

# Reduction in permeability of concrete, mortar and plasters by a chemical which retards water percolation and salt transfer

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## Abstract

Capillary rise, chloride and other salt penetration are the major causes of damage to the structure and are closely related to 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. These result in salt efflorescence, corrosion in metals, alkali aggregate reactions, sulphate attack through formation of gypsum and ettringite, freeze and thaw disintegration, erosion, carbonation, etc. They have a serious destructive effect on the structure as a whole. Heritage and old buildings which are devoid of damp proof courses 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 an indigenous chemical 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.

*Keywords: Boral-chemical, permeability.*

## 1 Introduction

Moisture percolation 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 favorable environment for corrosion

## **2 Disintegration mechanism**

### **2.1 Exposure to aggressive chemicals**

Certain chemicals like inorganic acids, organic acids and 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 and 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 Chloride ion diffusion**

Water containing destructive  $\text{Cl}^-$  ion removes the passivity of concrete and corrodes the fully or partially embedded steel.

### **2.5 Sulfate attack**

The attack of sulphate causes two major forms of deterioration namely the reaction of  $\text{Na}_2\text{SO}_4$  and  $\text{Ca}(\text{OH})_2$  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.

## 2.6 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.

## 2.7 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.

## 2.8 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 Properties of the chemical used

The major constituents used in the chemical are zinc hydroxide, aluminium hydroxide, potassium chloride, calcium sulphate, silicon hydroxide and mild sulphuric acid.

The data of scan electron microscopy tested in S. N. Bose National Center for Basic Sciences is presented below for the chemical:

Table 1: EDAX ZAF Quantification at S. N. Bose National Center for Basic Sciences.

Elem	Wt%	At%	K-Ratio	Z	A	F
O K	37.48	55.70	0.0537	1.0395	0.1377	1.003
Mg K	6.48	6.34	0.0212	1.0020	0.3247	1.0054
Al K	2.78	2.45	0.0105	0.9375	0.3857	1.0088
Si K	0.45	0.38	0.0022	1.0029	0.4865	1.0158
S K	13.70	10.16	0.1037	0.9966	0.7392	1.0271
Cl K	25.49	17.09	0.1591	0.9546	0.6404	1.0071
K K	0.31	0.19	0.0019	0.9536	0.6182	1.0152
Ca K	12.40	7.35	0.0849	0.9757	0.7016	1.001
Zn K	0.92	0.33	0.0080	0.8770	0.9870	1.000

Figure 1 shows the spectra of the liquid chemical sample analysed by scan electron microscope.

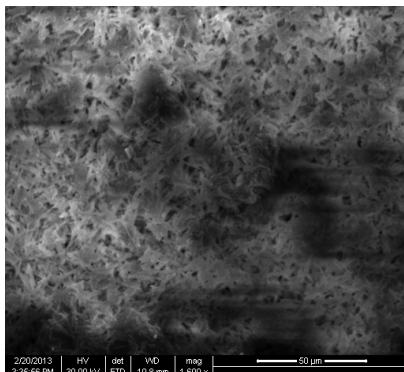


Figure 1: Scan picture of the chemical observed under microscope.

### 3.1 Behaviour of the chemical with cement and lime

When a spoon of chemical is mixed with cement slurry and lime slurry (both liquid), the liquid slurry in both cases transforms into dense semisolid matter with reduction in water pores and with passage of time it becomes more and more dense.

Figures 2 and 3 show the transformation of liquid cement slurry to semisolid paste on application of the chemical.



Figure 2: Transformation of liquid cement slurry to semisolid paste on application of the chemical.



Figure 3: Transformation of liquid lime slurry to semisolid paste on application of the chemical.

### 3.2 Behaviour of the chemical with lime mortar

The lime brick dust mortar in composition of 1:3 is prepared. The same composition of lime brick dust mortar is prepared but added with chemical 5% by weight of lime. Both samples were cured and then sent to the laboratory for Energy Dispersive X ray analysis (EDAX) under scan electron microscope.

As per figure 4, it is observed that in the mortar with chemicals there are rod type features which are absent in ordinary mortar without chemical.

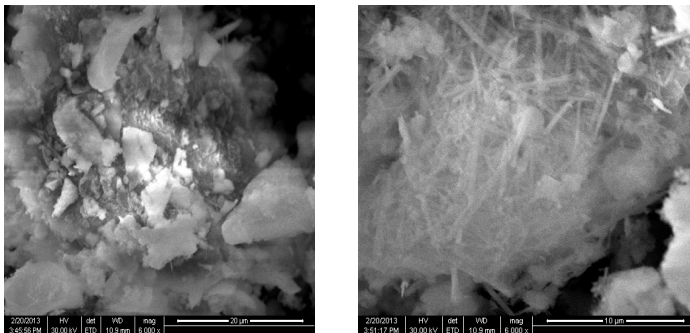


Figure 4: Micro level photo of lime brick dust mortar with chemical at three different angles.

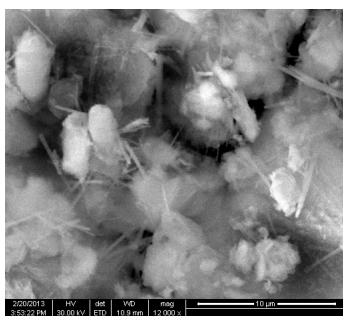


Figure 4: Continued.

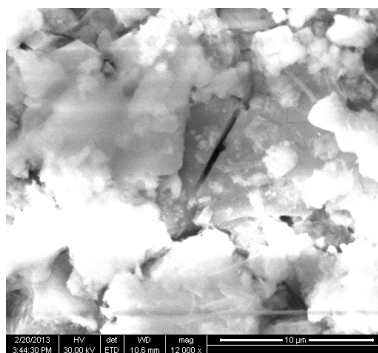
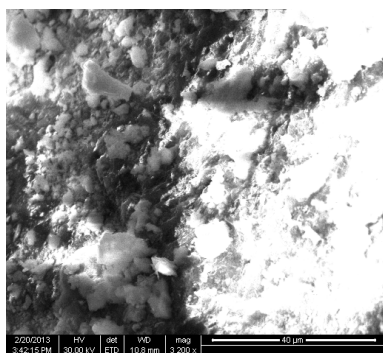
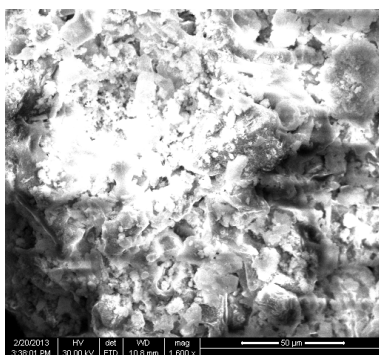


Figure 5: Micro level photo of lime and brick dust mortar without chemical.

#### 4 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 and Portland slag



cement. Some were casted without chemical admixtures and the rest were casted with chemical admixtures with 2% by weight of cement. The water permeability, chloride permeability, compressive strength and setting time were ascertained on all test samples.

#### 4.1 Compressive strength (average)

Table 2: Samples made with Ordinary Portland Cement (OPC – 43 grade conforming to IS 8112 – 1989).

		Specimen without chemical	Specimen with chemical 2% by weight of cement
i.	At 1 day	13.06MPa	11.90MPa
ii.	At 3 days	18.63MPa	20.74MPa
iii.	At 7 days	25.75MPa	25.33MPa
iv.	At 28 days	33.10MPa	30.56MPa

Table 3: Samples made with Portland Pozzolana Cement (PPC – conforming to IS 1489 Part 1 – 1989).

		Specimen without chemical	Specimen with chemical 2% by weight of cement
i.	At 1 day	15.03MPa	13.69MPa
ii.	At 3 days	21.33MPa	22.60MPa
iii.	At 7 days	24.67MPa	25.05MPa
iv.	At 28 days	31.44MPa	35.40MPa

Table 4: Samples made with Portland Slag Cement (PSC – conforming to IS 455 – 1989).

		Specimen without chemical	Specimen with chemical 2% by weight of cement
i.	At 1 day	9.74 MPa	4.95MPa
ii.	At 3 days	14.77MPa	22.75MPa
iii.	At 7 days	30.67MPa	29.90MPa
iv.	At 28 days	35.00MPa	35.00MPa

The results indicate that after short duration addition of chemical does not improve strength, but in the long term does improve the strength.



## 4.2 Setting time (initial and final)

Table 5: Samples made with Ordinary Portland Cement (OPC – 43 grade conforming to IS 8112 – 1989).

	Specimen without chemical	Specimen with chemical 2% by weight of cement
Initial setting time	1 hr 47 min	1 hr 54 min
Final setting time	4 hrs 37 min	4 hrs 25 min

Table 6: Samples made with Portland Pozzolana Cement (PPC – conforming to IS 1489 Part 1 – 1989).

	Specimen without chemical	Specimen with chemical 2% by weight of cement
Initial setting time	1 hr 35 min	1 hr 30 min
Final setting time	2 hrs 30 min	2 hrs 54 min

Table 7: Samples made with Portland Slag Cement (PSC – conforming to IS 455 –1989).

	Specimen without chemical	Specimen with chemical 2% by weight of cement
Initial setting time	0 hr 48 min	0 hr 44 min
Final setting time	2 hrs 52 min	2 hrs 34 min

The addition of the chemical does not have any effect on setting time.

## 4.3 Water permeability (as per DIN 1048)

### 4.3.1 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<sup>2</sup> (i.e. 0.5 MPa) for 72 hours.

Table 8: Samples made with Ordinary Portland Cement (OPC – 43 grade conforming to IS 8112 – 1989).

	Specimen without chemical	Specimen with chemical, 2% by weight of cement
Depth of water penetration after 72 hrs of constant pressure	145 mm (max)	30 mm (max)

Table 9: Samples made with Portland Pozzolana Cement (PPC – conforming to IS 1489 Part 1 – 1989).

	Specimen without chemical	Specimen with chemical, 2% by weight of cement
Depth of water penetration after 72 hrs	123 mm (max)	27 mm (max)



Table 10: Samples made with Portland Slag Cement (PSC – conforming to IS 455 – 1989).

	Specimen without chemical	Specimen with chemical, 2% by weight of cement
Depth of water penetration after 72 hrs	140 mm (max)	52 mm (max)

The permeability in concrete is significantly reduced by chemical.

**4.4 Chloride permeability**

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.

Table 11: Samples made with Ordinary Portland Cement (OPC – 43 grade conforming to IS 8112 – 1989).

	Specimen without chemical	Specimen with chemical, 2% by weight of cement
Total charge passing through disc samples in 6 hrs	2937 Coulomb	820 Coulomb

Table 12: Samples made with Portland Pozzolana Cement (PPC – conforming to IS 1489 Part 1 – 1989).

	Specimen without chemical	Specimen with chemical, 2% by weight of cement
Total charge passing through disc samples in 6 hrs	837 Coulomb	580 Coulomb

Table 13: Samples made with Portland Slag Cement (PSC – conforming to IS 455 – 1989).

	Specimen without chemical	Specimen with chemical, 2% by weight of cement
Total charge passing in disc samples in 6 hrs	921 Coulomb	630 Coulomb



The chloride permeability in concrete is significantly reduced by the chemical.

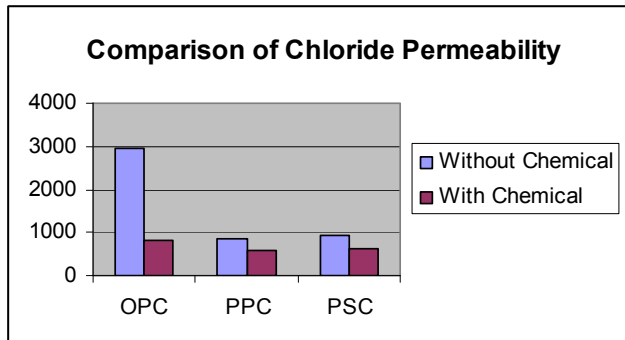


Figure 6: Chloride permeability improvement with the addition of the chemical.

#### 4.5 Water permeability for lime mortar

Samples of lime and brick-dust mortar 1:3 were tested for permeability under variable head permeameter along with some samples of the same type but mixed with the chemical 5% by weight of lime. It is found that there has been a reduction of permeability by 60% and that is due to reduction of void caused by the chemical.

### 5 Conclusion

- 1) The chemical plays a role in bonding thereby reducing the voids between cement, sand and aggregates, moist lime and brick-dust. The chemical forms certain bonds as it is evident from the microstructure under scan microscope. The crystal starts to grow and block the concrete pores and thereby reduces permeability.
- 2) The rising damp through capillary is reduced substantially enabling to block salts and corrosion in embedded metals.
- 3) In cement concrete the chemical reduces the permeability to a great extent without sacrificing the strength and setting time.
- 4) The chloride permeability is also reduced significantly and chances of corrosion are reduced.
- 5) Increase in the workability in concrete, plasters, mortar, lime wash etc. are achieved.
- 6) Can be used successfully for water proofing in several areas.

## References

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