-term strength also. The chloride ion penetration has been observed to be low in high volume fly ash concretes showing greater corrosion resistance.

Rashad [4] reviewed on high volume class-F fly ash and reported on porosity, drying shrinkage, water absorption, mechanical properties, absorption resistance, thermal properties of high volume fly ash concrete. Mehta investigated the performance of high volume fly ash concretes for sustainable development. Concrete with 50% replacement of cement by fly ash reduces the water demand, thermal cracking and drying shrinkage, and better durability against sulfate attacks and alkali-silica expansion. *Jelena et al.* [5] investigated on high volume fly ash concretes and their role in sustainable development. 30% replacement of cement by fly ash improved workability, durability and porosity, while more than 30% replacement of cement by fly ash reduces the water demand and improves the workability and durability in later ages. *Vanita et al.* [6] studied the durability of high volume fly ash concrete. More than 40% fly ash in total cement, 28 days strength of concrete seems to be low, while gaining strength after 90 days is greater. Durability of high volume fly ash concrete with 40% fly ash in total cement content improved the sustainability. *Priyanka et al.* [7] studied on static and dynamic modulus of elasticity of concrete mixes with different fly ash contents. Investigations on dynamic modulus of elasticity using ultrasonic pulse velocity on high strength concretes showed that the dynamic modulus of elasticity, E_d is 5% greater than the static modulus of elasticity, E_c. *Elawady et al.* [8] studied on the relationship among compressive strength, permeability and sorptivity of concretes with and without silica fume in four different curing conditions. Effect of cement content was also studied at two cement contents of 350 and 450 kg/m^3. Concrete possessing low sorptivity exhibited low permeability, and high compressive strength. *Meikandaan* [9] studied on workability of concrete. The compaction factor and vee-bee degree increase with increase in percentage of super plasticizer in any concrete. The compressive strength of lower grade concrete increases with the increase in the dosage of super plasticizer. The co-efficient of permeability in low grade concrete decreases with increase in dosage of super plasticizer. *Ramesh et al.* [10] studied on the performance of high volume fly ash (HVFA) concrete at elevated temperature up to 800^{O}C at 200^{O}C intervals for three hours duration. Cement was replaced with fly ash from 30% to 50%, and temperature was varied from 27^{O}C to 800^{O}C at an interval of 200^{O}C for 3 hours duration. The residual compressive strength, weight loss, and colour change were monitored. *Salim and Kumala* [11] investigated the behaviour of fly ash and ultra-fine fly ash concrete immersed in 3.0% Sulfuric acid and 1.5% Nitric acid solution. In sulphuric acid environment the losses of strength and mass were relatively less in concretes with cement partially replaced by 30% fly ash. *Verma et al.* [12] reported that high volume fly ash concrete has been proved to be an effective material in aggressive environments. *Rajagopalan and Chinnaraju* [13] reported on the durability of geopolymer concrete with GBFS (Granulated Blast Furnace slag), Fly ash (class F) and alkaline activators, exposed to 5.0 % sulphuric acid and chloride solutions. The strength of geopolymer concrete with GBFS in ambient curing conditions performs well compared to geopolymer concrete with GBFS blended with fly ash. Geopolymer concrete with 40% GBFS replaced by fly ash satisfies the durability properties. *Deotale and Pande* [14] investigated on durability of M30 grade concrete containing quarry sand and fly ash. Quarry sand in concrete with adequate fly ash as partial replacement of cement improved the durability. *Srinivas and Ramana Rao* [15] studied the acid resistance of low calcium fly ash and slag based geopolymer concrete. The geopolymer concrete exhibits high resistance to acids than controlled concrete. *Sunarmasto and Tyas* [16] reported on degradation of self-compacting concrete (SCC) under sulfuric acid attack**.** The degradation of self-compacting concrete (SCC) due to sulfuric acid attack on loss of compressive strength and change in diameter has been studied. The vulnerability of SCC to sulfuric acid attack could be reduced by partial replacement of cement with higher volumes of fly ash. *Chandrasekhar Reddy and Omkar* [17] investigated the durability of concrete with partial replacement of sand by quarry dust and cement by fly ash. The immersion of fly ash concrete in 5.0% concentrated Sulphuric acid (H_2SO_4) solution exhibited lowest resistant against H_2So_4 solution as compared with the control concrete. *Shinde and Gaikwad* [18] examined the progress of deterioration of concrete produced with fly ash based GFRC mixes exposed to chloride and sulphate solutions. Concretes with different glass fibers contents were immersed in acid for 10 days and investigated. The concrete with 1.0% of glass fibre content performed better than those with 0 and 2.0% fibers. *Krishna Swarup et al.* [19] discussed on durability of concrete by partial replacement of cement with bentonite and fly ash. The durability of concrete using fly ash and bentonite as partial replacement of ordinary Portland cement (OPC) has been studied. The cement was replaced by mixer of bentonite and flyash in equal proportions of 10, 15, 20, 25 and 30%. The H_2SO_4 acidic solution and NaOH base solutions of 10 molarity with 2.0% were used for durability studies. The present research study aims at performance of high volume fly ash concrete in different concentrations of H*2*SO*4*. Cement was replaced by fly ash at 0, 10, 20, 30, 40, 50, and 60% by weight.

3. EXPERIMENTAL PROGRAMME

3.1. Materials and mix proportion*s*

The cement used for this study was 53 grade Ordinary Portland cement. Class-F fly ash (FA) was used as partial replacement of cement. The coarse aggregate used for this study consisted of mix of 20mm and 12mm maximum size. Three different water-binder ratios of 0.40, 0.45 and 0.50 were adopted with 450 kg/m^3 in concrete mixes. Seven concrete mixes were cast at every water-binder ratio. Cement was replaced by fly ash at 0, 10, 20, 30, 40, 50 and 60%. The mix proportions and materials used for various mixes are shown in Tables 1, 2 and 3.

Table 1: Mix proportions of Fly Ash Concrete with 450 kg/m^3 Binder at 0.40 W-B Ratio.

Mix	FA, %	kg/m^3		
		C	W	w/b
FAC 450 0.40 00	0	450	180	0.40
FAC 450 0.40 10	10	405	180	0.40
FAC 450 0.40 20	20	360	180	0.40
FAC 450 0.40 30	30	315	180	0.40
FAC 450 0.40 40	40	270	180	0.40
FAC 450 0.40 50	50	225	180	0.40
FAC 450 0.40 60	60	180	180	0.40

Table 2: Mix proportions of Fly Ash Concrete with 450 kg/m^3 Binder at 0.45 W-B Ratio.

Mix	FA, %	kg/m^3			w/b
		C	FA	W	
FAC4500.4 00	0	450	0	203	0.45
FAC4500.4510	10	405	45	203	0.45
FAC4500.4520	20	360	90	203	0.45
FAC4500.4530	30	315	135	203	0.45
FAC4500.4540	40	270	180	203	0.45
FAC4500.4550	50	225	225	203	0.45
FAC4500.4560	60	180	270	203	0.45

Table 3: Mix proportions of Fly Ash Concrete with 450 kg/m^3 Binder at 0.50 W-B Ratio.

Mix	FA, %	kg/m^3			
		C	FA	W	w/b
FAC4500.5000	0	450	0	225	0.50
FAC4500.5010	10	405	45	225	0.50
FAC450 0.5020	20	360	90	225	0.50
FAC4500.5030	30	315	135	225	0.50
FAC4500.5040	40	270	180	225	0.50
FAC4500.5050	50	225	225	225	0.50
FAC4500.5060	60	180	270	225	0.50

3.2. Test specimen details

A pan mixer was used to mix the constituent materials such as cement, sand and coarse aggregate and prepared the fresh concrete. 150mmx150mmx150mm size cube specimens were cast in three layers, each layer was applied with standard blows. After filling fresh concrete in the moulds, the specimens were compacted using a table vibrator. The concrete cubes were vibrated until the air bubbles diminished appearing on the concrete surface. The concrete specimens were remained in the moulds at room temperature for 24 h. After 24 h of casting of concrete cube specimens were demoulded and placed in a water tank for a period of 28 days. Then the specimens were tested for determination of compressive strength in a universal testing machine. Average on three cubes results for compressive strength of concrete at the age of 28, 56, and 90days has been determined. The concrete cubes were removed from the curing tank after 28 days of curing and then surface dried under shade. The specimens were carefully aligned with the centre of the bearing plate for achieving uniform stress. As the circular metal block was brought on the specimen, the movable disc was rotated gently so that uniform and complete surface contact was ensured. The load was applied smoothly without jerk and increased gradually at a rate of approximately 13.73 N/mm^2/min until the crushing of concrete was observed. The maximum load applied on each concrete cube was recorded. The cube compressive strength of concrete was determined by dividing the maximum load by the area of contact of the bearing plate and expressed in N/mm^2.

3.3. Concentration of H_2SO_4

The chemical resistance of the concrete was investigated by immersing the standard cube specimens in the designated concentration of acid solution for different periods of immersion. After 28days of curing, the initial mass, diagonal dimensions, and compressive strength were measured. For studying the acid attack on concrete by various concentrations of H_2SO_4 solution, cubes of 150mm x 150mm x 150mm size were prepared using concrete mixes containing cement replaced by different percentages of fly ash. The concrete cube were cast and cured in water for 28 days. After 28 days all concrete cube specimens were surface dried in the air (atmosphere) for 2 days for constant weight. Subsequently, the weight concrete cubes were obtained for initial weight and then immersed in 1.0%, 3.0% and 5.0% sulphuric acid (H_2SO_4) solution for 7 and 28 days. After the required duration of immersion, the final weight of concrete cubes was determined for calculating the weight loss due to H_2SO_4 impact. The pH value of the acidic solution was 0.3 with 5.0% H_2SO_4 solution. The pH value was periodically checked and maintained at 0.3.

3.4. Immersion in acidic solution

The concrete cubes were immersed in 5.0% concentration of sulphuric acid solution, which was stored in a plastic container. The concentrated sulphuric acid of 98% purity with a density 1.85g/cc was used to prepare the sulphuric acid solution of 5.0% concentration. 50ml of concentrated H_2SO_4 was mixed with 950ml of distilled water to obtain one liter of acid solution. After 7 and 28 days of immersion in H_2SO_4 acid solution, the concrete cubes were removed from the acidic solution and were washed with potable water and kept in atmosphere for 2 days for obtaining constant weight. Subsequently, the weight of concrete cubes was obtained. The loss in weight of concrete with reference to the initial weight of the concrete is calculated as the percentage loss of weight of concrete due to acid attack. The weight of concrete was recorded as w_1. The concrete specimens were submerged so that there should a minimum level of 20mm acid water above the free surface of concrete. The pH value of the acid solution was monitored periodically using a pH meter and also by titration with standard alkaline solution.

$$\text{\% of weight loss} = \frac{(W_1 - W_2)}{W_1} \times 100$$

After 7 and 28 days of immersion of concrete in different concentrations of acid solution, change in mass, change in ultrasonic pulse velocity (UPV) and change in rebound hammer number were recorded. After 28 days of immersion, change in compressive strength was also observed.

4. TEST RESULTS AND DISCUSSION

Figure 1 shows the variation of percentage strength loss in concrete containing fly ash content from 0.0% to 60% by weight of cement due to immersion in solution with 1.0, 3.0 and 5.0% H_2SO_4 concentration. The total binder (cement + fly ash) content was 450 kg/m^3 with 0.4 water-binder ratio in all the concrete mixes. But the addition of fly ash as replacement of cement was varying from 0.0% to 60% .The percentage strength loss decreases with increase in fly ash content varying from 0.0% to 30%. The percentage strength reduction ranges between 4.09 with 30% fly ash content to 5.71 with 60% of fly ash. As the concentration of H_2SO_4 in the solution increases from 1.0% to 3.0%, there seems to be higher percentage loss of strength of fly ash concrete. In the control concrete mix, the percentage strength loss is 34.54 in the control concrete at 0.0 % fly ash. The percentage strength loss decreases with increase in percentage of fly ash replacement of cement from 0.0% to 60 %. There seems to be a gradual decrease in the percentage strength loss in concrete mixes with increase in the percentage of fly ash replacement of cement. The percentage strength loss decreases from 34.54 to 5.43 as the fly ash content increases from 0.0% to 60 %. 5.0% H_2SO_4 concentration exhibited significant strength loss of concrete.

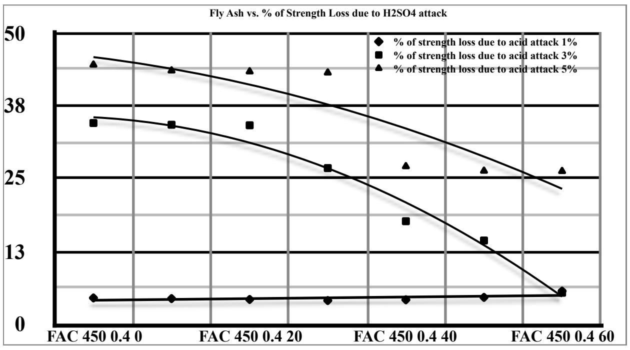

Figure 1: % strength loss in FAC 0.40 concretes with % fly ash immersed in 1.0, 3.0 and 5.0% H_2SO_4 solution.

As shown in Figure 1, % strength loss in control concrete immersed in 5.0 % H_2SO_4 concentration solution is 44.54, while it has been reduced to 26.29% as the fly ash content increased from 0.0% to 60%, the percentage strength decreases from 44.54 to 26.29. This shows that though the percentage strength reduction increases with increase in the concentration of H_2SO_4, there seems to be a confirmed trend that the addition of fly ash improves the performance of HVFA concrete against severe aggressive H_2SO_4 environment. The high volume fly ash concrete exhibited improved resistant against aggressive H_2SO_4 solution. The durability of concrete seems to be very much improved with the use of higher fly ash content. The loss of strength of concrete due to deterioration effect of H_2SO_4 environment has been significantly reduced with incorporation of high volume fly ash in cement in concrete mixes. The variation of percentage strength loss with percentage of fly ash replacement of cement is shown in Figure 2. The influence of H_2SO_4 concentration in curing solution is clearly demonstrated up to 30% replacement of cement by fly ash. There seems to be four and eight fold strength reduction in fly ash concrete when the concentrations were 3.0 and 5.0% as compared with that of solution with 1.0% H_2SO_4 concentration.

In concrete mixes containing 450 kg/m^3 of binding material at 0.45 water-binder ratio, the percentage strength in various concrete mixes with fly ash content varying from 0.0 to 60% by weight of content is observed, when immersed in 1.0, 3.0 and 5.0% concentration of H_2SO_4 solution. In general, the percentage strength loss in all the fly ash concrete mixes decreases with increase in fly ash content from 0.0 to 60%. The percentage strength loss increases with increase in the concentration of H_2SO_4. In 1.0% concentration H_2SO_4 solution, the strength loss ranges between 4.94% to 12.2 4% in various concrete mixes. In 3.0% concentration H_2SO_4 solution; the percentage strength loss varies from 25.71 to 13.20 as the fly ash content increases from 0.0% to 60% respectively. The strength loss is significantly higher in fly ash concrete immersed in 5.0% concentration H_2SO_4 solution, ranging from 43.50% to 24.30% as the fly ash content increases from 0.0% to 60% respectively. Figure 3 shows the comparison of strength loss in various concrete mixes. The variation of percentage strength loss in fly ash concrete mixes immersed in 1.0, 3.0 and 5.0% H_2SO_4 concentrations and with fly ash content varying from 0.0% to 60% is shown in Figure 2, with binder content of 450 kg/m^3 at 0.45 water-binder ratio.

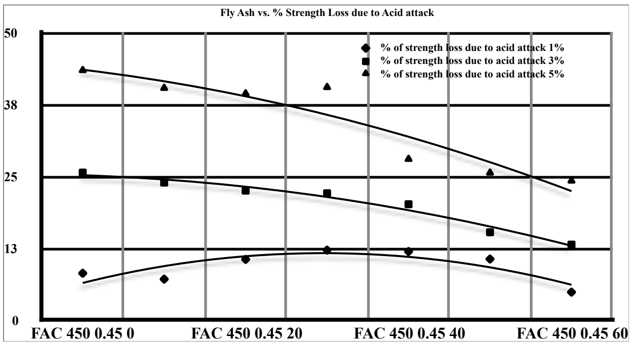

Figure 2: % strength loss in FAC 0.45 with % fly ash immersed in 1.0, 3.0 and 5.0% H_2SO_4 solutions.

The strength loss in concrete mixes containing with 450 kg/m^3 binder with 0.50 water-bonder ratio, different replacement of cement by fly ash varying from 0.0% to 60% has been observed. The variation of strength reduction in various concrete mixes at 1.0, 3.0 and 5.0% H_2SO_4 concentration and fly ash content is shown in Figure 3. The % strength loss in concrete mixes immersed in 1.0% H_2SO_4 concentration solution increases with increase in fly ash content up to 40% replacement of cement by fly ash, beyond which there has been a decreasing trend. Similar trend has been observed with 3.0% and 5.0% H_2SO_4 concentration also. The percentage strength reduction increases with increasing in fly ash content. As the concentration of H_2SO_4 in the immersed solution increases, the percentage strength reduction also increases. At higher water-binder ratio, there has been increasing percentage strength loss in the fly ash concrete mixes.

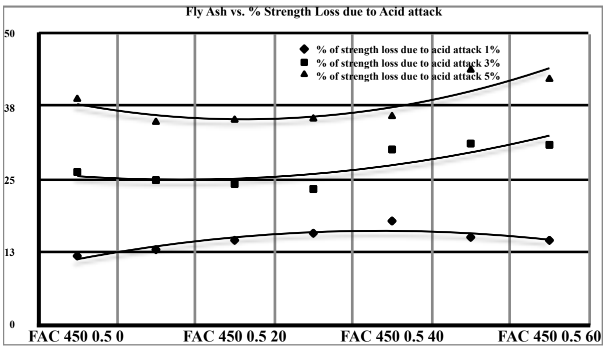

Figure 3: % strength loss in FAC 0.50 concretes with % fly ash immersed in 1.0, 3.0 and 5.0% H_2SO_4 solutions.

Figs. 4 shows the test results on weight loss of fly ash concrete with binder content of 450 kg/m^3 at 0.40 water-binder ratio with different H_2SO_4 of 1.0, 3.0 and 5.0% concentrations immersed for 7 days. The percentage weight loss of concrete in 1.0% H_2SO_4 concentration solution immersed for 7 days varies from 0.575 to 0.178 with various fly ash contents varying from 0.0% to 60% respectively.

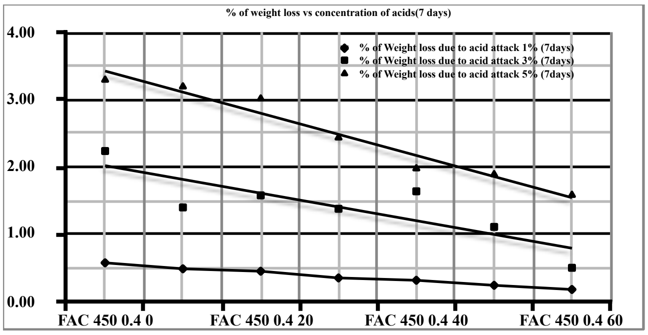

Figure 4: % weight loss in FAC 0.40 concretes with % fly ash immersed for 7 days in 1.0, 3.0 and 5.0% H_2SO_4 solution.

Figure 5 shows the comparison of test results on weight loss of fly ash concrete with binder content of 450 kg/m^3 at 0.40 water-binder ratio with different H_2SO_4 of 1.0, 3.0 and 5.0% concentrations immersed for 28 days. The strength loss varies from 1.1% to 0.41% with fly ash content increasing from 0.0% to 60% when the duration of immersion is 28 days. When the concrete specimens were immersed in 3.0% H_2SO_4 concentration solution for 7 days, the weight loss decreases from 2.24% with 0.0% fly ash content to 0.50% at 60% fly ash content. When the same concrete specimens were immersed for 28 days, the weight loss decreases from 3.98% to 1.1% at 0.0% and 60% fly ash contents respectively. The weight losses are 3.3% and 6.05% for 7 and 28 days immersion in 5.0% H_2SO_4 concentration solution in concrete with 0.0% fly ash, whereas the weight losses are 1.6% and 2.8% for 7 and 28 days immersion in 5.0% H_2SO_4concentration solution with 60% fly ash addition. It shows that there has been a decrease in the percentage weight loss with increasing fly ash content in concrete. At high concentration of H_2SO_4, % weight loss is high.

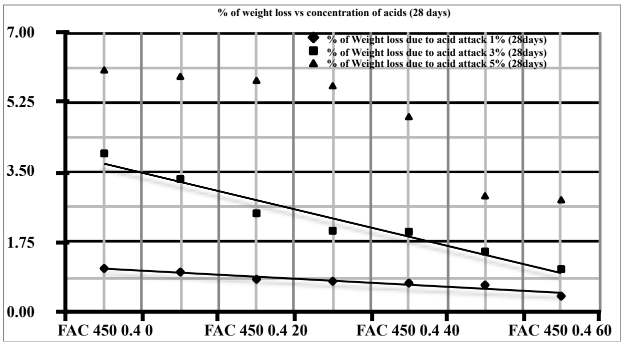

Figure 5: % weight loss in FAC 0.40 concretes with % fly ash immersed for 28 days in 1.0, 3.0 and 5.0% H_2SO_4 solution.

The influence of concentration of H_2SO_4 and duration of immersion has been investigated in various fly ash concrete mixes containing 0.0% to 60% replacement of cement by fly ash, with 450 kg/m^3 at 0.45 water-binder ratio, immersed in H_2SO_4 solution with 1.0, 3.0 and 5.0% concentrations. The weight loss in all these concretes is shown in Figure 6 for 7 days immersion and in Figure 7 for 28 days immersion. In concrete with 0.0% fly ash, the weight loss is 0.82% for 7 days immersion in 1.0% H_2SO_4 concentrated solution and the weight loss is 0.18% with 60% fly ash content. When immersed for 28 days, the weight loss decreased from 1.17% to 0.22% in concrete immersed in 3.0% H_2SO_4 solution, the weight loss decreases from 2.25% at 0.0% FA to 0.04% at 60% FA for 7 days immersion, whereas it decreases from 4.0% to 1.17% (60% of FA) when immersed for 28 days. As the H_2SO_4 concentration increases to 5.0, the weight loss for 7 days immersion decreases from 3.85% at 0.0% of FA to 2.12% at 60% FA, whereas for 28 days immersion, the weight loss decreases from 7.14% at 0.0% FA to 3.04% at 60% FA.

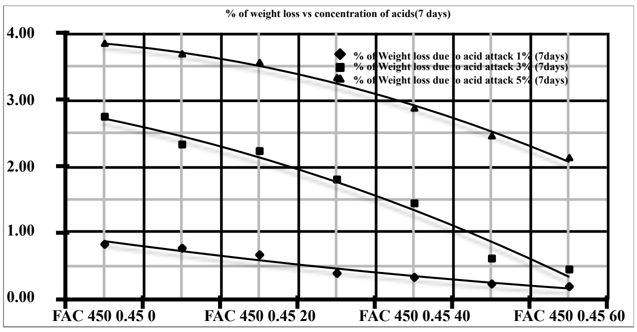

Figure 6: % weight loss in FAC 0.45 concretes with % fly ash immersed for 7 days in 1.0, 3.0 and 5.0% H_2SO_4 solution.

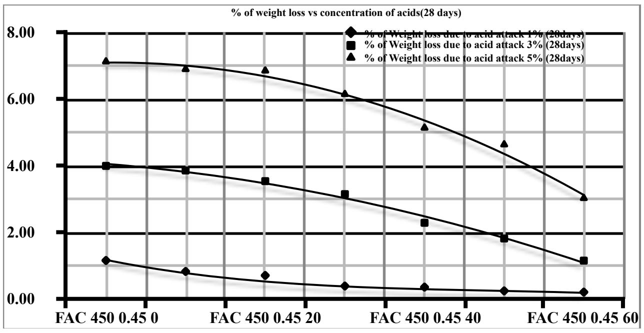

Figure 7: V% weight loss in FAC 0.45 concretes with % fly ash immersed for 28 days in 1.0, 3.0 and 5.0% H_2SO_4 solution.

In fly ash concrete mixes, the weight loss has been relatively less with binder content of 450 kg/m^3 at 0.5water-binder ratio, as shown in Table 10. The weight loss in concrete with 0.0% fly ash for 7 and 28 days immersion in 1.0% H_2SO_4 solutions are 0.627 % and 1.16% respectively with 60% fly ash in cement, the respective weight losses are 0.35% and 0.5% at 3.0% H_2SO_4 concentration, the weight loss decreases from 1.28% to 0.65% for 7 days immersion and from 3.39% to 1.5% for 28 days immersion respectively. When the concrete was immersed in 5.0% H_2SO_4 solution for 7 days, the weight loss decreases from 2.84% to 1.3%, as the fly ash content increases from 0.0% to 60%, whereas the weight loss decreases from 5.49% to 3.2% with 0.0% and 60% fly ash respectively for 28 days immersion. Figure 8 show the variation of percentage weight loss in concrete mixes with fly ash varying from 0.0% to 60% immersion for 7 days. Figure 9 shows the comparison and variation of percentage weight loss in various concretes immersed for 28 days. %weight loss decreases with increase in fly ash content and decreased in H_2SO_4 concentration.

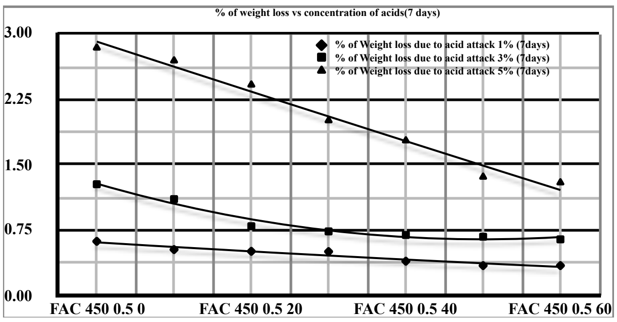

Figure 8: % weight loss in FAC 0.50 concretes with % fly ash immersed for 7 days in 1.0, 3.0 and 5.0% H_2SO_4 solution.

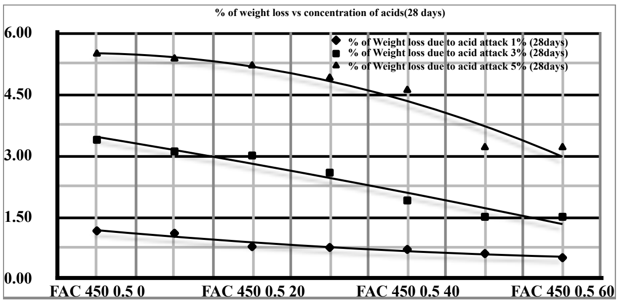

Figure 9. % weight loss in FAC 0.50 concretes with % fly ash immersed for 28 days in 1.0, 3.0 and 5.0% H_2SO_4 solution.

5 CONCLUSIONS

1. High volume fly ash concrete has been observed to be highly effective in achieving high strength, durability and performance under various environmental impacts.
2. As the volume of cement replaced by fly ash increases, there has been strength improvement.
3. As the volume of aly ash in cement increases, the resistance against H_2SO_4 solution has been significantly improved.
4. As the concentration of H_2SO_4 increases, there has been significant strength and weight loss due to deteriorating effect of H_2SO_4.
5. At higher percentage so fflya shh, the concretes exhibited improved strength, durability and reduced weight loss.

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