"Chemical admixtures in the reduction of permeability in concrete, mortar, renders and plasters of cement and lime"

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Abstract

Rising damp through capillary, carbonation, chloride and other salt penetration are the major causes of damage to the structure and are very much linked with permeability in concrete and mortar. In fresh concrete the space between the particles is completely filled up with water. The excess water in pores evaporates after the concrete hardens. The loss of moisture causes the volume of the paste to contract which in turn leads to shrinkage stress and shrinkage cracking. Moisture vapor transmission is also a function of relative humidity gradient between surfaces and permeability of concrete. The ingress of moisture, vapour and salts results in salt efflorescence, corrosion in metals, alkali aggregate reactions, sulphate attack through formation of gypsum and ettringite, freeze and thaw disintegration, erosion, carbonation etc.and have a serious destructive effect on the structure as a whole. Heritage and old buildings which are devoid of damp proof course and anti termite treatments are highly permeable to all these natural damaging agents and need serious attention. This paper intends to discuss the action of the chemical (PP Strength) when applied in fresh concrete and injected in mortars between brick layers for old and heritage houses. This chemical has been able to reduce the permeability to a substantial extent and many of the problems discussed above were by and large eliminated.

1. Introduction

Percolation of moisture through the pores particularly rising damp is a major cause of decay to materials like stone, brick, mortar and concrete. When coupled with high salt concentrations, severe damp can cause extensive fretting and crumbling of lower parts. Porous masonry draws moisture by capillary action from underlying soils. When the soil contains soluble salts, these are drawn into the network of pores in the wall. Consequently the salt builds up and grows as minute crystal. The crystal growth is sufficient to rupture the masonry. All masonry materials are to some extent porous. When the pores are connected so that air or water can pass through them, the material is said to be permeable. The height to which water will rise depends on the rate of evaporation of water from the wall surface. As moisture evaporates from either the outer or inner faces of a wall more moisture is drawn from below. The rate of flow depends on internal pore structure of masonry and concrete. Pores and increased permeability help in diffusion of chloride and carbon dioxide which has the ability to destroy the passivity and alkalinity of concrete, and initiates a favourable environment for corrosion.

2. Disintegration Mechanism

2.1 Exposure to aggressive chemicals

Certain chemicals like inorganic acids, organic acids, salt solutions attack various constituents of concrete, plasters and mortars. Acid attack on concrete, mortars is the reaction between calcium hydroxide and acid forming soluble calcium compounds which are leached away. When limestone or dolomite aggregates are used the acid dissolves them.

2.2 Freeze-thaw damage

Stresses result due to change in volume of water inside the pores and it may lead to severe damage. Hydraulic pressure develops when water in saturated pores freeze. The osmotic pressure caused due to the movement of water from smaller to larger pores along with thermal contraction of the constituents, the temperature gradient and chemical action affect freeze–thaw cycles.

2.3 Alkali silica reaction

Alkali silica reaction forms a gel-like substance and water acts as a catalyst to it. This causes stresses. The main factors that contribute to these stresses are available moisture along with the size and amount of reactive silica.

2.4 Sulfate attack

The attack of sulphate causes two major deterioration namely the reaction of Na_2SO_4 and $Ca(OH)_2$ to form gypsum and the reaction of the formed gypsum with calcium aluminate hydrates to form ettringite. In addition $MgSO_4$ reacts with all cement and lime compounds decomposing cement and lime and subsequently forming gypsum and ettringite.

2.5 Erosion

Cavitation causes erosion of concrete surfaces resulting from collapse of vapor bubbles formed by pressure changes within a high velocity water flow. Cavitation damage results in the erosion of cement matrix.

2.6 Chloride penetration

The penetration of chlorides starts at the surface, and then it moves upwards. The water capillary action takes chloride into the masonry and it diffuses upward. The diffusion rate depends on the permeability of mortar and concrete. The chloride removes the passivity of concrete, lowers the pH of concrete and turns the medium from alkaline to acidic accelerating corrosion process of embedded steel and other metals.

2.7 Carbonation

It is the reaction between acidic gases in the atmosphere and the products of cement/lime hydration. Normal air contains 0.3% CO_2 in low concentration. When the level of CO_2 in industrial atmosphere becomes higher, it penetrates into the pores of concrete by diffusion and reacts with calcium hydroxide. As a result pH level is reduced and consequently concrete protection of reinforcing steel is lost.

3 Experimental observation

3.1 Treatment on old lime mortar

In order to limit or prevent rising damp, tests were carried out on two samples of brickworks with lime-*surki* (brick dust) mortar and sand cement plaster to simulate the condition of existing masonry for old and heritage buildings of Kolkata.. The experimental samples of brick work of size 520 mm x 520 mm and height 200 mm at the base and 300 mm x 300 mm and height 1000 mm above the base with lime *surki* (brick dust) mortar 1:6 were made and plastered with 1:6 cement sand plaster. The samples are cured properly.

1. In the first sample, four mortar joints above skirting. 8 mm diameter holes were drilled at masonry joints at a spacing of 150 mm in consecutive 4 layers of mortar joints. The holes were cleaned by blowing air and 4 mm plastic tubes were inserted keeping 50 mm length of tube outside the hole and the tube was stabilized to the wall by special leak-proof mortar. The aqueous solutions of chemical in ratio of 1:10 were injected by using syringe to the capacity of 100 ml. The tubes were bent and tied with a chord. The operation was repeated on day 2 also. On the next day the plastic tubes were removed and were left open for drying for 3 days .Thereafter the holes were sealed by quick setting mortar. Moisture in dry condition was taken at a height 1 ft, 2 ft, 3 ft above skirting. Water is poured in vat, kept for 6 hrs and moisture reading is taken at the same locations.

2. In the second sample no treatment was followed. Moisture in dry condition was taken at a height 1 ft, 2 ft, 3 ft above skirting. Water is poured in vat, kept for 6 hrs and moisture reading is taken at the same locations.

The chemical has been also tried in some masonry walls of some heritage building and the results are being observed on a long term basis.

3.1.1 Results in Tabular Form

Moisture reading height above treatment	Sample without any treatment	Sample with injection of chemical comprising of sulphate and chloride of Zinc, Aluminium, Potassium and Calcium in solution.
D 1 ft	5.8	18.2
R 2 ft	7.1	13.2
Y 3 ft	8.6	9.8
W 1 ft	14.3	20.83
E 2 ft	11.6	14.4
T 3 ft	11.3	10.7

73.18 %

% increase in
11.50%
wet over dry

3.1.2 Bar Diagrams

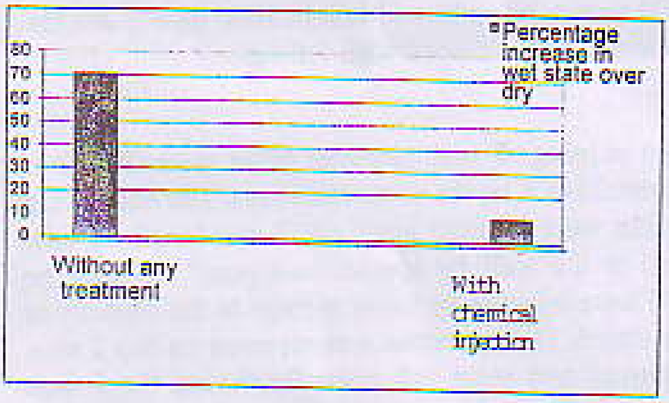


Fig 1. Percentage increase in wet state over dry

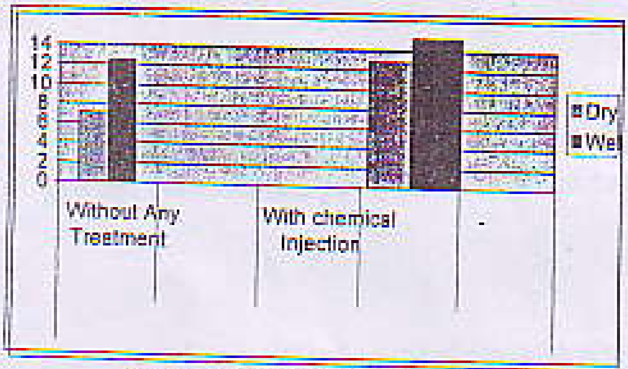


Fig2. Moisture Content in dry and wet conditions in various test cases

3.2 Treatment on fresh cement concrete

Concrete cubes and cylinders of appropriate sizes were cast in proportion of 1: 2: 4 with ordinary portland cement, Portland pozzolona cement, Portland slag cement .Some were casted without chemical admixtures and the rest were casted with chemical admixtures using PP strength (cement property enhancer) with 2% by weight of cement. The water permeability, chloride permeability, compressive strength and setting time was ascertained on all test samples.

3.2.1 Compressive Strength (average):

a) Samples made with **Ordinary Portland Cement** (OPC- 43 grade conforming to IS 8112-1989):

	Specimen without Chemical (Reference samples)	Specimen with Chemical (2% by weight of cement)
i) At 1day ---	13.06 MPa	11.90 MPa
ii) At 3 days ---	18.63 MPa	20.74 MPa
iii) At 7 days ---	25.75 MPa	25.33 MPa
iv) At 28 days ---	33.10 MPa	30.56 MPa

b) Samples made with **Portland Pozzolana Cement** (PPC- conforming to IS 1489 Part1-1989):

	Specimen without Chemical (Reference samples)	Specimen with Chemical (2% by weight of cement)
i) At 1day ---	15.03 MPa	13.69 MPa
ii) At 3 days ---	21.33 MPa	22.60 MPa
iii) At 7 days ---	24.67 MPa	25.05 MPa
iv) At 28 days ---	31.44 MPa	35.40 MPa

c) Samples made with **Portland Slag Cement** (PSC- conforming to IS 455-1989):

	Specimen without Chemical (Reference samples)	Specimen with Chemical (2% by weight of cement)
i) At 1day ---	9.74 MPa	4.95 MPa
ii) At 3 days ---	14.77 MPa	22.75 MPa
iii) At 7 days ---	30.67 MPa	29.90 MPa
iv) At 28 days ---	35.00 MPa	35.00 MPa

3.2.2 Setting time (Initial and Final):

a) Samples made with **Ordinary Portland Cement** (OPC- 43 grade conforming to IS 8112-1989):

	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
i) Initial setting time ---	1 hrs 47 min	1 hrs 54 min
ii) Final setting time ---	4 hrs 37 mm	4 hrs 25 min

b) Samples made with **Portland Pozzolana Cement** (PPC- conforming to IS 1489 Part1-1989):

	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
i) Initial setting time ---	1 hrs 35 min	1 hrs 30 min
ii) Final setting time ---	2 hrs 30 mm	2 hrs 54 min

c) Samples made with **Portland Slag Cement** (PSC- conforming to IS 455-1989):

	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
i) Initial setting time ---	0 hrs 48 min	0 hrs 44 min
ii) Final setting time ---	2 hrs 52 mm	2 hrs 34 min

3.2.3 Water Permeability (as per DIN 1048):

Water penetration test

In good quality concrete, there is no flow of water through the concrete. Water penetrates into the concrete to a certain depth, and an expression has been developed by **Valenta** to convert the depth of penetration into the coefficient of permeability, **K** (in meter per second) equivalent to that used in Darcy's law:

$$K=e^2v/(2ht)$$

Where e=depth of penetration of water in Concrete in metres

h=hydraulic head in metres,

t=time under pressure in seconds, and

v=the fraction of the volume of concrete occupied by pores

The value of v represents discrete pores, such as air bubbles, which do not become filled with water except under pressure, and can be calculated from the increase in the mass of concrete during the test, bearing in mind that only the voids in the part of the specimen penetrated by water should be considered. Typically v lies between 0.02 and 0.06.

The hydraulic head is applied by pressure which usually ranges between 0.1 and 0.7MPa. The depth of penetration is found by observation of the split surface of the test specimen after a given length of time. This value of e can be put in Valenta's expression given above.

It is also possible to use the depth of penetration of water as a qualitative assessment of concrete: a depth of less than 50mm classifies the concrete as 'impermeable'; a depth of less than 30 mm, 'impermeable under aggressive conditions'.

This method is included in German code DIN 1048 where the pressure is kept constant as 5 kg/cm^2 (i.e. 0.5 MPa) for 72 hours.

a) Samples made with **Ordinary Portland Cement** (OPC- 43 grade conforming to IS 8112-1989):

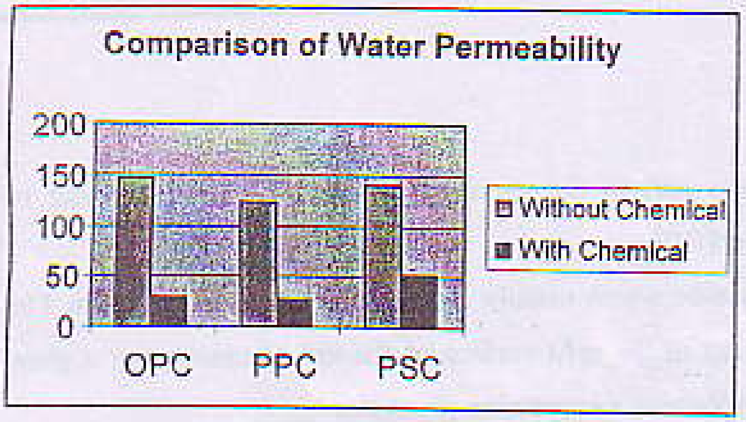
	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
Depth of water penetration after 72 hrs of constant pressure---	145 mm (max)	30 mm (max)

b) Samples made with **Portland Pozzolana Cement** (PPC- conforming to IS 1489 Part1-1989):

	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
Depth of water penetration after 72 hrs of constant pressure---	123 mm (max)	27 mm (max)

c) Samples made with **Portland Slag Cement** (PSC- conforming to IS 455-1989):

	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
Depth of water penetration after 72 hrs of constant pressure---	140 mm (max)	52 mm (max)



3.2.4 Chloride Permeability (as per ASTM C1202):

AASHTO T277 AND ASTM C1202 Rapid Chloride Permeability Test

This test method was originally developed by the Portland Cement Association, under a research program paid for by the Federal Highway Administration (FHWA). The original test method may be found in FHWA/RD-81/119, "Rapid Determination of the Chloride Permeability of Concrete." Since the test method was developed, it has been modified and adapted by various agencies and standard's organizations. These include:

- AASHTO T277, "Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete"
- ASTM C1202, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration"

Test Procedure

The test method involves obtaining a 100 mm (4 in.) diameter core or cylinder sample from the concrete being tested. A 50 mm (2 in.) specimen is cut from the sample. The side of the cylindrical specimen is coated with epoxy, and after the epoxy is dried, it is put in a vacuum chamber for 3 hours. The specimen is vacuum saturated for 1 hour and allowed to soak for 18 hours. It is then placed in the test device. The left-hand side (–ve) of the test cell is filled with a 3% NaCl solution.

The right-hand side (+ve) of the test cell is filled with 0.3N NaOH solution. The system is then connected and a 60-volt potential is applied for 6 hours. Readings are taken every 30 minutes. At the end of 6 hours the sample is removed from the cell and the amount of coulombs passed through the specimen is calculated.The test results are to be compared to the values in the chart below. This chart was originally referenced in FHWA/RD-81/119 and is also used in AASHTO T277-83 and ASTM C1202 specifications.

Table: Chloride Permeability Based on Charge Passed

Charge Passed Coulombs)	**Chloride permeability**	**Applicable for**
>4,000	High	High W/C ratio (>0.60) (conventional PCC)
2,000–4,000	Moderate	Moderate W/C ratio (0.40-0.50)(conventional PCC)
1,000–2,000	Low	Low W/C ratio (<0.40) (conventional PCC)
100–1,000	Very Low	(Latex-modified concrete or internally-sealed concrete)
<100	Negligible	(Polymer-impregnated concrete/Polymer concrete)

It is important to understand that these ranges were established on laboratory concrete by the test method described above. The ranges should be used only for comparison purposes. The test is meant only to give an indication as to how the concrete tested relates to the values in the chart or to other concrete being tested under the test procedure.

a) Samples made with **Ordinary Portland Cement** (OPC- 43 grade conforming to IS 8112-1989):

	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
Total Charges passing through disc samples in 6 hrs---	2937 Coulomb	820 Coulomb

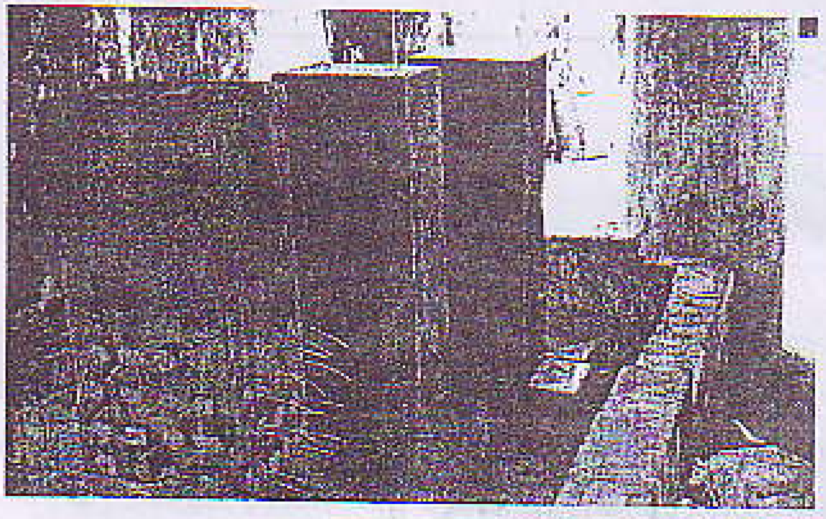
b) Samples made with **Portland Pozzolana Cement** (PPC- conforming to IS 1489 Part1-1989):

	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
Total Charges passing through disc samples in 6 hrs---	837 Coulomb	580 Coulomb

c) Samples made with **Portland Slag Cement** (PSC- conforming to IS 455-1989):

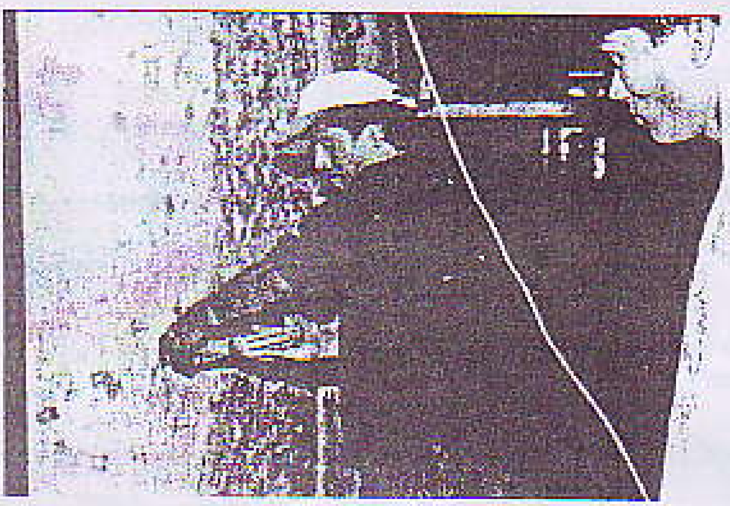
	Specimen without Chemical (Reference sample)	Specimen with Chemical (2% by weight of cement)
Total Charges passing through disc samples in 6 hrs---	921 Coulomb	630 Coulomb

4. Photographs of treatments.



Tubes inserted in lime mortar joints and chemical is injected.

Moisture reading is taken through moisture meter



In situ application of chemical injection

5. Conclusion

i. The chemical injected crystallizes in contact with lime and cement. The chemical penetrates insides pores of concrete. The crystal starts to grow and block the concrete pores and thereby reduces permeability.

ii. The rising damp through capillary is reduced substantially enabling to block salts and corrosion in embedded metals.

iii. In cement concrete the chemical reduces the permeability to a great extent without sacrificing the strength and setting time.

iv. The chloride permeability is also reduced significantly and chances of corrosion are reduced.

v. Increase in the workability in concrete, plasters, mortar, lime wash etc. are achieved.

vi. The chemical can be applied on mortar joints in masonry walls over skirting in old and heritage buildings and can be used as an additive to grouting admixtures especially rubble infill between two layers of brick works .

Acknowledgement

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