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Performance of Concrete Bridge Deck Surface Treatments

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PERFORMANCE OF CONCRETE BRIDGE DECK
SURFACE TREATMENTS

by

Tyler Nelsen

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

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BRIGHAM YOUNG UNIVERSITY

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ABSTRACT

PERFORMANCE OF CONCRETE BRIDGE DECK SURFACE TREATMENTS

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Department of Civil and Environmental Engineering

Master of Science

The purpose of this research was to identify the types of surface treatments available for use on concrete bridge decks and to determine which materials are most capable of providing long-term protection from contamination by chloride ions. The products addressed in this report primarily include urethanes, silicon-based sealers, and epoxies. An extensive literature review was conducted to document common overlay distresses, performance histories, and properties of specific surface treatment products currently available in the industry. In addition, three reports summarizing in-house experiments performed by the Utah Department of Transportation between 1995 and 2003 regarding various types of surface treatments were reviewed as part of this research. Finally, a nationwide questionnaire survey was conducted to investigate the state-of-the-practice with regard to surface treatment applications on bridge decks by state departments of transportation throughout the United States.

Of the three types of materials addressed in this research, epoxy-based products have the greatest ability to protect concrete and remain uncracked with an acceptable level of skid resistance. Silicon-based products do not crack because they seep into the pores of the concrete, but they do not protect the concrete from the wearing effects of

traffic or improve skid resistance. Published field studies indicate that urethane surface treatments do not resist the effects of traffic as well as epoxy-based materials, nor do they offer a substantial decrease in expense or health risk when compared to epoxy-based products.

The results of the nationwide questionnaire clearly indicate that bridge deck surface treatments are valuable as both chloride barriers and skid-resistant wearing courses. No standard practice appears to exist with regard to timing of surface treatments, however. Some states arbitrarily apply surface treatments at 10 to 12 years after construction, other states wait until cracking has become fairly considerable before action is taken, and still other states apply surface treatments when the chloride content of the concrete reaches a certain level. Because concrete decks with significant cracking are not ideal substrates for polymer applications, surface treatments should be applied as preventive measures early in the service lives of bridge decks to effectively prevent chloride concentrations from reaching critical levels.

This research suggests that epoxy-based surface treatments should be specified for concrete bridge decks when both a chloride barrier and improved skid resistance are desired. If a chloride barrier is all that is needed or desired, a silane surface treatment should be considered; silane treatments are less expensive and easier to apply than epoxy treatments. When a large amount of epoxy is to be mixed, automatic proportioning equipment that can precisely monitor and control the ratios of components should be employed.

ACKNOWLEDGEMENTS

It would be wrong to finish this thesis without expressing my thanks to the people who were so critical to its success. First, I would like to thank Dr. W. Spencer Guthrie, whose tireless efforts and seemingly endless patience I will never forget. Second, I would like to thank Dr. Fernando Fonseca and Dr. Mitsuru Saito for taking time out of their busy schedules to be my committee members. Lastly, I am grateful to my wife and daughter for an endless source of hugs and encouragement; indeed, they are the reason I stayed in school and was successful there.

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CHAPTER 1

INTRODUCTION

1.1 PROBLEM STATEMENT

The application of polymer concrete surface treatments to concrete bridge decks is an effective tool for combating the wearing effects of ever-increasing use that are beginning to show in an alarming number of bridges within the United States. In the 1990s, spending estimates for replacing damaged portions of roadway in the United States were as high as \$400 billion (1). At the heart of this problem are the tons of salt deposited on America's roads and bridges every year to keep the riding surfaces free of ice during the winter months. In Syracuse, New York, alone, 10,000 tons of salt are spread onto the roads each year (2). The resulting salt-water solution migrates into the pavement cracks and the concrete pores. Eventually, this salt solution comes in contact with the reinforcing steel on which the bridge relies for strength. Subsequent corrosion of the steel quickly leads to bursting stress in the concrete, which leads to more cracking of the concrete that further facilitates the intrusion of chloride ions (salt) into the bridge deck.

The concept of the bridge deck overlay is a simple and logical one. In essence, it entails the application of a layer of material that will ideally prevent water, oxygen, and especially chloride ions from penetrating the bridge deck surface. Some overlay systems have two distinct layers, a lower layer that is effective at waterproofing and an upper layer that provides skid resistance and protects the lower layer from the damaging effects of traffic and ultraviolet (UV) rays. Other overlay systems are single-layer, homogeneous mixes of chemicals and aggregates. The application process can vary widely from product to product. Some products are simply spread onto the deck surface and then showered with aggregates to enhance its roughness. Other products require special machinery to apply and precisely mix the chemicals to ensure proper

performance. The goal of this research was to identify types of surface treatments that effectively prevent the ingress of chloride ions into concrete bridge decks. The products addressed in this report primarily include urethanes, silicon-based sealers, and epoxies.

1.2 OUTLINE OF REPORT

Chapter 2 of this report presents various types of overlays, and Chapter 3 discusses common overlay distresses and typical causes of overlay deterioration. Chapter 4 contains a comprehensive literature review centered on performance evaluations of available polymer concrete products. Chapter 5 focuses specifically on research performed by the Utah Department of Transportation (UDOT) on polymer concrete overlays. Chapter 6 discusses specific overlay products currently available in the industry. Chapter 7 is a summary of the responses of state departments of transportation (DOTs) to a nationwide questionnaire survey regarding polymer bridge deck overlays. Chapter 8 presents the conclusion and recommendations resulting from this research.

CHAPTER 2

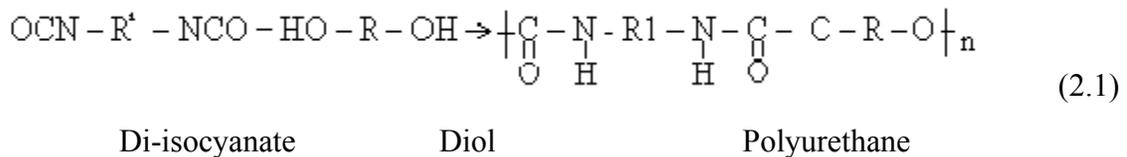
TYPES OF POLYMER OVERLAYS

2.1 POLYMER OVERLAYS

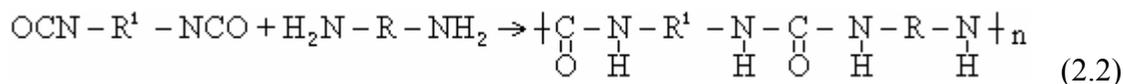
The overlay materials discussed in this report may be categorized as one of three types: urethane, silicon-based, or epoxy. This chapter provides a brief discussion of each of these three types, with emphasis placed on the differences in molecular structure and physical properties between them.

2.2 URETHANE

The *Handbook of Coatings for Concrete* refers to polyurethane (PU) as the single most versatile class of polymer in the world (3). PU elastomers were first discovered in 1937 (3). They are available as foams, which are used in soft furniture and insulation; solid PU elastomers, which are used for shoe soles, auto parts, and tires; and adhesives, such as binders, coatings, and paints. PU is made by reacting di-isocyanate (DI) and a polyol as shown in Equation 2.1 (3).



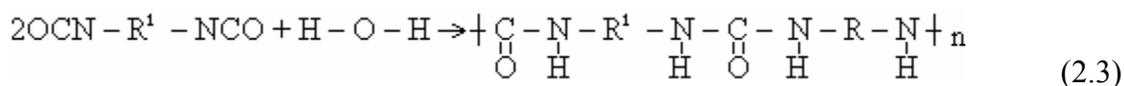
Other equally important reactions occur between DI and other active hydrogen-containing materials (amines and water) as shown in Equations 2.2 and 2.3 (3).



Di-isocyanate

Amine

Polyurea



Di-isocyanate

Water

Polyurea + CO₂

Equations 2.1 to 2.3 show that di-isocyanate is common to all PUs and is perhaps the single most important element in these materials (3). DI monomers come in different forms; however, the two most common forms are aromatic and aliphatic, as illustrated in Figures 2.1 and 2.2.

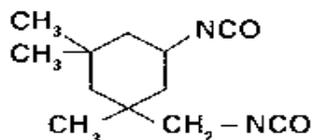
The properties of PUs vary depending on the type of DI used, the conditions under which the reaction takes place, and the material combined with the DI (3). Table 2.1 presents a brief and very general summary of the characteristics generally associated with aliphatic and aromatic PUs (3). Aromatic isocyanates receive a poor rating with regard to weather resistance because they discolor readily when exposed to UV light. If

Aliphatic di-isocyanates

HDI
hexamethylene di-isocyanate



IPDI
isophorone di-isocyanate



m-TMXDI
meta-tetramethylxylene di-isocyanate

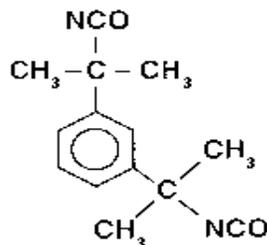


FIGURE 2.1 Aliphatic di-isocyanates (3).

Aromatic di-isocyanates

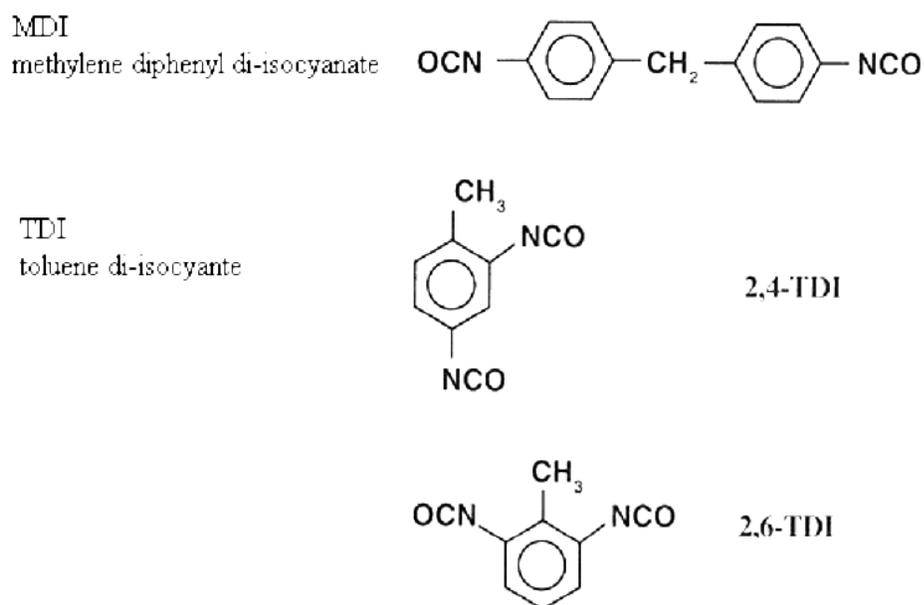


FIGURE 2.2 Aromatic di-isocyanates (3).

TABLE 2.1 Effects of Di-isocyanate on Polyurethane Properties

Property	Aliphatic	Aromatic
Chemical Resistance	Good	Excellent
Weather Resistance	Excellent	Poor
Flexibility	Good	Fair
Hardness	Good	Excellent
Abrasion Resistance	Good	Excellent
Heat Resistance	Good	Very Good
Water Resistance	Very Good	Excellent

color is not a concern or if dark pigments are used, aromatic di-isocyanates can otherwise exhibit high durability.

In their basic form, all of the isocyanates shown in Figures 2.1 and 2.2 are toxic, with the exception of methylene diphenyl di-isocyanate (MDI), which is not commonly used (3). Nearly all DIs must undergo processes to increase their molecular weight and decrease their volatility in order to make them safer to handle. A common way to

increase the molecular weight of the DI is to pre-react it with a polyol having a high molecular weight to form a “prepolymer.” This process results in larger molecules with “pendant” DI groups that will still react properly when required to do so (3). The prepolymer is significantly safer than the original monomer. It also remains in a liquid state until mixed with more polyol or water to form solid PU. The properties of the PU may vary with the type of polyol used to decrease the hazards associated with the DI.

Another method commonly employed to increase safety when using DI is to create an adduct (3). Adducts are formed in the same way as prepolymers, but they are usually characterized by the use of polyols with low molecular weights. Even though these materials have low molecular weight, they are considerably safer than the original DI monomer because they are less volatile (3). In addition to reducing the level of volatility, these light-weight polyols also increase the hardness of the material (3). The final properties of PUs will vary depending on the type of polyol used to form the prepolymer. Table 2.2 lists some common polyols and their traits (3).

Each material listed in Table 2.2 represents a polyol group. Materials engineers should understand how polyols affect the finished product in order to make informed decisions regarding which one(s) to use. Engineers, however, are often forced to compromise between desired traits and cost (3). For example, polycarbonates and acrylates receive higher ratings in nearly all performance categories but are significantly more expensive than polyether and polyester polyols (3).

Generally, PUs used for coating purposes are supplied in two parts, the DI prepolymer and the polyol. Once these two materials are mixed, the resulting chemical reaction, which is given in Equation 2.4, leads to increased viscosity and short pot life (3):

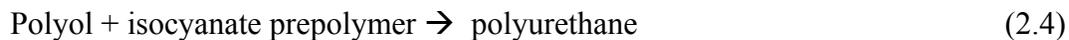


TABLE 2.2 Effects of Polyols on Polyurethane Properties

Property	Polyester	Polyether	Polycarbonate	Polyacrylate
Chemical Resistance	Fair	Fair	Fair	Good
Weather Resistance	Good	Fair	Good	Excellent
Flexibility	Excellent	Excellent	Excellent	Good
Hardness	Fair	Poor	Fair	Good
Abrasion Resistance	Good	Poor	Good	Good
Heat Resistance	Poor	Poor	Fair	Good
Water Resistance	Good	Fair	Good	Good

The pot life of PUs is limited because, once the components are mixed, the molecules begin to attach themselves together and to the sides of the container in which they are mixed (3). The materials are not pre-mixed by the manufacturer so as to prevent them from becoming solid blocks of plastic inside the containers.

PUs are also supplied as moisture-cure systems. These systems are pre-mixed in one container and are designed to react with the moisture found in the atmosphere and substrate at the time of application. The advantages of using a moisture-cure system are the elimination of any mixing required at the time of application and an unlimited shelf life (3). Mistakes in mixing can have very negative effects on the performance of PUs. A drawback associated with these single-component materials is that they are heavily influenced by the relative humidity at the time of application. Also, application is limited to thin layers; otherwise, bubbles of carbon dioxide, which are produced during the curing process described by Equation 2.2, will be trapped within the layer (3). Table 2.3 summarizes the curing characteristics of moisture-cure systems as a function of relative humidity at the time of application (3).

TABLE 2.3 Effect of Humidity on Moisture-Triggered Systems

Relative Humidity, %	Cure
0-20	Very Little Cure
20-30	Very slow Cure
30-45	Slow Cure
45-80	Good Cure
80-90	Slight Gassing
90-100	Severe Gassing

The environmental sensitivity of these materials can be greatly reduced, however, through the use of a latent hardener that reacts with atmospheric moisture (3). Proponents of PUs argue that, if price is not a factor, a PU solution is available for nearly any problem.

2.3 SILICON-BASED SEALERS

Silicon-based weatherproofing materials are effectively and widely used to prevent chlorides from penetrating concrete. When selecting a silicon-based sealer, an engineer should consider its performance characteristics. To be effective, the sealer must resist water absorption, prevent chloride penetration, penetrate into the substrate to a measurable degree, not stain surfaces to which it is applied, function over long periods of time in alkaline environments, and not pose a significant threat to health or the environment (4). Although no single product completely satisfies all of these requirements under all conditions, some come closer than others.

Silicon-based sealers can be classified by the nature of the molecules attached to the central silicon atom. The two types of molecules typically attached to the silicon atoms in these materials are the organic hydrocarbons, or organofunctional groups, and the hydrolyzable or silicon functional groups in the form of chloro and alkoxy groups (4). The ratio of the number of organofunctional and hydrolyzable groups in each molecule has a profound impact on the performance of the material as a weatherproofing agent. Three molecular structures are commonly available for weatherproofing: Q, T, and D. Experts in the field of silicone-based weatherproofers generally agree that the T-structure is the most stable and durable configuration (4). Figure 2.3 illustrates a T-structure molecule.

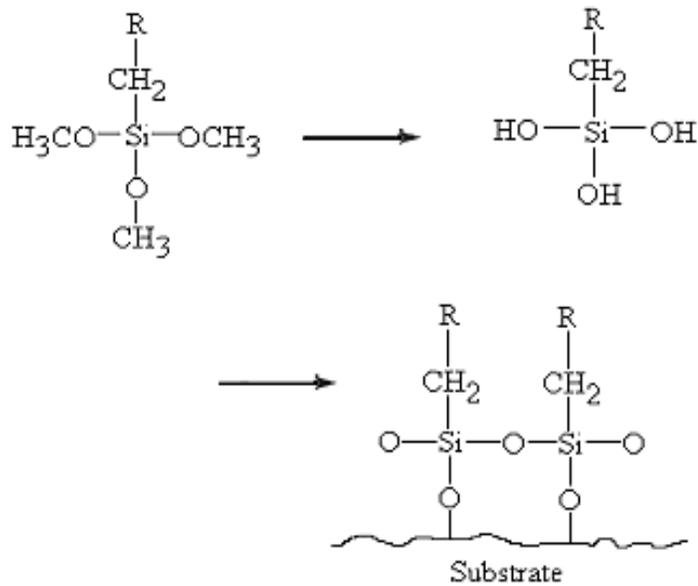


FIGURE 2.3 T-structures (4).

Silane, siloxane, and siliconates are examples of T molecules. T molecules are composed of three silicon-based functional groups and one organofunctional group. The silicon functional groups attach the molecule to the concrete and to the other molecules to form a solid network of interlinked molecules that coat the concrete (4). The organofunctional group gives these materials their hydrophobic qualities and longevity in alkaline environments (4).

Silane has significant advantages over other T-molecule waterproofing structures. Siliconates are inferior because they require special treatments after application before they will begin to bond to the concrete (4). In addition, siliconates do not react well with substrates with high alkali content, such as concrete, and therefore perform poorly in bridge deck applications (4). Siloxanes are inexpensive and yet effective weatherproofers in the short term, but they lack any significant resistance to alkali and therefore do not last long when applied to concrete.

The pore water in concrete contains high levels of alkali and hydroxide ions (OH^-). These ions attack the bonds between the silicon-based functional groups and the concrete (4). The factor that sets some waterproofing sealers apart in this regard is the nature of the lone alkyl group attached to the silicon atom. Some products have an organofunctional group that is more effective, due to size and shape, at blocking the

damaging OH^- ions and protecting the molecule, as illustrated in Figure 2.4 (4). Ions can more readily penetrate coatings that employ smaller alkyl groups.

Another characteristic of silicon-based sealers that could be used to rank their effectiveness is their ability to penetrate into the concrete and provide a uniform level of protection throughout the penetrated depth of concrete. Sealers that penetrate the concrete are better protected from harmful UV rays and traffic (4). Factors that control the depth to which a sealer will penetrate a substrate include porosity, moisture content, pH, and silica content of the substrate (4). Sealers that penetrate deeply into the substrate last longer because more time is required to wear them away (4).

Silanes are effective at penetrating concrete, and they also offer the most uniform level of protection throughout the penetrated layer of concrete (4). Knowing the extent of penetration is useful to engineers predicting how much concrete can be worn away before the surface will suffer a significant decrease in protection. Silanes are more effective at penetrating concrete than siloxane because silane molecules are smaller than siloxane molecules and significantly smaller than the concrete pores (4).

The rate at which the sealant molecules react with the materials in the substrate is also a factor governing the depth of penetration (4). As sealers react with the moisture in the substrate, their size increases greatly. Thus, a sealer that reacts very fast or is introduced into concrete containing excess moisture has less probability of penetrating deeply into the concrete. On the other hand, fast-reacting sealers form bands of protection that are more uniform throughout their depth (4). An ideal sealer should penetrate to a useful depth while still offering reasonably uniform protection throughout that depth.

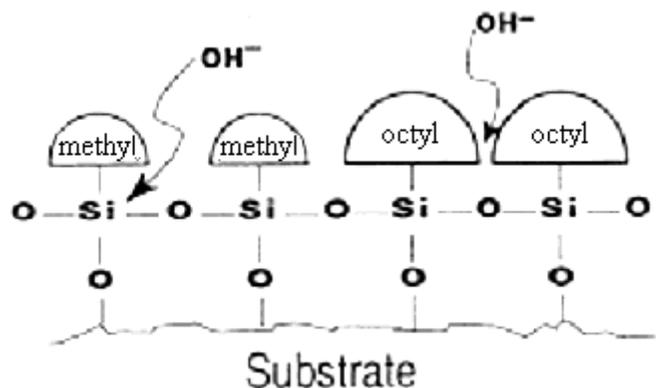


FIGURE 2.4 Protection from OH^- ions (4).

Another way by which the performance of a sealer can be judged is its ability to prevent water from being absorbed into the concrete. The American Society for Testing and Materials (ASTM) C 642, Standard Test Method for Density, Absorption and Voids in Hardened Concrete, is a standard for measuring water absorption in concrete. Sealers protect the concrete by chemically bonding a layer of hydrophobic molecules to the concrete. The effectiveness of such a layer depends largely on the nature of the organofunctional group. As with alkali resistance, larger organofunctional groups provide better protection (4).

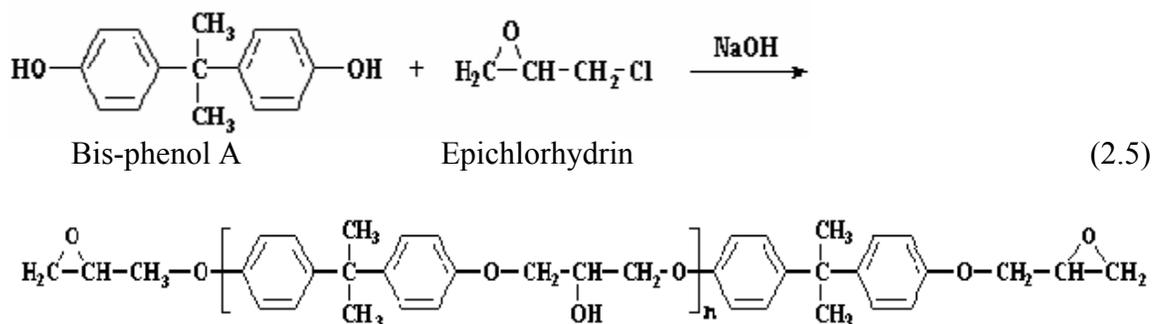
Silane sealers therefore have the most to offer in terms of long-term protection. Research has shown that concrete treated with silane and an acrylic top coat exhibits a higher level of protection than does concrete treated with silane only (5).

2.4 EPOXY

Epoxy resin is a substance commonly used as an adhesive and a protective coating.

Epoxy resin was first used as a road and bridge deck coating in the United States (6).

Epoxy is typically made by combining epichlorhydrin and bis-phenol A (3). The external conditions present during the reaction, as well as the proportions of these two ingredients, affect the properties of the final epoxy product (7). Equation 2.5 shows the structure of these two components, as well as the final epoxy resin (7).



Immediately after being mixed with a curing agent, this material begins to form links that transform the epoxy into a three-dimensional thermosetting resin (7). This new material is renowned for its adhesive abilities and strength; in fact, the adhesive strength of epoxy often exceeds the tensile strength of the concrete, which is typically 500 psi to

600 psi, to which it is applied (8). If the coating is properly installed, the epoxy will cling tenaciously to the bridge deck and to the aggregates that are mixed into the overlay to improve skid resistance. Epoxy components are supplied in separate containers and mixed just prior to use. The reaction rate is slow even in the presence of heat, but this can be overcome by introducing additional agents into the mix.

A wide array of materials can be added to the basic components of epoxy to make its final properties more desirable (7). Diluents are materials that reduce the viscosity of the mixture and allow it to more deeply penetrate cracks before hardening. Conversely, inert filler materials are used to increase viscosity and to make the system less expensive by reducing the need for more expensive components. Filler materials can also be used to alter physical properties such as compressive strength, hardness, thermal conductivity, and expansion.

Epoxy is usually a hard and brittle material, so flexibilizers are used when a tougher, more flexible epoxy is desired, such as in the case of a bridge deck protective coating. Fire retardants may also be added to an epoxy to reduce its flash point. Many resins will react with epoxy to form what is known as an “alloyed” polymer system; these resins are often called resinous modifiers. An alloyed polymer system ideally combines the benefits associated with both of the resins involved. Cure accelerators are catalysts that increase the rate at which the epoxy bonds and hardens. Reinforcements such as glass and carbon fiber can be added to the epoxy system to increase its strength.

By incorporating these filler materials and a proper curing agent, epoxy can be engineered to have all the properties necessary to make it a successful overlay material (7). For example, epoxy can have high chemical resistance and low shrinkage, harden quickly, and form a barrier to moisture and chloride ions (7).

CHAPTER 3

FAILURE MECHANISMS OF POLYMER OVERLAYS

3.1 OVERLAY FAILURE

Once a polymer concrete is in place, it may fail, vanish, or otherwise cease to be effective for a number of reasons. This chapter discusses materials selection; surface preparation; drainage; aggregate selection; mixing, curing, and application of polymers; and the effects of UV rays on polymer overlays. This chapter also includes a section on interpreting overlay distresses.

3.2 MATERIALS SELECTION

Deciding which material to use for an overlay can be difficult because many factors contribute to the success or failure of this type of project. One of the first things to consider is the coefficient of thermal expansion of the bridge deck compared to that of the overlay material. Polymer concrete and traditional concrete have different coefficients of thermal expansion. As the polymer concrete cures, it shrinks and hardens and, in doing so, creates potentially severe shear strains at the overlay-concrete interface. These strains are exacerbated by the thermal strains introduced into the system as the bridge deck and overlay warm and cool from day to day and season to season. Differential strains across the overlay-concrete interface contribute directly to the occurrence of overlay delamination.

Use of a flexible and solvent-free epoxy or urethane helps avoid delamination (9). Generally, a good polymer overlay material will bond to the concrete substrate with a minimum tensile strength of 250 psi, and it will have a compressive strength of at least 500 psi. To ensure adequate flexibility and resilience, the material should have tensile elongation of at least 30 percent and a tensile strength greater than 2,000 psi. The viscosity of the material should be low enough to ensure that it is easy to mix, place, and finish. Low-viscosity materials may also provide a stronger overlay-concrete bond because the low-

viscosity material will be more invasive of the concrete surface texture and form a system that is more monolithic in nature than a high-viscosity material. The gel time of the material should be between 15 and 45 minutes so it sets quickly but allows workers enough time to apply it. The use of solvents and other components that evaporate during curing should be avoided because they inevitably lead to shrinkage cracking. Materials that do not contain solvents are often referred to as consisting of “100 percent solids” because in theory no part of the material evaporates during curing (10). Table 3.1 provides a list of useful ASTM standards that can be employed to determine the properties of prospective overlay materials.

TABLE 3.1 Common ASTM Tests for Plastics

Test Property	ASTM Standard
Linear Thermal Expansion	D 696
Impact Strength, Izod	D 256
Tensile Strength	D 638
Tensile Elongation	D 638
Tensile Modulus	D 638
Flexural Strength	D 790
Flexural Modulus	D 790
Compressive Strength	D 695
Hardness, Rockwell	D 785
Water Absorption	D 570
Peel Strength	D 903
Direct Tensile Bond	D 4541
Ultimate Tensile Strength	D 412
Tear and Abrasion Resistance	D 1004
Wet Skid Resistance	E 27
Wear Resistance	C 501
Compressive Strength	C 579
Bond Strength	C 882
Epoxy-Concrete System Specifications	C 881
Epoxy-Concrete Thermal Compatibility	C 884

3.3 SURFACE PREPARATION

Before a surface treatment material can be placed, the substrate onto which it will be bonded must be meticulously prepared to receive it (10). Polymer concretes commonly form bonds with concrete that are stronger than the concrete itself. In other words, when the bond is placed in tension, the polymer will actually break the concrete before the polymer bond fails (9). This tremendous strength is useless, however, if the substrate is deteriorated concrete, loose debris, or any one of a number of substances that should have been removed prior to application (10). Failing to properly clean the surface contributes to the occurrence of delamination and blistering, which lead quickly to cracking. Surface preparation commonly entails, in addition to thoroughly cleaning the deck surface, the repair of any significant cracking, and the search for and repair of concrete that is weak, delaminated, or in other ways unsuitable (10, 11).

An example of unsuitable concrete would be concrete with chloride contents very near or above 1.5 lbs/yd³ in the vicinity of the reinforcing steel. At this concentration, a high probability exists that the steel will begin to corrode very soon, if it has not already begun (12). Another example of unsuitable concrete is concrete with excessive cracking. Simply overlaying cracked surfaces is unacceptable. Damaged areas must be repaired before the surface is overlaid (11). Once the surface is cleaned and repaired, roughening the surface by shot-blasting is often beneficial. Shot-blasted areas should be cleaned with a vacuum to ensure that no residue remains on the deck (10).

Excessive moisture in the substrate at the time of application can also contribute to the early demise of an overlay. In the case of epoxy overlays, the upward movement of water vapor toward the concrete surface can lead to condensation of moisture at the interface between the old concrete and the epoxy layer. The moisture may then form a kind of barrier between the concrete and the epoxy that will result in a weaker bond than would otherwise be expected. The moisture content can be evaluated by taping a 4 ft-by-4 ft polyethylene sheet to the concrete. If moisture collects on the underside of this sheet in less time than the time it takes for the epoxy to cure, then the substrate should be allowed to dry before the epoxy is applied (9).

Another problem associated with mixing water and epoxy is blushing. Blushing is a clouding of the epoxy surface finish due to the reaction of moisture with the hardening agent

(13). This clouding is actually a waxy coating to which additional layers of epoxy will not adhere. If blushing occurs, it must be removed before additional layers of epoxy can be applied. Non-blushing epoxies exist, but they are more expensive than blushing epoxy (14). Blushing is often caused by the moisture in the atmosphere, so if a blushing epoxy is to be used on a bridge deck, it should be applied under the driest conditions possible, where low humidity and a dry substrate are preferable (14).

In the case of urethane coatings, unless water is the intended reactant, a reaction with water will alter the final properties of the overlay. This unintended change in the properties of the coating could render it incapable of fulfilling its purpose. In addition to this, the reaction with water yields carbon dioxide, as demonstrated in Equation 2.3 which can cause detrimental bubbles and pin holes to form in the overlay (3). If drying the substrate is not feasible, then a moisture-insensitive overlay should be considered.

3.4 DRAINAGE

Some overlays have asphalt concrete as the wearing course on top of the waterproofing layer or membrane of urethane or epoxy. If this design is to be used successfully, water must not be allowed to accumulate in the region where the asphalt is bonded to the membrane. If water ingress occurs in this region, stripping is likely to result from the repeated hydraulic pressures induced in the asphalt material by traffic loads and freeze-thaw cycles (12).

Stripping is the displacement of asphalt cement by water, which leaves aggregates free to move. This condition can be avoided through the use of specially formulated asphalts.

High-density and low-void-content asphalts work well; however, a balance must be met with regard to density and voids because instability can result from overly dense asphalts subject to heavy traffic loads and elevated temperatures (12). Therefore, anti-stripping agents, stiff binders, and high-quality aggregates may be needed to produce asphalt that will be successful in this application. In addition, adequate drainage should be provided to prevent water from ponding on the deck surface. Water that is allowed to reside on the deck surface for excessive amounts of time will have more opportunity to cause problems (12).

3.5 AGGREGATE SELECTION

Improper selection of aggregates can also lead to early failure of an overlay. Aggregates play a crucial role in determining the impact and abrasion resistance of the surface. Surfaces that will be subjected to high traffic volumes should be equipped with aggregate that will not fail under demanding conditions. The aggregate should be a material that resists fracturing and polishing, such as pure aluminum oxide, emery, basalt with aluminum oxide, or greywacke (10). Surfaces with comparatively lower traffic volumes may be adequately treated with weaker aggregates like silica sand. In both cases, however, the aggregates should be dry and relatively free of dust at the time of mixing. Using dry, clean aggregates is important for the same reason that bridge deck surface preparation is important. Strong aggregates that will not stay bonded to the overlay are ineffective (10).

3.6 MIXING, APPLICATION, AND CURING

As described in Chapter 2, urethane and epoxy overlay materials are commonly supplied as two separate materials that must be mixed prior to application. When the components are mixed, they chemically react to form a solid layer of molecules interlocked in three dimensions. If the components are not mixed in the proper proportions, unreacted materials will remain in the membrane and interfere with the formation of an intact layer, thus preventing the overlay material from hardening to its maximum potential. Soft overlays such as this are more likely to suffer from rutting and aggregate loss. Human error can be avoided through the use of automated mixing equipment; however, this equipment should be closely monitored to ensure it is working properly at all times (10).

Once the deck is prepared to receive a new layer, the choice of application method must be made. The build-up method involves applying an even layer of epoxy or urethane to the bridge deck and then covering it with a layer of aggregates. This process is often repeated to increase the layer thickness to a desired depth. The other common method of applying overlays of this type is called the slurry method. This method involves mixing the aggregates and chemical binder, usually urethane or epoxy, and then applying the mixture to the bridge deck (10). Both methods are generally acceptable and can be used to achieve favorable results.

Once the material is in place, allowing it to cure sufficiently before permitting trafficking is important. Cure times vary from product to product, but generally polymer concretes can withstand traffic loads within a few hours, assuming they cure under favorable conditions. An understanding of how cure times vary with environmental conditions is crucial for estimating the time needed for a given product to fully cure. Traffic can damage polymer surface treatments that are not fully cured (10).

3.7 EFFECTS OF ULTRAVIOLET RADIATION

When considering all of the factors that could contribute to the eventual failure of a polymer surface treatment, the effects of UV radiation should not be ignored. Composite materials, such as carbon fiber, that use thin layers of epoxy to cover and protect delicate fibers within the matrix are susceptible to being seriously damaged by UV radiation. For this reason, the majority of research regarding UV damage of polymers has been focused on composite materials (15). The UV rays absorbed by the polymer in urethane and epoxy have the potential to cause scission reactions to take place within the layer nearest the surface. These reactions cause molecules to break up into smaller, lighter structures that are more easily eroded, thus exposing previously unexposed molecules to the UV rays (15). Given enough time, the effects of UV radiation can cause a significant amount of material to vanish. In the case of a bridge deck overlay, the damaging effects of UV radiation are fairly inconsequential because the overlays are relatively thick and the radiation only affects a thin layer of material on the surface, which is largely shielded from the sun by aggregates (15). In the case of epoxy, the UV rays will also cause the overlay to take on a yellowish tinge (14), which is mainly a cosmetic concern and not a threat to the integrity of the overlay. Darker surface colors and an abundance of aggregates would cause any yellowing that occurred to be much less noticeable than with a lighter color such as white or clear. However, selecting a material that will resist the effects of UV radiation, or at least one that is not particularly vulnerable to UV damage, is important regardless of the layer thickness.

3.8 OVERLAY DISTRESS EVALUATION

When evaluating distresses in an overlay, engineers should remember that localized “patchy” areas with multiple distresses are often associated with construction deficiencies, while

distresses exhibited somewhat uniformly across the deck surface are often associated with material inadequacies. The structure itself can also cause damage to an overlay. For example, in St. Louis, Missouri, the Poplar Street Bridge was overlaid with an epoxy surface. After 8 years of cold winters and intense traffic loads, the surface was in excellent condition, but delamination and cracking were present in about 0.5 percent of the bridge deck surface; the distresses were attributed to movements in the steel deck plates over which the overlay was applied rather than to inadequacies in the overlay material itself (16).

Polymer concrete surface treatments can add years to the life of a bridge deck. They may be applied quickly, but special care must be taken to select a material appropriate for the intended application and install it as required by the manufacturer. Failure in either of these two areas can result in an expensive disappointment.

CHAPTER 4

PERFORMANCE EVALUATION OF POLYMER OVERLAYS

4.1 LITERATURE REVIEW

The *Handbook of Coatings for Concrete* (3) contains a wealth of information regarding polymer concrete. The authors point out a number of strengths and weaknesses characteristic of urethanes and epoxies. According to them, the major disadvantages of epoxy systems are a limited shelf life and poor low-temperature curing properties. The advantages of using epoxies are that under the right conditions they are very useful as sealants and have excellent bonding characteristics, which is particularly helpful in maintaining skid-resistant surfaces (3). The urethane systems comprise such a massive number of substances, each with its own unique properties, that finding the one best suited for a particular job can be difficult (3). This chapter briefly summarizes a number of articles that have been published in various journals and magazines regarding the use of polymer concrete surface treatments in the United States.

4.2 SUMMARY OF PUBLISHED ARTICLES

In February of 2003, *Practical Periodical on Structural Design and Construction* published the results of a study performed by the Alabama Department of Transportation (ADOT). In that study, ADOT evaluated the performance of overlays on 19 bridges (17). Four decks were protected with a 0.25-in. overlay of a urethane polyester concrete called Sylcrete; 12 were covered with a 0.375-in. layer of polyester polymer concrete; two were protected using a 0.375-in. layer of a product known as Flexogrid, which is a type of epoxy co-polymer concrete; and one deck was overlaid using 0.5 in. to 0.75 in. of a product called Novachip, a polymer modified emulsion membrane (18).

Results of the study clearly separated these products based on durability. The urethane polyester concrete overlays lasted three years each and “left much to be desired”

during that time (17, p. 21). This product had poor wearing properties and was thus deemed too soft; at the end of the 3-year life cycle, the overlay was “almost gone” (17, p. 21). Of the 12 bridge decks protected using polyester polymer concrete, four lasted less than 1 year, and the remaining eight decks had each been in service for about 10 years at the time the data were published and were only then nearing the end of their effectiveness.

The aforementioned eight polyester deck treatments required acceptable levels of maintenance over their 10 years of service. The bridges overlaid with Flexogrid had been in service 8 years at the time of ADOT’s appraisal. Both of the overlays were described as being in “mint” condition (17, p.21). The Novachip overlay had only been in service for 3 years, but at the time of the evaluation it, too, was in pristine condition. All of the overlays were installed by the manufacturers of the specific overlay materials being used, except for the urethane polyester concrete; therefore, the possibility exists that this material was installed incorrectly. The bridges protected by urethane had about twice as much traffic as those protected by polyester polymer concrete, but they lasted less than half as long (17). The reduced life suggests that this particular urethane had inferior durability and/or the contractor that installed the material did so incorrectly. Applying the material just as the manufacturer indicates is vital to minimizing the risk of overlay failure.

In addition to the aforementioned web site, National Cooperative Highway Research Program Report 297, *Evaluation of Bridge Deck Protective Strategies*, offers extensive comparisons between various methods of protecting bridge decks. This report makes a direct comparison between epoxy-based and polyurethane membranes. The report concludes that polyurethane is more effective at halting the progression of chloride ions into the underlying concrete. However, given proper maintenance practices, both methods should be capable of preventing chlorides from reaching the upper layer of reinforcing steel in most bridges before the typical 50-year bridge service life expires (12). The limiting factor for bridge deck membranes is the wearing course, or protective layer, placed over the membrane. These layers do not last as long as the membrane in most cases, and care must be taken to ensure that the wearing layer is free of cracks and that it is replaced before excessive wear exposes the underlying membrane (12). Traffic wear can degrade the membrane very quickly, and cracks in the membrane will in turn diminish its effectiveness in affected areas. The typical life span of a successful wearing

course is 10 to 15 years, given proper maintenance (12). Perhaps the Alabama bridges coated with urethane had an inferior wearing course resulting from weak aggregates, improper proportioning of binder to aggregates, or other reasons.

The Poplar Street bridge in St. Louis, which was discussed briefly in Chapter 3 because of the outstanding resilience of its epoxy overlay, is worth mentioning again because all 226,000 square feet of the deck overlay had been constructed in just 20 working days. Given favorable conditions, the chemicals in these types of overlays can cure within hours and be ready to receive traffic (16). Smaller jobs can begin in the evening, and the bridge can be opened to traffic by morning. Curing typically occurs within 2 hours at 90°F and within 8 hours at 60°F degrees Fahrenheit (16).

The *Handbook of Coatings for Concrete* also mentions that applying a silicon-based sealant to the deck before applying an overlay can be beneficial. Using both urethane- and silicon-based sealants on a single project, although more complicated, can prove to be highly effective (3). In fact, the South Dakota Department of Transportation (SDOT) research office released a report in which the authors recommend that SDOT should abandon its method of sealing bridge decks with linseed oil and adopt the use of silicon-based sealers (19). The researchers based this recommendation on extensive field and laboratory tests. SDOT found that 100 percent silane is most effective at actually penetrating the concrete to which it is applied and was highly effective at preventing the migration of chloride ions into the deck (19). Also, *Road Management Journal* published an article entitled, “Sealers Shown to Lengthen the Service Life of Concrete Bridges Exposed to Chloride,” in which they reported that silane out-performed both water- and solvent-based epoxy treatments (20).

In an article entitled, “Penetrating Sealers: A Comparison of Epoxy, Moisture-Cured Urethane, and Siloxane Technology on Concrete, Rust, and an Inorganic Zinc Coating,” 12 coatings were compared to identify the type that produced the strongest bond to various substrates. For both mature and green concrete, the epoxy coatings dominated in the categories of concrete penetration and bond strength. Interestingly, the researchers noted that deep penetration was not required to achieve a strong bond to green concrete. This article states that the best penetration of concrete was achieved by

thin-film epoxies and methacrylates with low viscosity and 100 percent solids, and the highest bond strength was achieved using a high-build epoxy (21).

In a report published by the Virginia Transportation Research Council, a number of common methods for protecting concrete bridges from chloride intrusion were compared. Thin epoxy overlays have a number of advantages over other protection methods involving more conventional concretes. Epoxy overlays are typically very thin and therefore permit rapid repair of spalls and other defects that do not significantly affect the riding quality of the overlay. Another benefit of a thin overlay is that it contributes minimal dead load to the overall weight of the system to which it is applied. Furthermore, because epoxy overlays are flexible, they are less likely than standard concretes to crack and delaminate. The report states that an epoxy overlay could last between 15 to 30 years depending on traffic conditions (22). Considering the experiences of other agencies, however, this life span may be somewhat optimistic.

In another article on epoxy overlays, the performance characteristics of a section of the New Jersey Turnpike and a two-lane bridge in Ohio are discussed. The section of the New Jersey Turnpike is located at the No. 14 toll plaza near the Newark International Airport. One lane in the plaza was overlaid with epoxy by the New Jersey Turnpike Authority (JTA) in 1977 (23). The lane that received the epoxy treatment was subject to particularly heavy truck and bus traffic. The JTA reported that after 15 years and approximately 243 million vehicles, the epoxy surface had not reached the end of its projected service life and was still providing “excellent” skid resistance and protecting the underlying concrete from moisture and chloride (23). The overlay performed so well that the same material was used to overlay all of the lanes in the plaza, or approximately 86,000 square feet, 6 years later. (23).

In 1983, the Ohio Department of Transportation (ODOT) applied the same epoxy used by JTA in 1977 to a bridge. ODOT reported that during 10 years of service the epoxy coating required only minimal amounts of maintenance and that the epoxy overlay had more than doubled its original life expectancy and was still in use (23).

4.3 LITERATURE REVIEW SUMMARY

Research results currently available clearly indicate that polymer bridge deck overlays, particularly epoxy-based overlays, can be used successfully in a variety of conditions. Polymer concrete surface treatments can be applied quickly and can last for many years when properly constructed and maintained.

CHAPTER 5

UDOT EXPERIMENTAL OVERLAY EVALUATIONS

5.1 UDOT FIELD REPORTS

The following chapter is a brief review and evaluation of three field reports compiled by UDOT. These field reports address three bridge overlay projects involving three different overlay materials. One of the projects used an epoxy-based product called Flexogrid; another one used a silicon-based sealer, and a third project involved a material called methacrylate.

5.2 FLEXOGRID BRIDGE DECK OVERLAY

UDOT 98-03 is a report concerning bridge F-596 on State Route (SR) 154 and bridge F-595 on SR 202. Both bridges were overlaid in 1998 using a material known as Flexogrid. The performance of this material as reported by UDOT was consistent with evaluations of the material made by other state DOTs (17). The bridges were inspected in 1999 and 2003, and concrete samples from the F-596 bridge deck were tested for chloride content. The information provided in the report summarizing the chloride contents of bridge deck F-596 is given in Table 5.1. Because the approach slab was not treated with the Flexogrid product, it was used as a control section. For both deck sections, a measurable reduction in salt content at nearly all tested depths occurred between the years 1998 and 1999, but reported salt contents then increased between 1999 and 2003.

TABLE 5.1 Deck Chloride Concentrations on Structure F-596 (24)

Depth (in)	Chloride Concentration (lb of Chloride / yd ³ of Concrete)					
	Approach Slab			Flexogrid Deck		
	1998	1999	2003	1998	1999	2003
0.5	16.5	4.47	5.96	7.98	3.73	9.32
1.0	5.69	1.12	2.65	4.42	0.86	0.89
1.5	0.31	1.16	1.16	3.76	0.82	1.90

While chloride concentrations may be reasonably expected to increase over time, reductions in salt concentrations are not expected; applying a polymer overlay to a bridge deck should not markedly reduce the amount of chlorides already in the concrete. One possible explanation for the collected data is that the concrete samples used for salt-concentration testing were removed before the surface was prepared to receive the new substrate. During deck preparation, existing undesirable material is commonly removed. If the upper 1.5 in. of material was removed in 1998 after its chloride content was recorded and used to represent the 1998 chloride content of the new material, the large decrease in chloride concentrations might be rationally explained.

Another possible explanation for the reduction in measured chloride concentrations is chloride migration. Chloride ions in high concentrations tend to migrate to areas of lower concentration. Therefore, in the case of a bridge deck, ion concentrations closer to the surface will decrease as ions diffuse deeper into the concrete. This effect would be more pronounced in the section treated with Flexogrid, which was presumably sealed against continuing ingress of chloride ions; however, the measured salt contents at lower depths do not suggest that the proposed redistribution of ions occurred.

Furthermore, different methods of chloride determination may have been used for testing in different years, or the sampling locations may not have been the same from year to year. Due to spatial variability in the permeability of concrete, different chloride concentrations will develop at different locations on a bridge deck. These hypotheses are just speculation, however, because no explanation was given for the chloride reduction, and little detail was provided regarding deck preparation, Flexogrid placement, sampling, or chloride determinations. Also absent from this report was any mention of deck

distress or lack thereof. If cracks were present in the overlay, chloride ingress will likely be much higher in those areas in future years.

The report also discussed the skid resistance provided by the Flexogrid overlay. Those measurements were consistent; they did not contain a large number of outlying data points. Flexogrid provides a level of skid resistance that falls well within acceptable ranges (24).

5.3 SILANE CONCRETE SEALER

An experimental project utilizing silane to seal 159,900 square yards of concrete was performed on northbound Interstate 15 (I-15) between mile posts 327.77 and 332.19 (25). The contract for this job was awarded in 1995, but work did not begin until May 1996 because of weather conditions. The product used on this project was ATS-42, which is composed of alkyltrialkoxo silane with 42 percent solids, available from Advanced Chemical Technologies. The purpose of this project was to seal smaller cracks (0.0625 in. wide and smaller) in the deck and thus prevent further intrusion of chloride ions.

As in the Flexogrid bridge deck overlay project, the measured chloride contents do not follow a logical trend. No information was given regarding how or where samples were collected. Samples collected at random from one year to the next could explain the rise and fall of chloride concentrations. Unfortunately, if this is the case, the usefulness of the study as far as tracking the rate of chloride penetration from one year to the next is limited. Also, no information regarding how the chloride contents were measured was given. More precise protocols for sampling and monitoring chloride content may be needed.

This experimentation also examined the effect of the sealant on the coefficient of friction, or skid resistance, of the bridge surface. UDOT engineers concluded that the sealant has little or no effect on skid resistance. Test results provided in this report are consistent and supported the conclusions of the investigation.

This report stated that the conditions during construction were damp and thus ideal for applying the sealant. However, the presence of excess moisture would likely increase the rate of hydration at the cost of penetration of the substrate. As explained in

Chapter 2, as silicon-based sealers hydrate, the molecules expand considerably, making them less able to travel down through pores in the concrete (25).

5.4 METHACRYLATE OVERLAY

An experimental project using methacrylate was conducted on the bridge located at 3600 West Bangerter Highway and 12600 South to Redwood Road (26). A protective layer of methacrylate was applied to the bridge with the intent of covering cracks and eliminating the penetration of chlorides.

The final cost of this project was five times more than the initial cost estimate. Specific information regarding the reasons behind this fact could be useful in the future but was not present in the report. Also, less than one year after the overlay was installed, it failed to meet minimum standards regarding skid resistance (26). The polyester resin could have been improperly mixed, placed under unfavorable conditions, given insufficient time to cure before traffic was allowed on it, or comprised of aggregates that were too weak to withstand the traffic loads to which they were subjected. Unfortunately, the report prepared by UDOT documenting this project provided an outline of events but failed to give details needed to address these possible factors affecting the performance of the methacrylate overlay.

5.5 SUMMARY

The UDOT reports documenting experimental evaluations of specific bridge deck surface treatments could have been more useful as future references if additional information had been provided. Detailed descriptions of sampling methodologies and documentation of actual test locations selected for the research would have been a valuable asset for engineers needing to interpret the field data. Also, the methods by which concrete samples were extracted from the deck and tested for chloride concentrations should be given in future reports, including specific information about sample pulverization and calibration of laboratory equipment, for example. Any of this information might have been helpful in understanding why the results of the chloride measurements did not follow the expected pattern.

CHAPTER 6

SPECIFIC OVERLAY PRODUCTS

6.1 OVERVIEW OF PRODUCTS

This chapter presents an overview of various surface treatment products currently available in the industry. Topics include physical properties, installation requirements, and material types. This chapter is not intended to serve as an instruction manual for installing the materials. Before using any of these products, the user must carefully read the directions provided by the manufacturer to ensure the success of the project and the safety of the workers. The products discussed in the chapter are presented in Table 6.1.

TABLE 6.1 Surface Treatment Products

Product Name	Manufacturer
Flexogrid	Poly-Carb, Inc.
Flexdeck	Tamms Industries
Flexolith	Tamms Industries
T-48	Transpo Industries, Inc.
Thermal-Chem Mortar Resin #3	Thermal-Chem
Polyurea Membrane 181	Chemco
Wabo Guardian	Watson Bowman Acme Corporation
Fx-547	Fox Industries
Elastodeck 5000	Pacific Polymers
Silane 100 Plus	Concrete Science
Sikadur 22	Sika Corporation
Bridge Seal	Unitex Chemicals

6.2 FLEXOGRID

Flexogrid is produced by Poly-Carb, Inc. Poly-Carb asserts that Flexogrid is a combination of urethane and epoxy that provides a strong, yet flexible, material that is well suited to withstand the harsh conditions caused by weather, traffic, and the subtle movements of the bridge deck itself. Flexogrid is placed over the entire surface of the deck at thicknesses as small as 0.25 in. and provides a layer of protection that is both skid-resistant and waterproof. Flexogrid is a two-component liquid polymer system comprised of 100 percent solids that is mixed on the job site just before application. At the time of application, the ambient temperature must be at least 50°F. Flexogrid is completely non-porous and contains no solvents that would cause shrinkage as they evaporate. Research conducted by UDOT on bridge F-596 showed that this material can maintain a skid number greater than 50 for long periods of time. Flexogrid cures within a matter of hours, which minimizes bridge closure time. Flexogrid maintains its flexibility even in cold weather (27). Poly-Carb materials have been used on many job sites in North America. Figure 6.1 is an illustration of states in which Poly-Carb products have been used (28).

Poly-Carb's system of applying Flexogrid involves the use of a tractor-trailer in which the epoxy is mechanically mixed and heated and from which it is dispensed. The

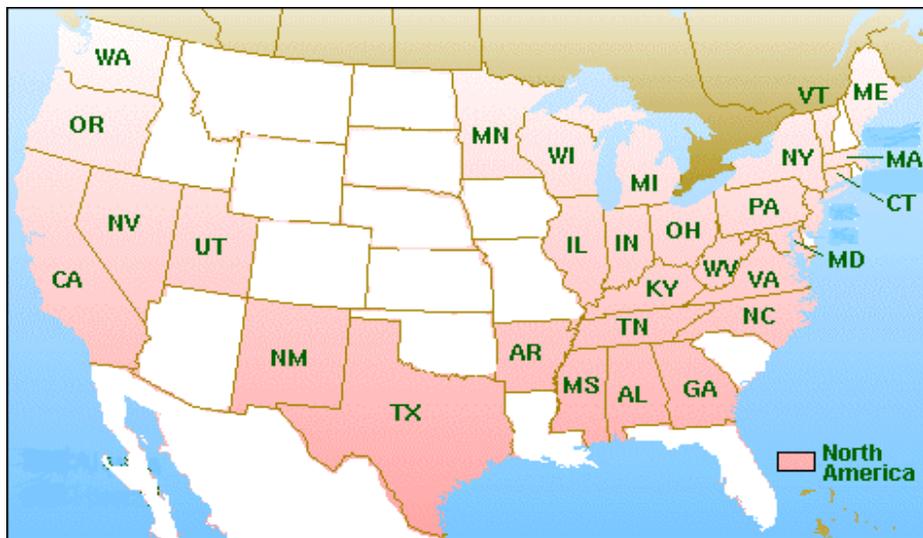


FIGURE 6.1 States with Poly-Carb projects (28).

process minimizes human error and greatly increases the speed at which the material can be applied. Other overlay systems involve mixing the polymer with a drill, one bucketful at a time. The Poly-Carb overlay construction process permits placement of thousands of square feet of Flexogrid before work must stop to mix more epoxy. Figure 6.2 is a picture of a Poly-Carb mobile mixing unit that automatically mixes and dispenses Flexogrid, as well as spreads aggregates onto the bridge deck.



FIGURE 6.2 Poly-Carb mobile mixing unit (27).

6.3 FLEXDECK SYSTEM

Flexdeck is produced by Tamms Industries and is designed to be a lightweight combination of urethane and epoxy ideal for protecting surfaces exposed to vehicular traffic. It is flexible, waterproof, and durable. Flexdeck will adhere to and protect concrete, steel, and wood. The aggregates embedded in the upper layers of this material provide ample skid resistance. The Flexdeck system resists most solvents, oils, gasoline, salts, detergents, and organic materials that commonly exist on roadways (29). The Flexdeck system consists of four distinct layers: a primer coat, a flexible membrane, a wearing coat, and a tie coat. The primer coat is a two-component epoxy resin. The flexible membrane is a two-component polyurethane material comprised of 100 percent solids. The wearing coat and tie coat are both two-component epoxy materials. The purpose of the tie coat is to provide the desired overlay color. These layers can be applied using a brush, roller, or sprayer. Table 6.2 summarizes many of the relevant material properties associated with Flexdeck (29).

TABLE 6.2 Flexdeck Material Properties

Property (Membrane)	Measurement
Gel Time, minutes	20-30
Initial Cure, hours	2.5
Temperature Range, °F	-45 to 266
ASTM D 412, 7-day, minimum	
Tensile Strength, psi	1200
Tensile Elongation, %	400-500
Tear Strength, ASTM D 1004, minimum, psi	100-120
Shrinkage	None
Property (Wear Coat/Tie Coat)	Measurement
Initial Cure, minutes	20
Tensile Elongation, psi	2000
Shrinkage, %	30

In order to provide the best results, each layer of the Flexdeck overlay must be applied under favorable temperature and humidity conditions, and the material onto which the layer is being applied must be prepared to receive the new layer. At the time of application of the Flexdeck primer coat, the ambient and substrate surface temperatures should be between 50°F and 90°F. The primer should be allowed to cure until it is no longer sticky to the touch. Curing requires 3 to 4 hours at 75°F.

Once the primer has cured, it is ready to receive the membrane layer. At the time of membrane application, the ambient temperature should be between 60°F and 80°F, and the relative humidity should be below 75 percent. If more than 24 hours has elapsed since the primer coat was applied or if the primer coat has become hard, a new layer of primer must be applied before the membrane layer can be installed.

As soon as the membrane layer has cured sufficiently to allow foot traffic, but before 24 hours passes, the wearing layer should be applied and the aggregates broadcast. This last step is often repeated to increase the thickness of the wearing layer (29). Once the binder has cured, the excess aggregate should be swept away before additional layers are added. Each of the layers in this system should be installed within 24 hours after the preceding layer is installed; thus, the tie coat should be applied within 24 hours after the final layer of wearing material has been applied (29).

6.4 FLEXOLITH SYSTEM

Flexolith, by Tamms Industries, is a two-component, low-viscosity, moisture-insensitive epoxy with 100 percent solids. Flexolith is intended for use in applications where resistance to mechanical and thermal movement is crucial. Flexolith cures quickly and at low temperatures. Table 6.3 summarizes relevant properties of this material, and Figure 6.3 shows which states have used Flexolith on one or more projects (30, 31).

TABLE 6.3 Flexolith Material Properties (30)

Property	Measurement
Mix Ratio by Volume	1:01
Gel Time, Class B, ASTM C 881, minimum °F	>30
ASTM D 638	
Tensile Strength, psi	2700
Tensile Elongation, %	30-60
ASTM D 695	
Compressive Strength, psi	5000
Compressive Modulus, psi	130,000
ASTM C 109 (3 parts Sand)	
Mortar Compressive Strength, psi	-
@ 4 hours at 75°F	1400
@ 24 hours at 75°F	7040
Hardness, Shore D, ASTM D 2240, minimum	65
Water Absorption, ASTM D 570, %	<0.5
Thermal Compatibility, ASTM C 884	Passes
Effective Shrinkage, ASTM C 883	Passes

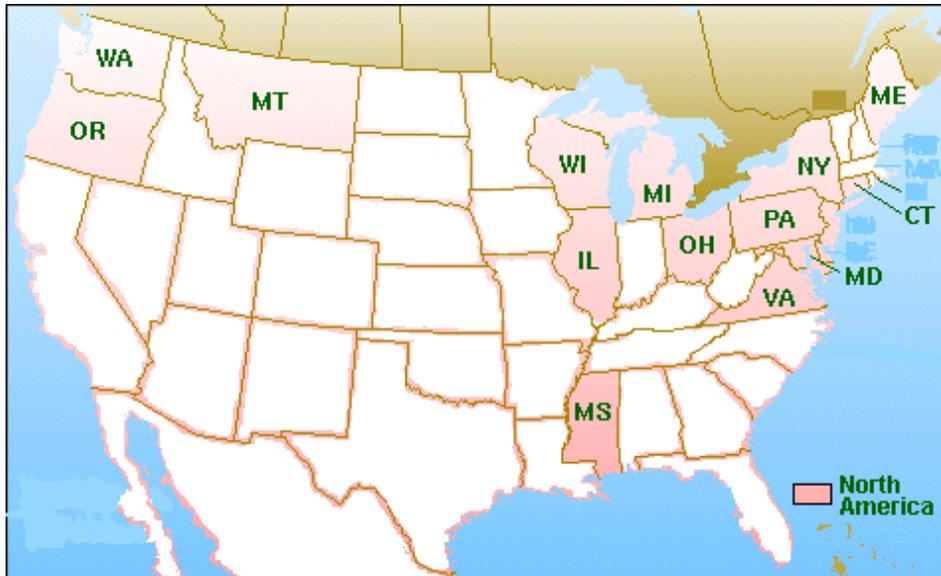


FIGURE 6.3 States with Flexolith projects (30).

6.5 T-48 THIN OVERLAY SYSTEM

Transpo T-48, by Transpo Industries, is a two-component, polysulfide, epoxy-based material intended for use as a wearing surface on bridge decks and other traffic-bearing surfaces. The layer formed by this system prevents moisture, chlorides, and other corrosive substances from penetrating the concrete bridge deck. Transpo Industries claims that this epoxy resin penetrates existing cracks and prevents them from propagating. T-48 is normally applied with a thickness between 0.25 in. and 0.50 in. The use of this material on a bridge deck only adds 3 to 4 pounds per square foot of dead load to the structure. Transpo Industries asserts that T-48 is UV resistant and highly elastic and provides good skid resistance.

T-48 is generally applied in one of two ways, single-application slurry or a multi-application “broom and seed” method similar to the build-up and slurry methods discussed in Chapter 3. Table 6.4 summarizes many of the relevant physical properties of T-48 (32).

TABLE 6.4 T-48 Physical Properties (32)

Property	Measurement
Mix Ratio, 2:1 by Volume	-
Brookfield Viscosity, cPs	1200-1600
Density, ASTM D 2849, lbs/gal	8.8 minimum
Pot Life, AASHTO T 237, @ 70°F, minutes	15-30
Flash Point, ASTM D 1310, °F	200 minimum
Solids Content, ASTM D 1644, %	100
Compressive Strength, ASTM D 695, psi	5000 minimum
Tensile Strength, ASTM D 638, psi	1800 minimum
Tensile Adhesion to Concrete, ACI 503R, psi	250 minimum
Tensile Elongation, ASTM D 638, %	45 minimum

6.6 THERMAL-CHEM MORTAR RESIN, PRODUCT #3

Mortar Resin No. 3 is a two-component, epoxy polymer with 100 percent solids.

Thermal-Chem has two variants of this product: standard Product No. 3 and Fibrous Mortar Resin 306. Both of these products are suited for use on traffic-bearing surfaces, but Resin 306 contains glass filler that increases the flexibility and tensile elongation of the overlay. This product is typically used when the deck is subject to vibrations or flexural movement caused by heavy traffic (33). Product No. 3 is available in normal- and rapid-cure formulations. Normal curing can take place at temperatures greater than 40°F, while rapid-cure material will cure at temperatures as low as 0°F (33).

These products have three main limitations. First, the manufacturer discourages the use of solvents; the pot life of Product No. 3 is long enough that solvents should not be needed. The second and third limitations have to do with moisture at the time of application. Product No. 3 can be applied to a damp surface, but not in the presence of free-standing water. If this product is used during periods of high humidity, it will blush. While blushing does not detract from the physical properties of the overlay, the blush

must first be removed with soap and water if another layer of epoxy is to be applied (33).
 Table 6.5 summarizes the relevant physical properties of Product No. 3 (33).

TABLE 6.5 Thermal-Chem Product No. 3 with Approved Silica Sand

Test	Normal Cure	Rapid Cure
Pot Life, hours		
32°F, Class A	-	0.6
50°F, Class B	1	0.5
72°F, Class C	0.75	0.4
90°F, Class C	0.7	0.3
Bond Strength, ASTM C 882, psi		
86°F	4800	4800
-55°F	-	5000
Compressive Strength, ASTM C 579, psi		
1 day	9600	9800
3 days	11,300	11,800
7days	14,000	14,200
Mortar Flexural Strength, ASTM D 790, psi	3200	3210

6.7 CHEMCO 181 POLYUREA MEMBRANE

The Chemco Systems, Inc. 181 polyurea membrane is a solvent-free, two-component polyurea resin and hardener. It is intended for use as an impact- and abrasion-resistant membrane for concrete slabs and decks. The 181 membrane can be applied with a sprayer or manually with a device such a squeegee. It is corrosion-resistant and can be used as a grout for non-structural cracks, saw cuts, and joints in concrete. It also reportedly performs well on asphalt (34). Good results can be obtained whether the surface is damp or dry. Typical application thicknesses range from 15 mils to 60 mils, so the dead load increase associated with this product is relatively low. This product can be applied to a surface as cold as 40°F and still cure. The 181 membrane does not become brittle when exposed to sunlight for long periods of time. This material cures rapidly but still has a pot life long enough to allow for application of the material once the

components have been mixed. Table 6.6 summarizes the important material properties associated with this product (34).

TABLE 6.6 Chemco 181 Membrane Material Properties

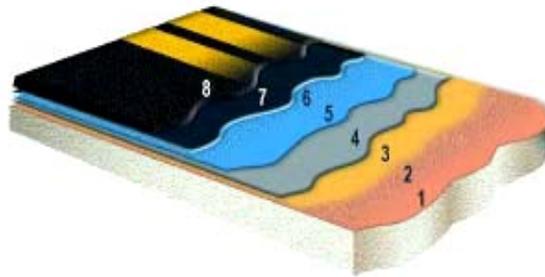
Property	Measurement
Mix Ratio	1:1
Color	Blue-Gray
Gel Time, minutes	12
Cure Time, hours	2
Tensile Strength, psi	1250
Elongation to Break	3.75
Bond Strength, ASTM D 4541, psi	350-500

6.8 WABO GUARDIAN

Wabo Guardian, by Watson Bowman Acme Corporation, is a tough, elastomeric membrane applied between a concrete bridge deck and an asphalt overlay for the purpose of preventing chloride ions and water from penetrating the concrete. Wabo Guardian is a multi-layer system that employs both epoxy and polyurethane. The epoxy, known as Conipox 605, is used to seal the concrete and provide an ideal surface to which a single-component polyurethane spray, referred to as Conipur 79, is applied. This surface treatment material is intended to adhere to aggregates and provide an ideal bonding surface for the next layer in the system, Conipur 255. Conipur 255 is a two-component, solvent-free, spray-on polyurethane waterproofing membrane. The last layer of the system is Conipur 267; this layer also consists of a two-component polyurethane, but it is applied with a squeegee and provides a wearing surface when combined with silica gravel. Wabo claims that spraying the polyurethane will ensure best results because it creates a seamless coating that is less likely to leak. In addition to the spray-applied polyurethane layer, a final polyurethane layer loaded with aggregates is applied to provide good shear and tensile bond strength at its interface with the traffic-bearing asphalt layer. Each layer of the system has unique physical properties that are summarized on the company web site; however, no quantitative information is given

regarding how the system as a whole performs under various test conditions. Figure 6.4 is a visual summary of the layers in this system.

The main limitation of this system is that the layers are susceptible to harm if excess moisture is present during application. Wabo Guardian should not be applied to surfaces that are damp or have active water vapor transmission, such as slabs on grade, if inclement weather is predicted to occur within 24 hours (35). Another limitation is that this system has eight layers. Reason suggests that as the complexity of any system increases, so does the required installation time and the potential for human error.



1. Conipox 605 Preconditioning Coat
2. Fire-Dried Silica Sand (supplied by others)
3. Conipur 79 Adhesion Promoting Coat
4. Conipur 255 Waterproofing Membrane
5. Conipur 267 Wear Coat
6. Silica Gravel (supplied by others)
7. Tack Coat (supplied by others)
8. Asphalt Overlay (supplied by others)

FIGURE 6.4 Wabo Guardian Bridge Deck System (35).

6.9 FOX INDUSTRIES FX-547

Fox Industries FX-547 is a two-component polyurethane protective coating for traffic-bearing surfaces such as bridge decks. FX-547 provides good skid resistance and retains its color and physical properties even when subjected to prolonged exposure to direct sunlight. The manufacturer of FX-547 claims that the material performs well in temperatures ranging from -20°F to 200°F . Other important physical properties of FX-547 are summarized in Table 6.7.

TABLE 6.7 FX-547 Properties

Property	Measurement
Pot Life @ 72°F, minutes	25
Cure Time @ 72°F, hours	4 (Foot Traffic)
Tensile Strength, psi	700
ASTM D 412	
Tensile Elongation, %	200 minimum
Pull-Off Test, psi	850
Bond Strength, ASTM D 4541, psi	Concrete Failure

FX-547 is not recommended for application on wet surfaces or on surfaces at temperatures below 50°F. Cooler temperatures prolong the curing process considerably. FX-547 should be applied in relatively thin layers with either a roller or a brush. If an additional layer of FX-547 is desired, it should be applied no sooner than 8 hours, but not later than 5 days, after installation of the previous layer (36).

6.10 PACIFIC POLYMERS ELASTODECK 5000 T.C. SYSTEM

Elasto-Deck 5000, by Pacific Polymers, is a single-component, moisture-cured polyurethane system. This system consists of two layers, an Elasto-Deck 5001 base coat and an Elasto-Glaze 6001 AL top coat with aluminum-oxide or silicone-carbide grit. Elasto-Deck 5000 is intended for use on parking decks, roofs, and floors because it provides an anti-skid, textured finish.

The main limitation of the product is that, once a container has been opened, all the material inside must be used immediately, as the material will cure in the presence of moisture in the air. Also, in addition to standard deck preparation, the deck must be primed with Elasto-Deck Primer (37). Many of the physical properties of this product are summarized in Table 6.8.

TABLE 6.8 Elasto-Deck 5000 T.C. Physical Properties

Property	Base Coat No. 5001	Top Coat No. 6001 AL
Hardness, Shore A	55	95 ± 5
Ultimate Tensile Strength, ASTM D 412, psi	975	4490 ± 10%
Ultimate Elongation, ASTM D 412, %	825	210 ± 10%
Adhesion, ASTM D 903, lbs per linear in. (Peel Strength)	90 (Primed Concrete)	N/A
Abrasion Resistance, ASTM C 501	No Change in Weight	No Change in weight
Tear Resistance, ASTM D 1004, lbs per linear in.	220	520 ± 10%
Weight per Gallon, lbs	10 ± 0.2	9.39

6.11 BARACADE SILANE 100

Barcade Silane 100, by Tamms Industries, is a single-component product that is supplied in a ready-to-use state. The product is a colorless, non-yellowing water repellent that is able to penetrate deeply into concrete and masonry. This product is intended to protect concrete against the harmful effects of water intrusion, deicing chemicals, freezing and thawing, and other contaminants such as acid rain. Barcade Silane 100 contains no solvents. The product is typically applied to concrete with airless spray equipment. The concrete should dry for at least 24 hours before application. Table 6.9 summarizes relevant physical properties of the product (38).

TABLE 6.9 Baracade 100 Physical Properties

Property	Measurement
Silane, %	100
Resistance to UV	Excellent
Abrasion Resistance	Excellent
Penetration in Concrete, in.	0.2
Water Absorption Reduction, %	
1 day	94
3 days	89
Chloride Reduction, %	91

6.12 CONCRETE SCIENCE SILANE 100 PLUS

Silane 100 Plus, by Concrete Science, is effective at repelling water and oil. It is advertised as a “neat” silane, which means that no solvents are used in it. The manufacturer of this material claims that the molecular structure of this product is smaller than conventional silanes and penetrates deeper into the concrete. Like all silanes, Silane 100 Plus is an effective barrier to chloride ions. Another advantage is that silane does not trap moisture below the surface of the concrete.

The main limitations of this product are that it is not recommended for asphalt or other non-masonry materials, and it should not be applied when the air temperature is above 90°F or on windy days. Also, this product is not recommended for use below grade or where hydrostatic pressure is present. The shelf life of this material is about one year from the date it was manufactured if the packaging remains unopened. This material is simple to apply; all that is required is to thoroughly wet the surface and broom out the puddles as the material penetrates the substrate. The excess silane can be wiped away with a clean towel (39).

6.13 SIKADUR 22 LOW-MOD EPOXY BROADCAST OVERLAY SYSTEM

Sikadur 22, by Sika Corporation, is a two-component, moisture-tolerant epoxy resin with 100 percent solids that is specifically designed to provide a seamless, skid-resistant, protective overlay for bridge decks. Sikadur 22 can be used with a primer, although it is not required. This material conforms to ASTM C 881, Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete; is easy to mix; and provides long-term

abrasion resistance even in hot weather. Table 6.10 summarizes many of the relevant physical properties associated with Sikadur 22 (40).

Sika Corporation lists a number of limitations for Sikadur 22. First, this product is not to be used if either the ambient or substrate temperature is below 40°F. Second, this material is not to be applied to a surface that is visibly wet, as this may negatively affect the properties of the resin as it cures. In addition, any moisture in the deck at the time of the overlay application will be trapped under the overlay and will act as a vapor barrier. This product is not to be applied to exterior, on-grade substrates. Furthermore, prolonged UV exposure changes the appearance of this material (40).

TABLE 6.10 Sikadur 22 Physical Properties

Property	Measurement
Shelf Life, years	2
Viscosity, cPs	2500
Pot Life, minutes	30
Mix Ratio	1:1 by Volume
Tensile Strength, ASTM D 638, psi	5900
Elongation to Break, %	30
Shear Strength, psi	5400
Compressive Strength, psi	6300

6.14 UNITEX BRIDGE SEAL

Bridge Seal, by Unitex Chemicals, is a low-viscosity, two-component epoxy product. Preparation involves manually proportioning the material in a 1:1 ratio and mixing it with a drill for 3 minutes. Once the epoxy has been spread onto the deck surface, oven-dried silica sand is broadcast onto the bridge deck until the particles no longer stick (41). As with all epoxy products, the bridge deck must be cleaned and prepared to receive the overlay, and the temperature of the bridge must be at least 40°F (41). Bridge Seal will cure and be ready for traffic after 4 hours if the bridge deck temperature is 77°F or greater. The main limitation of Bridge Seal is that it must be applied in only one layer.

Also, Bridge Seal is not intended for use on slab-on-grade in climates where freezing occurs (41).

CHAPTER 7

QUESTIONNAIRE SURVEY RESULTS

7.1 SURVEY PURPOSE

A questionnaire survey was conducted to determine the extent to which polymer concretes are used to protect bridges throughout the United States. The study was directed primarily at identifying practices utilized by state DOTs in climates with freezing temperatures. Thirty-eight state DOTs were selected for the survey, and individuals most capable of describing the state-of-the-practice concerning bridge deck surface treatments were identified through telephone calls to each state DOT office. Responses were received from the following 19 states: Delaware, Idaho, Illinois, Kansas, Michigan, Missouri, Nevada, New Jersey, New Mexico, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Carolina, South Dakota, Vermont, Wisconsin, and Wyoming. The survey included five questions intended to solicit information about the respondent, such as the person's name, job title, and contact information, and nine questions regarding the experiences of the respondent state with polymer concrete surface treatments. Survey responses are summarized in the following sections.

7.2 PARTICIPANTS

The majority of the survey respondents were state transportation engineers and maintenance specialists. Specific participant information is not included in this report because the purpose of obtaining contact information from those who participated in the survey was to facilitate follow-up questioning as needed. The following questions 1 to 5 were used to obtain information about the respondent:

Question 1. What is your name?

Question 2. What is your job title?

- Question 3. For which state department of transportation do you work?
- Question 4. What is your phone number?
- Question 5. What is your e-mail address?

7.3 SURVEY RESULTS

The survey had nine questions related to bridge deck overlays. Most of these questions had multiple-choice answers, but others required short-answer responses. This section presents the survey questions, as well as a brief summary of the results obtained for each question.

- Question 6. What is your primary purpose in applying surface treatments to bridge decks?

The responses indicate that states reporting the use of bridge deck surface treatments utilize them as either a chloride barrier or a skid-resistant wearing course, or both. Ohio and South Carolina are the only states that did not indicate that their bridge deck overlays were intended to behave as a chloride barrier.

- Question 7. When during the service life of a concrete bridge do you apply surface treatments?
- Question 8. How do you determine when surface treatment should be applied during the service life of a concrete bridge?

Responses to questions 7 and 8 are summarized together because of the substantial overlap in provided information. No standard practice appears to exist with regard to timing of surface treatments. Some states arbitrarily apply surface treatments at 10 to 12 years after construction, other states wait until cracking has become fairly considerable before action is taken, and still other states apply surface treatments when the chloride content of the concrete reaches a certain level. For example, in Idaho, surface treatments are applied to the deck when the chloride content at a depth of 2 in. is between 2 and 3 lbs/yd³ of concrete. This last approach is the most logical based on the

findings of this research; however, research has shown that a chloride concentration of 2 to 3 lbs/yd³ is too high to avoid corrosion (12). Idaho should therefore consider applying overlays sooner than the current practice suggests. Concrete with significant cracking is not ideal because the cracks will reflect through the overlay in a relatively short amount of time. States which simply wait for a certain number of years before applying an overlay will likely end up applying an expensive overlay to a bridge that is badly cracked and/or highly contaminated with chloride ions and therefore unsuited for effective restoration using polymer overlays.

In the state of Idaho, structures of particular importance are treated with an overlay at the time of construction. One shortcoming of a policy such as this is that it does not take into consideration the movement of the bridge that occurs just after construction due to settlement. If the overlay application is delayed for 1 year after construction, chloride contents will still be very low, and any cracking due to settlement will likely be present and ready to be bridged by the overlay material.

Question 9. What type of surface treatments do you typically use?

Only one of the states responding to the survey indicated that they used purely urethane-based polymer material, while nearly all of the other states reported using epoxy-based materials. This trend supports the findings of field tests and other research presented in this report. Epoxy overlays consistently out-perform urethane-based overlays without any significant increase in cost or health risk. In addition to using epoxy, some states reported the use of silicon-based sealers and methacrylates.

Question 10. What construction specifications do you use to ensure good performance of surface treatments applied to concrete bridge decks?

Of all the states that answered this question, New Mexico has the most aggressive policy. New Mexico requires that product manufacturers guarantee that the overlay will last at least 5 years. Prior to overlay application, the product representatives can require

certain repairs to be made to the deck, or they can decline the contract. If a company will not agree to guarantee their surface treatment for at least 5 years, New Mexico will engage the services of a different company willing to meet the guarantee requirements. Most states require that a product representative be present at the time the polymer overlay is applied. Deck preparations such as shot-blasting are fairly universal. Illinois indicated that they actually tape a plastic sheet to the bridge deck in compliance with ASTM D 4263 to confirm the absence of moisture in the concrete. Illinois also requires that a pull-off test be performed after the overlay has cured.

Question 11. What are the most common modes of failure for the surface treatment you use?

Cracking and delaminating were the most commonly reported modes of failure. No respondents reported overlay failures due to loss of skid resistance or damage caused by exposure to UV light.

Question 12. What are the overall advantages and disadvantages of the product you use?

Many of the participants in this survey did not answer this question, and those who did gave very brief explanations. The respondents indicated that polymer surface treatments extend the life of the bridge deck and they cure quickly.

Question 13. Do you specifically avoid using any certain types of brands of surface treatment?

None of the survey respondents answered this question.

Question 14. Do you conduct periodic inspection and maintenance of surface treatments applied to concrete bridge decks?

States responding to this question indicated that they perform bridge inspections every 2 years in accordance with the National Bridge Inspection (NBIS) program requirements. Routine bridge inspections are the only way to effectively monitor the condition of bridge structures over time. Computer programs such as PONTIS are used by DOTs to aid in tracking changes in bridge condition over time and optimizing agency resources.

Many respondents appeared to have little experience with polymer concrete; thus, the amount of specific information that could be obtained from the survey was limited. Nevertheless, the survey responses demonstrated that polymer concrete surface treatments have been used successfully in numerous states and support many of the facts presented in earlier chapters of this report. Possible topics for further research concerning the efficacy of surface treatments on concrete bridge decks include optimum timing of application based on chloride concentrations and quantifying the number of years subsequently added to the surface life of bridge deck

CHAPTER 8

CONCLUSION

8.1 SUMMARY

Corrosion of reinforcing steel in concrete bridge decks as a result of winter applications of deicing salts is a serious problem in the United States. However, the application of polymer concrete surface treatments to concrete bridge decks can be an effective method of resisting concrete deterioration. UDOT funded this research to specifically investigate the performance of urethane, silicon-based, and epoxy overlays. A comprehensive literature review was conducted to document types of overlays, common overlay distresses, performance histories, and properties of specific surface treatment products. In addition, three reports summarizing in-house experiments performed by UDOT between 1995 and 2003 regarding various types of surface treatments were reviewed as part of this research. Finally, a nationwide questionnaire survey was conducted to investigate the state-of-the-practice with regard to surface treatment applications on bridge decks by state DOTs.

8.2 FINDINGS

Polymer concretes have the ability to halt the migration of water and chloride ions into concrete. Numerous departments of transportation have tested polymer surface treatments and determined that if properly installed and maintained to a reasonable degree, these products can be expected to last 10 to 15 years and in some cases even longer. Polymer concretes take significantly less time to cure than traditional concretes, so roadways can be reopened to traffic in a short period of time. Polymer concrete surface treatments are much thinner than concrete overlays, so curb

heights and bridge approach slabs do not need to be adjusted, and the additional dead load on the bridge deck is minimal. Bridge maintenance specialists must decide on a case-by-case basis if the merits of these products justify the additional costs associated with them.

Of the three types of materials addressed in this research, epoxy-based products have the greatest ability to protect concrete and remain uncracked with an acceptable level of skid resistance. Silicon-based products do not crack because they seep into the pores of the concrete, but they do not protect the concrete from the wearing effects of traffic nor improve skid resistance.

Before a surface treatment can be applied to a bridge deck, the surface of the deck must be meticulously cleaned and repaired. Failure to adequately prepare the deck prior to treatment application dramatically increases the possibility that the treatment will fail prematurely. The use of automated mixing equipment when using two-component epoxy products can greatly increase the speed at which the overlay can be mixed and applied, as well as reduce the likelihood that a mixing error will occur.

The purpose of reviewing available UDOT field reports related to this topic was to summarize the objectives, procedures, and conclusions of these experiments. Unfortunately, the documentation of each experiment lacked detailed information about the experimental methodologies; therefore, meaningful conclusions about the value of the experimentation could not be drawn.

The results of the nationwide questionnaire clearly indicate that bridge deck surface treatments are valuable as both chloride barriers and skid-resistant wearing courses. No standard practice appears to exist with regard to timing of surface treatments, however. Some states arbitrarily apply surface treatments at 10 to 12 years after construction, other states wait until cracking has become fairly considerable before action is taken, and still other states apply surface treatments when the chloride content of the concrete reaches a certain level.

The survey results also indicate that epoxy-based products are used far more extensively than urethane products. Only one of the 19 states responding to the survey indicated that they used purely urethane-based polymer materials, while nearly all of the other states reported using epoxy-based materials. This trend supports the findings of

field tests and other research presented in this report. Epoxy overlays consistently outperform urethane-based overlays without any significant increase in cost or health risk. In addition to using epoxy, some states reported the use of silicon-based sealers and methacrylates.

Cracking and delaminating were the most commonly reported modes of failure for polymer surface treatments. At least one state requires a 5-year performance guarantee from the overlay manufacturer against these distresses, however, and another state requires that a pull-off test be performed after the overlay has cured. No respondents reported overlay failures due to loss of skid resistance or damage caused by exposure to UV light.

While many respondents appeared to have little experience with polymer concrete, the survey responses demonstrated that polymer concrete surface treatments have been used successfully in numerous states and support many of the facts presented throughout this report.

8.3 RECOMMENDATIONS

This research suggests that UDOT should use epoxy-based surface treatments for concrete bridge decks when both a chloride barrier and improved skid resistance are desired. If a chloride barrier is all that is needed or desired, UDOT should consider using a silane surface treatment; these treatments are less expensive and easier to apply than epoxy treatments. When a large amount of epoxy is to be mixed, UDOT should require the contractor to use automatic proportioning equipment that can precisely monitor and control the ratios of components. This practice should minimize the occurrence of human error in the mixing process.

Because concrete decks with significant cracking are not ideal substrates for polymer applications, UDOT should apply a surface treatment as a preventive measure early in the service life of a bridge deck so that chloride concentrations do not approach critical levels before the overlay is installed. For example, application of the overlay within the first 1 or 2 years after construction probably permits sufficient time for the bridge to settle, so that any resulting cracking will occur before the overlay is placed, but

does not allow time for significant chloride concentrations to develop in the bridge deck within the vicinity of the reinforcing steel.

Possible topics for further research concerning the efficacy of surface treatments on concrete bridge decks include optimum timing of application based on chloride concentrations and quantifying the number of years subsequently added to the surface life of bridge deck. However, when UDOT conducts in-house experiments on bridge deck surface treatments in the future, engineers should thoroughly document the data collection and analysis procedures they utilize. Detailed descriptions and photographs illustrating the condition of tested decks will make the project reports valuable references for engineers making future decisions about applying surface treatments to similar structures.

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