POLYMER IMPREGNATION OF CONCRETE BY METHYL METHACRYLATE AND ITS EFFECTS ON MECHANICAL PROPERTIES AND CORROSION OF STEEL IN CONCRETE

Changiz Dehghanian

Isfahan University of Technology
Department of Chemical Engineering
Isfahan, Iran.

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Abstract Freezing and thawing resulting from the ingression of water into concrete causes cracking or spalling. Corrosive ions such as chloride or sulfate penetrate the concrete surface and eventually reach the reinforcing steel. This causes the steel to corrode.

Because of the high maintenance and replacement costs, responsible officials should be increasingly concerned about the growing number of prematurely deteriorated concrete structures. One of the practical methods for reducing the high cost of repair is partial impregnation of concrete by polymers. In this paper, partial impregnation of concrete by methyl methacrylate for protection against deterioration of concrete is evaluated. Parameters such as the monomer system, drying time, drying temperature, soaking time, curing time and temperature are evaluated. All these parameters affect the economics of polymer impregnation of concrete. The results of this study show that corrosion of steel in the polymer impregnated concrete is lower than non- impregnated concrete. In addition, the mechanical properties of polymer impregnated concrete in comparison to concrete without polymer are improved.

چکیده نفوذ آب بداخل بتون و سیکل یخ زدن و ذوب شدن آن باعث شکاف و تخریب بتون می گردد. یونهای خورنده از قبیل یون کلریاسولفات از سطح بداخل بتون نفوذ کرده و نهایتاً به فولاد در داخل بتون میرسند. این عمل باعث خورده شدن فولاد در بتون می شود. بعلت هزینه سنگین تعمیر و جایگزینی، مسئولین باید توجه زیادی به این موضوع داشته باشند که تعداد زیادی از سازه های بتونی قبل از گذراندن عمر مفید خود از بین میروند. یك روش عملی برای کاهش هزینه سنگین تعمیر سازه های بتونی، اشباع جزئی بتون بوسیله پلیمر می باشد. در این مقاله، اشباع جزئی بتون بوسیله متیل‌متاکریلیت برای حفاظت برعلیه تخریب بتون ارزیابی شده است. پارامترهائی از قبیل سیستم منومر، زمان خشك کردن، درجه حرارت خشك کردن، زمان خیس دادن و زمان و درجه حرارت بعمل آوردن بررسی شده است. تمام این پارامترها بر روی اقتصاد پروسس اشباع بتون بوسیله پلیمر اثر می‌گذارد.

نتایج این مطالعه نشان میدهد که خوردگی فولاد در بتون اشباع شده بوسیله پلیمر کمتر از بتون بدون پلیمر است. بعلاوه خواص مکانیکی بتون اشباع بوسیله پلیمر بهتر از بتون بدون پلیمر می‌باشد.

INTRODUCTION

Many concrete structures such as bridge decks, parking garages and sea structures which were expected to last for more than 40 years are requiring major repairs after 5 to 10 years and some of them must be replaced after 15 years [1]. Numerous techniques have been suggested to prevent the corrosion of steel in concrete. The criteria presently used in selecting a method are feasibility, cost and safety. One of the techniques employed for reducing the deterioration of concrete is partial impregnation of concrete by polymer. The main purpose of this study was to develop and evaluate a concrete which is partially impregnated by polymers. Polymer impregnation of concrete involves the polymerization of a liquid monomer which has partially or fully saturated the pores of previously cured (hardened) portland cement concrete. In full impregnation, the monomer is forced through the entire bulk of concrete. In partial impregnation the monomer soaks into the surface layer of the concrete. In both, the polymerization is then conducted to fill the cracks and voids in the concrete.

In the application of partial impregnation of concrete by polymers, parameters such as the monomer system, drying time, drying temperature, soaking time, curing time and temperature will determine the economics of the process. Then these parameters must be optimized in order to reduce costs.

A monomer system usually consists of a monomer, an initiator and a cross-linking agent. An initiator is used in order to initiate the polymerization of the monomer and a crosslinking agent is used for obtaining strong interchain bonding. There are several monomers, initiators and cross-linking agents which can be used. In this study, a monomer of methyl methacrylate (MMA) was used because of its low viscosity and suitable cost [1,2,3] compared with the other monomers.

With this monomer, Azobis-isobutyronitrile (AIBN) and trimethylol propane trimethy acrylate were chosen as the initiator and cross-linking agents respectively. The monomer system used in this study consisted of 88.5% (w/w) methyl methacrylate as the monomer, 1.5% azobia isobutyronitrile as the catalyst initiator and 10% trimethylolpropane trimethyacrylate as the cross-linking agent.

EXPERIMENTAL PROCEDURES

The experiments described below were done in the Corrosion Laboratory of Corrosion Specialists, Inc. in the U.S.A. This laboratory was equipped with all instruments and facilities needed for conducting the tests.

Three laboratory expriments were conducted on several 30× 30×17.5 cm concrete slabs. These samples were poured using the standard mix design shown in Table 1. These samples were then cured in a 100% humidity cabinet for 28 days. After curing, the slabs were dried at 110°C(230°F) for 24 hours and then enclosed in a polyethylene bag to prevent moisture from re-entering and left to cool to room temperature 25°C (77°F). A 10 cm wooden dam was sealed with putty to the slabs and a 0.32 cm layer of room dried sand was spread on the surface of the slabs.

In the first experiment, different amounts of monomer systems were applied to the sand. Each dam was covered with polyethylene wrap to inhibit monomer evaporation and the time the monomer system was applied was recorded. The monomer was allowed to soak until the sand felt dry to the touch. To reduce

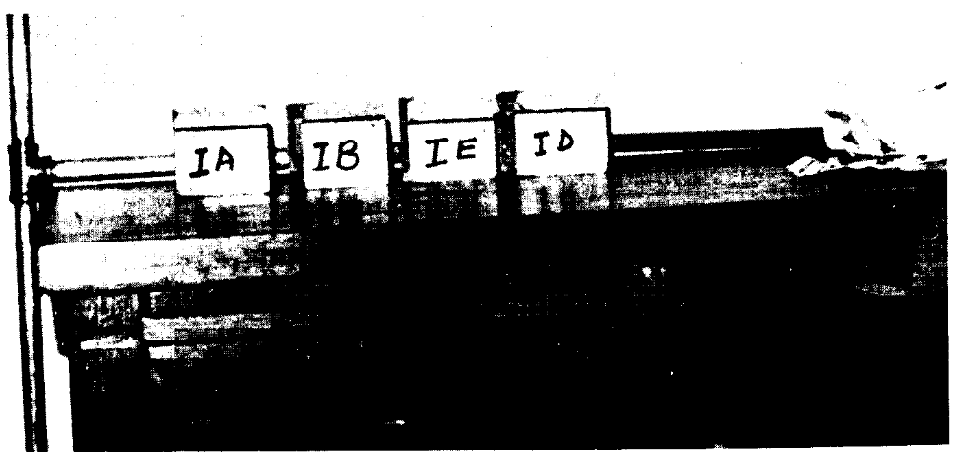

Figure 1. Impregnated Slabs Showing Polymer Depth.

error, the sand was felt for dryness frequently. The time the sand felt dry to the touch was recorded. The difference between the two times gave the soaking time. The monomer was polymerized by heating the slab with steam for 2.5 hours. The slabs were then cut open to determine the depth of impregnation (see Figure 1). When the slabs were cut open, two bands of discoloration were revealed. The discoloration nearer the surface was gray while the one further from surface was relatively light in color. To be sure the two bands contained polymer, a drop of water was applied to three different areas: 1) the gray colored portion, 2) the light gray colored portion, and 3) the slab interior where there was no discoloration. Both drops from areas 1 and 2 beaded and showed definite contact angles and since the contact angle of water on untreated concrete is zero (which was proved by the drop on area 3) the test indicated that polymer was present in both color bands. The depth (h) in inches of the entire discolored portions was measured. Figure 2 shows a graph of depth (h) with respect to the square root of the soaking time.

In the second experiment, the same type of slabs as previously described was used. This experiment was done in a similar manner to the previous experiment. However, the various monomer loadings were known, and it was not necessary to cure the slabs.

The sand was felt to determine the soaking time. This method of determining the soaking time might be expected to introduce an error in the result. Curing of the monomer soaked into slabs was not done here.

In the third experiment, the same types of slabs were used as in the two previous experiments. This experiment was done exactly as the experiment dealing with monomer penetration versus time using various known monomer loading.

Enough soaking time was allowed for each monomer loading. Curing time was 2.5 hours for each study. The slabs were cut open and the depth of penetration was measured.

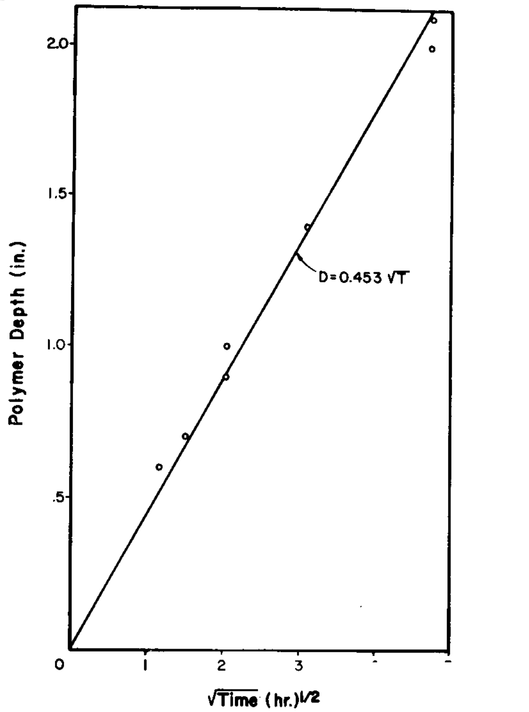

Figure 2. Polymer Depth Vs. Square Root of Soak Time.

RESULTS AND DISCUSSION

Figure 2 shows a graph of penetration depth versus the square root of soaking time. This plot indicates a straight line relationship which is in agreement with theoretical developments [4]. This figure also shows that the rate of monomer penetration decreases as the soaking time increases. To put this result to use, the depth of impregnation required is selected and the amount of soaking time necessary to achieve this depth is obtained from Figure 2. Since a depth of at least 2.54 centimeters (1 inch) of impregnation of concrete is usually desired, a soaking time of at least 4 hours (see Figure 2) is required. The problem of evaporation of the monomer during soaking is more pronounced with a longer period of soaking time.

Figure 3 is a plot of loading versus the square root of soaking time. A straight line was obtained. To apply this result, select the depth of impregnation required and read off the amount of soaking time necessary to give this depth from Figure 2. The maximum

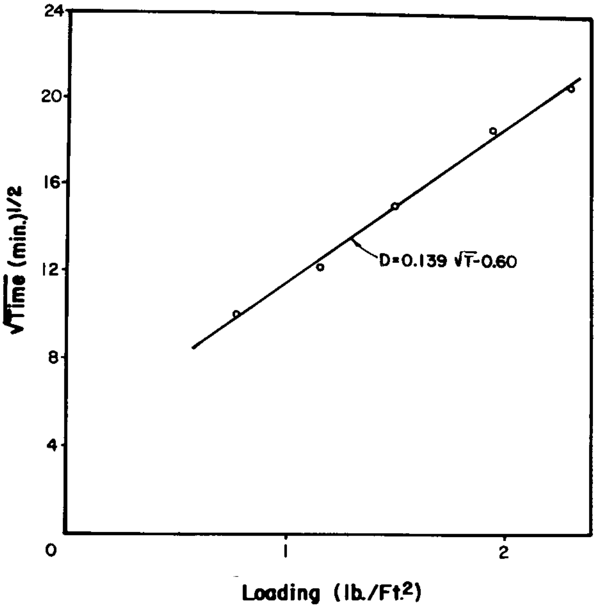

Figure 3. Square Root of Soak Time as a Function of Monomer Loading.

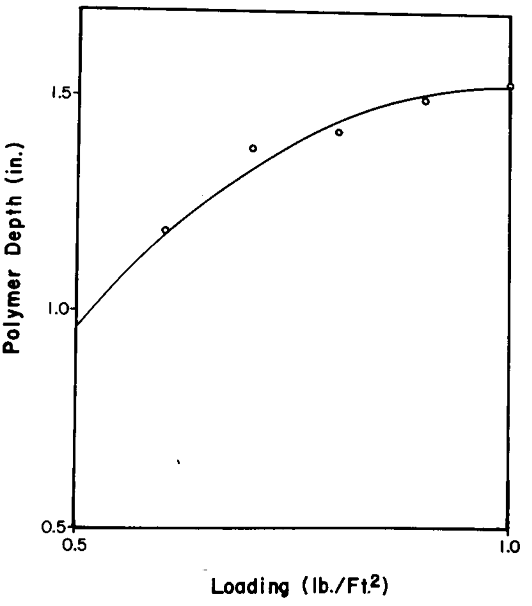

Figure 4. Polymer Depth as a Function of Monomer Loading.

monomer loading that can be expected to soak completely into concrete within the given time is obtained from Figure 3. As an example, supposing a 2.5 cm (1 inch) of impregnation is required. A 2.5 cm (1 inch) of impregnation takes 4 hours soaking time (see Figure 2), which in turn gives 0.733 gm/cm^2(1.5 lbs/ft^2) monomer loading (see Figure 3). Note that it is not necessary to use this maximum monomer loading to obtain the desired depth of impregnation/penetration. This was checked using cured samples.

Figure 4 is plot of loading versus depth of penetration. A fairly smooth curve was obtained. For 2.54 cm (an inch) depth of penetration, 0.293 gm/cm^2(0.6 lbs/ft^2) monomer loading is required. Thus, it is not necessary to use the 0.733 gm/cm^2(1.5 lbs/ft^2) monomer loading obtained from the soaking time requirement (Figure 3). There were sources of error in the monomer loading versus soaking time experiment. Evaporation of monomer reduced the actual monomer loading. The qualitative method of touching the sand in order to monitor its dryness had an element of error in it that could be significant. Thus a 0.293 gm/cm^2(0.6 lbs/ft^2) monomer loading and 4 hour soaking time should give 2.54 cm (an inch) depth of impregnation.

In order to determine the effectiveness of polymer impregnation of concrete other tests such as the measurement of mechanical properties of concrete and the rate of diffusion of chloride and water into concrete were conducted. For diffusion of chloride into concrete, the specimens were exposed to salt water for two months, then the amount of chloride diffused into the concrete as a function of depth was measured by the Berman Technique [5]. For determination of water uptake into concrete, the concrete samples initially were oven dried at 105$^{\circ C}$ for one hour then their weights were measured. These dried samples were placed into water for two months and their weights were measured again. The difference between these two measurements was recorded as the water uptake. These results are given in Table 2. The results show that diffusion of chloride and water into polymer impregnated concrete is much lower than the concrete without polymer. This in turn shows that corrosion of steel in the concrete with polymer is much lower than the concrete without polymer. In addition, the com-

Components	Weight
Course Aggregate	46.97 to 47.8
Fine Aggregate	30.57 to 33.58
Cement (Type I)	15.45 to 16.55
Water	6.07 to 6.37
Water/Cement ratio	0.393 to 0.385

pressive strength in polymer impregnated concrete is in the range of 44.81 Mpa to 68.94(6500 to 10,000 lbs/in^2) while in control slabs it was about 20.68 to 28.26 Mpa (3000-4100 lbs/in^2) The resistance of polymer impregnated concrete slabs against sulfuric and chloric acid was fairly good while this resistance was lower for the control slabs. These results were also in good agreement with some other works [4,6].

CONCLUSION

From this study the following results can be drawn.

1. Application of partial polymer impregnation of concrete by methylmethacrylate increases the resistance of concrete against damages caused by freezing and thawing due
2. Application of partial polymer impregnation of concrete by methylmethacrylate reduces the rate of diffusion of chloride or other corrosive ions into concrete which in turn reduces the corrosion rate of steel in concrete.
3. Partial polymer impregnation of concrete by methyl methacrylate increases the resistance of concrete against diffusion of acid which in turn increases the life of concrete structures.
4. Partial polymer impregnation of concrete by methyl methacrylate improves the mechanical properties of concrete such as compressive strength.
5. Application of partial polymer impregnation by methyl methacrylate can be economical if parameters such as monomer loadings, drying time, soaking time and polymerization temperature are optimized.

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Table 2. Comparison of some concrete properties for the concretes with and without polymer.

Properties	Concrete with polymer	Concrete without polymer
Compressive Strength (psi)	6500-10000	3000-4100
Resistance against acid	Excellent	Weak
Diffusion of Chloride after 2 months exposure	0 to 0.1% Cl^- based on weight of cement at 1.27 centimeters form concrete surface	0.25% Cl^- based on weight of cement at 3.8 centimeters from concrete surface and 1.75% cl^- at 0.76 centi meters from surface
Diffusion of water after 2 months exposure	70 to 80% reduction in water in comparison to concrete without polymer	Saturated with water

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