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Upshot of Fly Ash and Silica Fume on Durability Properties of Pre-stressed Concrete

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Abstract*— Concrete structures which are the practical importance are those concerning its strength, durability, shrinkage, creep etc. Of these, the strength of concrete has a greater significance as the strength is related to the structure of hardened cement paste and gives an overall picture of the quality of concrete. The durability of concrete is the one that performs satisfactorily under anticipated exposure conditions during its service life span. The material and mix proportions used should be in such a way that it maintains its integrity and protects the embedded metal from corrosion. In this paper, the durability of concrete has been investigated with the use of admixtures such as fly ash, silica fume and super plasticizer. The durability of cubes with and without admixtures, and corrosion resistance of cylinders with and without admixtures have been conducted.

Index Terms—**Durability, Fly ash, Poles, Prestressed Concrete, Silica fume, Strength, Super plasticizer.**

I. INTRODUCTION

Concrete is a versatile material, which can be used in virtually all engineering projects. It suffers from several drawbacks such as low tensile strength, permeability to liquids and consequent corrosion of reinforcement, susceptibility to chemical attack and low durability. There are a number of unfavorable conditions that threaten the serviceability of reinforced concrete structures. Corrosion attacks on structures cause damage and lead to failure of the structural elements or the whole structure. These lead to high maintenance costs (or) premature replacement of the structures themselves. Chemical influences on the concrete surfaces due to environmental impact can also affect their long term performance. Concrete poles are subject to corrosion of the steel reinforcement, resulting in further strength deterioration and expensive maintenance. Regular maintenance is essential to prolong the serviceability of these poles.

II. REVIEW OF LITERATURE

TehminaAyub, et al [1] have done research on the durability characteristics of the concrete containing fly ash (*FA*), silica fume (*SF*), ground granulated blast furnace slag (*GGBS*), metakaolin (*MK*) and rice husk ash (*RHA*). Durability related properties reviewed include permeability, resistance to sulfate attack, alkali-silica reaction (*ASR*), carbonation, chloride ion penetration, freezing and thawing, abrasion, fire, acid, and efflorescence. Permeability of concrete depends upon the content of alumina in mineral admixtures, higher the alumina content lesser the permeability causes higher resistance to sulfate and chloride ion penetration. Sulphate resistance of concrete incorporating mineral admixtures depends upon the content of alumina in mineral admixtures, higher the alumina content higher the resistance. Coarse *FA* has been found effective to prevent *ASR*. Use of a minimum 50% *GGBS* in concrete suitably prevents alkali-silica reaction, if the alkalis are only contributed by cementitious materials. *MK* reduces rapid expansion due to alkali-silica reaction when compared to control and *SF* concrete. Replacement of cement between 10 and 15% with *MK* may be adequate to overcome the harmful expansion caused by *ASR* in concrete; however it depends on the nature of the aggregates. *RHA* suppresses the expansion due to alkali-silica reaction by trapping the alkalis through supplementary hydrates. Combined use of relatively small levels of *SF* (e.g., 3 to 6%) and moderate levels of high CaO *FA* (20 to 30%) is very effective in reducing expansion due to *ASR*. The carbonation is increasing with the addition of mineral admixtures because of higher water binder ratio and lesser content of portlandite in hydrate products due to pozzolanic reaction. Chloride ion diffusion is dependent on the permeability of concrete, therefore inclusion of *FA*, *GGBS*, *SF*, *MK* or *RHA* in concrete generally increase the resistance against chloride ion diffusion. Inclusion of *FA* or *GGBS* in concrete requires air entraining admixture to increase the resistance against freeze and thaw. Conversely, there is no increase in resistance against freeze and thaw due to inclusion of *SF*. Use of *MK* or *RHA* in concrete gives very good resistance against freeze and thaw and does not necessarily requires air entraining admixture.

Semion Zhutovsky et al [2] have done research on internal curing of high performance concrete (HPC) by pre-saturated lightweight aggregates which is a well established method of counteracting self-desiccation and autogenous shrinkage. However, by introducing the internal water reservoirs, strength and durability properties can be injured. Tests by the widely accepted methods of durability assessment, such as resistance to chloride penetration, air permeability, water absorption, autogenous and drying shrinkage and mass loss, were conducted on HPC mixes made at water to cement ratios in the range of 0.21- 0.33. The effect of internal curing on the

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durability related properties of high performance concretes as a function of water to cement ratio is reported. No serious degradation in durability related properties was revealed. Air permeability of HPC was reduced by IC, except at early ages. Sorptivity and mass loss were increased by IC, due to the increase of total porosity by 3 - 4%. The effect of IC on resistance to chloride penetration varied with w/c ratio. While for the w/c ratio of 0.33, an improvement was observed, at lower w/c ratios, the effect was minor. For internally cured concretes, reduction of w/c ratio did not result in perceptible improvement of durability. Reduction of w/c for internally cured HPC had a beneficial effect on drying shrinkage. It seems that using pumice which has very high open porosity in combination with vacuum absorption is a very effective strategy for elimination of autogenous shrinkage.

Haibing Zheng et al [3] have done research and presented the effect of a surface-applied corrosion inhibitor on the durability of concrete by using capillary water absorption test, chloride penetration test, and accelerated carbonation test. Results showed that the inhibitor applied on the surface of hardened concrete improved the properties of water resistance, chloride resistance, carbonation resistance, thus the durability of concrete. The surface applied corrosion inhibitor blocks the pores on the surface of concrete. Transportation of water, chloride ion, and carbon dioxide into concrete is inhibited. The durability of concrete is improved. This effect, however, gradually decreases with an increase in the water/cement ratio. The main function of the surface-applied corrosion inhibitor is to prevent steel corrosion. The improvement in the durability of concrete further protects the reinforcement. Unlike surface coatings, the surface applied corrosion inhibitor cannot form a protective layer on the surface of concrete, and its effect on the microstructure of concrete is limited to the surface. Therefore, the surface applied corrosion inhibitor can improve the durability of concrete, but this effect may weaken with time.

III. SCOPE AND OBJECTIVE

Scope

Durability property of concrete is essential to improve the life of the structures. The scope of the investigation is to study the effect of admixtures on durability. The deficiency of conventional RCC & PSC poles has been rectified by modifying the mix design.

Objectives

- To select the suitable admixtures to improve the strength and durability characteristics
- To find out the optimum percentage of replacement of cement by admixtures
- To design concrete mix for M40 concrete with various proportions of admixtures
- To study the durability properties of PSC electric poles

IV. EXPERIMENTAL INVESTIGATION

In this experimental investigation, an attempt has been made to study the durability properties of fly ash, silica fume added concrete cubes. The materials used for this experimental work are cement, sand, water, fly ash, silica fume and super plasticizer.

Cement: Ordinary Portland cement of 53 grade was used in this experimentation conforming to I.S. – 12269-1987.

Sand: Locally available sand [zone II] with specific gravity 2.65, water absorption 2% and fineness modulus 2.92, conforms to IS 383-1970.

Coarse aggregate: Coarse aggregates of size 20mm and 12 mm have been selected for the study. The fineness modulus of 20 mm is 5.94 with specific gravity of 2.7 and 12 mm size having specific gravity of 2.70, fineness modulus of 2.73, conforming to IS 383-1970.

Water: Potable water was used for the experimentation.

Fly ash: Fly ash obtained from local suppliers was used in this investigation and it satisfied the IS: 3812 Specification of Specific gravity and Blaine specific surface area were 2.30 and 2.68 m^2/kg respectively.

Silica Fume: Silica fume imparts improvement to rheological, mechanical and chemical properties. It improves the durability of concrete by reinforcing the microstructure through filler effect and thus reduces segregation and bleeding. Silica fumes of specific gravity 2.34 in powder form are used in the study.

Super Plasticizer: To impart additional workability, a super Plasticizer (Conplast SP430) 0.6 % to 0.8% by weight of cement was used as per IS – 9103:1999.

Mix Proportions

In this study, the high strength concrete of M40 grade was considered. BIS code procedure as per IS: 10262-1982 was followed for finding the mix proportions of the concrete specimen.

Water binder ratio considered for M40 grade was 0.4. Table 1 shows the summary of materials required for control concrete mix used in this investigation.

Table 1 Mix Proportion of Concrete

Concrete grade M40	Materials required per m^3 of Concrete			
	Cement (Kg)	Coarse Aggregate (Kg)	Fine Aggregate (Kg)	Water (Litre)
	450	1100	660	200

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Table 2 Details of Mix Proportion for Concrete Mix M40

Mix No.	Cement Kg/m^3	Coarse Aggregate Kg/m^3		Fine Aggregate Kg/m^3	Fly ash Kg/m^3	Super plasticizer Lit/m^3	Micro silica Kg/m^3	Water Lit/m^3
		20mm	12mm					
A	450	725	483	660	-	-	-	200
B	400	725	483	660	100	-	-	200
C	400	725	483	660	100	4	50	160

Accelerated Corrosion Test

In the present study, the corrosion process was accelerated by impressing a constant DC voltage between the steel bar (as anode) and stainless steel plate (as cathode) and the variation of current with time was recorded. The cylinder specimen with a centrally embedded steel bar was partly immersed in a 4% NaCl solution in the beginning stage. After 3 weeks, 5% NaCl solution was prepared and the specimens were immersed. A potential of 12V (DC power supply) was applied across the specimens, the reinforcement steel bar being connected to the positive terminal and stainless steel sheet being connected to the negative terminal of the DC power supply.

Fig.1 Half – Cell Potentiometer test

Half-cell potential test (HCP) is generally considered a non-destructive and rapid indicator to check the probability of steel corrosion in concrete. HCP test was carried out on all the faces of cylinder specimens after completion of accelerated corrosion test as per the guidelines specified in ASTM C876. Cu/CuSO4 electrode was used as the reference electrode.

Durability Test

Water Absorption Test

After 28 days of curing, the specimens were taken out from the curing tank. The specimens were dried for 24 hours. The dried specimens were weighed accurately and noted as dry weight. The dried specimens were immersed in water. Weight of the specimen at pre-determined intervals was taken after wiping the surface with dry cloth. This process was continued for not less than 48 hours or up to constant weight is obtained in two successive observations.

Sulphate Attack Test

When concrete is exposed to environment containing aggressive chemicals, it leads to deterioration of concrete which can be assessed in terms of loss in weight of concrete. To study the acid resistance of concrete, the cubes of concrete were cured and then immersed in 5% Na_2SO_4 solution up to 28 days. After 28 days of immersion, the specimens were taken out and visually observed for the deterioration of the concrete due to sulphate attack. The specimens were weighed once again and the weight was compared with normal concrete in order to calculate the percentage of loss in concrete and also the loss of strength.

Fig.2 Sulphate attack on cubes

Chloride Attack Test

A non-porous container is selected and chloride solution has been prepared by adding 5% sodium chloride in distilled water. This solution is stirred well so that all the sodium chloride salts get dissolved in the solution. The initial weights of these cubes are found. Then they are immersed in a chloride solution. After drying the cubes, the change in weight was found and also the compressive strength of concrete cubes was found.

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Fig.3 Chloride attack on cubes

Acid Attack Test

For acid attack test, concrete cubes of size 150 x 150 x 150mm were prepared. The specimens were cured in curing tank for 28 days. After 28 days, all specimens were kept in atmosphere for 2 days for constant weight. Subsequently, the specimens were weighed and kept immersed in 5 % sulphuric acid (H_2SO_4) solution for 28 days. After 28 days of immersion in acid solution, the specimens were kept in atmosphere for 2 days for constant weight. After drying the cubes, the changes in weight were found and also the compressive strength of cubes was found.

Fig.4 Acid attack on cubes

V. RESULTS AND DISCUSSION

Compressive Strength

The compressive strength of concrete was found for the control concrete and the admixtures used concrete after 28 days curing. Table 3 shows the compressive strength of cubes with and without admixtures.

Table 3 Results of Compressive Strength

Age of concrete	Type of concrete		
28 day Compressive strength N/mm^2	C.C	C.C with fly ash	C.C with Fly ash and silica fume
	48.5	55.2	56.8

It is observed that the compressive strength of concrete is high in admixture added concrete when compared to the ordinary concrete at the age of 28 days. In this, fly ash and silica fume added concrete shows high compressive strength when compared to others.

Method used to induce the corrosion

The method used to induce corrosion is Galvanostatic method which is otherwise called Accelerated corrosion method. The cylinders placed in plastic tank were subjected to a current from an external D.C source. The stainless steel plate, which acts as cathode was immersed in the NaCl solution. The stainless steel plate was 1.5 mm thick. The current was adjusted using knobs provided in D.C rectifier to maintain a constant current throughout the test.

Half-Cell Potential

The half-cell potential test was carried out on all faces of all the cylindrical specimens. The half-cell potential values obtained for different types of mixes. It is evident that the half-cell potential values for types of mixes are more negative than -350mV with respect to Cu/CuSO4 electrode (ASTM C876 criteria for greater than 90% probability of reinforcement corrosion). The concrete mix with silica fume has reduced the corrosion of 81.82% when compared to the conventional concrete. The Fly ash mix has reached only 63.63% of corrosion when compared to the value of conventional concrete corrosion at 550 hours.

Table 4 Results of Half-cell potential test

DoT	VALUES			
HOURS	CC	FA	SF	PSC POLE
50	-377	-	-	-337
100	-657	-	-	-414
150	-	183	185	-525
200	-	160	147	-561
250	-	70	141	-632
300	-	-85	-29	-710
350	-	-126	-73	-
400	-	-222	-369	-
450	-	-399	-470	-
500	-	-	-517	-
550	-	-	-599	-

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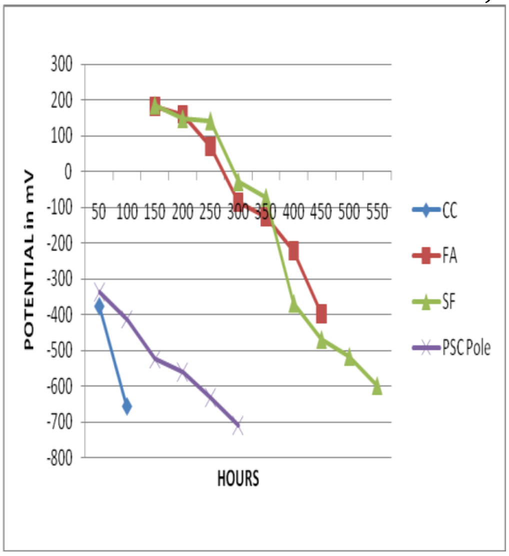

Fig.5 Corrosion exposure for conventional concrete Vs Different mixes

Durability Properties of Concrete

Results of Water Absorption Test

Table 5 shows the water absorption test results of average % water absorption of concrete cube specimens of control concrete and admixtures used concrete.

Table 5 Average % water Absorption

Sl. No.	Mix Id	Average weight of Cubes (Kg)		Average % water absorption
		Before	After	
1	CC	8.475	8.619	2.55
2	FA	8.332	8.552	2.64
3	SF	8.369	8.537	2.01

It is observed that the average water absorption of concrete cubes are low in admixtures used concrete compared to the ordinary concrete at the age of 28 days. In this, silica fume shows very low water absorption % compared to the others.

Results of Sulphate Attack Test

Table 6 shows the sulphate attack test results of average % gain in weight of concrete cube specimens of control concrete and admixtures used concrete immersed in Na2SO4.

In this, silica fume shows very low % gain in weight of concrete cubes compared to others.

Sl. No.	Mix Id	Weight of Cubes (Kg)		Average % Gain in Weight
		Before	After	
1	CC	8.473	8.600	1.49
2	FA	8.369	8.602	2.78
3	SF	8.439	8.506	0.79

Table 6 Average % Gain of Weight in Sulphate Attack Test

Results of Chloride Attack Test

Table 7 shows the chloride attack test results of average % gain in weight of concrete cube specimens of control concrete and admixtures used concrete.

Table 7 Average % Gain of Weight in Chloride Attack Test

Sl. No.	Mix Id	Weight of Cubes (Kg)		Average % Gain in Weight
		Before	After	
1	CC	8.600	8.760	1.86
2	FA	8.456	8.562	1.25
3	SF	8.575	8.650	0.874

From the above table, it is observed that the average chloride attack of concrete cubes is low in admixtures used concrete compared to the ordinary concrete at the age of 28 days. In that silica fume shows low % gain in weight of chloride attack concrete cubes compare to the others.

Results of Acid Attack Test

Table 8 shows the Acid attack test results of average % loss in weight of concrete cube specimens of control concrete and admixtures used concrete when it is immersed in H_2SO_4 solution.

Table 8 Average % Loss of Weight in Acid Attack Test

Sl.No.	Mix Id	Weight of Cubes (Kg)		Average % Loss in Weight
		Before	After	

1	CC	8.477	8.205	3.20
2	FA	8.296	8.175	1.458
3	SF	8.299	8.156	1.723

From the above results, it is observed that the average acid attack of concrete cubes is low in admixtures used concrete compared to the ordinary concrete at the age of 28 days. In this test, fly ash shows very low % loss in weight of concrete cubes compared to others.

VI. CONCLUSIONS

Based on the results of experimental study, the following conclusions are drawn:

i) By adding fly ash, the compressive strength of the concrete is increased by 13.8%.

ii) By adding silica fume and fly ash combination, the compressive strength of the concrete is increased by 17.11%.

iii) The concrete containing fly ash is exhibiting larger periods of corrosion initiation of about 450 hours.

iv) The concrete containing both silica fume and fly ash, takes more time than that of fly ash alone for the initiation of corrosion.

v) The test pieces of the prestressed concrete electric pole, when subjected to the accelerated corrosion exhibits steady state of corrosion propagation rate.

vi) The durability properties of the concrete have been improved by adding fly ash / silica fume.

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