Corrosion Behaviour of Steel Reinforcement in Different Pozzolana Cement Concretes - Part I - Laboratory Investigation

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EXCEPTING some exposure studies carried out in Northern Norway and U. K and some laboratory studies carried out in USA and Japan, very little attention has been paid to the systematic study of corrosion aspect in reinforced pozzolana concrete. Caution must be exercised in the selection and use of pozzolana as their properties vary widely and some may have adverse effects on concrete. A detailed investigation was therefore undertaken on the behaviour of pozzolana cement concrete in comparison with portland cement concrete from the point of view of corrosion of reinforcements. Three representative flyash samples and one reactive surkhi sample from Indian sources were included in the investigation.

In part I, laboratory results of aqueous extract, permeation, diffusion and electrochemical studies accelerated corrosion tests are included. In part II the data from the field exposure studies at Mandapam Camp over a period of 4 years are presented and discussed.

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

Portland Cement Concrete
Delhi flyash Cement Concrete
Neyveli flyash Cement Concrete
Panki flyash Cement Concrete
Surkhi Cement Concrete.

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

A pozzolana is essentially a silicious material, which, while in itself possessing no cementaticus properties will in finely divided form and in the presence of water, react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Portland Pozzolana cement is an intimately ground mixture of portland cement clinker and pozzolana with the possible addition of Gypsum or an intimate and uniform blend of portland cement and fine Pozzolana[1]. The general advantages claimed for Portland pozzolana cements are the improved durability combined with some economy and reduction in heat evolution obtained in marine, hydraulic and underground structures. As much as 4 million tons of fly ash are already being produced in India every year as a waste product resulting from the burning of the pulverised coal in different Thermal Power Stations[2]. Central Road Research Institute, New Delhi, has standardised the manufacture of 'Reactive Surkhi' a burnt clay pozzolana[3].

Fly ashes from different sources vary considerably in both chemical composition and physical properties due to differences between the coals from which they are derived and the conditions of burning. Depending on the type of clay, reactive properties of Surkhi are also likely to vary. Though the literature mentions that fly ash improves plasticity and cohesiveness of the mix, it is not wholly true of the Indian fly ashes[4],[5]. The water requirements of Indian flyash mortars have been found to be higher in comparison to some of the foreign fly ashes which are known to reduce water requirements[6]. Use of Indian fly ashes is not likely to improve sulphate resistance because of their high alumina content[7]. Reactive Surkhi is expected to make mortars and concretes more waterproof and more resistant to alkalis and salt solutions. The presence of unburnt carbon and sulfur in flyash may enhance the corrosion of reinforcement. The sulfur present in the flyash is usually in the form of sulphate and has an effect similar to that of sulphates present in the normal portland cement. Unburnt carbon may decrease the electrical resistance. Consequently it is to be expected that mortar and concrete prepared with with admixture of fly ash would have properties different from portland cement mortar and concrete. Caution must be excercised in the selection and use of pozzolanas as their properties vary widely and some may introduce adverse qualities into concrete.

Excepting some exposure studies carried out in Northern Norway and UK and same laboratory studies carried out in USA and Japan, very little attention has been paid to the systamtic study of corrosion aspect in reinforced pozzolona concrete.

A preliminary investigation carried out earlier at the Central Electrochemical Research Institute with a sample of fly ash received from Delhi Thermal Power Station showed that very much larger quantities of chloride and sulphate are extracted from this fly ash than from portland cement[3]. Fly ash from Neyveli Lignite Corporation was found to be different from fly ash from coal. A detailed investigation was therefore undertaken on the behaviour of pozzolana cement and pozzolana cement concrete in comparison with portland cement and portland cement concrete from the point of view of corrosion of reinforcements. Three representative fly ash samples supplied by the Central Building Research Institute and the reactive Surkhi sample produced by Road Research Institute are included in the investigation.

In Part I, the results of the laboratory investigation namely aqueous extract studies, permeation and diffusion studies, electrochemical studies, accelerated corroeion tests etc., are discussed. In Part II the data collected from the field exposure studies at Mandapam Camp over a period of 4 years are presented and discussed.

EXPERIMENTAL

I. *Materials Used*

1. Portland Cement conforming to ISS 269-1958.
2. Pozzolanas supplied by Central Building Research Institute, Roorkee *viz.*
   i) Flyash from Delhi Thermal Power Station.
   ii) Flyash from Panki Thermal Power Station.
   iii) Flyash from Neyveli Thermal Power Station.
   iv) Reactive Surhki produced by CRRI, New Delhi.
3. Local river sand conforming to ISS 383 1963 washed free of soluble salts.
4. Local granite aggregate conforming to ISS 383-1963 washed free of soluble salts.
5. Mild steel abraded on 120 emery wheel and degreased with trichloroethylene.
6. AR grade chemicals for analysis and LR grade chemicals for other purposes.

II. *Preparation of Specimens :* Blending of pozzolana with portland cement was done in an electrically operated ball mill. Concrete specimens were prepared on a vibrating table to the mix design given in Table 1. Distilled water was used for mixing portland cement. Specimens were prepared using specific water cement ratios determined by plastic consistency tests.

TABLE I

Proportions of concrete mixes with and without Pozzolana (Mix design by C.B.R.I., Roorkee)

Parts by weight for 28 day's compressive strengths of 3000 and 4000 Psi

Material	Plain concrete		Fly ash concrete		Surkhi concrete	
	3000 Psi	4000 Psi	3000 Psi	4000 Psi	3000 Psi	4000 Psi
Cement	1	1	1	1	1	1
Pozzolana	—	—	0.35	0.35	0.25	0.25
Sand	2.89	1.91	3.18	1.96	3.75	3.14
Gravel	3.32	2 61	4 39	3 49	3 29	3.58
Water	0.52	0.46	0 65	0.58	0.48	0 46

III. *Preparation of Aqueous Extracts :* Extracts from portland pozzolana mixtures were prepared by mixing with distilled water in the ratio of 1 : 2 by weight, shaking for 1 hour on a flask shaker and filtering.

Extracts from set cement and set concrete specimens were prepared by crushing the specimens, demoulded after 24 hours, of setting, so as to pass through No. 75 micron IS sieve, mixing with distilled water in the ratio 1 : 2, shaking for 1 hour and filtering.

In the case of extracts for free chloride studies, powder and distilled warter were mixed in the ratio 1 : 1.

IV. *Standard Analytical Procedures were adopted.*

V. *Hollow Space Experiments :* Cylindrical specimens as shown in Fig. 1, were prepared on a vibrating table. For water permeation studies, hollow space was closed by a concrete stopper,

sealed, immersed in deionised water and the rate at which the water permeates through the concrete wall into the hollow space from outside was followed with time. For chloride diffusion studies the hollow space was filled with distilled water, closed, sealed and the specimen immersed upto the stopper in 1% NaCl solution. The diffusion rate was calculated by estimating the chloride in distilled water of hollow space. Same procedure was adopted for sulphate diffusion studies, excepting that the specimen was immersed in 1% Na_2SO_4 solution and the sulphate in distilled water of hollow space was estimated periodically.

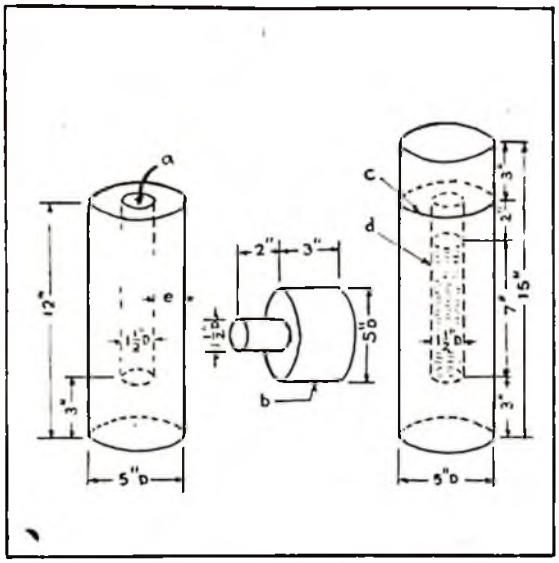


Fig. 1. Details of the specimen for hollow space expriments
a lower portion containing hollow space b closure
c. bees wax-rosin joint d. solution collected in the hollow space and e. concrete cover

VI. *Electro Chemical Measurements :* Mild steel rod of 25 mm diameter and 5 cm long with a 0.6 cm diameter 6 cm long stem was used as test specimen. The steel specimen was embedded in concrete of 7.5 cm dia and 10 cm long size.

a) For potential-time studies the concrete was kept immersed in distilled water and the potential of steel was measured against saturated calomel electrode by Pogendorff Null Method.

b) For polarisation studies, an auxilliary steel electrode was used. The concrete was kept immersed in distilled water and at various anodic and cathodic current densities the steady potential of the test rod was obtained.

c) Anodic polarisation studies at a constant anodic current of 290μA/cm^2 were made by immersing the test rod in the given solution and making it anode and using a steel cathode. If the potential rose to the oxygen evolution potential and remained there for a test period of 5 minutess, the given solution was considered inhibitive otherwise corrosive.

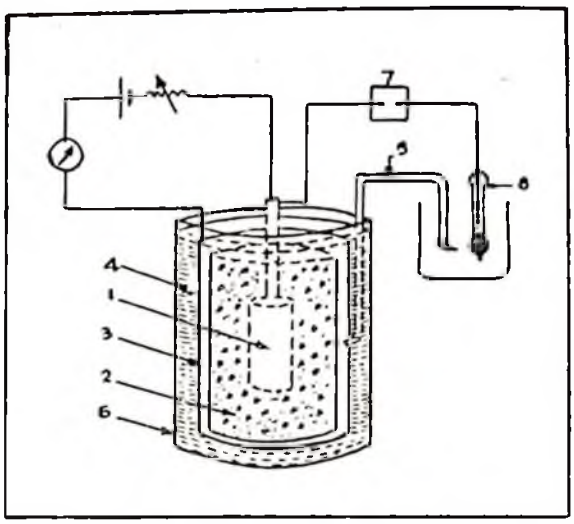


Fig. 2. Set up for Electrochemical Measurements
1. Mild steel test specimen with stem 2. Concrete specimen 3. Mild steel auxiliary electrode 4. Electrolyte 5. KCl Agar Agar Bridge 5. Glass Container 7. Vacuum Tube Voltmeter 8. Saturated Calomel Electrode

VII. *Electrical Resistance Studies :* Ten cm cube concrete specimens were prepared and kept immersed in distilled water. During measurement, cubes were removed from water and the resistance measured in wet condition. The cube was placed in between two mild steel panels of 10 cm × 10 cm size and resistance 'R' was measured through a conductivity bridge. Good pressure contact was achieved by using a plastic fixture and wet cotton paddings as shown in Fig. 3. Specific resistance ρ ($\rho = 10R$) was followed with time

VIII. *Accelerated Test :* Test method consists in regular wetting of concrete surfaces wirh synthetic sea water 3 times in 7 hours and warming the surface by means of heating coils. The surface is kept dry for the next 17 hours and this wetting and drying process is repeated till the end of the test period. 0.9 cm dia and 7.5 cm long m. s. rod was embedded in 10 cm concrete cube with 1.3 cm cover and subjected to the above test. At the end of the test period, cube was broken, m. s. rod

removed, visually observed for rust spots and weight loss determined after derusting in Clarke's solution.

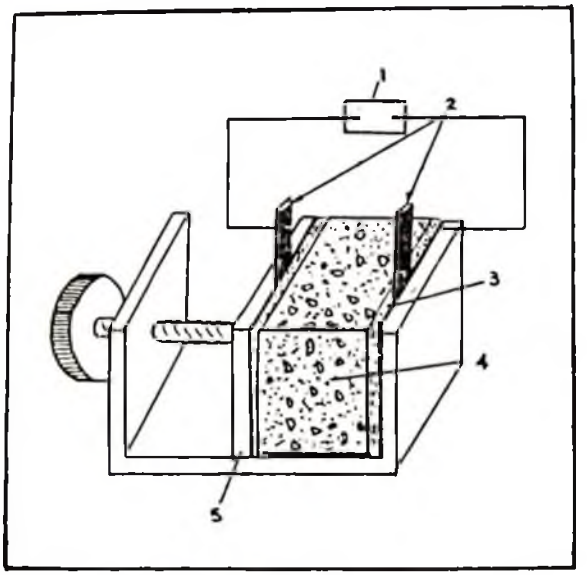


Fig. 3. Set up for Resistance Studies
1. Conductivity Bridge 2. Mild Steel Plates (Electrodes)
3. Cotton Packing 4. Concrete Test Specimen
5. Sliding P V C Device

RESULTS AND DISCUSSION

I. *Studies on aqueous extracts :* The chemical composition of portland cement and pozzolanas is given in Table 2. The carbon content of Delhi flyash is somewhat more than that of Panki flyash. Otherwise their compositions are similar, Neyveli flyash has much higher CaO and MgO than the above two flyashes. Surkhi has also a higher carbon content.

It is seen from Table 3(a) that the extract of portland cement contains 30 ppm of chloride. It is much less in the case of flyashes but more in the case of Surkhi. Soluble sulphate content of Surkhi and flyashes is only a fraction of that of portland cement. While Neyveli flyash has a significant amount of alkalinity in the aqueous extract, other flyashes and Surkhi have negligible alkalinity. After admixture with cement in the recommended proportions, the soluble chloride extracted is of the same order i.e. 30 ppm in the case of all the pozzolana cements as can be seen from Table 3(b). The extract of Panki flyash cement is corrosive, probably due to the lower alkalinity of the extract. It is not clear why Surkhi-cement extract is corrosive. It is interesting to note that, after setting, the extracts of these cements contain as little chloride as portland cement (12 ppm) and all the extracts are inhibitive as can be seen from Table 3(c). The sulphate has completely reacted during setting. From Table 3(d) it is seen that the extracts of the concrete specimens also contain no sulphate, little chloride and are inhibitive. CaO content of pozzolanas is only a fraction of that of portland cement and unlike portland cement, the pozzolanas do not give rise to alkalinity by themselves which is necessary for the protection of embedded steel in concrete. However the higher CaO content of Neyveli fly ash is reflected in the significant alkalinity of its aqueous extract. The portland pozzolana cements give lower alkalinity in their aqueous extracts than portland cement showing that free lime in portland cement reacts with the silicicus

TAELE II

Chemical composition of Portland Cement and Pozzolanas

	Portland cement*	Delhi flyash*	Neyveli flyash**	Panki flyash**	Surkhi**
CaO	63.5%	2.23%	11.01%	2 41%	4.73%
Silica	22.2%	58.06%	46.90%	59.1 %	59.07%
MgO	3.5%	0.69%	2.67%	0.65%	0.34%
Al_2O_3	6.19%	26 9 %	33.4 %	28.08%	22.57%
Acid sulphate	1.44%	0.28%	0 97%	0.22%	—
Ferric oxide	2.11%	4.83%	4.55%	6.04%	8.09%
Loss on ignition	2.4 %	5.11%	2.78%	2.98%	4.96%

*Analysis made at CECRI, Karaikudi

**Chemical composition details furnished by CBRI, Roorkee

TABLE 3

a) *Extracts from portland cement and pozzolanas*

	Portland cement	Delhi fly ash	Neyveli fly ash	Panki flyash	Surkhi
Chloride ppm	30	10	20	14	47.5
Sulphate, ppm	320	50	10	85	46
Alkalinity	0.074 N	0.0005 N	0.029 N	0.0005 N	0.0005 N

b) *Extracts from portland cement and portland-pozzolanas cement*

Chloride, ppm	30	30	23	25	29
Sulphate, ppm	320	180	34	160	370
Alkalinity	0.074 N	0.059N	0.05 N	0.031 N	0.055 N

c) *Extracts from set cement specimens*

Sulphate Nil

Chloride, ppm	12	12	traces	10	11
Alkalinity	0.07N	0.058N	0058N	0.056N	0.05N

Nature of extract : in (b) & (c) } Inhibitive in all cases.

d) *Extracts from Concrete Specimens : 3000 and 4000 PSI Concretes*

	Portland cement		Delhi flyash		Neyveli flyash		Panki flyash		Surkhi cement	
	3000 PSI	4000 PSI	3000 PSI	4000 PSI	3000 PSI	4000 PSI	3000 PSI	4000 PSI	3000 PSI	4000 PSI
Chloride ppm	15	10	5	10	12	5	9	4	12	10
Alkalinity	0.043N	.041N	0.035	0.40N	0.034N	0.04N	0.037N	0.04N	0.036N	0.037N

Sulphate nil in all cases.

Nature of extract : Inhibitive in all cases.

and aluminious materials in the flyash. This is more marked in the case of Panki flyash. Though pozzolana cements do not extract more chloride or sulphate than portland cement, the aqueous extracts of Panki flyash and Surkhi cements become corrosive because of lower alkalinity caused by reactions of free lime with fly ash. It is interesting that when the cement is allowed to set, due to the liberation of free lime, the alkalinity level in the extracts goes up, with the result that all the extracts are inhibitive. Even then the alkalinity of set portland cement is significantly higher than that of set pozzolana cements. This difference in regard to the alkalinity is reduced in the case of concrete. It is useful to point out that extracts of powdered cement concrete and powdered pozzolana concrete all give inhibitive extracts and all give an alkalinity of around 0.04N. An alkalinity of 0.04N appears to be optimum from the point of view of passivation of steel reinforcement in concrete. Pozzolana concrete structures are therefore as good as portland cement concretes from the point of view of optimum alkalinity and sufficiently low percentages of chloride and sulphate to get inhibitive extracts.

II. *Studies on Water Permeation and Salt Diffusion :* Hollow space experiments showed that there was no water permeation at all in all the cases during the 180 days test period. This indi-

cated that water permeation reported earlier (34cc/dm²/year) for portland cement concrete and 3.6 cc/dm²/year for Delhi flyash concrete prepared by hand compaction becomes negligible when the method of compaction is changed to compaction on a vibrating table.

Table 4 gives the results on chloride diffusion studies. Chloride diffusion rate decreases with time in all the cases. In the case of portland cement concrete, alkalinity value increases with time whereas in pozzolana concrete is more or less

TABLE IV

Chloride Diffusion Studies

	Test duration in days	Chloride ppm/day		Alkalinity		Nature of Extract	
		3000 psi	4000 psi	3000 psi	4000 psi	3000 psi	4000 psi
Portland cement concrete	15	2.40	0.40	0.009N	0.015N	C	I
	30	3.50	0.23	0.013N	0.017N	C	I
	45	0.55	0.10	0.016N	0.017N	I	I
	90	0.22	0.05	0.02 N	0.024N	I	I
Delhi flyash cement concrete	15	0.98	0.59	0.09 N	0.006N	C	C
	30	0.59	0.17	0.010N	0.01 N	C	I
	45	0.22	0.15	0.008N	0.009N	C	C
	90	0.07	0.045	0.009N	0.009N	C	C
Neyveli fly ash cement concrete	15	0.35	3.07	0.009N	0.009N	C	C
	30	0.12	0.35	0.009N	0.009N	I	C
	45	0.14	0.18	0.009N	0.009N	C	C
	90	0.04	0.11	0.009N	0.01 N	I	C
Panki fly ash cement concrete	15	0.99	0.28	0.007N	0.009N	C	I
	30	0.43	0.06	0.008N	0.009N	C	C
	45	0.12	0.07	0.007N	0.007N	C	C
	90	0.13	0.04	0.006N	0.008	C	I
Surkhi cement concrete	15	0.72	0.12	0.006N	0.004N	C	I
	30	0.35	0.23	0.007N	0.005N	C	C
	45	0.16	0.10	0.008N	0.003N	C	I
	90	0.04	0.085	0.010N	0.007N	I	C

I — Inhibitive C — Corrosive

same throughout the test period. This again indicates that the maximum alkalinity that may be reached in pozzolana concrete will be lower than that of portland cement concrete. The difference between 3000 PSI and 4000 PSI concrete is not clear. The rate of chloride diffusion, decreases with the test duration and the steady rate is in the range of 0.04-0.1 ppm/day.

Table 5 gives the results on sulphate diffusion studies. The results are erratic but in general the rate diminishes in a small quantity with time, The alkalinity of hollow space extracts in the case of pozzolana concrete is much lower than that in the case of portland cement concrete. The extracts are always inhibitive in the case of portland cement concrete whereas the extracts are corrosive or inhibitive in the case of pozzolana concretes. Extract from Panki fly ash concrete is found to be corrosive throughout. Surkhi cement concrete also in general gives corrosive extract. The diffusion rates are also somewhat higher in these cases.

III. *Electrochemical Studies :* Figs. 4 and 5 show the variation of potential with time of steel embedded in 3000 psi and 4000 psi concretes respectively. The initial potential varies considerably, falls with time, fluctuates and after 45 days drifts to a more positive value than at the end of 30 days. More noble potential is obtained with pozzolana concrete than with portland cement concrete. The final potentials obtained in 4000 psi concrete are more negative than that in 3000 psi concrete. This appears to be due tc increased cathodic polarization brought about by reduced oxygen diffusion. The most negative rest potential obtained in 3000 psi concrete (600mV Vs SCE) is more noble than the passivation potential of iron in NaOH solution. Similarly in 4000 psi concrete, the rest potential at the end of 60 days are all more noble than – 600mV.

The polarisation studies as can be seen from figures 6(a) and 6(b) show that the anodic and cathodic behaviour of steel in all the concretes are identical. Thus it can be concluded that the electrochemical of steel in pozzolana concretes is not quite different from that in portland cement concrete.

IV. *Electrical Resistance Studies :* It is seen from figures 7(a) and 7(b) that all the concretes have an initial specific resistance of 3k ohm cm. There is a twofold increase in resistance with time in the case of portland cement concrete, but the pozzolana concrete show three fold to six fold increase.

TABLE V

Sulphate diffusion studies

	Test duration in day	SO_3 ppm/day 3000 psi	SO_3 ppm/day 4000 psi	Alkalinity 3000 psi	Alkalinity 4000 psi	Nature of extracts 3000 psi	Nature of extracts 4000 psi
Portland cement concrete	15	0.90	traces	0.017 N	0.013 N	I	I
	30	0.31	0.30	0.12 N	0.014 N	I	I
	45	—	0.33	—	0.015 N	—	I
	90	0	0.04	0.022 N	0.021 N	I	I
Delhi fly ash cement concrete	15	0	0 36	0.09 N	0.010 N	I	I
	30	2.84	1 00	0.01 N	0.010 N	C	C
	45	0 60	0.41	0.009 N	0.010 N	C	C
	90	0	0 05	0.08 N	0.009 N	I	I
Neyveli fly ash cement concrete	15	1.4	0	0.008 N	0.008 N	C	I
	30	0.09	0	0.009 N	0.090 N	I	I
	45	traces	traces	0.009 N	0.01 N	I	I
	90	0	—	0.010 N	—	I	—
Surkhi cement concrete	15	1.73	35.33	0.006 N	0.006 N	C	C
	30	19.67	9.95	0.008 N	0.006 N	C	C
	45	1.54	traces	0.007 N	0.008 N	C	C
	90	0.08	traces	0.008 N	0.006 N	I	C
Panki fly ash cement concrete	15	0.5	0	0.009 N	0.008 N	C	C
	30	—	0.5	—	0.01 N	—	I
	45	0.5	0.42	0.001 N	0 008 N	C	C
	90	0.2	0.17	0.008	0.007 N	C	C

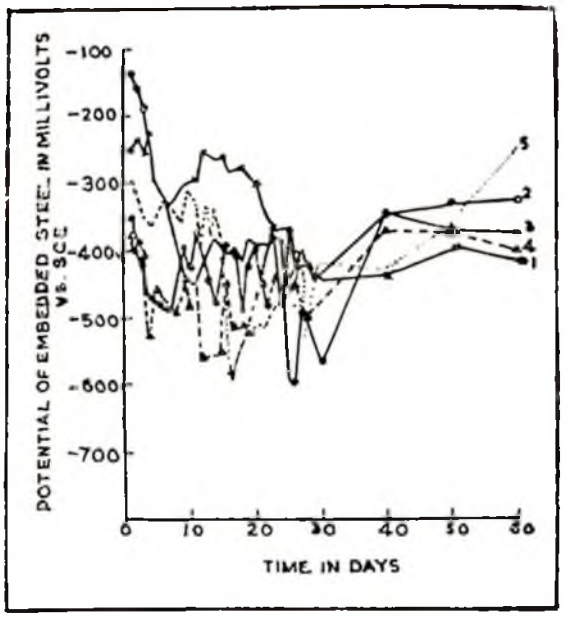


Fig. 4. Potential Time Studies in 3000 SPI Concrete
1. Portland Cement Concrete 2. Panki Flyash Cement Concrete 3. Neyveli Fly ash Cement Concrete 4. Delhi Fly ash Cement Concrete 5. Surkhi Cement Concrete

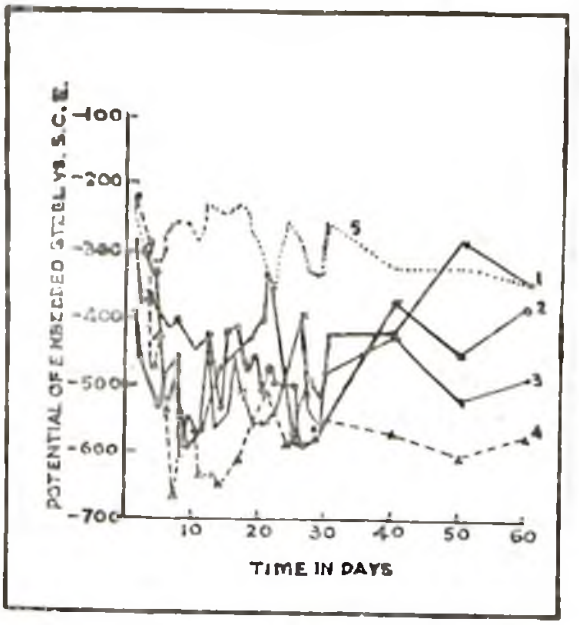


Fig. 5. Potential Time Studies in 4000 PSI Concrete
1. Portland Cement Concrete 2. Panki Fly ash Cement Concrete 3. Neyveli Fly ash Cement Concrete 4. Delhi Fly ash Cement Concrete 5. Surkhi Cement Concrete

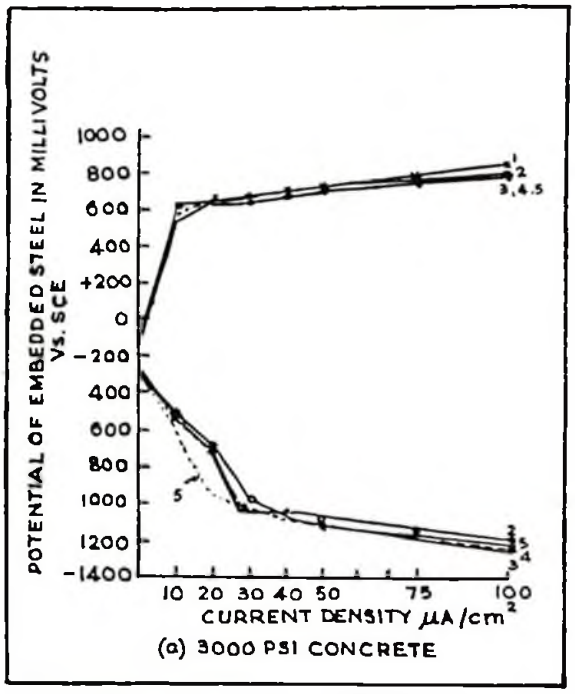


Fig. 6. Polarisation Studies in 3000 PSI Concrete
1. Portland Cement Concrete 2. Panki Fly ash Cement Concrete 3. Neyveli Fly ash Cemegt Concrete 4. Delhi Fly ash Cement Concrete 5. Surkhi Cement Concrete

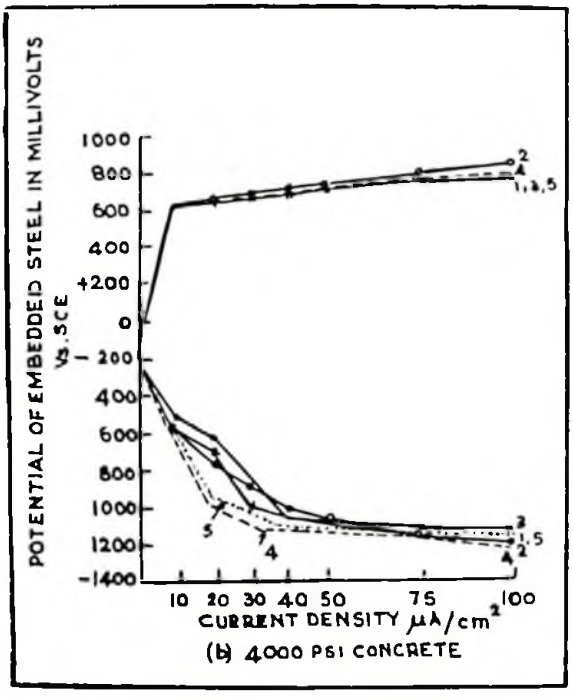


Fig. 7. Polarisation Studies in 4000 PSI Concrete
1. Portland Cement Concrete 2. Panki Fly ash Cement Concrete 3. Neyveli Fly ash Cement Concrete 4. Delhi Fly ash Cement Concrete 5. Surkhi Cement Concrete

Both 3000 and 4000 psi concretes show similar specific resistance. The highest specific resistance is obtained with Surkhi concrete. The fact that the electrical resistance of pozzolana concrete is very much higher than that of portland cement concrete indicates that the pozzolana concretes are more tightly packed and perhaps the connected pores are fewer and smaller. This is possible because the pozzolana reacts with the free lime liberated during setting to form calcium silicate compounds.

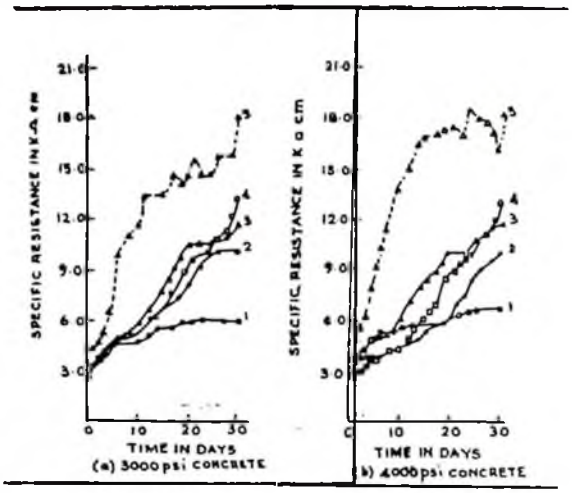


Fig. 8 Fig. 9

Fig. 8. Electrical Resistance Studies in 3000 PSI Concrete
1. Portland Cement Concrete 2. Panki Fly ash Cement Concrete 3. Neyveli Fly ash Cement Concrete 4. Delhi Fly aah Cement Concrete 5. Surkhi Cement Concrete

Fig. 9. Electrical Resistance Studies in 4000 PSI Concrete
1. Portland Cement Concrete 2. Panki Fly ash Cemant Concrete 3. Neyveli Fly ash Cement Concrete 4. Delhi Fly ash Cement Concrete 5. Surkhi Cement Concrete

V. *Accelerated Test :* The results of the alternate welting with sea water and drying are given in Table 6. There is not much difference in the performance of portland cement and different pozzolana concretes. All show evidences of rusting under this aggressive test condition. 4000 psi concrete is able to provide a better barrier than 3000 psi concrete. Panki fly ash and Surkhi appears to show rusting to greater extent. It is of interest to note that only in the case of Panki fly ash cement and concrete, the embedded steel showed rust spots after setting and curing.

The reaction of soluble chloride with the aluminates is taking place as efficiently in pozzolana concrete as in portland cement concrete is brought about by the constancy of free chloride to total chloride ratio (Table 7).

TABLE VI

Accelerated wetting and drying tests

Test duration : 60 days

Type of concrete	Visual observation		Weight loss in mgs	
	3000 psi	4000 psi	3000 psi	4000 psi
Portland cement	Rust spots	Single rust spot	45	negligible
Delhi fly ash cement	Rust spots	Rust	65	30
Neyveli fly ash cement	Rust spots	Good	50	nil
Panki fly ash cement	Rust spots	Single rust spot	100	negligible
Surkhi cement	Rust spots	Good	70	nil

TABLE 7

Studies on free chloride

Chloride added % by wt of cement or pozzolana cement	Free chloride available after curing % by weight of cement or pozzolana cement				
	Portland cement	Delhi fly ash cement	Neyveli fly ash cement	Pannki fly ash cement	Surkhi cement
0.3	0.09	0.03	0.04	0.05	0.04
0.6	0.03	0.09	0.12	0.13	0.13
1.2	0.23	0.20	0.24	0.27	0.20

CONCLUSIONS

i. Though the electrochemical behaviour of steel in pozzolana concretes is not quite different from that in portland cement concrete, studies on aqueous extracts show that the alkalinity of concrete can be reduced by part substitution of portland cement by flyash Surkhi cements are corrosive due to such reduction in alkalinity.

ii. The electrical resistance of pozzolana concrete is very much higher than that of portland cement concrete but this fact has no bearing on the corrosive behaviour of steel embedded in such concretes.

iii. Panki fly ash cement and Surkhi cement concretes appear to show rusting to somewhat greater extent in the accelerated laboratory test. Negligible rusting was observed in 4000 psi concrete.

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