Technical Bulletin No. 6

The Pennsylvania State University Research Report Defines the Mechanism Which Provides Corrosion Inhibiting and Waterproofing Properties of IPANEX Modified Concrete

BACKGROUND

A research study was completed at The Pennsylvania State University in December of 1998, concluding that the use of the alkaline earth silicate admixture, IPANEX, in concrete improves durability of the concrete by inhibiting corrosion of reinforcement steel.

The cooperative research effort between university-industry-government was jointly sponsored by IPA Systems, Inc., the Pennsylvania Turnpike Commission and The Pennsylvania State University.

The research was conducted under the direction of Dr. Paul J. Tikalsky, Associate Professor of Civil and Environmental Engineering and Dr. Barry Scheetz, Professor of Civil and Nuclear Engineering.

In conducting the study, the research team took samples from bridges along the Pennsylvania Turnpike. Cores were taken from precast concrete panels. Control bridge panels not containing IPANEX were cast in 1974. IPANEX treated panels tested were cast in 1973 and 1986. All concrete was cast according to the same specifications with the exception that some contained IPANEX.

All of the bridges are located near Bedford, Pa., with similar exposure to deicing salts, precipitation, drainage and temperature.

The information in this Technical Bulletin was taken from the text of a report titled, *Evaluation of Ipanex on the Durability of Pennsylvania Turnpike Bridges,* dated December 1998.

INTRODUCTION

The poor durability of concrete members in bridge superstructures and substructures is the primary cause of bridge deterioration and subsequent need for repairs, rehabilitation or reconstruction. Although loading and fatigue factors also affect the service life of bridge girders, the service life of concrete bridge decks and substructures is predominately controlled by the microstructural quality of the concrete matrix. Factors such as permeability, level of shrinkage cracking, porosity and void structure can diminish or extend the life of a concrete member by several times. The selection and use of admixtures, cementitious material, mixing procedures, construction techniques and curing regimes affect microstructural quality. The research study investigated a specific admixture that contributes to improving the microstructural properties of portland cement concrete.

OBJECTIVE

The objective was to evaluate the long-term performance of concrete containing IPANEX, using the records of the Pennsylvania Turnpike Commission and those of IPA Systems, cores cut from box-culverts along the Pennsylvania Turnpike and a service bridge over the Pennsylvania Turnpike. The research study evaluated the microstructural properties of the concrete containing IPANEX to determine the in-situ role of IPANEX in concrete durability.

The goals of this research were as follows:

- Identify the role of IPANEX in the performance of highway and infrastructural concrete;
- Identify the long-term presence or effect of IPANEX in concrete;
- Define the mechanism by which IPANEX improves the performance of concrete;
- Document findings in a referenced publication.

VISUAL SURVEY

A visual survey by the researchers of the structures at mile markers 133.4, 134.4 and 153.1 in 1998 reveals that the decks containing IPANEX are in very good condition after 25 years of service and show no further deterioration since the 1991 detailed inspection. While there is one isolated area of deterioration, it appears to be caused by a structural defect and not chemical attack.

In contrast, the control bridge deck at mile 134.4 displays serious deterioration. Delamination or spalling exists in approximately seventy percent of the panels.

I-76 BRIDGES 1973-1991

Summary of Visual Observations (approximate values)

WJE Data

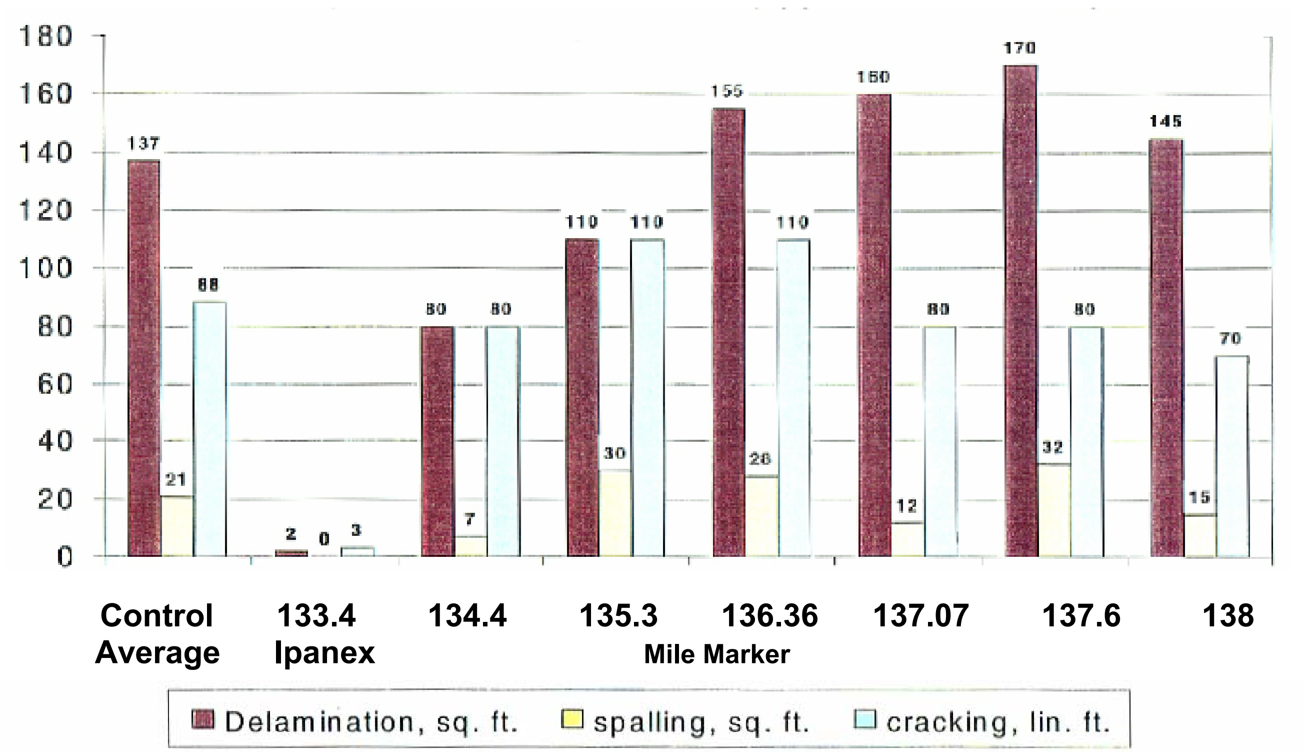

Figure 1. *Deck on Bridge 133.4 has the Ipanex*

The most serious deterioration exists below the roadway median. The panels below the ends of the bridge also display serious delamination and spalling. This control bridge is not an isolated example, but was selected as representative of all the control culverts cast in 1974 on this part of the highway (mile markers 134.4, 135.3, 136.36, 137.07, 137.6, 138). A visual survey, performed by Wiss, Janney, Elstner Associates in 1991 is analyzed (Figure 1).

The deck of the overpass at mile 153.1, which contains IPANEX, is in very good condition, while curbs alongside the roadway, which do not contain IPANEX, have spalled. This deck was placed in 1986.

SPECIMENS AND MATERIALS

To determine the role of IPANEX in concrete, core samples were taken from three precast bridge decks of the Pennsylvania Turnpike (according to ASTM C 42 Standard *Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*). Two of the bridges contained IPANEX admixture. The other bridge contained no IPANEX. IPANEX is an alkaline earth silicate admixture that chemically interacts with portland cement to improve physical and chemical properties of concrete. IPANEX is added at the job site, batch or precast plant at a recommended dosage rate of 1% by weight of cement.

MICROGRAPH STUDIES

Environmental Scanning Electron Microscopy (ESEM) was used to evaluate the microstructure of concrete containing IPANEX and to compare with control specimens. A goal of this research was to identity the long-term presence of IPANEX in concrete. IPANEX will affect the hydration in a manner that should be recognizable when comparing control specimens with specimens containing IPANEX.

Figure 2 shows a split screen view of each sample at a magnification of 4300 times. In the photo of a typical 25-year-old IPANEX-containing concrete, a different microstructure is evident. Hydrated cement grains are discernible, however they are engulfed in a continuous interconnected matrix. Unlike the control, the concrete containing IPANEX shows few discernible borders of cement grains. The microstruclure is more continuous. It appears that IPANEX causes calcium silicate hydrate to nucleate and grow in the areas that would otherwise be void space. Furthermore. the presence of alkali silicates may be reducing the zeta potential, thereby acting as a particle dispersant. The combination of particle dispersion and increased nucleation provides an explanation for the refined microstructure observed in the micrograph of IPANEX concrete.

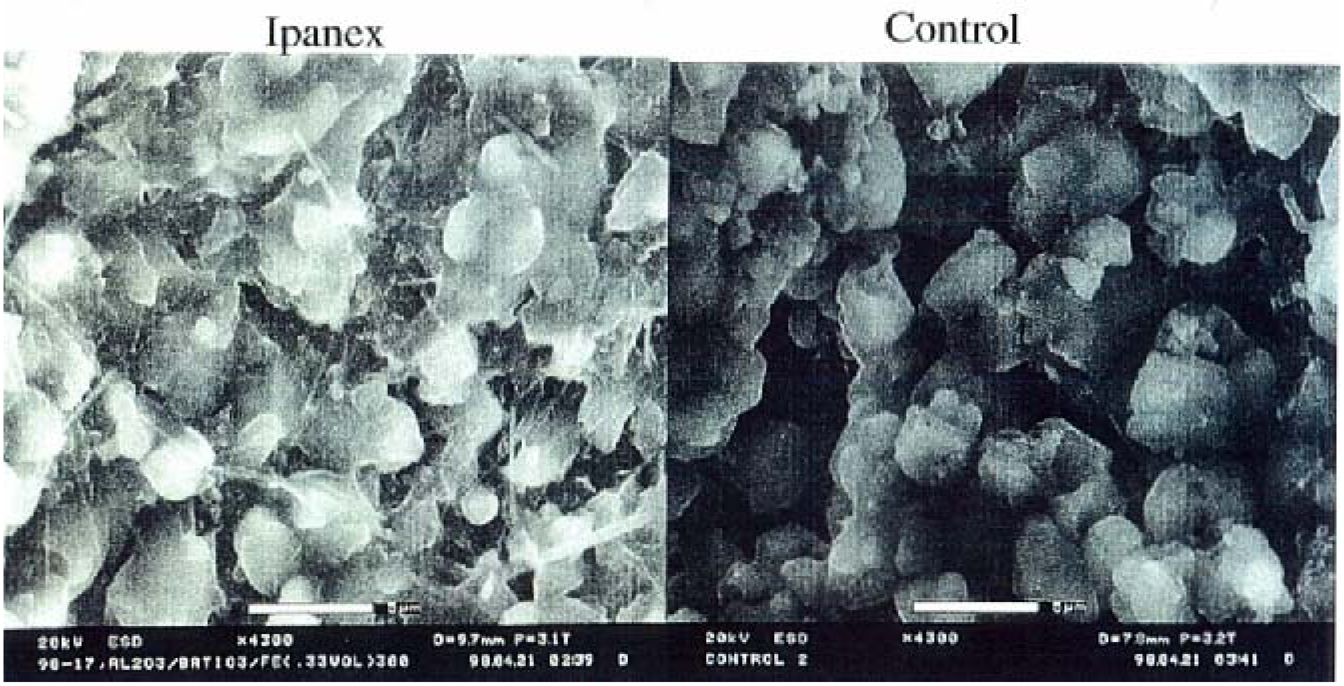

Figure 2. *At a magnification of 4300 times, hydrated cement grains are still discernible in the IPANEX concrete, however they are engulfed in a continuous interconnected matrix. Unlike the control, the concrete containing IPANEX shows few discernible borders of cement grains. The microstructure is more continuous.*

WATER PERMEABILITY

In order to quantitatively determine the effect *of* IPANEX, water permeability experiments were conducted on control and IPANEX-containing concrete specimens. The test was a pressure induced permeability test. A concrete specimen was placed within Tygon® tubing, and a lateral confining pressure of 3.45 MPa (500 psi) was applied to the tubing. At one end of the specimen, water was introduced with a driving pressure of 2.07 MPa (300 psi). At the opposite end *of* the specimen, an electronic balance measured the mass of water passing through the specimen. The mass of water collected was then converted to volume. The samples typically ran for seven days, and if no appreciable flow was observed the test was terminated (See Figure 3 for setup).

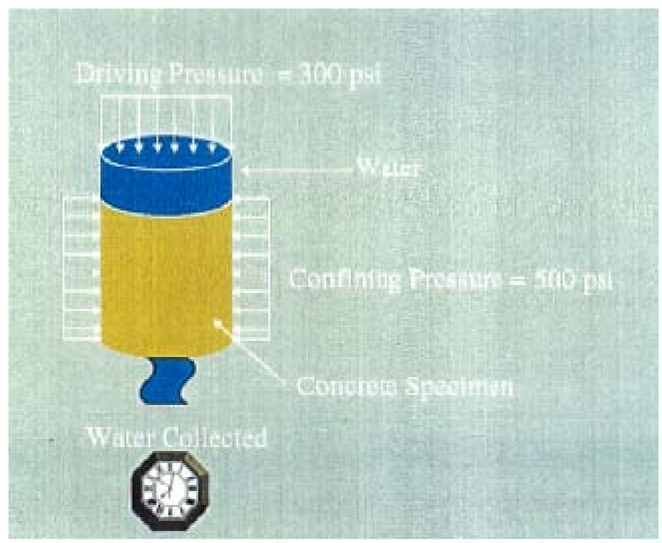

Figure 3

Results are given in a plot of volume of flow vs. time, from which the flow rate was calculated. The initial portion *of* the curve is nonlinear accounting for the saturation of the sample. Once the curve becomes linear, the slope of the line gives the flow rate of water through the sample.

Using Darcy's law, one can use flow rate, Q(cm^3/s), viscosity *of* water, v(cP), the length of the sample, l(cm), the cross-sectional area of the sample, A(cm^2), and the driving pressure, ΔP(atm), to determine the coefficient of permeability, k(darcy).

$k=(vQl)/(A\Delta P)$

Four specimens were tested for permeability, two control and two containing IPANEX. The first control specimen was tested for 95 hours and produced a permeability of 0.22 microdarcy. The second control specimen produced water, but did not achieve a constant flow after seven days, and was subsequently shut down. The specimens with IPANEX were tested for seven days and produced no appreciable water. Figure 4 displays the results for samples with and without IPANEX for comparison.

WATER PERMEABILITY
CONTROL VS. ADMIXTURE

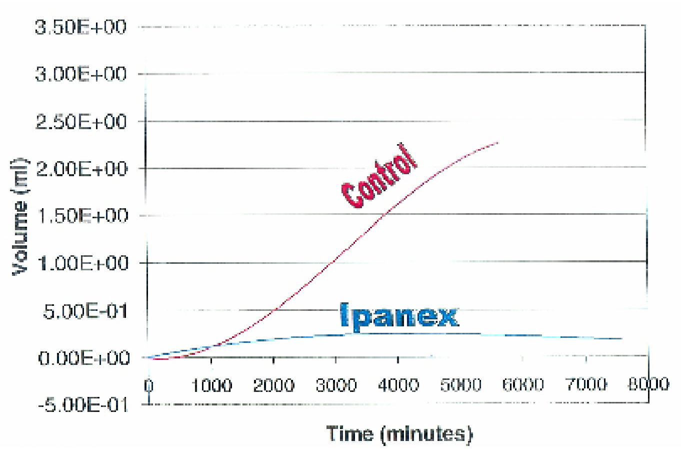

Figure 4

RAPID DETERMINATION OF CHLORIDE ION PERMEABILITY (AASHTO T 277)

Specimens were prepared and tested for resistance to chloride ion penetration according to AASHTO T 277. Each sample was 51 mm in length with a diameter of 76 mm. This size is slightly smaller than the traditional core size for this test, so the recommended correction for sample diameter is applied in the calculations. The samples are vacuum saturated and sealed into a voltage cell that contains a 3% NaCl solution at one side and a 0.3 N NaOH solution at the other. The specimens were tested with an applied voltage of 60 V for six hours. A calibrated shunt resistor was used to measure the current passing through the specimen. These values were used to calculate total coulombs, giving the total amount of charge passed through the sample during 6 hours.

The average charge passed for the duration of the test for the control was 2967 coulombs, while the IPANEX concrete average was significantly higher at a value of 5417 coulombs. AASHTO T 277 would classify the control results as moderate chloride ion penetration, while IPANEX concrete would be classified as having a high amount of chloride penetration. See paragraph 3 of the conclusions.

CONCLUSIONS

1. ESEM photos show that the concrete with IPANEX enjoys a more continuous microstructure than the control concrete. This is especially evident at the boundaries of hydrated cement grains. The borders of hydrated cement grains in IPANEX concrete have extended beyond that of the control concrete and grown into a continuous matrix of hydrated paste. The uniformity of the microstructure suggests that IPANEX is working in the manner of a plasticizer on the electrical double layer of the system. The particles are dispersed on the microscopic level allowing the silicates to initiate hydration between particles. IPANEX acts like a rheological aid, dispersing during the high-shear mixing and producing the refined microstructure.

2. Comparison of water permeability for IPANEX and control concrete shows that the concrete with IPANEX performs significantly better in preventing external penetration of water than control specimens. This is especially reinforced in the visual survey of in-place bridges. The bridge decks with IPANEX have performed well, while the control bridge decks have experienced serious cracking, delaminations and spalling.

3. The concrete containing IPANEX had much higher chloride ion permeability values according to AASHTO T 277 procedures than control concrete. These results did not agree with the results of the acid soluble chloride test performed by WJE, 1991. This suggests that the chemistry of IPANEX may be producing a false-high value for chlorides passed through the concrete when AASHTO T 277 procedures are used. AASHTO T 277 states, "This test can produce misleading results when calcium nitrite has been admixed into a concrete." The electro-potential charge of some components of IPANEX may be producing a similar effect, and therefore rendering misleading results. This test (AASHTO T 277) should not be used in evaluating concrete containing IPANEX.

4. In order for rebar corrosion to exist, three conditions must exist: presence of water at the rebar level; presence of oxygen at the rebar level; and an electrical potential. The half-cell potential test from WJE, 1991, shows that the electrical potential in these bridge decks is appropriate for corrosion to occur, but no corrosion is evident. This indicates that the corrosion system must be deprived of one of the other two components necessary for corrosion. From the water permeability test results, we can determine that the lack of penetrable water at the rebar level inhibits or stalls the corrosion reaction.

5. IPANEX has greatly extended the life of the precast bridge panels. This has a positive impact on the life cycle cost of the bridges made with this material. The improved hydration conditions and more refined microstructure from the use of IPANEX has improved the structures' resistance to corrosion and salt intrusion.

IPA Systems, Inc. • 2745 North Amber Street • P.O. Box 26869 • Philadelphia, PA 19134 • 215-425-6607 • 800-523-3834
Fax 215-425-6234 • Email info@ipasystems.com • Visit our website www.ipasystems.com