Enhanced corrosion resistance of rebar embedded in fly ash added concrete: Role of "k" factor

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In India, the abundant availability of fly ash necessitates the increase in the addition of fly ash in pozzolana cement from 25 to 35%. Higher replacement level of fly ash reduced the development of early age strength of concrete. By adopting the cement efficiency factor (k) when designing the fly ash added concrete, either equal or more compressive strength has been attained. In the present study, by adopting this factor, the concretes having strength of 20 and 35 MPa were designed at 40% replacement of fly ash. The enhanced corrosion resistance of rebar was evaluated by conducting chloride migration test, potential-time studies and 90 days chloride ponding test. Results were compared with Ordinary Portland cement (OPC) and Fly ash added concrete (FAC) without k factor. The studies reveal that the diffusion co-efficient of chloride is less in FAC- with k than that of OPC and FAC without k concretes. In 1% chloride contaminated concrete, the rebar in FAC- with k shows more passive potential than the other two concretes. Under 90 days chloride ponding test, the corrosion resistance of rebar in FAC is 3-7 times more than that of the rebar in OPC concrete. The reduced chloride ion penetration increased the corrosion resistance of rebar. The 40% replacement of fly ash reduced the alkalinity of FAC-without k whereas the OH⁻ ions concentration increases in FAC-with-k and maintained the passivity of rebar in presence of chloride. Hence in addition to early strength development, the enhanced corrosion resistance of rebar in FAC- with k is mainly because of reduced chloride ions penetration and increased OH⁻ ions concentration.

Keywords: Fly ash, Pozzolana cement, Efficiency factor, Chloride diffusion, Corrosion rate

Addition of supplementary cementitious materials is one of the methods of reducing the permeability of concrete. Fly ash is one among them and widely used in India because of its abundant availability. The addition of fly ash to concrete improves various properties of concrete both in hardened and fresh state. It increases the workability and reduces bleeding[1] in plastic state. It reduces the heat of hydration during hardening of concrete and causes reduction of cracking[2]. In hardened concrete it reduces the permeability by the formation of additional calcium hydrates by pozzolanic reaction[3]. Recently, BIS also amended the code of practice for Portland pozzolana cement (IS: 1489:1991) and the limits of fly ash addition have been increased from 10–25% to 15–35%[4]. Economically and environmentally the addition of fly ash in concrete may be advantageous but practically because of its slower pozzolanic reaction the development of strength is less when compared to Portland cement concrete[5-7]. The replacement of fly ash in cement and consumption of $Ca(OH)_2$ in pozzolanic reaction caused the reduction of OH⁻ ions and this may affect the passivity of rebar embedded in the concrete containing chloride[8,9]. Recently by adopting the cement efficiency factor (denoted as 'k') in designing the fly ash added concrete, the early as well as latter strength of concrete were improved which is equal to or more than that of the Portland cement concrete. The 'k' factor is defined as the part of the fly ash, which can be considered as equivalent to Portland cement, having the same properties as the concrete without fly ash (obviously, k=1 for Portland cement). By adopting this factor, the level of replacement of fly ash increases from 15% to 75%[10]. Smith adopted a 'k' value of 0.25 for fly ash[11] replacement up to 20%. German standard specified a value of 0.3 for fly ash replacement up to 10-15% whereas British code recommended a value of 0.3 for replacement of 50% fly ash. The most recent CEB-FIP model code proposed an efficiency value of 0.4 for replacements between 15-40% fly ash. Ganesh Babu and Siva[12,13] adopted three k factors namely k_7, k_{28}, k_{90} for each curing period and concluded that the values of these factor depend on w/c ratio, replacement level, type of fly ash and curing time[8]. Bharatkumar *et al.*[14] also

adopted three different 'k' factors for three curing periods in designing the high performance concrete using fly ash. The BIS permits to increase the fly ash replacement up to 35% without mentioning the value of 'k' as adopted in other countries.

In the present investigation by adopting 'k' factor in designing the fly ash added concrete, its effect on reduction of chloride ions penetration, increase of OH⁻ ions concentration, corrosion of rebar in presence of chlorides, diffusion coefficient of chloride were studied. Results were compared with ordinary Portland cement concrete (OPC) and also in fly ash added concrete (FAC) without adopting this 'k' factor. The evaluation was carried out at 40% replacement of fly ash added concrete. The mix design was done by the method given by Smith[11] and 'k' value of 0.41 as suggested by Ganesh Babu and Siva[12] has been used.

Experimental Procedure

Materials

Concrete specimens having characteristic compressive strength of 20 (M20) and 35MPa (M35) at 28 days of curing were used through out the investigation. Ordinary Portland cement conforming to IS: 8119[15] was used. The fly ash collected from Neyveli Lignite Corporation, Neyveli which satisfied the physical and chemical requirements as specified in IS: 3812[16] has been used. The chemical composition of cement and fly ash used is given in Table 1. The physical properties of fly ash are given in Table 2. Well-graded river sand and good quality crushed blue granite were chosen as a fine and coarse aggregate respectively. The different size fractions (20 mm and 20 mm down graded) of coarse aggregate were taken and recombined to a specified grading as shown in Table 3. The details of mix proportions used for casting the M20 and M35 concrete are given in Table 4. The 16 mm diameter cold twisted high yield strength deformed bar (Fe-415 grade-CTD bar) conforming to I.S.1786[17] was used and its chemical

Table 1—Chemical composition of cement and fly ash

Chemical compound, %	OPC	Fly ash
SiO_2	21	52
Al_2O_3	5.4	28
Fe_2O_3	4.6	1.0
CaO	63	11
MgO	0.6	3.5
Loss on ignition	2.0	1.92

Table 2—Physical properties of fly ash

Colour	Whitish grey
Bulk density	1.12 g/cm³
Specific gravity	2.285
Soundness	0.3
Fineness	3250 cm²/g
Moisture	0.03%
Pozzolanic activity index at 7 days	73% of control mortar

Table 3—Grading of fine and coarse aggregate

Fine aggregate		Coarse aggregate	
Sieve size (mm)	Cumulative % retained	Sieve size (mm)	Cumulative % retained
4.75	0	20	4
2.36	1	16	18
1.18	20.4	12.5	38
0.600	59.8	10	60
0.300	92.2	4.75	100
0.150	98	—	—
<0.150	100	—	—
Fineness modulus	2.66	Fineness modulus	7.20

Table 4—Mix proportion of M20 and M35 grade concrete

Grade	Mix Proportion C:F:F.A: C.A	Cement kg/m³	Water kg/m³	Fly ash kg/m³	Fine aggregate kg/m³	Coarse aggregate kg/m³	w/c+f	28 days strength MPa
M20-OPC	1:0:2.19:3.73	308	194	0	676	1148	0.63	31
M20- FAC (without k)	1:0.4:2.19:3.73	185	194	123	676	1148	0.63	27
M20- FAC (with k)	1:0.67:2.49:5.3	219	190	146	561	1160	0.53	31
M35-OPC	1:0:1.76:2.05	434	217	0	767	890	0.50	43
M35-FAC (without-k)	1:0.4:1.76:2.05	260	217	174	767	890	0.50	31
M35-FAC (with k)	1:0.67:0.94:1.99	306	210	205	485	1031	0.42	40

C:F:F.A:C.A-Cement:flyash:Fine aggregate:Coarse aggregate

composition was C, 0.17; Mn, 0.66; Si, 0.115; S, 0.017; P, 0.031% and Fe, balance. Potable water was used for casting the concrete specimens.

Specimen preparation and method of measurement

Chloride diffusion co-efficient of concrete

Concrete disc of size 85 mm in diameter and 40 mm in thickness were cast and cured for 28 days. After 28 days of curing, the chloride diffusion test was carried out under electro-migration test condition using diffusion test cell. The schematic diagram of diffusion test cell is shown in Fig. 1. Two halves of the PVC containers of dia 90 mm with 100 mm long were fixed on both the sides of the concrete specimen. One side of the container was filled with 10% NaCl solution whereas the other was filled with 0.1 M NaOH. Titanium substrate insoluble anode (TSIA) was kept immersed on both sides of the container. Compartment containing NaCl and NaOH was connected to the − ve and + ve terminal of the power supply respectively. A voltage of 10V was impressed between the two TSIA anodes. Periodically the chloride concentration in NaOH compartment was determined by Mohr's method[18]. The experiment was conducted till steady- state condition was reached. It was observed that after 120 h the steady-state condition was reached and experiment was performed upto that period. The chloride diffusion co-efficient was calculated using Nernst-Planck equation as follows[19]:

$$D = JRTL/ZFCU \qquad \ldots (1)$$

where D = Chloride diffusion co-efficient (cm^2/s); R=Universal gas constant, (8.314 J/K-mol); T= Absolute temperature (K); F=Faraday number (9.648 $\times 10^4$ J/v-mol); Z=Valence of chloride ions ($Z=1$); L=Thickness of concrete specimen (cm); J= Flux of concrete, mol/cm^2-s; C= Upstream concentration of chloride ions (mol/L); and U=Potential applied (V).

From the calculated D, the time taken to reach threshold chloride level for initiation of corrosion at the rebar surface was determined. Water-soluble chloride of 0.15% by weight of cement as specified in ACI building code 318[20] has been taken as threshold chloride concentration for initiation of corrosion. Using Browne's[21] analytical solution to Fick's second law of diffusion, the D is related as below;

$$C_x = C_s [1 - \text{erf} (x/2\sqrt{D_a} t)] \qquad \ldots (2)$$
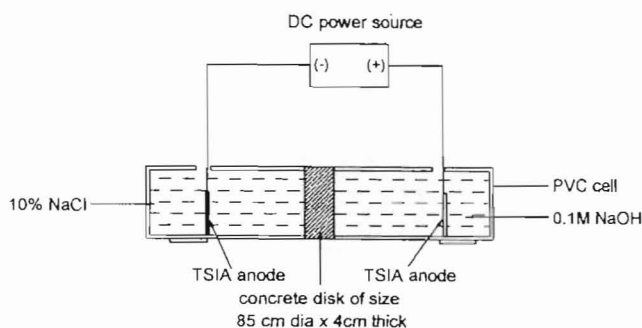

Fig. 1—Test set-up for chloride diffusion test

where C_x=chloride concentration at x (mol/L); C_s=chloride concentration at the concrete surface (mol/L); D_a=Apparent chloride diffusion coefficient (cm^2/s); t=Exposure time (s); x=cover depth (m). Using the Eq. (2), by assuming C_s =0.5 M (the highest concentration observed in marine environment), C_x = 0.15% by weight of cement and cover=50 mm (x), the time taken to initiation of corrosion was determined.

Potential –time behaviour in chloride contaminated concrete

Measurement of corrosion potential is one of the non-destructive methods to know the status of rebar qualitatively. The corrosion resistance of rebar in presence of chloride was determined by measuring the potential over a period of 90 days. Cylindrical concrete specimens having a size of 5 cm dia x 10 cm height were cast in which 7.5 cm length of 16 mm dia cold twisted deformed (CTD) rebar was centrally embedded at the clear cover of 17 mm.1% chloride by weight of cement was added at the time of casting. After 28 days of curing, to accelerate the corrosion process the specimens were subjected to alternate wetting in potable water and drying test. The specimens were kept immersed in potable water for 16 h and exposed to sunlight for 8 h. During the exposure, the potential was measured once in 7 days, using saturated calomel reference electrode. Measurements were made on duplicate specimens and the average value is reported.

90 days chloride ponding test

Cubical concrete specimens of 150 mm size were used for chloride ponding test. A rebar of 16 mm dia having 100 mm length of bar was cut and pickled in inhibited HCl solution to remove the initial rust. After taking the electrical lead from the bar, it was embedded at 20 mm cover from one side of the

specimen as shown in Fig. 2. After 28 days of curing, a plastic trough was fixed on one side of the of the specimen from which the rebar was embedded. Then all the specimens were taken to exposure yard and 3% NaCl solution was ponded on the top of the specimen. Duplicate specimens were cast for each strength of concrete. The experiment was conducted over a period of 90 days. During the exposure, the potential and corrosion current were made periodically.

The corrosion current was measured using the corrosion rate monitor developed by CECRI[22]. Stainless steel electrode of size 100x80 mm was used as an auxiliary electrode. This was placed on a wetted sponge below which saturated calomel reference electrode was placed. The rebar embedded in the concrete specimen acts as a working electrode. The length of the counter electrode was more than the exposed length of the rebar and by means of this current was distributed uniformly throughout the length of the rebar. Using a potentio-static method, a potential of 20 mV was applied and the change in current (DC) was measured after 5 min. From that, the R_p value was calculated. By applying AC frequency of 1000 Hz with an amplitude of 20 mV, the IR compensation (arises from the concrete resistance) was carried out. Assuming the Stern -Geary constant as 26 mV[23], the corrosion current and corrosion rate was calculated as:

$$I_{corr} = \frac{B}{R_p} \qquad \qquad \dots (3)$$

$$\text{Corrosion rate (mmpy)} = 0.0116 \times I_{corr} \qquad \dots (4)$$

where, B=Stern-Geary Constant, 26 mV for both active and passive state of rebar; R_p=Polarisation resistance ohms-cm^2; I_{corr} = Corrosion current, $\mu A/cm^2$. The measurements were made initially as well as at the end of 90 days.

Determination of Cl⁻ and OH⁻ ions

After 90 days of exposure, core sample of size 5 cm dia of 45 mm depth was taken from the center of the each specimen as shown in Fig. 2. Each core sample was sliced to three slices of 15 mm thickness. Then they were powdered and sieved through 150 μm sieve. 20 g of this powdered sample was taken in a closed container and dissolved in 60 mL of distilled water. After 48 h, the mixture was shaken for 10 min
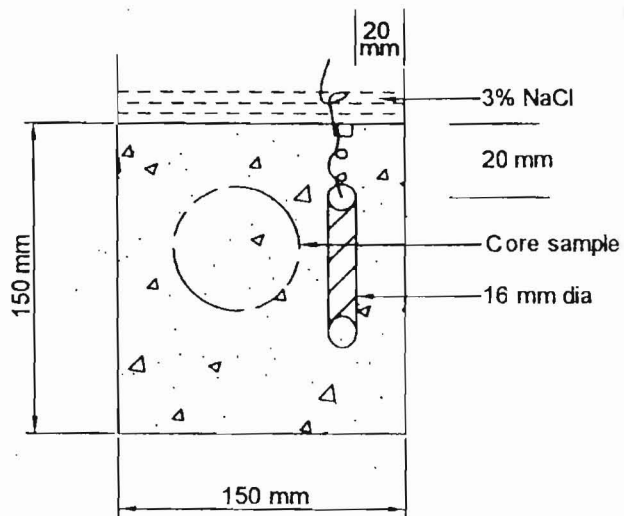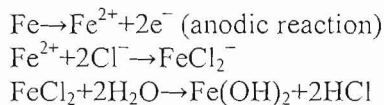

Fig. 2—Specimen configuration – 90 days chloride ponding test

and the solution was decanted. In the decanted solution, the water-soluble chloride was determined by Mohr's method[18]. The reduction of OH⁻ ion was determined by titrating against standard sulphuric acid of 0.1 N H_2SO_4, using phenolphthalein as an indicator[24].

Results and Discussion

Chloride diffusion co-efficient of concrete

The strongly alkaline nature of concrete prevents the corrosion of rebar by the formation of iron oxide on the metal surface. Soluble chlorides penetrate through the cover concrete right upto the rebar, and in presence of oxygen, chloride and water, the corrosion of reinforcement will take place. The reactions involved in the process can be represented by the following reactions;

$Fe \rightarrow Fe^{2+} + 2e^-$ (anodic reaction)
$Fe^{2+} + 2Cl^- \rightarrow FeCl_2^-$
$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl$

$Fe(OH)_2$ is oxidized further and forms rust. The formation of rust results in an increase in volume compared with the original rebar so that swelling pressures will cause cracking and spalling of the concrete. Thus permeability of the concrete is one of the causes for the lack of durability of structures in marine environment.

Chloride permeability is one of the intrinsic properties of the concrete to be assessed independently so as to know the long-term durability

of concrete structures in marine environment. The main mechanism for transport of chloride ions through crack-free concrete is by diffusion. As the rate of chloride ion penetration due to diffusion is slow[25], the process can be accelerated[26] by the application of an electrical field 10 V.

Table 5 compares the chloride diffusion co-efficient of Portland cement concrete with fly ash added concrete. It is observed that both in M20 and M35 concrete, diffusion coefficient of FAC - with k is less than that of OPC concrete whereas not much reduction is observed in FAC-without k. The diffusion rate was reduced by 3.5 times if the strength of concrete is increased from M20 to M35. FAC- with k has both an additional cement and fly ash content which increases the formation of calcium silicate hydrates during the pozzolanic reaction[27]. These secondary hydrates fill the pores and reduce the diffusion of chloride. It is also observed that the time taken to reach the critical chloride content for initiation of corrosion is increased considerably in FAC-with k both in M20 and M35 concretes.

Potential-time behaviour in chloride contaminated concrete

As per ASTM C 876[28], the following criteria have been applied while interpreting the potential –time data.

Potential, mV versus SCE	Probability of corrosion (%)
More –ve than -275	> 90 (active)
Between -275 to -125	Uncertain
More + ve than -125	< 10% (passive)

Figures 3 and 4 compare the potential-time behaviour of rebar in M20 and M35 –1%Cl⁻ added concrete respectively. In OPC, the rebar initially shows a potential value of –422 mV and tends to move towards the negative direction and attains a value of –475 mV at the end of the exposure. As per ASTM, this potential value indicates the corrosive condition of the rebar. In FAC- without k, the initial value is –529 mV and attains –246 mV at the end of the exposure. Probably the rebar inside the concrete is in uncertain condition. In FAC-with k, the initial value is –244 mV and attained a potential value of –198 mV at the end of 90 days. From Fig. 4, it is observed that the rebar in FAC with and without k showed a passive potential than the rebar in OPC. At the end of 90 days of exposure, it is –166, –187 and –380 mV in FAC with, without k and OPC concrete respectively. Data emphasis that the rebar in OPC
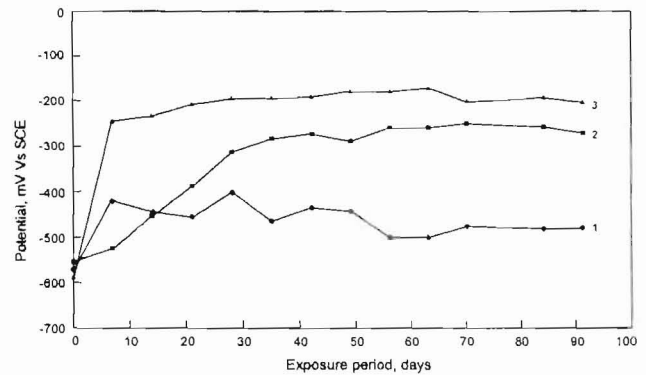

Fig. 3—Potenial-time behaviour of rebar embedded in M20-1% chloride contaminated concrete. 1. OPC concrete 2. Fly ash added concrete without k 3. Fly ash added concrete with k
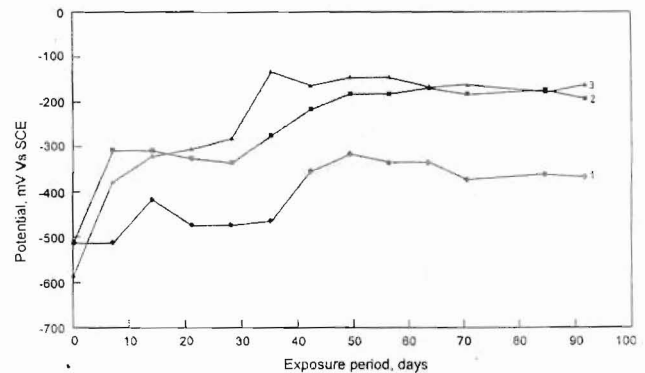

Fig. 4—Potenial-time behaviour of rebar embedded in M35-1% chloride contaminated concrete. 1. OPC concrete 2. Fly ash added concrete without k 3. Fly ash added concrete with k

Table 5—Chloride diffusion co-efficient

Grade	Replacement levels, %	Chloride diffusion co-efficient, cm²/s	Predicted years to reach critical chloride content
M20	0	2.49×10^{-8}	8
	40 (with out k)	2.22×10^{-8}	9
	40 (with k)	1.99×10^{-8}	10
M35	0	7×10^{-9}	29
	40 (with out k)	7.53×10^{-9}	27
	40 (with k)	4.61×10^{-9}	44

concrete is -193 mV more negative and it is more active than the rebar in FAC concretes.

The Al_2O_3 in the fly ash reacts with added chloride and forms more chloroaluminates (Friedel's salt) and this reduces the amount of free chloride[29]. The alumina fraction of the glass phase allowed the dissolution of Al^{3+} ions into alkaline solution[30] and

pozzolanic reaction consumes the released hydroxl ions. To maintain the ionic neutrality, more number of the negatively charged chloride ions were adsorbed into the interlayer of calcium-silicate hydrates. In FAC, fly ash reacts more readily with the chloride ions as it contains more attractive sites available for reaction than the OPC[26]. These factors contributed to the higher chloride binding capacity of FAC in 1% chloride contaminated concrete and hence make the rebar more corrosion resistant.

Chloride ponding test
Potential measurements

Figure 5 compares the potential-time behaviour of rebar under 90 days chloride ponding test in M20 concrete. The rebar in OPC shows an initial potential of −248 mV and tends to move in more negative direction, attained a potential value of −450 mV at the end of 86 days. In the case of FAC-without k, the initial potential of the rebar is −184 mV and attains a value of −277 mV at the end of the exposure. But in FAC- with k the rebar shows an initial potential of −179 mV and attained a more active potential of −460 mV at the end of exposure. Under this test, the rebar both in OPC and FAC-with k behaves in a similar manner and the value showed that the rebar was in active condition. But the potential of rebar in FAC-without k shows the passive condition of rebar.

But in M35 grade concrete (Fig. 6), after 28 days, the rebar in OPC concrete has more active potential than the rebar in FAC with and without k till the end of the exposure. The final potential at the end of 86 days is −381, −136 and −200 mV in OPC, FAC-without k and FAC-with k respectively. The data indicates that the reduced permeation of chloride in FAC makes the rebar in passive condition.

Corrosion rate using RCC corrosion rate monitor

Table 6 compares the corrosion rate of rebar in M20 and M35 concretes. In M20 concrete, the rebar in OPC shows corrosion rate value of 0.0088 mmpy initially which increases to 0.0305 mmpy at the end of 90 days. The value is 0.0050 and 0.0010 mmpy at the end of 90 days in FAC-without k and with-k respectively which is 7-3 times less than that of OPC concrete. Similar trend is observed in M35 concrete also. Initially the rebar in all the three concretes shows more or less same corrosion rate whereas at the end of 90 days, the rebar in FAC shows 3-5 times lower value than that of OPC concrete.
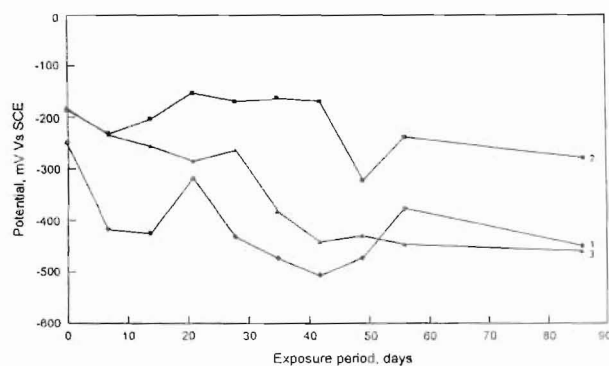

Fig. 5—Potenial-time behaviour of rebar embedded in M20-Under 90 days ponding test. 1. OPC concrete 2. Fly ash added concrete without k 3. Fly ash added concrete with k
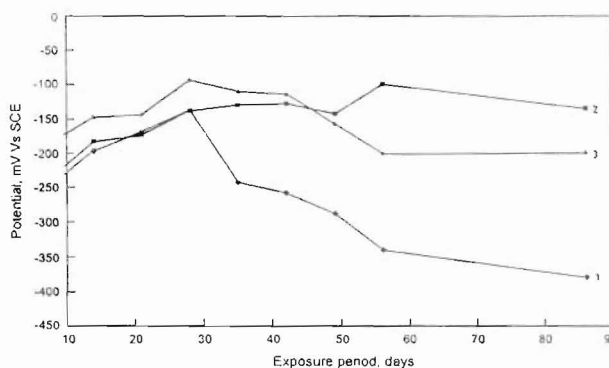

Fig. 6—Potenial-time behaviour of rebar embedded in M35-Under 90 days ponding test. 1. OPC concrete 2. Fly ash added concrete without k 3. Fly ash added concrete with k

Table 6—Comparison of corrosion rate-Under 90 days ponding test

Type of concrete	M20 Grade Corrosion rate (mmpy)		M35 Grade Corrosion rate (mmpy)	
	Initial	At the end of 90 days of exposure	Initial	At the end of 90 days of exposure
OPC- Concrete	0.0088	0.0305	0.0019	0.0110
FAC- with out k	0.0019	0.0050	0.0018	0.0020
FAC- With k	0.0013	0.0100	0.0019	0.0040

Determination of Cl− and OH− ions concentration
Cl− ions concentration

Table 7 compares the chloride ion concentration of FAC with OPC concrete at different depths. From the table, it is clearly evident that both FAC- with and without k having the less chloride concentration at all depths than the OPC concrete. This is observed in

Table 7—Chloride ions concentration at different depths-Under 90 days ponding test

Grade of concrete	Depth (mm)	Chloride concentration, % by wt of cement		
		OPC	FAC-without k	FAC-with k
M20	0-15	1.11	0.55	0.41
	15-30	0.88	0.22	0.12
	30-45	0.60	0.09	0.05
M35	0-15	0.36	0.29	0.17
	15-30	0.09	0.08	0.03
	30-45	0.06	0.04	0.04

Table 8—OH⁻ ions concentration at different depths: Under 90 days ponding test

Grade of concrete	Depth (mm)	OH^- ions concentration (mM/L)		
		OPC	FAC-without k	FAC-with k
M20	0-15	1326	1224	1326
	15-30	2142	632	1938
	30-45	2040	459	2244
M35	0-15	1938	1734	2346
	15-30	2652	1122	2550
	30-45	1734	439	877

both the strength of concretes. In M20 concrete, at 0-15 mm depth in FAC-with and without k, the chloride penetration is 2-2.7 times less than that of OPC concrete. At other depths such as 15-30 and 30-45 mm, 4-12 times reduction in chloride concentration is observed in FAC than that of OPC concrete. Compared to FAC-without- k, the chloride penetration is less in FAC with k.

In the case of M35 concrete, at 0-15 mm depth when compared to OPC, in FAC- with k, 2.4 times reduction in chloride ion penetration is observed whereas in FAC- without k, only 1.4 times reduction is observed. The trend is not changed in other remaining depths also. From the data it is also observed that in OPC by increasing the strength of concrete from M20 to M35, the chloride penetration is reduced by 3 times at 0-15 mm depth whereas by 10 times at 15-30 mm depth.

Thus, it can be inferred that the reduced chloride ion penetration in FAC is mainly attributed by the pore filling effect of fly ash by pozzolanic reaction. In addition to the reduction of total porosity, the pozzolanic reaction increases the discontinuous and tortuous nature within the existing pores and reduces the chloride diffusivity which in turn reduces the corrosion rate of rebar in FA concretes.

OH ions concentration

From Table 8, it can be seen that the reduction of OH⁻ ions concentration is observed in FAC- without k when compared with OPC whereas the concentration is increased in FAC with k. This observation is very important in restoring the passivity of rebar in presence of chloride. The variation of OH⁻ ions concentration with depth is mainly because of variation in cement content present in the core sample taken for analysis. This may vary from one sample to

another because of heterogeneity of concrete. Hague and Kayyali[18] also reported the reduction of OH⁻ ions in medium and high strength fly ash added concretes. In M20 concrete (Table 4), though in FAC-with-k the replacement of fly ash is more than in FAC-without k, the higher cement content in FAC-with k causes more OH⁻ concentration. In FAC, the pozzolanic reaction consumes calcium hydroxide and decreases the OH⁻ ions concentration. The results also confirm that though $Ca(OH)_2$ consumption has occurred both in FAC with and without-k , the increased OH⁻ ion concentration in FAC-with k, is mainly from the alkali salts of additional cement content. The dissolution of sodium and potassium salts from the cement contributed to the alkalinity of the concrete[8]. Data emphasizes the necessity of adopting k factor in designing the fly ash added concrete, if the replacement level is 40%, from durability consideration.

In field, for early strength development use of k factor is necessary in designing the fly ash added concrete if the fly ash content is more than 20%. It is clear that FAC-with k increases the corrosion resistance of rebar considerably. FAC- with k may have more resistance against carbonation induced corrosion than the OPC and FAC without k because of higher OH⁻ ions concentration.

Conclusions

(i) At 40% replacement level, the chloride diffusion co-efficient of FAC-with k is 25-50% less than that of OPC.

(ii) In 1% chloride contaminated concrete, both in M20 and M35 concrete, the rebar embedded in FAC-with k shows more passive potential than the rebar in OPC concrete. Higher OH⁻ ion

concentration in FAC- with k maintained the passivity of rebar in presence of chloride.

(iii) Under 90 days chloride ponding test both in M20 and M35 concretes the rebar in FAC-without k shows more passive potential than the rebar in other two concretes. Because of reduced chloride ions concentration, the corrosion resistance of rebar in FAC is 3-7 times more than that of the rebar in OPC concrete.

(iv) The reduction of alkalinity in FAC –without k is increased considerably in FAC-with k which restored the passivity of rebar in presence of chloride and makes the rebar more corrosion resistant.

Nomenclature

k-Cement efficiency factor

FAC-Fly ash added concrete

OPC-Ordinary Portland cement concrete

M20-Characteristic compressive strength of concrete after 28 days of curing is 20 MPa

M35-Characteristic compressive strength of concrete after 28 days of curing is 35 MPa

CTD-Clod twisted deformed rebar

D-Diffusion coefficient of chloride

R_p- Polarisation resistance of rebar

I_{corr}-Corrosion current

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