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Polymer Concrete for Construction and Repair of Bridges

Béton de polymère pour la construction et la réparation de ponts

Polymer-Betone für Bau und Reparatur von Brücken

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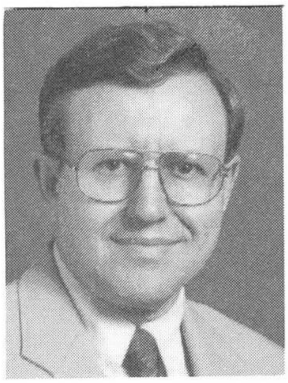

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SUMMARY
The use of concrete-polymer materials for bridge deck construction and repair has increased significantly. Polymer concrete repairs and overlays have proven to be fast, durable, and cost effective. The use of polymers for sealing cracks has been found to be very simple, effective, and economical.

RÉSUMÉ
L'utilisation des matériaux en béton à fibres de polymère pour la construction et la réparation des ponts a considérablement augmenté. Les réparations et les recouvrements en béton de polymère ont montré qu'elles étaient durables et efficaces. L'utilisation de "polymères" pour sceller les fissures est très simple, efficace et économique.

ZUSAMMENFASSUNG
Die Anwendung von Polymer-Beton für die Erstellung von Brückenfahrbahnplatten und Reparaturen hat deutlich zugenommen. Ausbesserungen und Ueberzüge aus Polymer-Beton sind schnell ausgeführt und dauerhaft. Die Anwendung von Polymeren für die Versiegelung von Rissen ist einfach, wirksam und kostengünstig.

1. INTRODUCTION

The development of latex-modified concrete (LMC) in the mid-fifties marked the first beginning in the United States of the use of concrete-polymer materials. Styrene-butadiene (SBR) latex was first used for a bridge deck overlay in Michigan about 30 years ago [1]. Polymer concrete (PC) began to be used in the United States for bridge repairs in the 1970's, and later polymer concrete overlays were used for new and old bridges. More recently high molecular weight methacrylate (HMWM) has been used to seal cracks in bridges.

The most widely used monomers and resins used to produce polymer concrete for bridge applications are methyl methacrylate (MMA), polyesters, HMWM, and epoxies. It is essential that their strength, coefficient of thermal expansion, and elongation be properly selected for the intended application.

2. PROPERTIES

The properties of polymer concrete are highly dependent upon the monomer or resin used, aggregate type and gradation, polymer content, and temperature. Compressive strengths generally range from 50 to 100 MPa while flexural strengths range from 10 to 25 MPa. Modulus of elasticity usually varies from 3,500 MPa to 30,000 MPa although some polymer concretes used for overlays have values as low as 1,000 MPa. The coefficient of thermal expansion ranges from values slightly higher than for portland cement concrete to 3 or 4 times as great. Curing shrinkage is usually several times greater than for PCC, although for PC made of some polymers such as epoxies, the shrinkage is less than for PCC.

Creep, at a given stress level, is higher than that of PCC. Specific creep, measured in strain per unit stress, is in the same range of creep for PCC (2). At elevated temperatures, however, creep of PC increases significantly. Fatigue of PC is similar to PCC when the stress ratio, i.e. ratio of applied stress to modulus of rupture, is considered; however, based on absolute stress, PC has considerably more fatigue resistance (Fig. 1)[2].

Durability of PC is usually excellent when compared to PCC. The much higher impermeability of PC results in much greater resistance to freeze-thaw deterioration and chemical attack. Abrasion and wear are good to excellent.

The polymer content of PC, which varies as a function of the aggregate size and gradation and mixing methods, is usually in the range of 6 to 15 percent. The density of PC is usually about 90 to 95 percent of PCC made with the same aggregate.

3. STRUCTURAL BEHAVIOR

Polymer concrete is not being used for entire beams or bridge decks. However, it has been extensively used for partial depth and full depth repair of bridge decks. Some full depth repairs span several meters. Load-deflection tests on reinforced beams indicate good ductility (Fig. 2). Load-deflection behavior can be predicted with reasonable accuracy. Ultimate strength of PC beams can be predicted by using an equivalent rectangular stress block similar to that used for PCC except with slight modifications to the stress block constants [3].

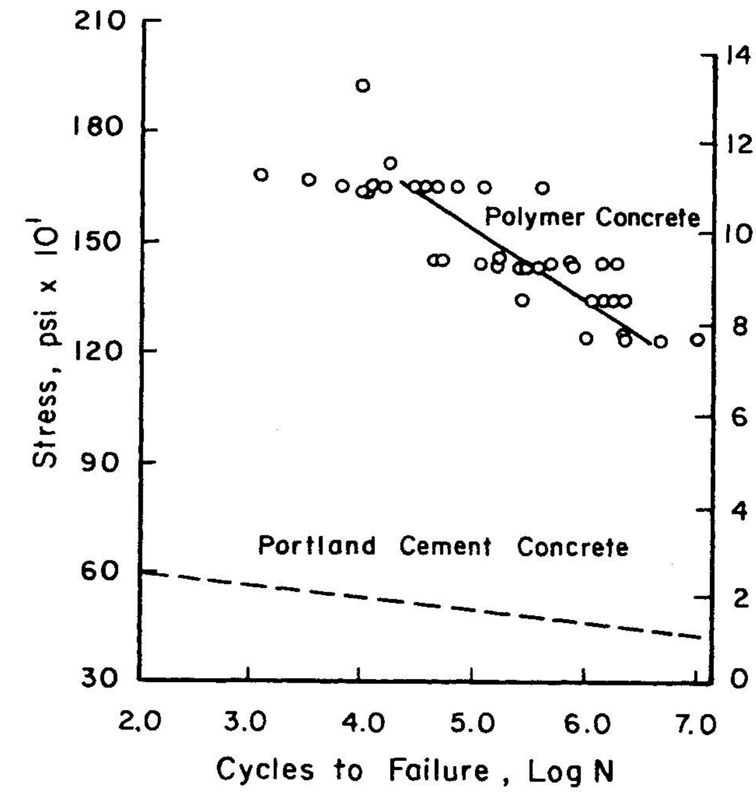

Fig. 1: Comparison of Fatigue Strength of Beams for R = 0.05 and R = 0.25

4. POLYMER CONCRETE APPLICATIONS

4.1 Repairs

The initial uses of PC in the United States was for repair of bridges. The very good bond between PCC and most polymer concretes and the very rapid cure time (30 to 90 min.) in a wide range of ambient temperatures make PC an attractive repair material. There are several ways of batching and placing PC. In all methods the finishing is similar to that of PCC.

4.1.1 Preplaced Aggregate

The simplest method is to preplace the blended aggregate in the repair area and then pouring or injecting monomer until the aggregate voids are filled. This method requires (1) a low viscosity monomer such as MMA and (2) relatively shallow lifts of 100 mm or less. The quality and resulting strength are not as high as for the other methods, but minimum equipment and clean-up are required.

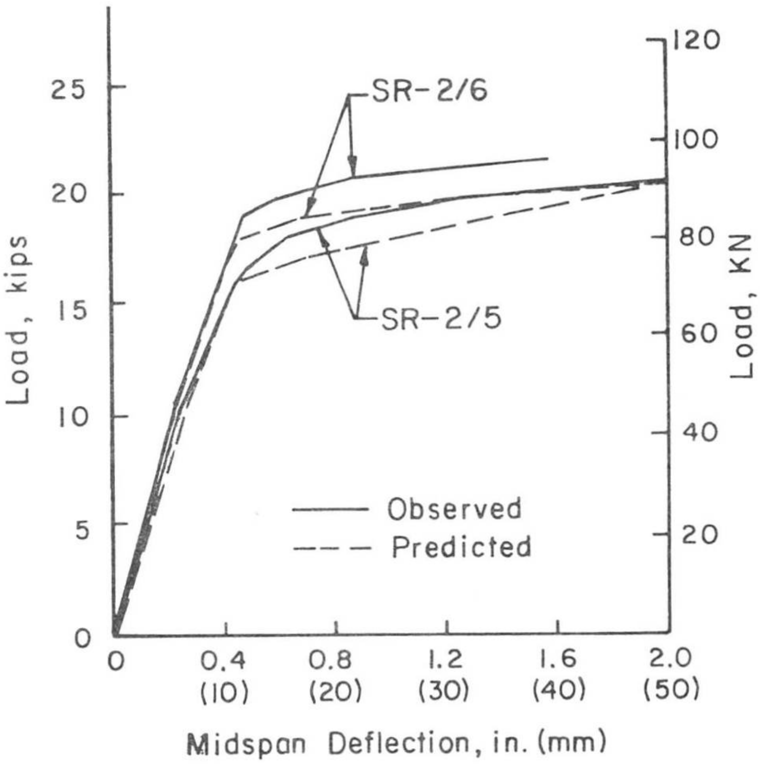

Fig. 2: Load-Deflection Responses for Beams (SR-2/5 has 4.0% steel and SR2/6 has 5.6% steel)

4.1.2 Batched Polymer Concrete.

The most common method, especially for commercially-available polymer concretes, is to batch the PC in small drum mixers (Fig. 3). The commercially-available PCs usually come in two components: a container of monomer and a bag of dry materials which includes graded fine aggregate, initiator, colorants, and thickners. When mixed together, a material with the workability of grout is produced. By adding an amount of coarse aggregate up to the volume of the PC mortar, the batch can be extended and made less costly.

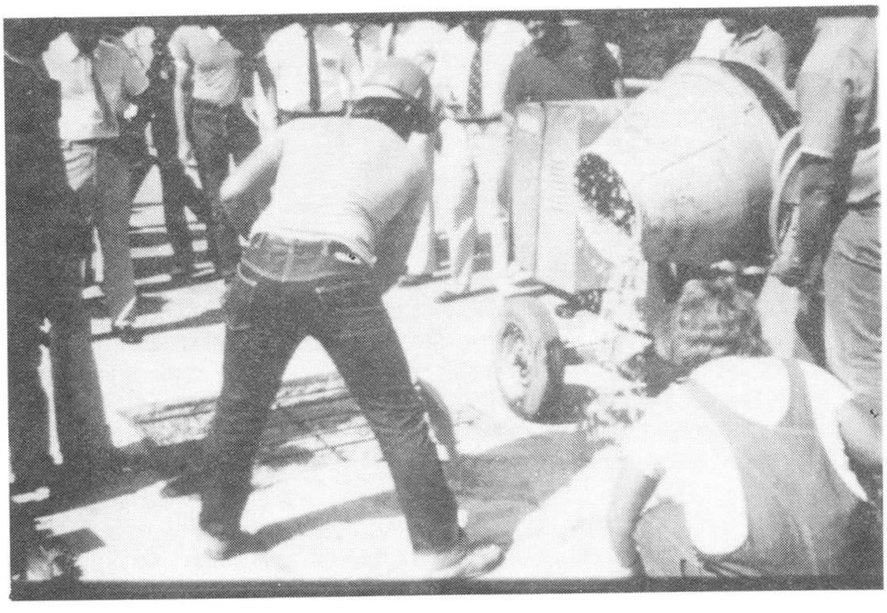

Fig. 3 Placing PC into Repair Area on Bridge

Automated batching equipment has been successfully used. Mobile concrete batching equipment used for PCC has been adapted to store all of the PC components and mix them in the mixing auger. The volume of material can be easily controlled, and the mixing time can be reduced to about one minute which is very important in hot weather to provide more time for placing and finishing.

4.2 OVERLAYS

4.2.1 Advantages

The need for overlays to provide protection and skid resistance for new and old bridge decks has created a market for PC overlays. PC has several advantages as an overlay:

1. Provides very good bond to PCC.
2. Requires a thickness of about 10 to 15 mm which results in a minimum dead load and eliminates the need to reconstruct the approach slabs.
3. Permits the construction of overlays during the night or day between periods of maximum traffic due to the fast curing of the PC.

4.2.2 Evaluation of Materials and Performance

Many monomers and resins have been used to construct PC overlays. Not all of them have resulted in durable overlays, however. MMA, polyesters, and epoxies are the materials most often used to construct overlays. Epoxy asphalt concrete has been found to provide a good wearing surface for bridge decks. The binder is a proprietary epoxy asphalt [4].

The State of Virginia has had a very active PC overlay program since 1981. Their experience has shown that the tests which provide the best indication of performance are:

1. Tensile elongation (ASTM D 638).
2. Rapid permeability test (AASHTO T 277).
3. Shear bond test in which the overlay - PCC interface is subjected to direct shear.
4. Tensile bond test recommended by ACI 503R.
5. Thermal cycling test in which cores or cylinders with overlays are subjected to thermal cycling in air between - 18°C and 38°C for up to 300 cycles. At different times during the test specimens are removed and tested for permeability and bond strength.

Virginia recommends that the tensile elongation be in the range of 20 to 50 percent. Their current choice is a polyester resin which has an elongation of 23 percent and has a modulus of 335MPa [5].

Generally the high modulus and the relatively high coefficient of thermal expansion of epoxies have resulted in poor performance as a binder for PC overlays. However, there are a few epoxies with a relatively low modulus which produce a PC with a modulus of only ~ 100MPa. Overlays made of those materials have been in place up to 10 years.

4.2.3 Overlay Applications

Polymer concrete overlays have been widely used to protect bridge decks. The applications require that a clean, dry, sound surface be provided. Shot blasting, similar to sand blasting except that small steel balls are used, is one of the most common methods. Polyester overlays are often applied in layers. A truck-mounted spray bar is used to apply the catalyzed resin (Fig. 4) at a rate of 9.3 Pa followed by a uniform layer of silica sand at a rate of 90 Pa. A second layer of resin (12Pa) is followed by a second layer of sand. A third application of resin (14.6 Pa) is followed by a third layer of sand. The thickness is about 10 mm [5].

Epoxy PC overlays have been successfully placed by using automatic mixing and dispensing units used for producing precast PC. Vibratory screeds are used to level the mix and additional aggregate is broadcast onto the surface to provide a non-skid surface. Such an overlay was used on the Brooklyn Bridge [6].

Epoxy asphalt concrete overlays are produced in a modified hot-mix asphalt plant and applied and compacted with standard asphalt paving equipment [6]. Many large bridges in the U.S. including the Golden Gate, have been successfully overlaid with this material.

PC has also been used as a wearing surface on aluminum orthotropic bridge decking. The shop-fabricated aluminum panels have a PC wearing surface applied in the shop. The panels are then attached to the bridge girders in a relatively short time. The PC/aluminum decking weights 18 to 25 lbs/ft^2 which is 1/6 to 1/8 the weight of a conventional concrete deck. The PC wearing surface is 3/8-in. thick. Although polyester was used initially, epoxy PC is currently being used since tests showed that it had superior performance [7].

Electrically conductive polymer concrete overlays have been developed for use in cathodic protection systems. Several resins, including polyester and vinyl ester, have been used with various types of coke breeze to produce composites with our electrical resistivity of 10 ohm-cm or less. These materials can be sprayed on bridge sub-structures including vertical and overhead surfaces [8].

It is estimated that at least 100 bridges in the United States and Canada have been overlaid with PC. About 20 have used epoxy; most of the rest were constructed with polyester PC, although a few have used MMA. The in place cost for polyester PC overlays in Virginia in 1985 ranged in cost from $30.50 to $43.00 per sq. m. [5].

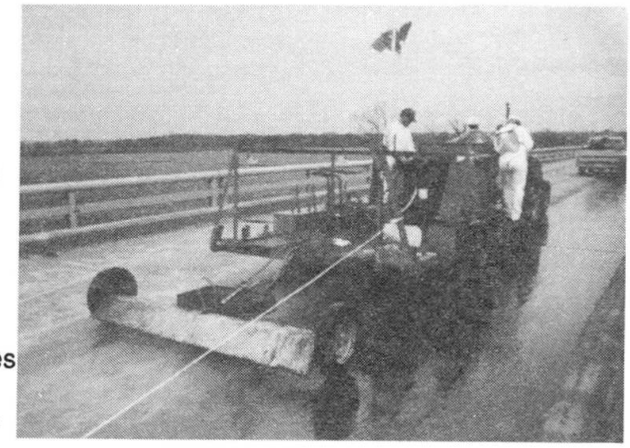

Fig. 4. Polyester Resin Applied by Spray Bar for Construction of Overlay

PC headers have been used in Texas at bridge joints when asphalt concrete overlays are added. The excellent bond to portland cement concrete and the very good impact resistance of the cast in place PC have resulted in a very durable header. The headers are about100 mm wide and 40 mm high.

5. POLYMER CRACK REPAIR

5.1 Monomer

Monomers have been developed which have the ability to penetrate open, narrow cracks in portland cement concrete, fill most of the crack and structurally bond the concrete (9). High molecular weight methacrylate (HMWM) has a viscosity nearly as low as MMA, but has a higher flash point and low odor. Similar to MMA, HMWM can be cured at a wide range of ambient temperatures.

5.2 Laboratory Tests

Laboratory tests have been performed on cracked reinforced portland cement concrete slabs. The variables were crack width at the surface (0.2 to 2 mm) and moisture levels. Monomer was brushed on the surface of the slab and permitted to cure. Slabs were then recracked and cut perpendicular to the cracks. The recracking stress averaged about 90 percent of the initial cracking stress. About 90 percent of the new cracks were outside the repaired cracks. For dry concrete, over 80 percent of the crack length was filled. For wet concrete permitted to dry for at least 24 hours, at least 50 percent or more of the crack length was filled.

5.3 Field Applications

Many bridge decks have been treated with HMWM. In some cases the bridges were new, with cracks resulting from plastic shrinkage. In other cases bridges were up to 40 years old. The procedure for treating a bridge deck consists of:

(1) Cleaning the bridge deck using a light sand blast if the surface is contaminated.

(2) Pouring monomer onto the deck and brooming it into the cracks or, for larger areas, applying monomer with a truck-mounted spray bar.

(3) Applying a light application of sand on the surface to improve skid resistance. Although the surface usually appears slick, the skid resistance is about the same after the treatment as before.

The application rate is about 2 to 3 sq. m/l and the cost ranges from 3 to 5 sq. m.

6. OTHER DEVELOPMENTS

With the trend toward precast construction, there is a strong likelihood that PC will find an even greater role in the construction of bridges. Precast PCC bridge deck panels with a factory-applied thin PC overlay would provide a tough, durable water-tight membrane and wearing surface. Ribbed or sandwich panels with a PC top skin reinforced with steel fibers could potentially result in a strong, lightweight, durable panel.

Hollow precast median barriers are currently being manufactured in the U.S. Due to their low weight they can be economically transported to the site where they are filled with concrete to provide the needed mass. The smooth, attractive, durable PC exterior requires less maintenance than conventional PCC barriers. It should also be possible to produce lightweight, complex-shaped PC guard rails that are aesthetically pleasing.

7. CONCLUSIONS

The use of polymer concrete has been found to be a very effective material for repairing bridges. The excellent bond, rapid curing, and excellent mechanical properties result in cost effective and durable repairs.

The use of high molecular weight methacrylate monomer for repairing cracked bridge decks provides a relatively low cost, simple and effective method.

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