

An Investigation into the Prevention of Water Associated Problems in Concrete using Chem-Crete Pavix™ CCC-100 Impregnation.

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Abstract

The results of a laboratory investigation into Chem-Crete Pavix™ CCC-100 concrete impregnation, an innovative technology that minimizes the water associated problems of concrete, are presented in this paper. This product has been trialed and used in industrial projects for several years. The central mechanism of the technology is the formation of different crystals inside the pores of the concrete and a repellency action. Laboratory results indicate significant reduction of freeze-thaw deterioration, chloride ion diffusion, and crack formation for concrete treated with Chem-Crete Pavix™ CCC-100.

Keywords: Waterproof, Concrete, Deterioration, Crystallization, Impregnation, Pavix.

1 Introduction

Due to its unique mechanical properties, reinforced concrete has become the largest volume structural material in the world. Concrete, however, is a porous media and penetration of undesired substances can cause progressive damage to it. Although water is essential for hydration in concrete during the hardening stages, it is an

undesirable substance that can cause severe damage during the service life of the structural element.

The repair of damaged concrete is expensive and there is a growing requirement for this throughout the developed world. For example, in the USA alone, it is estimated that the cost of repairing damaged bridges due to the deterioration of structural components reaches \$ 9.4 billion a year [1]. Elsewhere, in the UK, the annual value of the construction industry in repair works exceeds 60% of total activity. Most of the damage occurs as a result of the expansive corrosion of steel reinforcement, a situation aggravated by the frequent occurrence of inadequate concrete cover to the reinforcing bars. High levels of de-icing salt deposition is a contributing factor in the case of concrete bridges, highway pavement, multi-storey car-parks and other structures. Water penetration and chloride ion diffusion are the prime agencies for reinforcing bar corrosion.

A recent survey indicated that corrosion of steel reinforcement contributes about 40% to concrete deterioration, while freeze-thaw loading contributes 20% and crack formation 20% [2]. In these cases, repairs had been performed by traditional patching, coating and crack injection methods.

Moisture, directly or indirectly, contributes largely to the deterioration of reinforced concrete. Moisture associated problems can be summarized as follows:

Freeze thaw damage; the change in volume of water inside the pores of concrete causes stresses on particles adjacent to them. These stresses may lead to severe damage in the structure of the concrete.

Chloride ion diffusion; Water can carry destructive ions, such as chloride ions, that severely corrode the steel reinforcement in concrete. A review of the effect of chloride ion diffusion on concrete pore structure is presented elsewhere [3].

Alkali Silica Reaction (ASR); water is the catalyst for alkali silica reaction, which forms an expansive gel like substance that contributes stress in the structure of concrete.

Acidic attack; Water, especially ‘so called’ acid rain derived water, is acidic relative to concrete, therefore, the penetration of such water can cause acid-base reaction that damages concrete.

Sulfate attack; Sulfates can contribute deteriorating ions to the concrete substrate. A comprehensive study on the sulfate attack is given elsewhere [4].

A further summary of the above stated problems is presented elsewhere [5].

2 Performance Criteria

It is interesting to consider the performance requirements for a general purpose protective material for concrete. This excludes specific requirements for water containment.

High permeability, sub-standard reinforcement cover and cracks that give pathways for the ingress of chloride solutions are the most common, co-existing and destructive occurrences in structural concrete. At the same time, impermeable water-proofing systems are not appropriate for general protection of concrete. They are expensive and have vulnerable points in the issues of surface adhesion, mechanical wear, crack bridging, joint interfacing, thermal response and resistance to chemicals. Furthermore, the requirement for breathability under drying conditions is an overriding consideration and is frequently specified for the non-deck areas of highway bridges, for example [6]. Impermeable membranes cannot provide this. At a prescriptive level, an ideal protective material would (i) be applied as one permanent application (ii) not be surface vulnerable i.e. an impregnation rather than a surface coating, (iii) fill cracks from very fine up to structural level width, (iv) respond defensively to prevailing moisture conditions, (v) protect against freeze-thaw loading, (vi) reduce permeability, (vii) combat chloride ion effusion and ASR, (viii) not pollute the environment, (ix) not present a health risk for the workforce or the public at large and (x) be affordable. This study seeks to make a substantial step in positioning Chem-Crete Pavix™ CCC-100 in terms of the above performance criteria.

3 Traditional Protective Systems

Various protective systems are currently used to prevent or minimize water penetration into concrete and thus avoid the previously stated water associated problems. Water-proof coating systems are the most commonly used to prevent water penetration. These systems are mainly polymeric systems, such as epoxy resin, acrylic resins, and bitumen based systems. They can be installed on the positive or negative water pressure side of a structure, although lack of adhesion may severely limit effectiveness in negative side applications. A comprehensive study on the effectiveness of such systems has been reported [7], many of which are very effective in preventing water penetration. In terms of their resistance to acidic attack, sulfate attack, adhesion to different concrete substrates, service life and economic factors and other selection criteria, they fall well short of requirements. A further consideration is that penetration of water into the untreated faces and joints may also cause these systems to fail to protect concrete substrate. In terms of the performance criteria stated in section 2 above, traditional protective measures perform poorly.

4 Chem-Crete Pavix™ CCC100 Technology

At the end of the 20st century, established technology was still largely ineffective in solving the concrete deterioration problem, which is now costing hundreds of billions of dollars worldwide. With advancements in the 1990's, many technologies evolved, although very few have survived due to worker safety, environmental regulations and high cost issues.

This study presents the state of the art in protective crystallization technology in the form of Chem-Crete Pavix™ CCC-100, a material perfected at the beginning of the 21st century. A single application of this prevents the problems associated with deterioration and cracking in reinforced concrete structures. This technology is affordable to end users, environmentally friendly, worker safe, permanent and imparts concrete with a longer service life.

Chem-Crete Pavix™ CCC-100 is a water based product, with extremely low viscosity, that impregnates concrete by a single spraying application. It contains no VOC or toxic substances. It forms two types of non-remulsifiable crystals with hygroscopic and hydrophilic properties that block and prevent surface water

penetration, as well as delivering high repellency power. Through diminishing the water and moisture supply, Chem-Crete Pavix™ CCC-100 substantially reduces the corrosion risk to steel reinforcement, the opportunity for alkali silica reaction and freeze-thaw loading induced damage. Its crystals also fill significant cracks up to about 1/16 inch (1.6 mm) in width. At the same time, breathability, which is essential in order not to trap moisture inside the concrete mass, is provided because the crystals shrink under drying conditions. On account of their hygroscopic nature, they readily regain moisture and re-grow under wet conditions to provide the similarly essential water blocking action.

5 Experimental work

The experimental results of this study are for freeze-thaw loading, chloride ion penetration and permeability on a comparative basis, using control specimens and specimens treated with Chem-Crete Pavix™ CCC-100. In all, 300 cycles of freeze-thaw loading were applied, representing a severe and sustained real world environment.

Several mix designs were studied prior to the selection of a suitable mix design for this research. Since the material investigated in this research is primarily intended for pavement applications, the selected mix design was based on a typical pavement mix design. Each mix design was conducted for a predicted slump value of 5 inch (127mm), air content 5% and water cement ratio of 0.5

The following tests were conducted to evaluate the durability characteristics of Chem-Crete Pavix™ CCC 100 treated concrete and untreated control specimens and thus address the performance criteria given in section 2..

Resistance of Concrete to Rapid Freezing and Thawing (ASTM C 666-97)

Chloride Ion Permeability (ASTM C 1202-97, AASHTO T 277-93)

Specific Gravity, Absorption, and Voids in Hardened Concrete (ASTM 642-97)

Standard Test method for Determination of Water Absorption of Hardened Concrete Treated With a Water Repelling Coating (ASTM C 6489-99)

Microscopic Determination of Parameters in Hardened Concrete (ASTM C 457-98)

6 Test Results

6.1 Freeze-Thaw Testing

Freeze-thaw testing was performed in the Material Laboratory, University of Texas at Arlington (UTA). The equipment used to perform this test procedure consists of an automatic freeze-thaw loading facility and a length change comparator. 300 freeze-thaw loading cycles were performed on all specimens, with dimension and weight measurements obtained at approximately every 50 cycles.

For each design mix, eight 4 in. x 3 in. x 11¼ in. (101mm x 76.2mm x 285.8mm) specimens, with embedded gauge studs at each end, were cast in the laboratory in accordance with ASTM C-192.

The results, as shown in the Figure 1, indicate that the change in length due to freeze thaw loading of untreated samples is about three times than that for treated ones. This means that treating concrete with Chem-Crete Pavix™ CCC-100 reduces the stresses in the concrete by almost three folds. As shown in Figure 2, this is supported by the weight loss values obtained with untreated specimens in the same experiment, with no corresponding loss of weight occurring with the Chem-Crete Pavix™ CCC100 treated samples. The significance of these findings illustrates the prevention of crack formation, and thus a reduction of water penetration to the steel reinforcement and a resulting reduction of the corrosion risk problem.

6.2 Rapid Chloride Ion Permeability Test

The Rapid Chloride Ion Permeability is a standard test method performed according to ASTM C 1202-91 and AASHTO T 277-93. The permeability results obtained are expressed in terms of charge passing, measured in coulombs through a two inch (50.4mm) thick section of concrete specimen. For this, the test was conducted on the upper 2 inches (50.4mm) of concrete specimens since this zone was subjected to more environmental action. The age of the test specimens has significant effects on the test results, depending also in the type of concrete and curing procedure adopted. Other

parameters affecting permeability results are the w/c ratio, air content and aggregate gradation.

The test specimens used consists of both site cored and laboratory cast specimens. Cored specimens were taken from a two year old car park following treatment with Chem-Crete Pavix™ CCC-100. The laboratory prepared specimens were cast in the Material Laboratory of UTA along with the other test specimens. Experimental results for the permeability of cored and laboratory prepared specimens are provided in Tables 1 and 2.

The average chloride penetration of treated specimen is just below 2000 Coulombs, whereas, for untreated specimens, the chloride ion penetration is around 4000 Coulombs, which is considered to be high. In both different kinds of specimens, chloride ion penetration for untreated specimens is higher than for treated specimens. It should be noted that concrete with an average chloride penetration of less than 2000 Coulombs is considered durable.

6.3 Absorption and Related Tests

One of the key durability properties evaluated in this study was absorption and air void content. This reflects one of the main objectives to investigate the effectiveness of Chem-Crete Pavix™ CCC-100 in decreasing the water absorption capacity of concrete and, in turn, water related deterioration. The average water absorption test result of treated specimen was 2.1%, while the value for untreated specimen was 6.05% for water cement ratio of 0.5. For the concrete with water cement ratio of 0.35, the absorption capacity for treated specimens was 0.89% and that for the untreated specimens 3.98%.

6.4 Microscopic Investigation

For petrographic analysis, procedure A, the linear-traverse method was performed. The test was performed on both treated and untreated site cored and laboratory specimens. Data collected form this test was used to calculate the air content and various parameters of the air-void system of hardened concrete. The air-void content was 0.37% and 0.67% for the treated and untreated cored specimen, respectively, which is considered to be very low and an attribute of concrete with good freeze-thaw

resistance. The air-void content for both laboratory prepared treated and untreated specimens was 9.7%. The spacing factor for cored treated and untreated specimens was 0.016 in (0.406mm) and 0.0135 in (0.343mm), respectively. For laboratory prepared treated and untreated specimens, values were 0.0062 in. (0.157 mm) and 0.0052 in. (0.132mm), respectively. These results show that the air void content and spacing factors for both cored and laboratory prepared specimens are nearly the same.

7 Conclusions and Discussion

The main conclusions of this research are:

From dimensional measurements during freeze-thaw testing it was found that the damage rate of untreated concrete is nearly triple that of concrete treated with Chem-Crete Pavix™ CCC-100.

Unlike untreated specimens, all specimens treated with Chem-Crete Pavix™ CCC-100 suffered no weight loss damage after 300 freeze-thaw loading cycles.

Chloride ion penetration testing shows that treated specimens performed better than untreated ones and thus would have reduced corrosion risk for embedded steel.

Overall, it was shown that permeability is reduced significantly by the application of Chem-Crete Pavix™ CCC 100.

By applying Chem-Crete Pavix™ CCC 100 to concrete, the absorption ratio and permeable pore space is reduced significantly, making concrete less permeable.

8 References

[1] Report card for Americas infrastructure. 2003 progress report, an update to 2001 report card, American society of civil engineers, September 2003.

[2] Tilly G P, "Past performance of concrete repairs in "Proceedings of the conrepret performance based rehabilitation of reinforced concrete structures conference", Prague, 23rd June 2005, Czech Concrete Society.

- [3] Suryavanshi A. K. and Swamy R. N., Influence of penetrating chlorides on the pore structure of structural concrete, cement concrete and aggregates 20, (1) (1998) 169-179.
- [4] Crammond N., The occurrence of thaumasite in modern construction- a review, Cement and concrete composites 45 (2002) 393-402.
- [5] Bin Yair M., The durability of cement and concrete in sea water, Desalination 3, (1967) 147-154.
- [6] Chamberlain D.A., An approved alternative to Silane, Journal of the Concrete Society, Pub. Thomas Telford, England, February 2005
- [7] Barbucci A., Delucchi M., Cerisola G., Organic coating for concrete protection: liquid water and water vapor permeabilities, Progress in organic coating 30 (1997) 293-397.

Table 1 Chloride Ion Penetration Test (Site Cored Specimens)

Sample Number	Chloride ion Permeability(Coulombs)
Untreated 1	165
Untreated 2	125
Treated 1	55
Treated 2	69

Table 2 Chloride Ion Penetration Test (Laboratory Prepared Specimens)

Sample Number	Chloride ion Permeability(Coulombs)
Untreated 1	4074
Untreated 2	4211
Treated 1	1790
Treated 2	2064

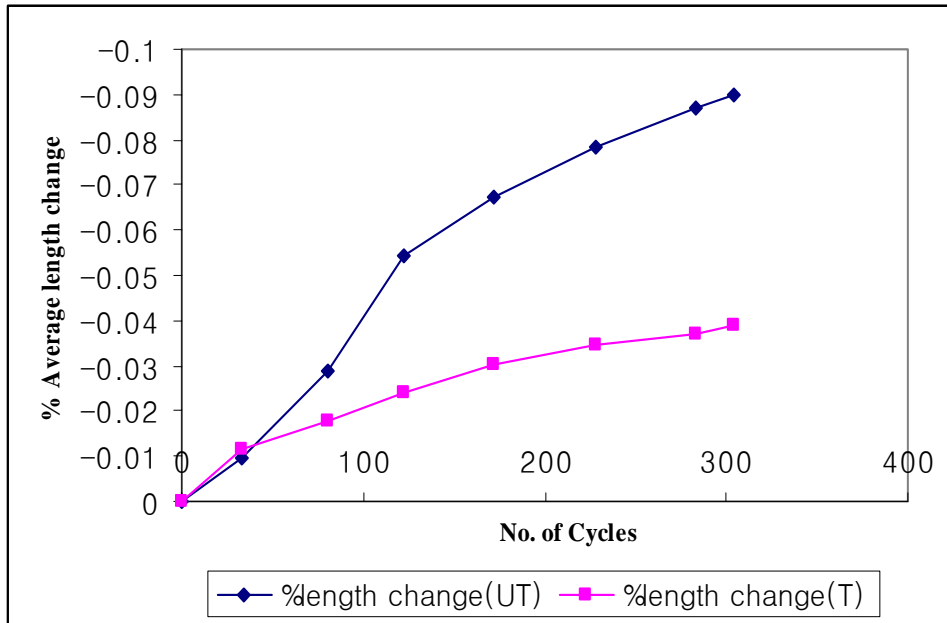


Figure 1 Percentage Length Change of Treated and Untreated Specimens (T: Treated, UT: Untreated)

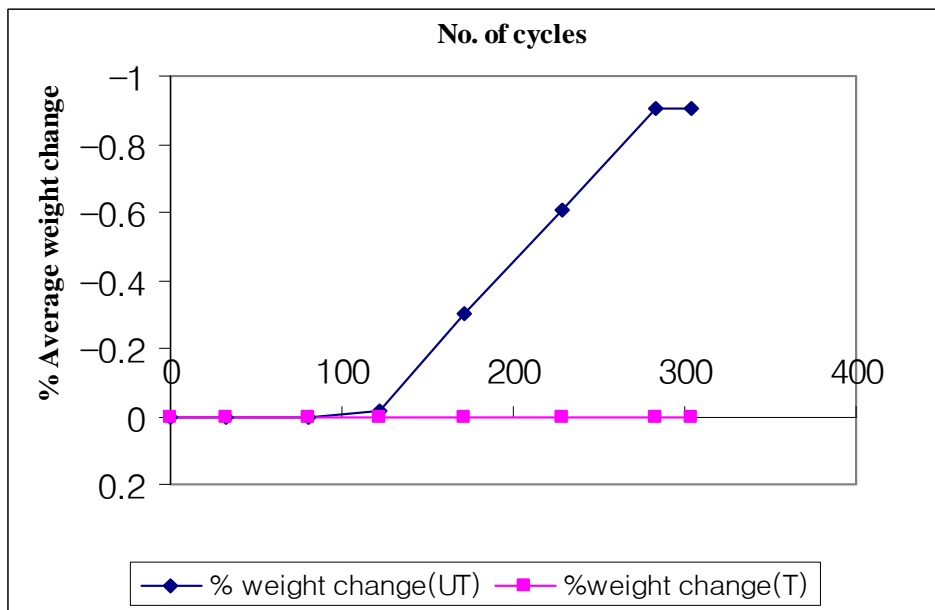


Figure 2 Percentage Weight Change (Loss) in Treated and Untreated Specimens

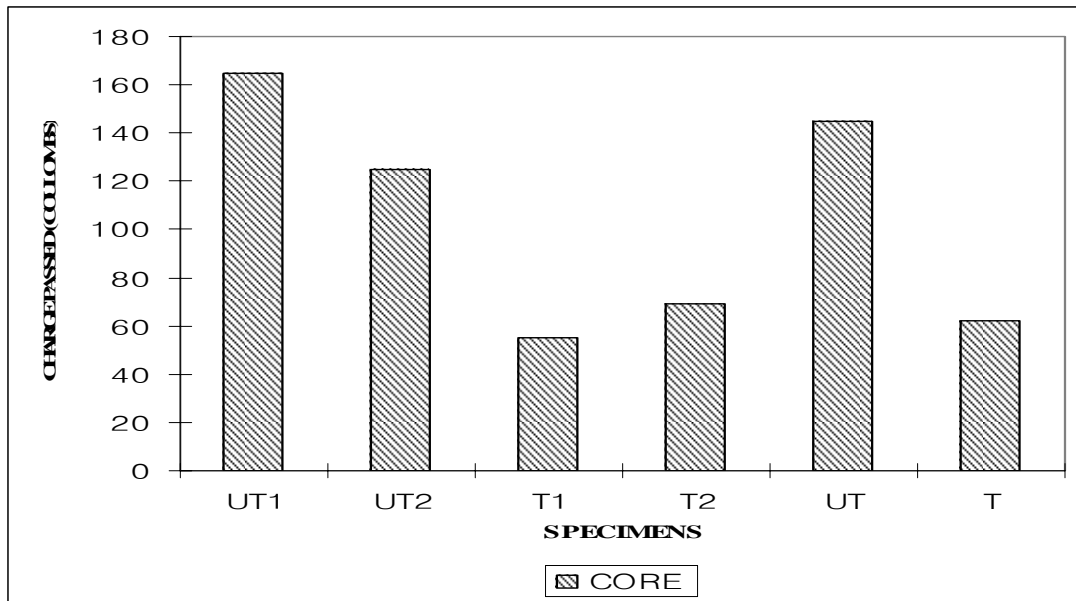


Figure 3 Permeability Test Results for Site Cored Specimens

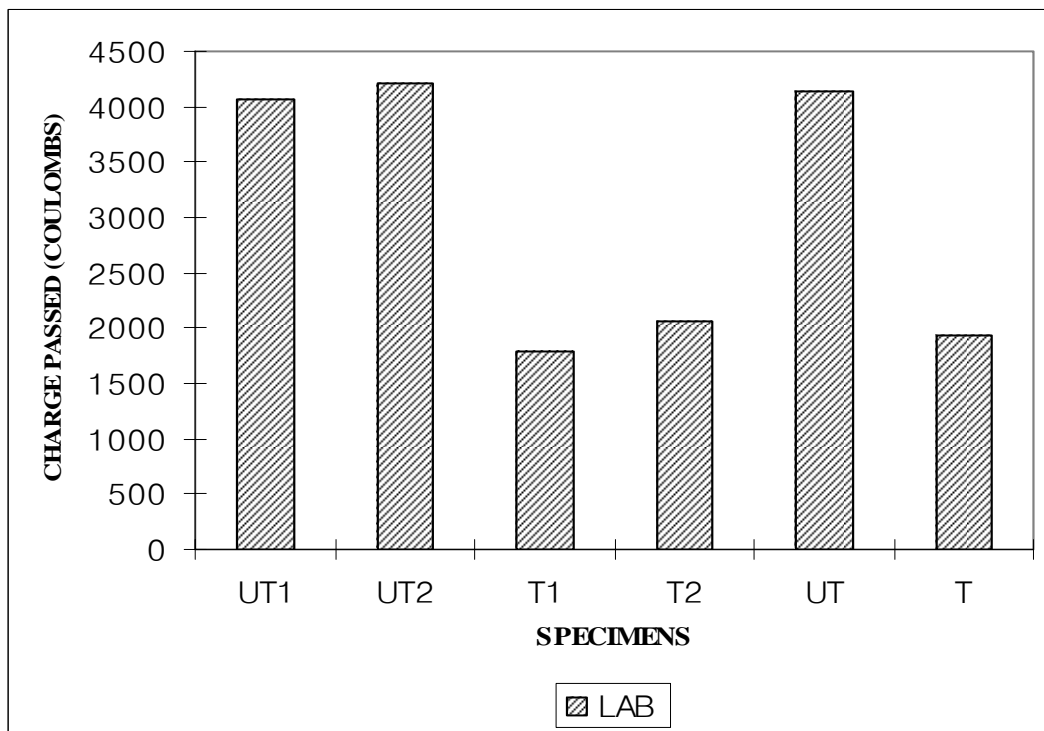


Figure 4 Permeability Test Results for Laboratory Prepared Specimens.