SP 169-1

Experience with Epoxy Polymer Concrete Bridge Deck Thin Overlays in Service for Over 10 Years

by Shree Nabar and Peter Mendis

Synopsis: Repair and maintenance of aging bridge decks and parking decks has become increasingly important due to concrete and steel deterioration from exposure to deicing salts, acid rain, and other hostile elements. Rapid curing thin polymer concrete overlay offers a cost-effective option in protecting and extending the service life of the deck. The paper discusses the performance, physical properties and application techniques using a flexible epoxy polymer overlay. The low modulus epoxy binder is designed to achieve a balance between toughness and flexibility. With the use of gap graded aggregates, the flexible epoxy binder system provides low permeability, enhanced skid resistance while accommodating thermal and mechanical stresses. The outstanding performance and service life of flexible epoxy overlays has been documented in the SHRP study in 1991. The importance of proper surface preparation and quality control during application is critical to the success and durability of the overlay.

Keywords: Aggregates; bridge decks; epoxy resins; mixing; parking facilities; permeability; polymer concrete; protective coatings (polymers); skid resistance

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One of the first bridge deck overlays, based on flexible low modulus epoxy polymer concrete, is celebrating its twentieth anniversary this year. Tests recently performed show that the overlay is still in good condition based on its retained bond strength and skid resistance. This paper discusses the experience, over the last twenty years, of flexible epoxy polymer concrete thin overlays as a protective and a wearing surface on bridge decks.

Concrete and steel are the main material components of a bridge deck. They share common properties of high strengths but this synergy is adversely affected by exposure to several factors. The porosity of concrete allows intrusion of deicing salts and chemicals contributing to the deterioration of concrete and corrosion of steel. Moisture intrusion through cracks in concrete followed by freezing and thawing, causes damage to both concrete and steel. Over time heavy traffic wears the surface away, leading to poor skid resistance and riding quality.

Escalating costs of deck replacement or rehabilitation especially due to downtime and traffic disruption restrictions, makes polymer concrete overlays a cost-effective and an attractive option to protect and extend the service life of the bridge deck.

What is a Polymer Concrete Overlay?

Polymer concrete is a composite material formed by physically blending an aggregate with a polymeric binder, formed by polymerizing monomers or reacting resins and hardeners. The polymer binds the aggregate together and imparts its own characteristic properties to the polymer concrete. It differs from latex-modified concrete in which water causes hydration of hydraulic cement. Commonly used polymeric binders are epoxies, polyesters, polyurethane and methyl methacrylate. These are two part systems with one component being the resin and the other being a hardener or a catalyst.

When to use Polymer Concrete Overlays?

Polymer concrete overlays are used commonly for repair, rehabilitation and preventive maintenance of decks if one or more of the following situations exist[1]:

- High permeability in the concrete.
- Deck needing improvement in skid resistance properties.
- Extend the service life of a deck where steel and/or concrete is repaired and rehabilitation of the deck is planned.
- Preventive maintenance of new decks, generally or in specific cases where incorrect concrete placement led to lack of proper air entrainment and air void system.
- No increase in deadweight is allowed and/or where traffic shutdown on the bridge beyond off-peak periods is not permissible.

Epoxy Polymer Concrete Overlays

The first generation epoxy overlays used in the 1950's were based on high modulus, coal-tar modified epoxy. These did not perform well because they were too brittle to withstand the thermal and mechanical movements caused by exposure to traffic and thermal cycling. They were applied as one coat application, which created inherent porosity causing delaminations. The current technology evolved out of these experiences and the ensuing learning curve. The epoxy polymer system presented in this paper achieves a fine balance of flexibilizing the epoxy without losing its toughness and tensile strength. The flexibility maintains the low modulus required to accommodate thermal and mechanical movements, while the tensile and compressive strengths help the overlay withstand impact and shear loads from the traffic. Use of a gap graded aggregate, instead of a well graded aggregate, is vital to the success of the overlay.

Two part flexible epoxy polymer concrete overlays have achieved a sizable market share for rehabilitation or preventive maintenance of new or old decks. Epoxies develop an exceptional bond to concrete and steel, are unaffected by the presence of alkalinity, possess rapid strength development even at temperatures up to 35°F, all of which have contributed to its impressive performance history and popularity.

Advantages of Epoxy Polymer Concrete

- Epoxy polymers have excellent bond strength with concrete. The high tensile strength holds the aggregate in place when subjected to traffic, yet is flexible enough to accommodate thermal and mechanical movements.

- Epoxies are not affected by alkalinity of concrete and have excellent chemical resistance to salts, oil, gasoline and chemicals.
- Have very little shrinkage and due to its low modulus properties any shrinkage stresses are relieved quickly.
- 100% solids, no volatiles, VOC compliant.
- Easy to work with because they are not flammable, have no strong odors, and are moisture insensitive during application and cure.
- Rapid curing permits installation during off-peak traffic periods. Lane closure, surface preparation, installation and curing all are accomplished during off-peak traffic period.
- High strength to weight ratio allows increased live load carrying capacity on the bridge. Typical epoxy polymer concrete overlay (0.375 " thick) weighs 6-8 lb./sq.ft. compared to latex modified concrete or asphalt (1.5" - 2.0 " thick) which weighs 16-20 lb./sq.ft.
- Epoxy polymer concrete has very high impermeability which prevents water and chloride intrusion into the deck. An Alberta Department of Transportation study[2] found that epoxy polymer concrete overlay extended the service life of the deck even where corrosion was active during installation.
- Depending on the type and gradation of the aggregate used, polymer concrete overlays improve pavement friction (skid resistance) and also improve riding quality. In one premiere installation of the epoxy polymer concrete overlay, reduction in noise level on the Brooklyn bridge[3] was a targeted, additional benefit of the overlay.

Components of Epoxy Polymer Concrete System

Epoxy polymer concrete system consists of resin (base), curing agent (hardener) and the aggregate. Each component plays a critical role in the performance of the overlay.

The epoxy binder is a carefully formulated two component system designed to optimize adhesion, low viscosity for ease of application, high flexibility and toughness. The high flexibility results in a low modulus property capable of accommodating mechanical and thermal movements. When the binder is combined with the gap graded (near single size distribution) aggregate, it forms a matrix in which the resin is the continuous phase. The gap graded nature of the aggregate permits interstices between the aggregate to be filled with the flexible resin allowing the entire system to absorb thermal and mechanical stresses without disbonding from the bond line or the aggregate. This fundamental benefit of the low modulus binder has been proven with over twenty years of successful field experience with flexible epoxy polymer overlays. Table 1 lists the properties of uncured and cured epoxy binder.

Aggregate--The aggregate used in this epoxy concrete overlay system is gap graded (uniform gradation) for reasons mentioned earlier. Although other types of aggregate have been used, testing and field experience has shown that aggregate containing high percentage of aluminum oxide offers the best performance for friction and skid resistance. The aggregate must have high compressive strength, be non friable, non expansive, and posses resistance to polishing. In both Multiple and Slurry methods of application mentioned in this paper, the aggregate is always broadcast in the final surface. Since this provides the traffic bearing surface, these properties are critical to the long term performance of the overlay. Table 2 and 3 show typical properties of such an aggregate .

Epoxy Polymer Concrete

The properties of the polymer concrete resulting after mixing of the epoxy binder and the aggregate and cure are described in Table 4.

Epoxy Polymer Concrete Overlays in Service at least Ten Years

Table 5 provides a list of key projects with flexible epoxy polymer concrete overlays on bridge decks. This partial listing, includes only overlays that have been in service for over 10 years.

Application of Overlays

Surface Preparation--Polymer concrete overlays should be applied to clean, dry and sound substrate. As simple as this sounds, the importance of proper surface preparation is often lost in the priorities of scheduling, conflicts in underestimating the costs required to do proper surface preparation, and in the past due to lack of quantitative standards. The overlay is subject to abrasion from traffic, snow plow blades, shear stresses from thermal cycling, attack from salt, moisture and deicing chemicals, and live load shear stresses caused by deceleration, acceleration or turning. It is therefore very important that the surface be clean and posses adequate profile so that a strong mechanical and chemical bond between the polymer and the substrate will be developed.

Surface preparation begins with a preliminary evaluation by trained personnel of the condition of the deck concrete and steel. Evaluating cracks, delaminations, extent of rebar/steel corrosion and other symptoms of distress should include finding the underlying causes.

A plan to repair the cracks, repair full depth or partial depth spalls/delaminations, and replace corrosion induced areas of concrete or steel should be formulated. The choice of proper materials and techniques should take into account the cure requirements and compatibility with the overlay.

Decks with new concrete should be cured for 28 days so that the moisture content is low enough so as to minimize excessive water vapor pressure which may cause failure of overlays.

The preferred method of surface preparation is by shot blasting. This closed system gives a clean, dust free surface with exposed aggregate which is ready to be overlayed immediately. In many larger projects, surface preparation and the application of the overlay are done in tandem.

Scarifiers, scabblers, and hydroblasting which are other commonly used methods for surface preparation are generally not suitable especially if rapid deck repairs is also a key objective. If, however, any of these methods are agreed upon initially, the time required for the surface to dry completely must be considered. In case of scabblers or scarifiers add the additional step of a light shot blast or high pressure water blast to remove any fractured concrete surface.

The all important question of knowing when the surface is clean enough is objectively determined by using the test method prescribed in ACI 503R, Appendix A, of the ACI Manual of Concrete Practice. The test method consists of bonding a steel disc to the cleaned surface using fast setting high strength adhesive. Using a hydraulic jack type fixture the steel disc is pulled by applying a vertical force. The tensile adhesive strength and the mode of failure is noted. If tensile adhesive strength is 1.7 MPa (250 psi) or greater, the surface preparation quality is acceptable. If the pullout value is less than 1.7 MPa and 90% failure occurs in concrete at a depth of 6 mm (1/4") or more, than the surface preparation quality is acceptable but the concrete quality may not be adequate.

Overlay Application--Epoxy overlays are applied by Multiple Layer Method or the Slurry Method.

Multiple layer overlays are constructed by applying the mixed binder to the surface using roller, notched squeegee, or brooms. While the binder is still wet, aggregate is broadcast to excess using mechanical or manual methods. The correct method of broadcasting is to let the aggregate fall vertically without violently disturbing the binder layer. Any wet spots appearing after the broadcast must be covered immediately with additional aggregate before the epoxy becomes tack-free. Saturation of the aggregate in the first broadcast should be avoided because the "wicking" action of the binder causes voids and reduced permeability in the overlay. After the binder is hard and cured, the excess unbonded aggregate is removed by vacuuming or brooming.

The second and subsequent layers are constructed by repeating the process. To ensure proper coverage rates of the binder, it is recommended that sections be marked on the deck. Each section represents the spread rate to be achieved by the amount of binder mixed each time. The Multiple Layer Method is easy, does not need sophisticated equipment and no highly skilled labor is required to install the overlay. Since at least two layers are needed, cure time requirements dictate relatively longer downtime compared to the slurry method. Table 6 shows the typical application rates for the binder and the aggregate.

Slurry Method overlays are applied by mixing the binder and aggregate, in the correct proportions, in either continuous or batch mixing equipment. The mortar slurry is distributed on the deck using gage rakes, trowels, draw or beam boxes and then screeded to specified thickness using vibratory screeds. Guide rails are used to achieve the proper thickness using manual or self propelled vibratory screeds. Immediately after screeding, excess binder from the binder rich slurry "bleeds" to the surface. The excess binder eliminates the need for a separate step of priming the surface and also provides a binder film at the top surface into which aggregate can be broadcast to achieve skid resistance. Dry, gap graded aggregate is immediately broadcast uniformly to an excess and until no wet spots appear. After the binder cures, unbonded aggregate may be removed by vacuuming or sweeping.

Curing--Curing time for an epoxy overlay depends on the ambient and surface temperatures, overlay thickness and the resin, hardener and aggregate temperatures. Table 7 outlines a typical cure schedule for epoxy overlays applied by either methods of application.

Quality Assurance Procedures in the Field

A clean and sound concrete and steel surface is as critical as the proper binder system and the application method. The adequacy of the surface preparation and concrete quality is evaluated in the field by ACI 503R test method. Instead of relying visually to detect presence of moisture, follow ASTM D 4263 in which a plastic sheet (polyethylene) is taped on the surface and is observed for specified time for any condensed moisture under the surface of the sheet.

Binder / Aggregate--The first step is to ensure proper storage conditions of the binder and aggregate. The resin, aggregate and hardener, should be conditioned at about 70° F for at least 24 hours, prior to application especially in extreme temperature conditions. Utmost care should be taken to ensure that the resin and hardener are mixed in the correct proportion, for the proper duration and that the mixing should result in a homogenous mix without air entrapment. When automated dispensing equipment is used to meter and mix the binder, recalibration should be done every time the equipment is stopped and/or started and when ambient temperature changes by 10°F. The aggregate gradation should be certified by the manufacturer and the field quality assurance involves making sure that the aggregate is dry and that it does not contain excessive fines. The accuracy of the mix ratio and mixing procedures, for calibration or application, is judged in the field by a quick check of the gel time using about 100 gms of the mixed binder. At frequent intervals, samples of the mixed binder with the proportionate amount of aggregate are cast into 2" cube molds using plastic inserts. In order to be to avoid scatter of compressive strength results, prepare these field samples for consistency by tamping the cubes in accordance with ASTM C109 method. At low temperature, if the binder viscosity is high, the binder loses its penetrating, wetting and self priming abilities. On the other hand, at temperature of 90°F and above, the binder sets up quickly, which if the entire placement operation is not well coordinated, can cause poor bonding and aggregate wet out. It is strongly recommended to install an overlay test patch using the proposed methods of surface preparation, binder/aggregate mixing, and application methods that are to be used to place the overlay. Using ACI 503R test method, a tensile adhesion pull out test is done on the overlay sample which, if acceptable, sets the standards and procedures that will be used on the project.

Quality assurance for the completed overlay, if possible, should be based on non destructive test methods. Where core samples are needed to assure quality, the representative areas should be carefully chosen and repaired immediately after sampling.

Presence of cracks and porosity is evaluated by measuring electrical resistivity according to ASTM D3633 test method. Typically resistivity values greater than 500 x 10^3 indicate an impermeable membrane while values below 200 x 10^3 can note presence of cracks and/or porosity.

Another test which corroborates the permeability value is the rapid chloride permeability test according to AASHTO T277. This method gives the coulomb rating of the overlay as a measure of permeability. The epoxy overlay has a coulomb rating typically below 100 which denotes an impermeable membrane. The bond strength to concrete is evaluated by using ACI 503R test method. Failure in the concrete substrate is indicative of an acceptable bond. Skid resistance is measured by using ASTM E501 (treaded tire test), ASTM E303 (British Pendulum test) or ASTM E524 (bald tire skid) test method.

Service Life of Epoxy Polymer Concrete Overlays

An accurate service life prediction of the overlay is rendered difficult due to the fact that bridge surface deterioration mechanisms are different for every bridge. An exhaustive survey of the existing performance conditions of various deck protection, repair and rehabilitation systems was undertaken under the Strategic Highway Research Program (SHRP).[5] The results of their evaluation on the flexible epoxy polymer overlays are found in Tables 8 and 9.

Trouble Shooting Overlay Problems

There are several variables that contribute to the success of an overlay and when more than one variable is suspected for causing the problem, it becomes extremely difficult to isolate the contribution of that variable and the interactive effects of other variables in contributing to the cause of the problem.

Overlay failures can be broadly classified into three categories -- Delamination / Debonding; Cracking / Increased Porosity; Loss of Skid resistance. The following briefly discusses how the Substrate, Binder/Aggregate, and Application methods can influence these failure modes.

Delamination / Debonding--Delamination/Debonding can be failure by itself or can be caused by the cumulative effects of other deficiencies in the overlay.

Improper or inadequate surface preparation is the single largest reason contributing to this mode of failure. The physical properties of the epoxy binder are achieved only when the resin and the hardener are mixed in the correct ratio and mixed intimately. Any deviation from the ratio or mixing can cause a myriad of problems which may not manifest immediately. In the Multiple layer method of application intercoat adhesion failures, in the form of surface delaminations may occur due to contamination between coats, waiting too long between the coats, or applying the binder to unbonded aggregate.

At overlay thickness greater than 1/2"(1.25 mm), the difference in the coefficient of thermal expansion between the epoxy overlay and concrete becomes significant. In an otherwise properly applied overlay, this aspect alone accounts for many delamination failures. Often overlooked is the need for proper details for termination of the overlay. Inadequate termination details at joints, drains, dividers and curbs cause water intrusion or edge delamination due to impact stresses.

Cracks in the Overlay--Though larger cracking may be evident visually, fine cracks or increased porosity can only be evaluated by tests mentioned earlier. Presence of large or moving cracks in the concrete, if untreated, will cause reflective cracking of the overlay. Excessive flexing of the sub-base, especially near joints, can induce fatigue stresses at the bond line leading to cracking and subsequent debonding.

Increased Porosity of the Overlay--Addition of solvents or thinners to the binder causes shrinkage and creation of voids after the solvent evaporates. Use of wet or damp aggregates prevents its bonding with the binder, eventually causing aggregate pop-outs and increased porosity. Application of the overlay over expansion joints is done by using either of these techniques--the joint is taped with a bond breaker tape, the overlay is applied over the entire surface including the taped areas, then the tape is pulled before the overlay has cured. The other method is to apply the overlay over the entire area and saw cut over the joints 24 hours after cure of the overlay. In both cases a flexible sealant is used to fill flush to the surface. Opening the overlay to traffic before sufficient cure and strength, may cause micro cracks which will grow with applied mechanical and thermal stresses.

Loss of Skid Resistance

The aggregate type and gradation is the major factor contributing to this property. Compromising any of these will reduce overlay's long term skid resistance proportionately.

Summary and Conclusions

Flexible epoxy polymer concrete overlays have established a long and successful track record. These applications have shown outstanding performance in protecting and extending the service life of bridge decks. Studies have shown that these rapid repair, rehabilitation and preventive maintenance systems retain skid resistance and permeability resistance for well over ten years.

The polymer discussed in this paper is a flexibilized epoxy binder. The gap graded aggregate combined with the high elongation and low modulus properties imparted by the epoxy binder accommodate movements due to thermal and mechanical stresses. The physical and performance properties of the flexible epoxy binder, the aggregate and the polymer concrete have been characterized in the paper.

Various bridge deck overlay projects using the flexible epoxy system have been listed. Results of data evaluation during the SHRP study in 1991 confirm the excellent performance of this epoxy overlay system that had been in service for over 15 years. The success of the overlay application is closely dependent upon proper surface preparation, application methods and a rigid infield quality assurance program. Some basic tools and test methods for proper quality assurance and application techniques have been outlined.