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APPLICATIONS OF CONCRETE POLYMER MATERIALS FOR THE REHABILITATION OF BRIDGE DECKS

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ABSTRACT: The rapid deterioration of concrete bridge decks as a result of the increased use of deicing salts is one of the most severe problems facing the highway industry today. One possible solution to the problem is the use of concrete polymer materials. The materials of prime interest are polymer-impregnated concrete (PIC) and polymer concrete (PC), both of which have excellent durability and strength properties. Three potential applications: repair of deteriorated bridge decks, polymer impregnation of new bridge deck surfaces, and full impregnation of precast deck panels have been studied in laboratory and field tests and the results have been encouraging. These results and economic considerations are described in the paper. The work in each of the areas is currently being implemented by the Federal Highway Administration.

INTRODUCTION

Deterioration of concrete bridge decks is caused by deicing salts, corrosion of reinforcing steel, freeze-thaw deterioration, spalling, and heavy traffic loads. This represents the most severe problem facing the highway industry today. In addition to being costly, bridge deck maintenance is difficult to perform under hazardous traffic conditions and presents delays and safety hazards to the traveling public because of lane closures, detours, traffic jams, and the increased risk of accidents. One approach to the problem is the use of concrete polymer materials in new highway construction and for repair work. The materials of prime interest are polymer-impregnated concrete (PIC) and polymer concrete (PC), both of which have excellent durability and strength properties.

PIC consists of a precast or cast-in-place portland cement concrete impregnated with a monomer system that is subsequently polymerized *in situ*. The polymer tends to fill the porous void volume of the concrete, which results in significant improvement in strength and durability properties.

PC consists of an aggregate mixed with a monomer or resin that is subsequently polymerized in place.

A third type of material, which represents a further development of PIC, is being utilized as a means of preventing chloride intrusion into cast-in-place bridge decks. This is a precast concrete that has been partially impregnated to a finite depth with a monomer that is subsequently polymerized.

PROPERTIES OF CONCRETE POLYMER MATERIALS

PIC is the most developed of the concrete polymer composites and the greatest improvements in structural and durability properties have been obtained with this material. For a concrete mix that produces specimens with a compressive strength of 5000 psi (35.2 MN/m^2), values > 20,000 psi (141 MN/m^2) are generally obtained after impregnation. Design values for PIC that cover the range of monomer systems used and many types of concrete have been published [1]. These values are as follows: compression 15,000 psi (105.6 MN/m^2), direct tension 1000 psi (70.4 MN/m^2), modulus of rupture 1300 psi (9.1 MN/m^2), shear 750 psi (5.3 MN/m^2), modulus of elasticity 6×10^6 psi (4.2×10^4 MN/m^2), and Poisson's ratio 0.2.

Equally significant improvements in durability have been obtained. Resistance to abrasion and cavitation are enhanced. The water absorption is reduced by > 99% and the resistance to chemical attack and freezing and thawing is enormously improved.

PIC is relatively impermeable to chlorides and its potential for preventing reinforcing steel corrosion and surface scaling has been demonstrated. After 267 daily salt applications, the maximum chloride concentration found at a depth of 1 in. (2.54 cm) was essentially zero [2].

Partially impregnated concrete is a variation of PIC which is designed for durability rather than high strength. This permits a saving in the amount of monomer and in ease of impregnation as compared with fully impregnated concrete. Laboratory tests have indicated that a penetration depth of 1 in. (2.54 cm) is adequate to prevent chloride penetration into the concrete [2]. Good resistance to abrasion and scaling is also obtained.

Due to its high strength, durability, and rapid curing rate at ambient temperatures, PC is being used on highways and bridges as a rapid patching material. Its potential for use as an overlay material is being evaluated. The material consists of a monomer and an aggregate. It is mixed and placed using techniques similar to those used for portland cement concrete [3]. Full strength is attained immediately after the polymerization reaction is completed. Depending upon the concentrations of promoter and initiator and the ambient temperature, this time can vary from a few minutes to approximately 4 hr. Compressive strengths up to 20,000 psi (141 MN/m^2) have been obtained when a methyl methacrylate-trimethylolpropane trimethacrylate monomer mixture was used in conjunction with a high quality aggregate [1]. Other structural property values include a tensile splitting strength of 1400 psi (9.9 MN/m^2), modulus of elasticity of 5.3×10^6 psi (3.7×10^4 MN/m^2), and a Poisson's ratio of 0.23. The creep is less than that of a high quality concrete.

The durability properties of PC are equally impressive. Water absorptions of < 1% are normally obtained and a high resistance to freeze-thaw damage is apparent.

BRIDGE DECK APPLICATIONS

Each of the materials described above are being evaluated to determine their applicability to highway structures. These studies are summarized below.

Partially Impregnated Concrete

The Bureau of Reclamation (USBR) [4] and the University of Texas [5] have developed methods for the partial impregnation of new bridge deck surfaces. A penetration depth of 1 in. (2.54 cm) appears adequate to prevent chloride penetration into the concrete and subsequent corrosion of the reinforcing steel. The USBR work culminated in October 1974 with the field treatment of a full-size bridge deck in the Denver area. Since that time full size bridges have been treated in Idaho, California, West Virginia, and Texas [6].

The partial impregnation process consists of drying the concrete, cooling it, applying monomer to the surface and allowing it to soak into the concrete, and heating the concrete to cure the monomer [4].

Detailed procedures used for the treatment of a bridge in Texas have been published. The bridge which was 17 years old and in good condition was treated in the following manner [6].

A thin (0.25 in.) (6.35 mm) layer of sand was applied to the bridge prior to drying. With the use of an insulated enclosure and hot air, the deck was dried for approximately 6 hr after the average surface temperature reached 260°F (127°C). The concrete was then allowed to cool overnight to 90°F (32°C).

A monomer mixture consisting of 100 parts by weight of methyl methacrylate (MMA), 5 parts trimethylolpropane trimethacrylate (TMPTMA), and 0.5 parts of a polymerization initiator azobis isobutyronitrile (AIBN) was used for impregnation.

The monomer was applied to the concrete at rates ranging from 0.6 lb/ft^2 (2.9 Kg/m^2) to 1.1 lb/ft^2 (5.4 Kg/m^2). In order to guard against premature polymerization, the test area was shaded during the soaking period which lasted 5 hr.

The monomer was polymerized using steam which was injected into the enclosure. During the curing operation the maximum surface temperature attained was 194°F (90°C). The entire curing operation required 2.5 hr.

After curing, the sand layer was brushed off. Cores taken from the deck indicated that the depth of impregnation ranged from 1 in. (2.54 cm) to 1.9 in. (4.8 cm), with the greatest depth occurring in the area where the largest amount of monomer was applied.

The cost for polymer impregnation may be estimated from bids received by the Texas State Department of Highways and Public Transportation [6]. One bridge is 751 ft (229 m) long with a 64 ft (19 m) roadway. The bids for this work ranged from \$5 to \$15/yd^2 (\$6 to \$17.94/m^2). Bids for the second bridge (207 x 42 ft)(63 x 13 m) were higher. Prices ranged from \$10 to \$50/yd^2 (\$11.96 to \$59.80/m^2).

Polymer Impregnation of Deteriorated Concrete

Methods for using monomer impregnation in repairing highly deteriorated and delaminated concrete have been demonstrated in the field and the work has reached the implementation stage [7]. A highly deteriorated bridge 120 ft (36 m) long and 30 ft (9 m) wide is currently being repaired using these techniques.

Highly deteriorated concrete can be readily impregnated with monomer and polymerized to form a composite with strength at least equal to that of the original concrete and with good bonding to the adjacent material. Since the presence of moisture prevents good bonding to the aggregate, it is essential to dry the concrete to a moisture level of $< 3\%$ prior to impregnation. This can be accomplished by blowing hot air across the top surface or, if complete closing of the structure is not possible, through and on the underside of the deck. Infra-red heaters can also be used.

Prior to impregnation, the underside of the deteriorated bridge deck must be sealed in order to prevent loss of monomer through cracks. This has been accomplished by applying a coating of standard polyester resin on the underside surface containing cracks. The resin can be applied with a brush or a paint roller. Curing is completed within 10 min.

Impregnation with a 95 wt percent MMA - 5 wt percent TMPTMA mixture has been performed by using a ponding technique in conjunction with a $\sim$ 0.5 in. (1.3 cm) layer of dried sand which served as a wick and an evaporation barrier. A 4 day soaking period was sufficient to fully saturate a 6 in. (15.2 cm) thick highly deteriorated structural deck.

Polymerization of the monomer was easily accomplished by heating the deck to 160°F (71°C) with hot air. Overnight heating was adequate to insure complete polymerization. The deck can be open to traffic during this operation, since vibration during polymerization does not affect the properties of the composites. Core specimens taken from reconstituted decks have had compressive strengths of approximately 5000 psi (35.2 MN/m^2).

Since only a limited number of small-scale field tests have been performed, only the material costs associated with drying, impregnation, and polymerization processes have been determined. Assuming a monomer loading of 15 wt percent, the materials required to reconstitute a highly deteriorated 6 in. (15.2 cm) thick deck will cost approximately \$6.50/ft^2 (\$70/m^2). Although this cost is high, considerable savings in man-power costs should be possible because the deteriorated deck does not have to be stripped and replaced. This will shorten the repair period. Traffic control costs would also be reduced since vehicles can be maintained on a portion of the structure during the repair process. Therefore the use of PIC, with its high strength, fast-curing characteristics, and good durability, can result in minimum traffic delays and improved safety and in some cases eliminate the necessity of constructing expensive detours. In such cases, the material cost becomes insignificant.

Polymer Concrete Patching Materials

Because the material can be cast in place, cures quickly at ambient temperature, and develops high strength, PC appears suitable for use in the repair of highway structures where traffic conditions allow closing of the area for only a few hours.

Field testing of PC materials containing MMA-TMPTMA and polyester-styrene has been in progress for approximately 6 years and to date no detrimental effects have been noted. The most severe test performed to date was the repair of two large holes (measuring 30 x 2 x 1.25 ft (9 x 0.6 x 0.4 m) and 20 x 2 x 1.25 ft (6 x 0.6 x 0.4 m)) on the Major Deegan Expressway in New York City [8]. To date no significant deterioration is apparent, and it is hoped that the use of PC has resulted in permanent repair of the bridge deck.

When compared with the material cost of portland cement concrete, PC appears expensive. Earlier estimates [9] ranged between \$170 and \$300/yd^3 (\$222 and \$392/m^3). In the New York City work the cost was \$260/yd^3 (\$340/m^3). Mixing and placement costs were \$248/yd^3 (\$324/m^3). The PC material cost represented only 4% of the total project cost, insignificant when repairs on major arterial highways are performed. Other concretes that cure just as rapidly but which appear to be less durable than PC would have similar installation costs but higher future maintenance costs.

The repairs on the Major Deegan Expressway were completed within eight working days and all the work was confined to non-peak hours (10 AM - 3 PM). At least one traffic lane on a roadway was kept open at all times. This, in conjunction with a detour, resulted in minimum inconvenience to the public.

CONCLUSION

The deterioration of concrete bridge decks and pavements presents many highway organizations with major problems of providing safe and satisfactory riding surfaces. Concrete polymer materials, with their excellent durability and strength properties, are beginning to be applied to highway construction and maintenance and offer potential benefits of an increase in service life and a reduction in the costs, safety hazards, and inconveniences in performing maintenance and repair work.

Polymer-impregnated concrete (PIC) is highly resistant to freeze-thaw damage and water penetration and provides protection from deicing salt penetration and resultant corrosion of reinforcing steel. A precast, prestressed PIC bridge deck system has been developed that incorporates the advantages of a precast, prestressed system for rapid construction, strength, and durability.

A cost estimate for the PIC precast bridge deck system indicated that the initial cost may be as much as 83 percent greater than the cost of a membrane and asphalt topped cast-in-place deck. Considering long-term costs of both construction and maintenance, the economics of using PIC becomes more favorable. This is particularly true for structures in which the concrete may not be fully satisfactory because of conditions causing rapid deterioration and frequent repair.

A surface-impregnation technique has been developed as a method of protecting newly constructed concrete bridge decks from damage resulting from the use of deicing salts. A method and equipment capable of impregnating a concrete deck with polymer to a depth of at least 1 in. (2.54 cm) have been developed. Five decks have already been impregnated and several others are planned.

The techniques for repairing highly deteriorated and delaminated bridge decks by monomer impregnation have been demonstrated in field tests in which a 6 in. (15.2 cm) thick section of deck was impregnated. Cores taken from the reconstituted deck had compressive strengths and water absorptions of 5000 psi (35.2 MN/m^2) and 1.6% respectively. Based on these results, work to repair an entire deck is being performed by the New York State Department of Transportation.

Field evaluation of the use of polymer concrete as a means of rapidly filling holes in major arterial highway bridges has been in progress in New York City for 48 months. No signs of deterioration are apparent. The New York State Department of Transportation plans to make further use of this technique.

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