Corrosion Behaviour of Steel Reinforcements in Different Pozzolana Cement Concretes

Part II – Field Exposure Studies at Mandapam Camp, Tamil Nadu

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IT was pointed out from the laboratory investigations that though the part subsitution of cement by the different pozzolanas studied is not likely to increase the susceptibility of embedded steel in concrete significantly, the fact that alkalinity of concrete can be reduced by such part substitution is to be kept in mind. The results of the accelerated laboratory test also failed to throw much light on the comparative performance. The results of diffusion studies were also quite erratic.

In order to compare the results obtained from short term laboratory studies with the actual long term performance under practical aggressive conditions, field exposure studies were carried out at Mandapam Camp, Tamil Nadu which is considered as one of the most aggressive sites in the world. Important parameters like cover thickness, salt contamination, exposure period, protective measures like inhibited cement coating to steel are considered under this field exposure studied. The results obtained over a period of 4 years are reported here.

EXPERIMENTAL

The details about the materials used and the concrete mix design for two different strength viz. 3000 PSI and 4000 PSI are given in Part I.

Casting of Concrete Cubes : Test specimens were weighed and attached to the threaded ends of the four arms of the cross-shaped holder, Fig. 1. By the use of this holder, it is possible to have in the same concrete cube. different cover thickness of 13 mm, 25 mm, 38 mm and 50 mm by having arms of different lengths. This significantly reduces the number of concrete cubes to be cast with regard to the important parameter namely, cover thickness.

The steel cross with weighed test specimens was placed in a 150 mm standard cube cast iron mould and the raw concrete placed and the mould was vibrated on a vibrating table to have uniform packing and compaction, Fig. 2. Concrete cubes were demoulded after 24 hours and kept immersed in deionised water for 28 days at room temperature.

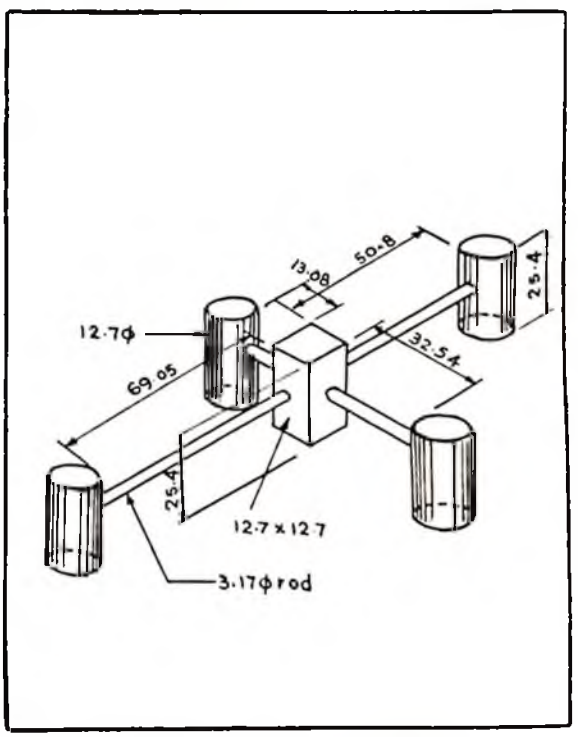


Fig. 1. Set up for reinforcement at different cover thickness in the same cube

Mixing Water : Calculated amounts of sodium chloride and sodium sulphate were dissolved in de-ionized water and this solution was used for mixing concrete. Calculation was based on minimum, average and maximum values of salts worked out earlier and given in Table 1.

Parameters Investigated : *1-3 salt contamination* : CECRI has worked out the ranges of

TABLE I

Constituents present in building materials and natural water

Content by weight percent

	Natural Water		Portland Cement		Sand		Granite Jelly	
	Chloride	Sulphate	Chloride	Sulphate	Chloride	Sulphate	Chloride	Sulphate
Min. value	0.0007	0.0003	0.0004	0.042	0	0.003	0	0.005
Avg. value	0.0517	0.011	0.0072	0.0841	0	0.009	0	0.009
Max. value	0.9494	0.1142	0.05	0.18	0.12	0.013	0	0.014

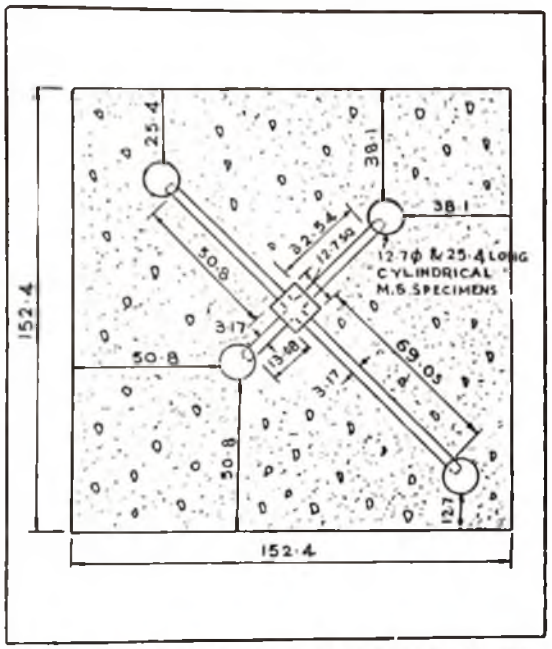


Fig. 2. Plan of concrete specimee with reinforecemant

chloride and sulphate that are likely to be present in concrete on the basis of analysis of a large number of samples of cement, sand and water and stone aggregate from varicus places[1-2]. The minimum, average and maximum amount of chloride and sulphate that can be present in concrete was incorporated in tha cubes and the performance of the reinforcement assessed.

4. Protection afforded by the inhibited cement slurry coating deve'oped at CECRI, when maximum amounts of chloride and sulphate are present in concrete.

In all the above four parameters, tho effects of cover thickness, exposure period, different strengths etc. were investigated.

Procedure adopted for the introduction of the different parameters — 1. *Minimum amount of chloride and sulphate in concrete :* The minimum amount required to be incorporated in each 150 mm cube of concrete was calculated and the soluble chloride and sulphate already present in cement and pozzolana were calculated for each cube and deducted. The balance amount in the form of sodium chloride and sodium sulphate was dissolved in deinoised water and this was used for mixing concrete.

2. *Average amount of chloride and sulphate in concrete* : The procedure was as in 1 except the calculation was based on the average amount to be incorporated in each concrete cube.

3. *Maximum amount of chloride and sulphate* The procedure was as in 1 excepting that the calculation was based on the maximum amount of salt to be incorporated in each cube.

4. *Inhibited cement slurry coating to steel in presence of maximum amount of salts in concrete :* The details about the coating have been discusssed earlier[3]. The test specimens were pickled in the deiusting solution, weighed and then phosphated using phosphating jelly. Two coats of the inhibited cement slurry were given at 24 hr interval and cured with the sealing solution. The coated specimens were than fixed in the steel set up and the concrete cubes were cast. The maximum amount of salts as mentioned against parameter 3 was dissolved in deionised water and this was used for mixing concrete.

RESULTS AND DISCUSSION

1. *Effect of Cover thickness :* The results for 3000 psi and 4000 psi concrete with maximum salt content are given in table 2. In the case of 3000 psi concrete, it is seen that excepting Surkhi concrete, corrosion rate is nil for cover thicknesses of

TABLE II

Effect of cover *Concrete Strength : 3000 and 4000 PSI. Salt Content : Minsmum Exposure Period : 2 Years*

S. No.	Details of cement concrete	Corrosion rate m.m p.y. Cover Thickness mm 13 mm 3000 psi.	13 mm 4000 psi.	25 mm 3000 psi.	25 mm 4000 psi.
1.	Portland	0(0)	0(0)	0(0)	0(0)
2.	Delhi flyash	0.0024 (30)	0 0039	0(0)	0(0)
3.	Neyveli flyash	0.0052 (50)	0.0015	0(0)	0(0)
4.	Panki	0.C062 (100)	0(0)	0.0006 (12)	(0)
5.	Surkhi	0.0246 (100)	0.0131	0.0141 (100)	0.0029

Figures in brackets indicate percentage of area of steel rusted. With 38 and 50 mm cover there was nc corrosion.

38 mm and above. For Portland cement concrete and Delhi flyash concrete, there is no corrosion even at 25 mm cover. At 13 mm cover there is corrosion in all concretes. When the strength is increased to 4000 psi, there is no corrosion at 25 mm for all concretes excepting Surkhi cement concrete. In the case of Surkhi cement concrete, corrosion becomes negligible only when 4000 psi concrete with 50 mm cover is used. The results for Surkhi cement concrete are somewhat erratic but the trend is clearly seen. It appears that a minimum cover of 38 mm may be necessary to avoid corrosion in fly ash concretes.

2. *Effect of strength of concrete :* The results for he m nimum cover of 13 mm are given for cc mparison for the two strengths 3000 psi and 4000 psi in Table 3. I is seen that in all cases that the corrosion rate is very much diminished by increasing the strength from 3000 psi to 4000 psi. Considering only the average salt content it is found that corrosion rate is reduced to zero at 4000 psi in all the fly ash cement concretes and also in the cement concrete. In presence of maximum salt, corrosion is reduced to varying extents in different fly ash concretes viz $\frac{1}{n}$ to $\frac{1}{2}$. in the case of Surkhi, the beneficial effects is felt only when minimum and average salts are present.

3. *Effect of salt content in concrete :* The results of 2 years exposure for 3000 psi concrete at 13 mm and 25 mm cover show that there is not much difference between maximum average salt contents. By increasing the initial salt contamination to the maximum extent, corrosion rate is

TABLE 3

Effect of strength of concrete (13 mm cover) Two ycars Exposure period

Details of concrete	Corrosion rate, mmpy Minimum salt 3000 psi	Minimum salt 4000 psi	Average salt 3000 psi	Average salt 4000 psi	Maximum salt 3000 psi	Maximum salt 4000 psi
1. Portland cement concrete	0	0	0.0014	0	0.0548	0.0087
2. Delhi flyash cement concrete	0.0024	0.0039	0.002	0	0.01	0 to 0.33*
3. Neyveli flyash cemect concrete	0.C052	0.0015	0.004	0	0.0137	0.003
4. Panki flyash cement concrete	0.0062	0	0.0077	0	0.0197	0.0130
5. Surkhi cement concrete	0.0246	0.0131	0.02	0.044	0.051	0.0511

increased appreciably. In pozzolana concrete the rate increases by 2 to 5 times.

4. *Effect of exposure period :* Table 4 shows that the corrosion rate in general increases with exposure period.

TABLE 4

Effect of exposure period

(Strength 3000 psi, Cover 13 mm)

Details of concrete	Minimum salt 2 years	Minimum salt 4 years	Average salt 2 years	Average salt 4 years
1. Portland	0	0.0021	0.0014	0.02
2 Delhi flyash	0.0024	0.0033	0 002	0.01
3. Neyveli flyash	0.0052	0.0031	0.004	0.0358
4 Panki flyash	0.0062	0.0065	0.0077	0.0282
5. Surkhi	0 02- 6	0.011	0.02	0,0512

5. *Relative performence of different pozzolanas :* The cumulative perfo mance of the different concretes under the different parameters viz salt contents and strength is presented in table 5. The

TABLE 5

Cumulative grading of different concretes

	Condition	Portland	Delhi	Neyveli	Panki	Surkhi
Minimum salt	3000 PSI(1)	1	2	3	4	5
2 years	4000 PSI(1)	1	3	2	4	5
Average salt	3000 PSI(1)	1	2	3	4	5
2 years	4000 PSI(4)	1	1	1	1	2
Minimum salt	3000 PSI(5)	1	2	3	4	5
4 years	4000 PSI(6)	1	3	2	4	5
Average salt	3000 PSI(7)	2	1	4	3	5
4 years	4000 PSI(8)	3	1	2	4	5
Maximum salt	3000 PSI(9)	5	1	2	3	4
2 years	4000 PSI(10)	2	4	1	3	5
Average		1.8	2.0	2.3	3.1	4.5
Grade		1	2	3	4	5

lowest corrosion rate in any test condition is given a grade of 1 and the highest corrosion rate is given a grade of 5. There are 10 test conditions and the cumulative performence is based on the average of the grades obtained from these 10 test conditions. It is seen that the overall grading is as follows.

Portland cement concrete	Lowest corrosion
Delhi flyash cement concrete	
Neyveli fly ash ,,	
Panki fly ash ,,	
Surkhi ,,	Highest corrosion

6. *Inhibited cement slurry coating to steel :* It was observed that the inhibited cement slurry coating is able to give almost complete protection to steel reinforcement even at 13 mm cover in all the different concretes, particularly Surkhi cement concrete which showed the highest corrosion rate in the absence of any coating to steel.

CONCLUSIONS

i. Field exposure studies show that a minimum cover of 38 mm may be necessary to avoid corrosion in pozzolana concrete. 4000 psi concrete offers better protection to steel than 3000 psi concrete. Corrosion rate increases with time of exposure.

ii. The relative performance of different pozzolana concretes in the order of decreasing corrosion resistance, is as follows :

Portland cement concrete
Delhi fly ash cement concrete
Neyveli fly ash cement concrete
Panki flyash cement concrete
Surkhi cement concrete.

iii. The inhibited cement slurry coating developed at CECRI is able to give complete protection to steel in all the pozzolana concretes even at the minimum cover of 13 mm.

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