EFFECTS OF DEICER SALTS AND ROADWAY CONTAMINANTS ON POLYMER IMPREGNATION OF BRIDGE DECK CONCRETE

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Cores, 4 in. (10 cm) wide, extracted from three 7-year-old concrete bridge decks were impregnated with methyl methacrylate to evaluate the effects of deicer salts and roadway contamination on polymer impregnation. All specimens were impregnated by soaking from the top (traffic) surface at atmospheric pressure for a sufficient period of time to achieve approximately 5 in. (12.7 cm) of penetration. Deicer salts, in the quantities measured in the three bridge decks, did not reduce the depth of polymer penetration or the volume of voids filled with polymer. However, the rate of penetration decreased as salt concentration increased. The rate of penetration was a linear function of the square root of time. Removal of roadway contaminants by lye, detergent, or sandblasting had no apparent effect on the rate or extent of polymer impregnation.

•DEVELOPMENT of polymer-impregnated concrete (PIC) in this country was largely the result of the work of Steinberg et al. (1) of Brookhaven National Laboratory. Several organic thermoplastic monomers were investigated in that work for use as impregnants. Of these monomers, methyl methacrylate (MMA) showed the greatest ability to significantly improve the physical properties of concrete, i.e., compressive and tensile strengths, modulus of elasticity, and water permeability and absorption. In addition, Whiting, Blankenhorn, and Kline (2) investigated epoxy (thermosetting polymer) impregnated concretes and showed that the compressive modulus and strength are functions of porosity, age, and other parameters.

Because of the significant physical improvements offered by PIC, it was suggested (3) that MMA could solve the problem of rapid deterioration of concrete bridge decks caused by deicer salts. Fowler, Houston, and Paul (4) demonstrated the feasibility of the use of PIC surface treatments for field use on bridge decks. In their work, the soak time (impregnation period) was an important variable in relation to depth of penetration, and an evaporation barrier was necessary to prevent excessive loss of monomer. Other work in this area is being conducted at Brookhaven National Laboratory, the U.S. Bureau of Reclamation, the California Department of Transportation, Lehigh University, and Pennsylvania State University.

Few, if any, data have been reported concerning the feasibility of impregnating sound concrete in bridge decks, which may contain road contaminants such as motor oil, linseed oil, grease, asphalt cement, dirt, and deicer salts. The purpose of this paper is to evaluate the effects of deicer salts and three cleaning methods on the impregnation of bridge deck concrete with MMA that has been impregnated from the wearing surface.

EXPERIMENTS

Materials

Concrete cores were taken from three 7-year-old bridge decks with an average daily traffic (ADT) of 5,160 in 1969. The three decks were in excellent condition and did not display large cracks, spalled areas, or potholes. The concrete used in the construction of the three decks was required to meet the Pennsylvania Department of Transportation specifications for class AA reinforced vibrated concrete. Type 1 portland cement was used, and glacial sand and crushed limestone were the aggregates. The average slump, air content, and flexural strength for the concrete used in these decks are given in Table 1 (5).

The impregnation system consisted of methyl methacrylate (MMA), trimethylpropane trimethacrylate (TMPTMA), and 2, 2′-azobisisobutyronitrile (AZO) mixed in the ratio of 100:10:0.5 parts by weight respectively.

Coring of Bridge Decks

Twenty-six cores were taken from the three bridge decks. The coring positions represented the lateral range of the different use areas on a bridge deck: water tables and truck and passing lanes. Duplicate cores were taken from these areas so that chloride determinations could be made. Figure 1 shows the positions from which the cores were taken.

Sample Preparation

The bottoms of the cores were trimmed with a diamond saw to provide specimens that were 4 in. (10 cm) wide by approximately 5 in. (12.7 cm) long. The cores were then dried in a forced draft oven at 115 C for 72 hours and then for 24 hours at 115 C in a vacuum oven at 29-in. (98-kPa) Hg vacuum. After cooling under the vacuum, the sides of the cores were painted with a coat of epoxy. A metal ring, 1 in. (2.5 cm) high and 4 in. (10 cm) wide, was bonded to the top of each core with epoxy to provide a reservoir for ponding the monomer during the impregnation of the cores.

Deicer Salt Content

The chloride titration procedure (6) was used to determine the quantity of deicer salts in the cores. Chloride analyses were performed on cores 1-2, 1-4, 1-6, 2-2, 2-4, 2-6, 3-5, 3-6, and 3-8. To provide the cement paste sample used in the titrations, the cores were first split by using the tensile splitting method. The cement paste was then extracted as a fine powder by drilling on the split face with a 3/16-in. (4.8-mm) carbide drill bit. The positions drilled were in the cement paste areas, and care was taken to avoid any large aggregate particles. Cement paste samples were obtained from four areas on each core [0 to 1/4 in. (0 to 6 mm), 1/4 to 3/4 in. (6 to 19 mm), 3/4 to 1 3/4 in. (19 to 44 mm), and 1 3/4 to 3 3/4 in. (44 to 95 mm) in depth from the wearing surface].

Impregnation of Cores

The impregnation of the dried cores with the MMA system was accomplished by allowing the monomer to soak through the cores from the wearing surface; only an evaporation barrier was provided above the free monomer surface. The rate of impregnation was determined by periodic weighing of the specimens during impregnation. Completion of impregnation was assumed to occur when the monomer exuded uniformly from the bottoms of the specimens.

Table 1. Average concrete control parameters.

Bridge Structure Number	Slump (in.)	Air Content (percent)	Flexural Strength (psi at 7 days)
6254 NB	2.2	6.5	769
6254 SB	2.2	6.5	641
6258 NB	2.2	6.2	956

Note: 1 in. = 2.54 cm. 1 psi = 6.895 kPa.

Figure 1. Coring positions of bridge decks 6254 NB (1-1 to 1-9), 6254 SB (2-1 to 2-9), and 6258 NB (3-1 to 3-8).

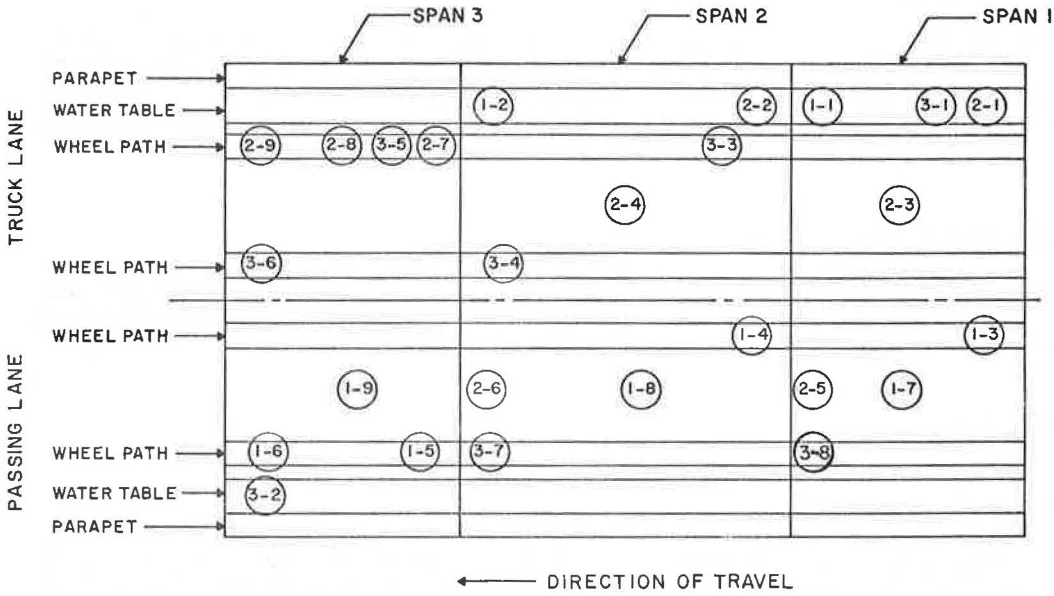
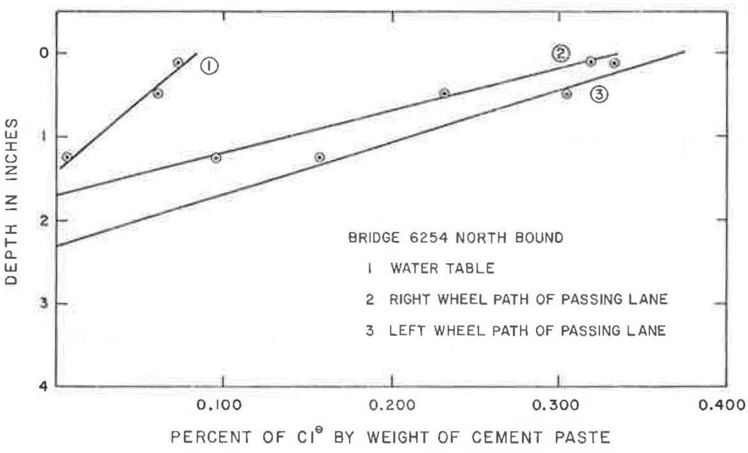


Figure 2. Chloride content of bridge 6254 NB.



Cleaning of Cores

It was assumed that the heaviest traveled areas would have the greatest amount of surface contamination. Therefore, six cores were taken from the truck lane: three from the right wheel path and three from between the wheel paths. The surfaces of these cores were cleaned by three methods (detergent, lye, and sandblasting). Cores 1-7 and 2-7 were scrubbed for 5 min with a 20 percent by weight detergent solution, cores 2-7 and 2-8 were scrubbed for 5 min with a 20 percent by weight lye (NaOH) solution, and cores 1-9 and 2-9 were cleaned by sandblasting at 75 psi (517 kPa) for 10 min.

Water Absorption

After the cores were impregnated and the MMA system was polymerized in a constant temperature water bath at 167 F (75 C), they were dried at room temperature for 15 days. The cores were then vacuum saturated with water and allowed to soak for 24 hours. Water absorption was measured by the weight gained because of the penetration of the water during vacuum saturation.

Estimate of Core Porosity

A section was cut from each core, dried as previously cited, vacuum saturated with water, and placed under water at 75 psi (517 kPa) for 24 hours. The porosity was determined by the weight gained during saturation.

RESULTS

Deicer Salt Content

Typical results of the nine bridge deck cores analyzed for chlorides are shown in Figure 2. The concentrations of the chlorides appear to decrease linearly as a function of depth. This agrees with other results concerning the durability of concrete bridge decks (7) for sound decks. The degree of contamination by chlorides was approximately the same for the areas investigated. For the areas not used by traffic, the concentrations were lower.

Impregnation

The percentage of monomer gained in 96 hours was calculated as follows:

$$\text{Percentage at 96 hours} = \frac{\text{monomer gained in 96 hours}}{\text{total monomer gained}} \times 100$$

The percentage of the volume of the core filled by the monomer system was calculated as

$$\text{Percentage of volume filled} = \frac{\text{weight of MMA system gained/density of MMA}}{\text{bulk volume of core}} \times 100$$

The impregnation data are given in Table 2. Figure 3 shows results of the impregnation

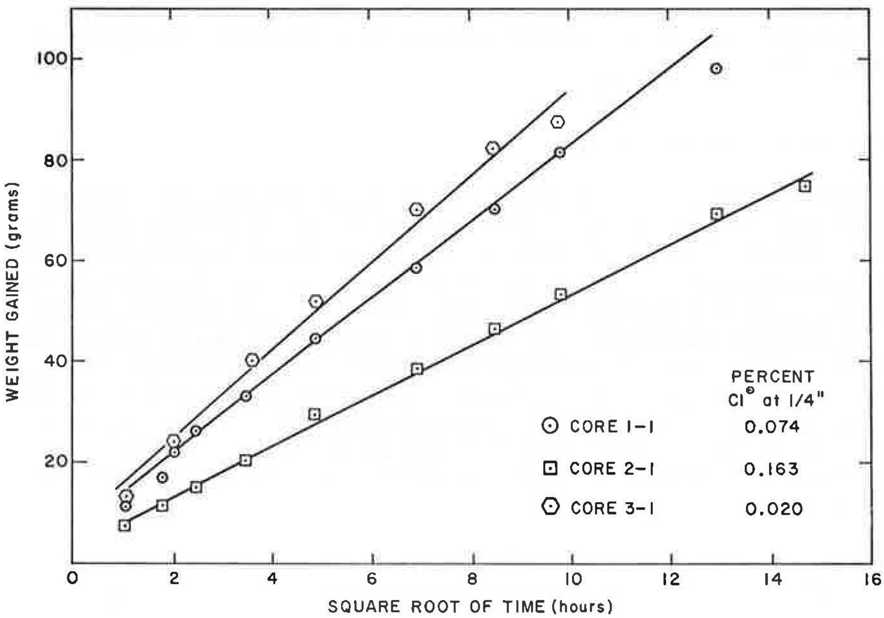
Table 2. Impregnation data for bridge deck core.

Core Number	Slope $(g/\sqrt{h})$	Monomer Gained at 96 Hours: Amount (g)	Monomer Gained at 96 Hours: Percent[a]	Total Monomer Gained (g)	Volume Filled (percent)	Chloride at 1/4 In.	Soak Time (days)
1-1	7.4	81.5	82.7	98.5	9.8	0.074	7
1-3	6.7	71.1	81.2	87.6	8.8	0.333	7
1-5	5.6	54.8	62.3	87.9	8.7	0.319	11
1-7	5.0	54.0	66.1	81.7	8.5	0.319	11
1-8	4.7	50.4	73.1	68.9	8.0	0.319	9
1-9	5.9	58.8	70.0	84.0	8.5	0.319	9
2-1	5.0	53.0	71.0	74.6	7.4	0.163	9
2-3	5.0	52.7	64.4	81.8	8.2	0.355	11
2-5	5.1	56.1	66.6	84.2	8.5	0.377	11
2-7	5.9	65.2	75.1	86.8	8.8	0.355	9
2-8	5.1	50.0	61.6	81.2	8.1	0.355	11
2-9	5.8	68.1	67.2	93.9	9.4	0.355	11
3-1	8.7	87.5	100.0	87.5	8.8	0.020	4
3-2	7.7	78.2	83.5	93.7	9.4	0.020	6
3-3	7.6	76.0	91.9	82.7	8.3	0.298	5
3-4	5.6	60.9	79.6	76.5	7.7	0.192	7
3-7	5.4	58.8	81.1	72.5	7.3	0.020	7

Note: 1 in. = 2.54 cm.

[a]Percentage of 5-in. (12.7-cm) core depth impregnated.

Figure 3. Weight gained as function of the square root of time.



of the concrete with MMA plotted as weight gained in grams as a linear function of the square root of time in hours (8, 9). The slope of the curve (the rate of impregnation) varied both with position on the bridge decks and from deck to deck for the three decks. Cores 1-1 to 1-9 and 2-1 to 2-9 of bridge decks 6254 northbound (NB) and 6254 southbound (SB) were in close agreement, and cores 3-1 to 3-8 of deck 6258 NB displayed a higher rate. The percentage of monomer gained at 96 hours (Table 2) varied considerably.

The lateral position of the cores on the decks was matched with the closest lateral position of the cores used for chloride analyses. The values of chlorides in the top ¼ in. (6 mm) were then assigned to the respective impregnated cores. These chloride values are also given in Table 2.

Correlation coefficients were calculated for the chlorides in the top ¼ in. (6 mm) versus the percentage of MMA at 96 hours and the percentage of volume filled with MMA. The correlation coefficients were compared for significance at the 95 percent confidence level. No significant correlation was established for percentage of chloride at ¼ in. (6 mm) versus total percentage of volume filled with MMA. However, significance at the 95 percent confidence level was established for the percentage of chlorides at ¼ in. (6 mm) and percentage of volume filled with MMA at 96 hours.

Figure 4 shows a cross section of an impregnated core. The almost uniform tone of the photograph indicates a high degree of uniformity in penetration by the monomer. However, the voids in the upper part of the core appear to be filled to a greater degree than do those near the bottom, as indicated by close visual examination.

Because of the small sample sizes of the cores subjected to the various cleaning processes, no statistical analyses were performed. However, a comparison of the percentage of MMA gained in 96 hours for the six cores that were cleaned (1-7, 1-8, 1-9, 2-7, 2-8, and 2-9) with the remaining cores from the same two bridge decks (Table 2) shows that contamination from materials considered here has no significant effect on polymer loading.

Water Absorption After Impregnation

The estimated porosity, the core volume filled with water and the estimated porosity filled by absorbed water after impregnation and polymerization, the estimated porosity filled with polymer, and the decrease in water absorption due to the soak impregnation are given in Table 3. After polymer impregnation, the majority of the cores showed between 2 and 4 percent volume filled with water. However, no significant correlation existed between the chloride content at ¼ in. (6 mm) and the percentage of volume filled with water by vacuum saturation. No significant correlation was established for the estimated porosity versus the rate of impregnation and the total monomer gained. The polymer filled approximately 50 percent of the estimated porosity. The water, after impregnation and polymerization, filled about 15 percent of the estimated porosity. The water absorption was decreased by about 85 percent after the soak impregnation technique was used.

DISCUSSION OF FINDINGS

When the soak method with MMA was used (4), the penetration depths were ¼ to 1½ in. (6 to 38 mm) in laboratory-prepared concrete. This paper has shown that a depth of at least 5 in. (12.7 cm) can be achieved in sound concrete from in-service bridge decks provided the concrete is thoroughly dried. The rate of impregnation was a linear function of weight gained in grams versus the square root of time in hours. This agrees with Washburn's equation (10) for a porous body that behaves as an assemblage of small cylindrical capillaries. In this equation, the volume of flow V that penetrates the given medium in time t behaves in accordance with

$$V = k\left(\frac{r}{\eta}t\right)^{1/2}$$

where r is the radius of the capillary, and η the viscosity of the liquid.

When the soak method is used, deicer salts appear to decrease the rate of impregnation of bridge deck concrete. However, bridge decks may be impregnated to a depth of 5 in. (12.7 cm) regardless of the presence of deicer salts.

The rate of impregnation and the percentage of monomer gained in 96 hours varied within each deck and from deck to deck. The monomer gained at 96 hours varied from 61.6 to 100 percent. This implies that, in 96 hours, the cores were impregnated from 60 to 100 percent of their 5-in. (12.7-cm) depth. Therefore, for a 96-hour impregnation period, penetration will be nonuniform at a depth of 5 in. (12.7 cm).

Because of the small number of cores that were cleaned, it is not possible to provide quantitative conclusions about the effect of roadway contaminants on the impregnation rate. However, the data indicate that bridge decks may be impregnated when heavy accumulations of contaminants are removed.

The percentage of volume filled by polymer and the percentage of the volume filled with water absorbed after impregnation are probably related to the two parameters that govern permeability: the porosity and pore size distribution. Because of this, it is probable that deicer salts in concrete at the concentrations found in this research do not appreciably change the permeability of the PIC.

Since there was no correlation established for porosity versus rate of impregnation and total monomer gained, the rate of impregnation and the percentage of the void volume filled with polymer may depend to a large extent on the pore size distribution rather than on the overall total porosity.

Water absorption was decreased to 15 percent of the original porosity when 50 percent of the porosity was filled with polymer, indicating that voids were made inaccessible by the MMA polymer in the concrete.

SUMMARY AND CONCLUSIONS

Cores were obtained from in-service bridge decks. Chloride contents of selected cores were determined by a titration technique. The remaining cores were dried by using forced air and vacuum ovens. They were impregnated by using the soak method with an MMA system, and the monomer was thermally polymerized.

Chlorides present at the concentrations reported do not affect the percentage of volume of voids filled or the impregnation depth achieved [5 in. (12.7 cm)] with the monomer system used. Chlorides do appear to decrease the rate of monomer impregnation when the soak method is used. Removal of roadway surface contaminants by three different procedures did not appear to affect the rate or extent of polymer impregnation.

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Figure 4. Cross section of core of polymer-impregnated bridge deck.

Table 3. Void volume with MMA and water.

Core Number	Estimated Porosity (percent)	Volume Filled With Water (percent)	Porosity Filled With Water (percent)	Porosity Filled With Polymer (percent)	Decrease in Water Absorption (percent)
1-1	17.7	3.9	22	55	88
1-3	18.4	2.9	16	48	84
1-5	16.7	3.1	19	52	81
1-7	19.0	2.2	18	45	82
1-8	17.6	5.0	29	45	71
1-9	15.1	1.3	09	56	91
2-1	14.1	2.2	16	52	84
2-3	20.7	5.8	23	40	77
2-5	19.7	3.6	13	43	87
2-7	16.0	1.5	09	55	91
2-8	15.4	0.8	05	53	95
2-9	19.0	1.3	07	50	93
3-1	17.2	3.3	13	45	87
3-2	16.6	2.8	16	57	84
3-3	16.4	2.5	15	51	85
3-4	18.5	3.6	20	41	80
3-7	15.5	2.2	14	47	86

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