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PERFORMANCE OF CONCRETE BRIDGE DECK SURFACE TREATMENTS

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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The purpose of this research was to identify 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. This research focused primarily on 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, and a nationwide questionnaire survey was conducted to investigate the state-of-the-practice with regard to deck surface treatment applications by state departments of transportation throughout the United States.
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, silane surface treatments should be considered, as they are less expensive and easier to apply than epoxy treatments. When a large amount of epoxy is to be mixed, automatic proportioning equipment should be employed. 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.</td></tr>
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INTRODUCTION

1.1 PROBLEM STATEMENT

The application of polymer concrete surface treatments to concrete bridge decks is an effective method 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. For example, 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 concrete pores, and, on bridges, ultimately comes in contact with the reinforcing steel. Subsequent corrosion of the steel quickly leads to bursting stresses in the concrete, which lead in turn to more cracking of the concrete that further facilitates the intrusion of chloride ions 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 the skid resistance of the wearing surface. Other products require special machinery to apply and precisely mix the chemicals to ensure proper performance. The objective 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

This report contains eight chapters. Chapter 1 introduces the research, and Chapter 2 presents various types of overlays. 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 findings 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*):

$$OCN-R^1-NCO-HO-R-OH \rightarrow \left[\underset{\overset{\|}{O}}{C} - \underset{\overset{|}{H}}{N} - R1 - \underset{\overset{|}{H}}{N} - \underset{\overset{\|}{O}}{C} - C-R-O \right]_n \qquad (2.1)$$

Di-isocyanate Diol Polyurethane

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*):

$$OCN-R^1-NCO+H_2N-R-NH_2 \rightarrow \left[\underset{\overset{\|}{O}}{C} - \underset{\overset{|}{H}}{N} - R^1 - \underset{\overset{|}{H}}{N} - \underset{\overset{\|}{O}}{C} - \underset{\overset{|}{H}}{N} - R - \underset{\overset{|}{H}}{N} \right]_n \qquad (2.2)$$

Di-isocyanate Amine Polyurea

$$2OCN-R^1-NCO+H-O-H \rightarrow \left[\underset{\underset{O}{\parallel}}{C}-\underset{\underset{H}{|}}{N}-R^1-\underset{\underset{H}{|}}{N}-\underset{\underset{O}{\parallel}}{C}-\underset{\underset{H}{|}}{N}-R-\underset{\underset{H}{|}}{N} \right]_n \quad (2.3)$$

Di-isocyanate Water Polyurea + CO_2

Equations 2.1 to 2.3 show that DI 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 color is not a concern or if dark pigments are used, aromatic DIs can otherwise exhibit high durability.

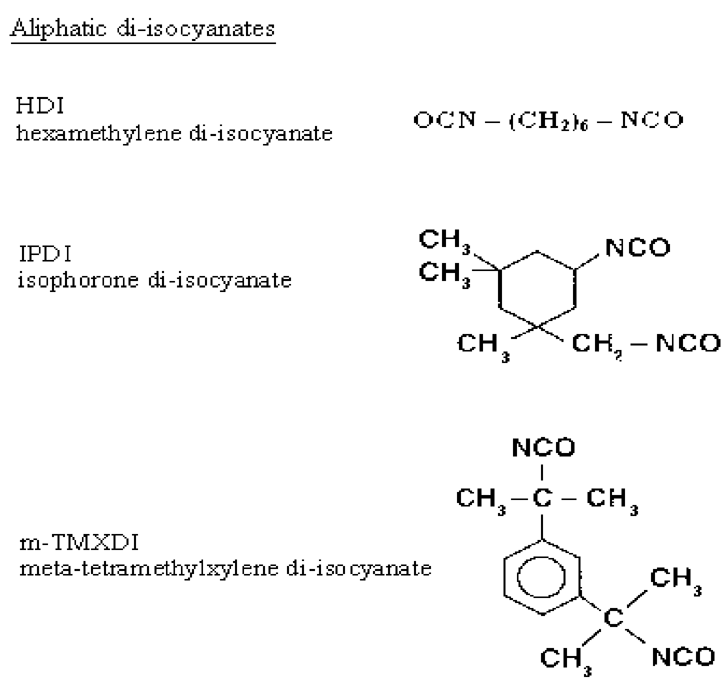


FIGURE 2.1 Aliphatic di-isocyanates (*3*).

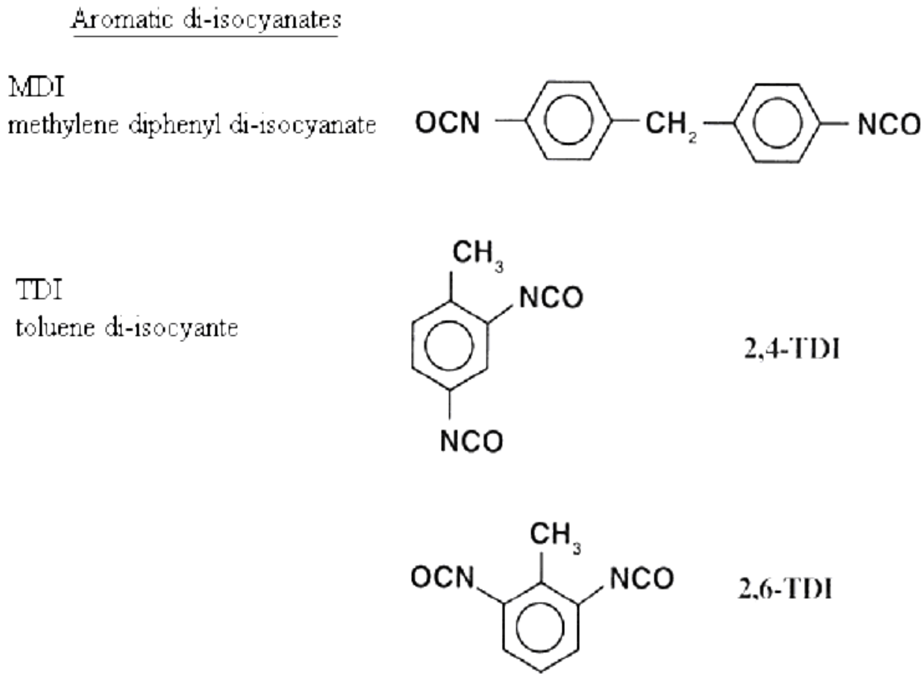


FIGURE 2.2 Aromatic di-isocyanates (*3*).

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

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, 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 the safety associated with 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. Engineers should understand how polyols affect the finished product in order to make informed decisions regarding which types to use, especially when they are 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*):

$$\text{Polyol} + \text{isocyanate prepolymer} \rightarrow \text{polyurethane} \qquad (2.4)$$

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

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

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 existing in the atmosphere and the 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 2.3, will be trapped within the layer (*3*). 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. 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

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, engineers should consider several 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 organic hydrocarbons, or organofunctional groups, and 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, illustrated in Figure 2.3, is the most stable and durable configuration (*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 that have 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 are comprised of smaller alkyl groups.

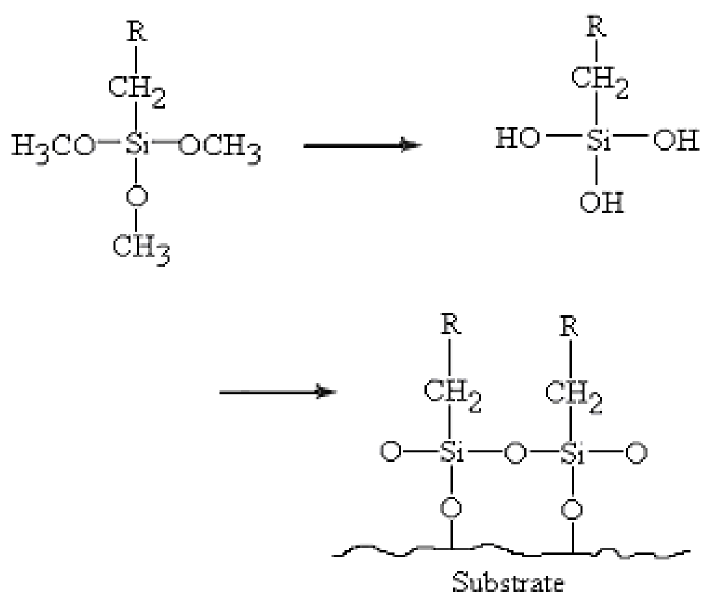


FIGURE 2.3 T-structures (*4*).

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 concrete layer (*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

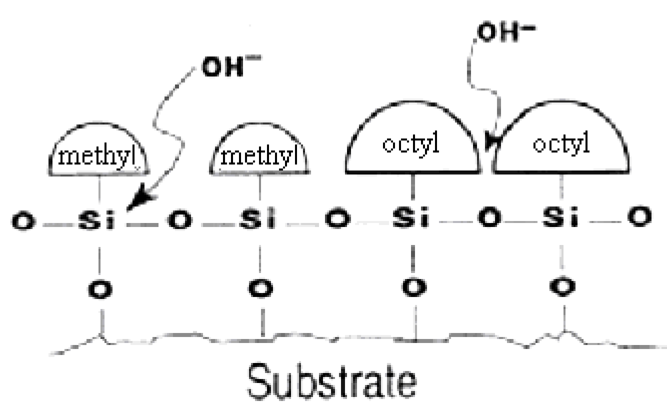


FIGURE 2.4 Protection from OH^- ions (*4*).

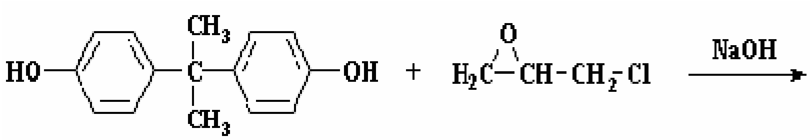
their depth (*4*). An ideal sealer should penetrate to a useful depth while still offering reasonably uniform protection throughout that depth.

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*).

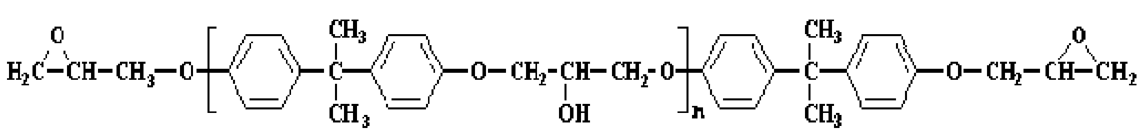
Silane sealers therefore have the most to offer in terms of long-term protection. Research has shown that the level of protection provided by silane sealers can be further increased if an acrylic top coat is also applied (*5*).

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 bis-phenol A and epichlorhydrin (*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*).



Bis-phenol A Epichlorhydrin (2.5)



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 should be 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 displacing the more expensive components. Filler materials can also be used to alter physical properties of epoxy, including compressive strength, hardness, thermal conductivity, and expansion.

Epoxy is usually a hard, 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 epoxy to increase its flash point. Many resins will react with epoxy to form 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 also 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*).

2.5 SUMMARY

The three primary categories of polymer overlays presented in this chapter are urethane, silicone-based, and epoxy treatments. Urethanes are comprised of DI and polyols and are available in two-component and single-component systems, but the latter material can be heavily influenced by the relative humidity at the time of application. Engineers should understand how polyols affect the finished product in order to make informed decisions about which types to use.

The performance of silicon-based sealers depends to a great degree on molecular structure, with the T-structure being generally accepted as the most stable and durable configuration. An ideal sealer should penetrate to a useful depth while still offering reasonably uniform protection throughout that depth. A sealer that reacts very fast or is introduced into concrete containing excess moisture has less probability of penetrating deeply into the concrete, while fast-reacting sealers form shallow bands of protection that are more uniform throughout their depth.

The relative proportions of bis-phenol A and epichlorhydrin determine the properties of epoxy surface treatments. The curing process transforms the epoxy into a three-dimensional thermosetting resin with adhesive strength often exceeding the tensile strength of concrete. Although epoxy is usually a hard, brittle material, flexibilizers can be introduced when a tougher, more flexible epoxy is desired, such as in the case of a protective bridge deck coating. Molecular structure and composition directly impact the physical properties of each of the polymer overlay materials reviewed in this research.

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 factors 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. The occurrence of different strains in the adjacent materials comprising the overlay-concrete interface contributes 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 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 classified as being comprised 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
Bond Strength	C 882
Compressive Strength	D 695
Compressive Strength	C 579
Direct Tensile Bond	D 4541
Epoxy-Concrete System Specifications	C 881
Epoxy-Concrete Thermal Compatibility	C 884
Flexural Modulus	D 790
Flexural Strength	D 790
Hardness, Rockwell	D 785
Impact Strength, Izod	D 256
Linear Thermal Expansion	D 696
Peel Strength	D 903
Tear and Abrasion Resistance	D 1004
Tensile Elongation	D 638
Tensile Modulus	D 638
Tensile Strength	D 638
Ultimate Tensile Strength	D 412
Water Absorption	D 570
Wear Resistance	C 501
Wet Skid Resistance	E 27

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 consists of 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 quickly lead 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 of chloride per cubic yard of concrete 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 failure 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 is required 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 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 can adversely affect 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 in an unbound state. This condition can be minimized 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 be more likely 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 components 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 prohibit 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. Curing times vary from product to product, but polymer concretes can generally 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

UV radiation is another factor that can contribute to the eventual failure of a polymer surface treatment. 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 polymers 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 bridge deck overlays, however, 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 in most cases (*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 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 to install it as required by the manufacturer. Failure in either of these two areas can result in an expensive disappointment.

3.9 SUMMARY

The performance of polymer overlays depends on several factors, including materials selection; surface preparation; drainage; aggregate selection; mixing, curing, and application of polymers; and the effects of UV rays. Minimum values of several material properties can be specified and measured using ASTM standards to ensure an adequate overlay-concrete bond. Failing to properly clean the concrete substrate may cause overlay delamination, blistering, and cracking, however, regardless of the quality of the polymer overlay itself. Positive drainage that prevents water from ponding on the deck surface reduces the chances of stripping and freeze-thaw damage in overlays, and the use of durable aggregates that resist fracturing and polishing is especially recommended for decks that experience high traffic volumes. Automatic proportioning and mixing equipment can be utilized with many overlay products to avoid human error and improve overall uniformity. Although the resistance of individual polymer materials to UV damage varies greatly, the presence of aggregates in many bridge deck overlays largely shields the polymer materials from the sun and therefore minimizes deterioration. Proper selection and application of materials should yield marked increases in bridge deck service life.

CHAPTER 4
PERFORMANCE EVALUATION OF POLYMER OVERLAYS

4.1 PERFORMANCE OF POLYMER OVERLAY MATERIALS

The *Handbook of Coatings for Concrete* contains a wealth of information regarding polymer concrete (*3*). The authors identify a number of strengths and weaknesses characteristic of urethanes and epoxies. They suggest that 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 that are 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 by various agencies regarding the use and performance of polymer concrete surface treatments in the United States.

4.2 LITERATURE REVIEW

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 3 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 at the time of the evaluation and was also 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 ADOT report, 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 PU membranes. The report concludes that PU 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 quality of the wearing course, or protective layer, placed over the membrane. Wearing surfaces do not last as long as membranes in most cases, so care must be taken to replace wearing layers 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 inadequacies.

The Poplar Street Bridge in St. Louis, Missouri, which was discussed briefly in Chapter 3 because of the outstanding resilience of its epoxy overlay, is worth mentioning again in this chapter 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 90ºF and within 8 hours at 60ºF (*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 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 the authors reported that silane out-performed both water- and solvent-based epoxy treatments in this respect (*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, researchers compared a number of common methods for protecting concrete bridges from chloride intrusion. Thin epoxy overlays have a number of advantages over other protection methods involving conventional concrete mixtures. 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 subjected 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 treatment 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 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 IN-HOUSE UDOT RESEARCH

The following chapter is a brief review and evaluation of three field reports prepared 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 methacrylate.

5.2 FLEXOGRID BRIDGE DECK OVERLAY

In 1998, bridge F-596 on State Route (SR) 154 and bridge F-595 on SR 202 were both overlaid with a material known as Flexogrid (*24*). 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 Bridge 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 alkyltrialkoxy 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 did 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 1 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 concentration 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 utilizing 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 this chapter are presented in Table 6.1.

TABLE 6.1 Surface Treatment Products

Product Name	Manufacturer
Baracade Silane 100	Tamms Industries
Bridge Seal	Unitex Chemicals
Elastodeck 5000	Pacific Polymers
Flexdeck	Tamms Industries
Flexogrid	Poly-Carb, Inc.
Flexolith	Tamms Industries
FX-547	Fox Industries
Polyurea Membrane 181	Chemco
Sikadur 22	Sika Corporation
Silane 100 Plus	Concrete Science
T-48	Transpo Industries, Inc.
Thermal-Chem Mortar Resin No. 3	Thermal-Chem
Wabo Guardian	Watson Bowman Acme Corporation

6.2 BARACADE SILANE 100

Baracade 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. Baracade 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 6.2 summarizes relevant physical properties of the product (*27*).

TABLE 6.2 Baracade 100 Material Properties (*27*)

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

6.3 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 (*28*). 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 40ºF (*28*). 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 a single layer. Also, Bridge Seal is not intended for use in slab-on-grade applications in climates where freezing occurs (*28*).

6.4 PACIFIC POLYMERS ELASTODECK 5000 T.C. SYSTEM

Elasto-Deck 5000, by Pacific Polymers, is a single-component, moisture-cured PU 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 of 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 (*29*). Many of the physical properties of this product are summarized in Table 6.3.

TABLE 6.3 Elasto-Deck 5000 T.C. Material Properties (*29*)

Property	**Base Coat No. 5001**	**Top Coat No. 6001 AL**
Hardness, Shore A	55	95 ± 5
Ultimate Tensile Strength, ASTM D 412, psi	975	4,490 ± 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

6.5 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 (*30*). 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 PU 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 6.4 summarizes many of the relevant material properties associated with Flexdeck (*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 50ºF and 90ºF. The primer should be allowed to cure until it is no longer sticky to the touch. Curing requires 3 to 4 hours at 75ºF.

TABLE 6.4 Flexdeck Material Properties (*30*)

Property (Membrane)	**Measurement**
Gel Time, minutes	20-30
Initial Cure, hours	2.5
Temperature Range, ºF	−45 to 266
ASTM D 412, 7-day, minimum	
Tensile Strength, psi	1,200
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	2,000
Shrinkage, %	30

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 60ºF and 80ºF, 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 (*30*). 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 (*30*).

6.6 FLEXOGRID

Flexogrid is produced by Poly-Carb, Inc. Poly-Carb describes Flexogrid as 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 50ºF. 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 (*24*). Flexogrid cures within a matter of hours, which minimizes bridge closure time, and maintains its flexibility even in cold weather (*31*). 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 (*32*).

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 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 and spreads aggregates onto the bridge deck.

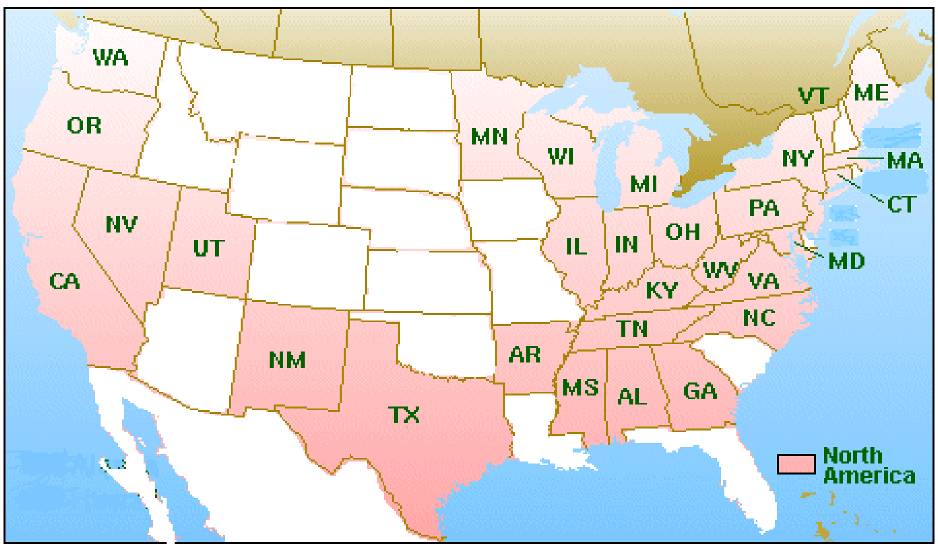


FIGURE 6.1 States with Poly-Carb projects (*32*).

FIGURE 6.2 Poly-Carb mobile mixing unit (*31*).

6.7 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 6.5 summarizes relevant properties of this material, and Figure 6.3 shows which states have used Flexolith on one or more projects (*33*, *34*).

TABLE 6.5 Flexolith Material Properties (*33*)

Property	Measurement
Mix Ratio by Volume	1:01
Gel Time, Class B, ASTM C 881, minimum ºF	>30
ASTM D 638	
Tensile Strength, psi	2,700
Tensile Elongation, %	30-60
ASTM D 695	
Compressive Strength, psi	5,000
Compressive Modulus, psi	130,000
ASTM C 109 (3 parts Sand)	
Mortar Compressive Strength, psi	
4-hour cure at 75ºF	1,400
24-hour cure at 75ºF	7,040
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

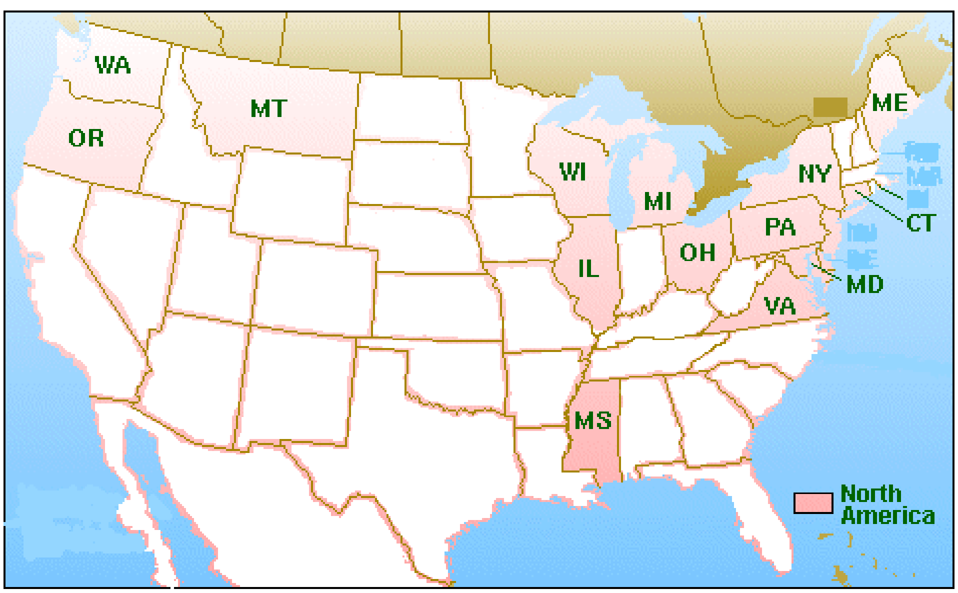


FIGURE 6.3 States with Flexolith projects (*33*).

6.8 FOX INDUSTRIES FX-547

Fox Industries FX-547 is a two-component PU 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 −20ºF to 200ºF. Other important physical properties of FX-547 are summarized in Table 6.6.

FX-547 is not recommended for application on wet surfaces or on surfaces at temperatures below 50ºF. 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 (*35*).

TABLE 6.6 FX-547 Material Properties (*35*)

Property	**Measurement**
Pot Life at 72ºF, minutes	25
Cure Time at 72ºF, 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

6.9 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 (*36*).

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 40ºF 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 6.7 summarizes the important material properties associated with this product (*36*).

TABLE 6.7 Chemco 181 Membrane Material Properties (*36*)

Property	Measurement
Mix Ratio	1:1
Color	Blue-Gray
Gel Time, minutes	12
Cure Time, hours	2
Tensile Strength, psi	1,250
Elongation to Break	3.75
Bond Strength, ASTM D 4541, psi	350-500

6.10 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 6.8 summarizes many of the relevant physical properties associated with Sikadur 22 (*37*).

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 40ºF. Second, this material is not to be applied to a surface that is visibly wet, as

TABLE 6.8 Sikadur 22 Material Properties (*37*)

Property	Measurement
Shelf Life, years	2
Viscosity, cPs	2,500
Pot Life, minutes	30
Mix Ratio	1:1 by Volume
Tensile Strength, ASTM D 638, psi	5,900
Elongation to Break, %	30
Shear Strength, psi	5,400
Compressive Strength, psi	6,300

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 (*37*).

6.11 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 facilitates deeper penetration 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 90ºF 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 (*38*).

6.12 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 6.9 summarizes many of the relevant physical properties of T-48 (*39*).

TABLE 6.9 T-48 Material Properties (*39*)

Property	Measurement
Mix Ratio	2:1 by Volume
Brookfield Viscosity, cPs	1,200-1,600
Density, ASTM D 2849, lbs/gal	8.8 minimum
Pot Life at 70ºF, AASHTO T 237, minutes	15-30
Flash Point, ASTM D 1310, ºF	200 minimum
Solids Content, ASTM D 1644, %	100
Compressive Strength, ASTM D 695, psi	5,000 minimum
Tensile Strength, ASTM D 638, psi	1,800 minimum
Tensile Adhesion to Concrete, ACI 503R, psi	250 minimum
Tensile Elongation, ASTM D 638, %	45 minimum

6.13 THERMAL-CHEM MORTAR RESIN, PRODUCT NO. 3

Mortar Resin No. 3 is a two-component, epoxy polymer with 100 percent solids. Thermal-Chem has two variants of this product, including 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 (*40*). Product No. 3 is available in normal- and rapid-cure formulations. Normal curing can take place at temperatures greater than 40ºF, while rapid-cure material will cure at temperatures as low as 0ºF (*40*).

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 relate to the 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 (*40*). Table 6.10 summarizes the relevant physical properties of Product No. 3 (*40*).

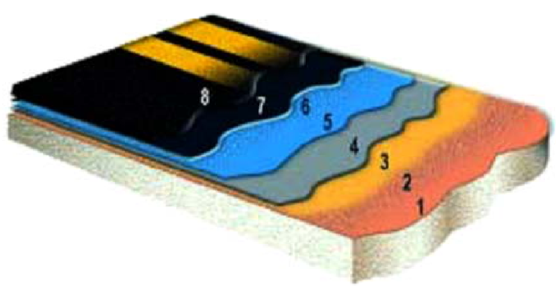
TABLE 6.10 Thermal-Chem Product No. 3 with Approved Silica Sand (*40*)

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	4,800	4,800
−55°F	-	5,000
Compressive Strength, ASTM C 579, psi		
1 day	9,600	9,800
3 days	11,300	11,800
7days	14,000	14,200
Mortar Flexural Strength, ASTM D 790, psi	3,200	3,210

6.14 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 PU. The epoxy, known as Conipox 605, is used to seal the concrete and provide an ideal surface to which a single-component PU 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 PU waterproofing membrane. The last layer of the system is Conipur 267; this layer also consists of a two-component PU, but it is applied with a squeegee and provides a wearing surface when combined with silica gravel. Wabo claims that spraying the PU will ensure best results because it creates a seamless coating that is less likely to leak. In addition to the spray-applied PU layer, a final PU 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 (*41*). 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 (*41*).

6.15 SUMMARY

Thirteen different surface treatment products were reviewed in this research. The physical properties, installation requirements, and material types were documented. Because the material properties and application procedures associated with the various overlay products vary greatly, users should carefully read the directions provided by the manufacturer to ensure the success of the project and the safety of the workers.

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. The survey was then e-mailed to each state for completion by the appropriate individual. Responses were received from the following 20 states: Delaware, Idaho, Illinois, Kansas, Michigan, Missouri, Nevada, New Jersey, New Mexico, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Carolina, South Dakota, Utah, Vermont, Wisconsin, and Wyoming. The survey included five questions soliciting information concerning the respondent, such as the person's name, job title, and contact information, and nine questions regarding the experiences of the respondent with polymer concrete surface treatments. Survey responses are summarized in the following sections.

7.2 PARTICIPANTS

The majority of the respondents were state bridge engineers or bridge maintenance specialists. Since participant information was collected to facilitate follow-up questioning as needed, specific information concerning each participant is not included in this report. The following questions were asked in regards to the participant:

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 included eight questions regarding concrete bridge deck overlays. This section provides a brief summary of the responses.

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

The responses received for this question are summarized in Figure 7.1. 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. The Ohio and South Carolina DOTs are the only states that did not indicate that their bridge deck overlays were intended to behave as a chloride barrier.

The DOTs that do not use surface treatments are the following: Delaware, Kansas, Ohio, Pennsylvania, Rhode Island, and South Carolina. Participants from the Illinois, Michigan, Missouri, Nevada, New Jersey, New Mexico, Ohio, Pennsylvania, Rhode Island, South Carolina, South Dakota, and Wisconsin DOTs all reported the use of surface treatments as wearing courses. Those participants that marked “other” generally apply surface treatments for maintenance purposes, including enhancing skid resistance, sealing cracks, and increasing deck surface life. Specifically, UDOT reported using surface treatments only as chloride barriers.

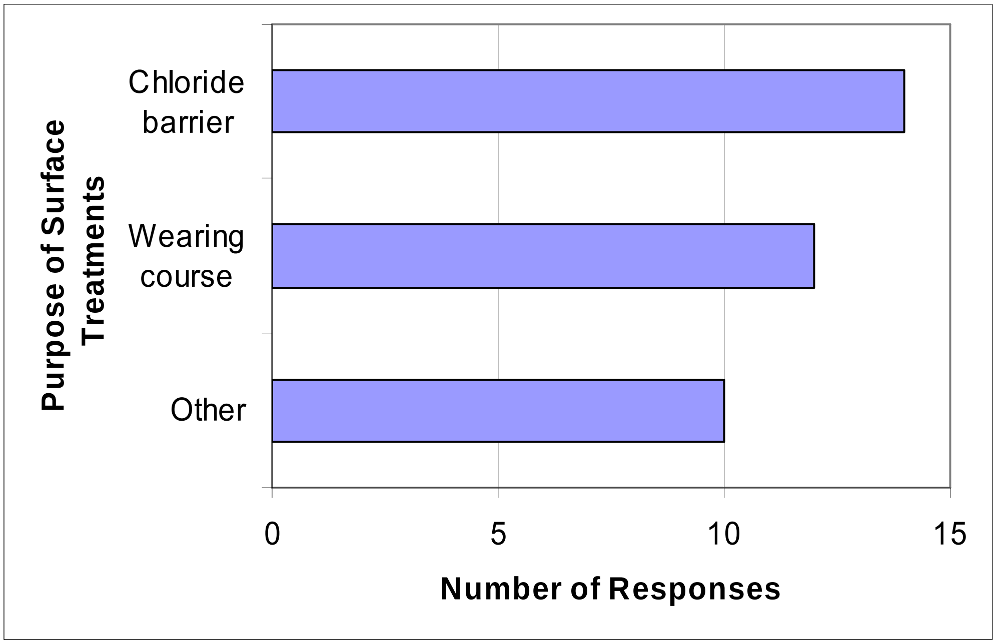


FIGURE 7.1 Purpose of surface treatments.

Question 7. When during the service life of a concrete bridge do you apply surface treatments?

Most participants stated that when significant deck cracking and/or deterioration of the deck occurred, overlays were considered. Most of the participants also suggested that they use overlays when the deck is undergoing rehabilitation. A few states have a set schedule for when decks receive an overlay. These states and their overlay schedules are listed in Table 7.1.

TABLE 7.1 Typical Application Frequency for Surface Treatments

State	Frequency
Idaho	Every 25 years
Missouri	Every 10 years
New York	Every 5 years for Silane sealer Every 12 years for waterproof membrane and asphalt overlay
North Dakota	Every 20 years
Wisconsin	Every 2 years for deck seal Every 25 years for concrete overlays

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

Figure 7.2 presents the distribution of responses for this question. Few state DOTs that claimed to use crack density as a gauge have a quantitative system of determining if surface treatments are necessary. The Nevada DOT participant remarked that even though no formal criteria exist for crack density, treatments are considered when cracking exists on at least 10 percent of the total deck area. The New Mexico DOT engineer explained that the frequency of repair depends upon the district budgets, so no statewide criteria could be set. The South Carolina DOT respondent reported that action is taken when crack widths exceed 0.007 in. The South Dakota DOT determines the type of treatment to use based upon the crack frequency; for a frequency of less than 5 ft, flood coats are used, while conventional treatments are used for larger frequencies. The Wyoming DOT participant commented that the crack severity and density were generally considered, but specific details were not provided.

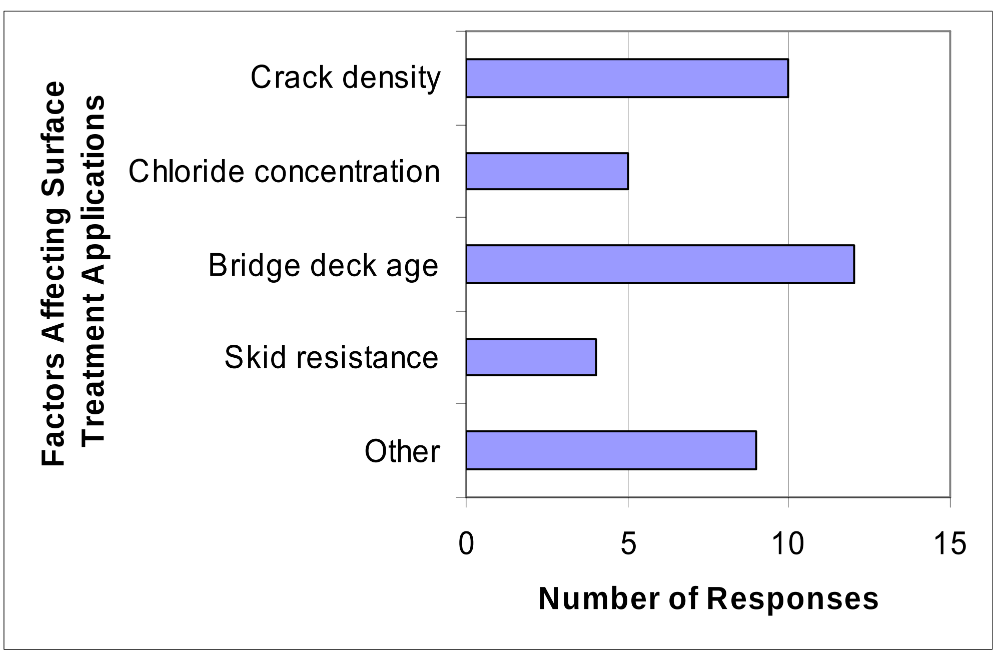


FIGURE 7.2 Factors affecting applications of surface treatments.

According to the Idaho, New Jersey, and Wisconsin DOTs, the threshold chloride concentration governing the application of surface treatments is approximately 2 to 3 lbs of chloride per cubic yard of concrete, measured at the depth of the reinforcing steel. The Nevada and Wyoming DOTs apparently consider chloride concentrations, but those respondents did not provide specific criteria.

These survey results suggest that state DOTs should reevaluate their maintenance schedules. For example, research has shown that a chloride concentration of 2 to 3 lbs per cubic yard of concrete is sufficient to initiate corrosion of the reinforcing steel (*12*). State DOTs should therefore consider applying overlays sooner than the current practice suggests. Furthermore, states that 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 unsuitable for effective restoration using polymer overlays. Concrete with significant cracking is not ideal because the cracks will reflect through the overlay in a relatively short amount of time.

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 due to settlement just after construction. 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 stable and ready to be bridged by the overlay material.

Criteria associated with bridge age are addressed in Table 7.1, but few quantitative criteria apparently exist for skid resistance. The Wisconsin DOT reportedly evaluates skid resistance based on current accident data, whereas the Wyoming DOT typically requires roads to have a skid resistance number of at least 30.

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

The number of responses for each type of surface treatment is given in Figure 7.3. Only one of the state DOTs responding to the survey indicated the use of purely urethane-based polymer overlay materials, while 11 of the other state DOTs reported using an epoxy-based and/or an epoxy-mixture material. 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 state DOTs reported the use of silicon-based sealers and methacrylates. The largest response was in the “other” category, where several treatments were mentioned consistently. For example, the Missouri, South Dakota, and Wisconsin DOTs use low-slump concrete, while concrete overlays constructed with silica-based admixtures are specified by the Idaho, New Jersey, Ohio, and Rhode Island DOTs. The Pennsylvania and Vermont DOTs use membranes, and, uniquely, the Nevada DOT utilizes a polyester-styrene overlay product. Tables 7.2 to 7.7 list the manufacturer names, product names, reported costs, and service lives of epoxy, epoxy-urethane, urethane, methacrylate, silicone, and other surface treatments, respectively, utilized by the participating state DOTs.

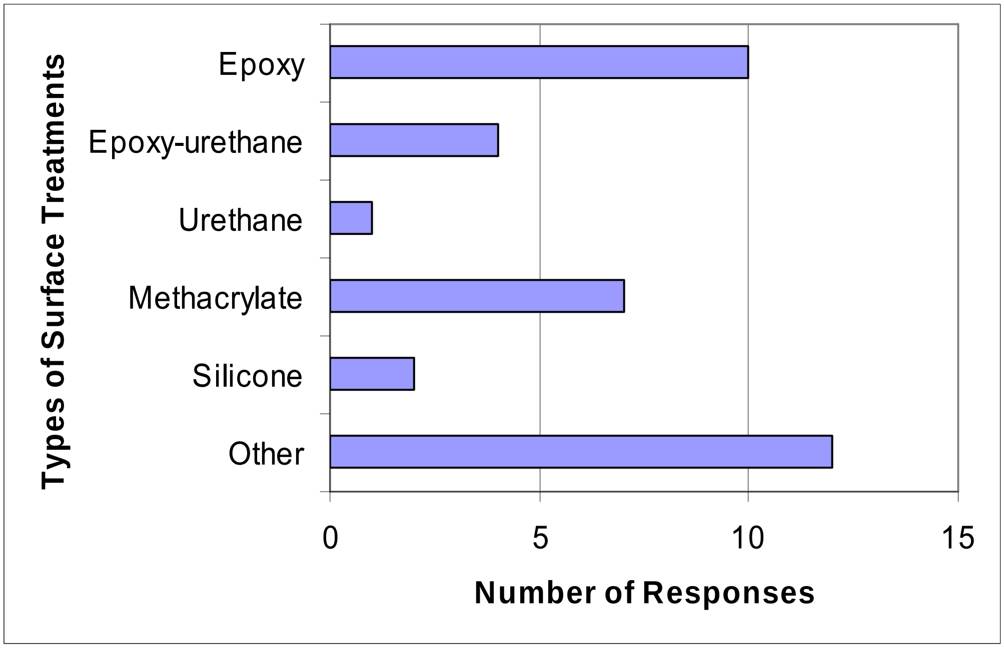


FIGURE 7.3 Common types of surface treatments.

TABLE 7.2 Epoxy Surface Treatment Products

State	Manufacturers and Products	Cost ($\$/yd^2$)	Service Life (yr)
Illinois	E-Bond Epoxies, E-Bond 526 Poly-Carb, Mark-154, Mark-162, and Mark-163 Flexogrid Sika, Sikadur 22 Tamms Industries, Flexolith Transpo Industries, Transpo T-48	-	-
Michigan	Axson, Akabond 811 E-Bond, 526 Lomod PolyCarb, Mark-163 Tamms Industries, Flexolith 216 Unitex, Propoxy Type III DOT	Depends	10 Minimum
Missouri	Generic Specification	45	10
Nevada	Transpo Industries, Poly-Carb	75	15
New Mexico	Polycarb Sika Tamms Industries Unitex	63	20
New York	Unitex PolyCarb	72	20
South Carolina	Sika	-	-
South Dakota	Transpo Industries, T48	30	10
Utah	Sika Unitex	-	-

TABLE 7.3 Epoxy-Urethane Surface Treatment Products

State	Manufacturers and Products	Cost ($\$/yd^2$)	Service Life (yr)
New Mexico	Unitex PolyCarb	72	20
Utah	Sika Unitex	-	-
Wisconsin	PolyCarb	30 to 40	15

TABLE 7.4 Urethane Surface Treatment Products

State	Manufacturers and Products	Cost ($\$/yd^2$)	Service Life (yr)
South Dakota	Degussa, Crack Sealer	-	-

TABLE 7.5 Methacrylate Surface Treatment Products

State	Manufacturers and Products	Cost ($\$/yd^2$)	Service Life (yr)
Nevada	Generic Specification	30	10
New Jersey	Sika, Pronto 19	-	-
New Mexico	Various Products	27	15 to 20
New York	Transpo Industries, Denedeck	38	-
Wyoming	Degussa, Degadur 330 Base Coat Degussa, Degadur 410 Seal Coat Degussa, Degadur Primer B-71	80 to 120	10 to 15

TABLE 7.6 Silicone Surface Treatment Products

State	Manufacturers and Products	Cost ($\$/yd^2$)	Service Life (yr)
New York	Chem-Trete, BMS 40-VOC	9	5 to 6
North Dakota	Alkylalkoxysilane Oligomerous Alkyl-Alkoxysiloxane	18 to 27	2 to 3

TABLE 7.7 Other Surface Treatment Products

State	Manufacturers and Products	Cost ($/yd^2)	Service Life (yr)
Idaho	Microsilica-Modified Concrete	270	30
Missouri	Low-Slump Concrete	60	30
Nevada	Generic Specification, Polyester Styrene	- 135	20 10
New Jersey	Latex-Modified Concrete Silica-Fume Concrete	-	20
New Mexico	Generic Specification, Epoxy Crack Sealer	9	20
Ohio	Silanes Reactive Silicates Gravity-Feed Resins	-	-
Pennsylvania	Latex-Modified Concrete Asphalt with Membrane	-	20 15
Rhode Island	Master Builders, Microsilica Mixes Sika, Microsilica Mixes	-	20
South Dakota	Low-Slump Concrete Asphalt with Membrane Silane Sealers	85 30 -	20 to 30 15 to 20 -
Wisconsin	Concrete	225	15

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

The responses to this question are summarized in Figure 7.4. Of all the state DOTs that answered this question, the New Mexico DOT has the most aggressive policy; product manufacturers are required to 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 a surface treatment for at least 5 years, the New Mexico DOT will engage the services of a different company willing to meet the guarantee requirements.

Many state DOTs require a product representative to be present at the time the polymer overlay is applied. Deck preparations such as shot-blasting, scarifying, and milling are fairly universal and were mentioned by all participating

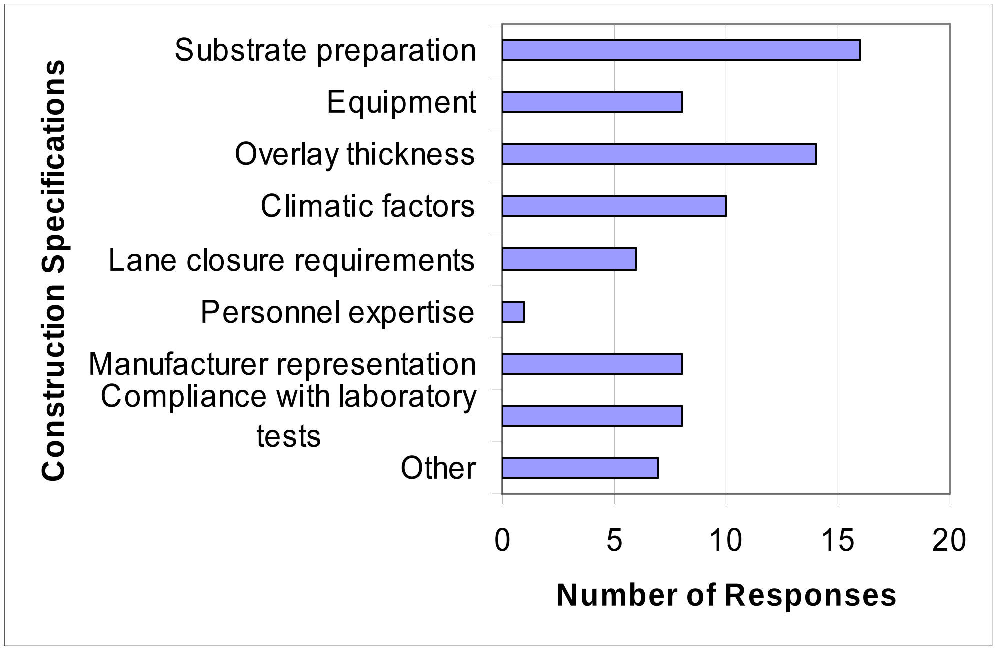


FIGURE 7.4 Construction specifications.

state DOTs except Delaware, Ohio, Kansas, and Vermont. While eight state DOTs indicated that they have equipment specifications, specific details were not provided. Overlay thickness was also uniform for all participating state DOTs. Concrete overlays are 1.5 in. to 2.0 in. thick, while epoxy-based overlays are 0.250 in. to 0.375 in. thick.

Regarding climatic factors, the common response was that decks must be dry and warm. Specifically, the Michigan, Nevada, and South Carolina DOTs indicated that the weather must be characterized by a minimum ambient temperature of 50°F and no moisture in the forecast. The Illinois and Nevada DOTs indicated that they actually tape a plastic sheet to the bridge deck in compliance with ASTM D 4263, Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method, to confirm the absence of moisture in the concrete. The Illinois DOT also requires that a pull-off test be performed after the overlay has cured. In the “other” category, the Nevada DOT indicated that contractors must be able to demonstrate past performance and compatibility of specific overlay materials and primers, such as the polyester-methacrylate system used in Nevada.

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

The different modes of failure and the response rates are given in Figure 7.5, which suggests that cracking and delamination are most common. While the Idaho, New Jersey, Rhode Island, and Wyoming DOTs all mentioned shrinkage cracking as a predominant distress type, the Rhode Island and Wisconsin DOTs blame cracking on a lack of quality control.

Eleven survey respondents mentioned delamination as a common mode of failure. Among these, the Illinois, Michigan, New Mexico, New Jersey, South Dakota, and Vermont DOTs typically blame the occurrence of delaminations on inadequate surface preparation or poor quality concrete to which the surface treatment is applied. The Missouri DOT respondent said that delamination has been observed on decks treated with low-slump concrete approximately 15 years after treatment; the Pennsylvania respondent also mentioned the occurrence of delamination after 15 years but did not indicate the type of treatment to which this statistic corresponded. The Wisconsin DOT participant reported that decks that

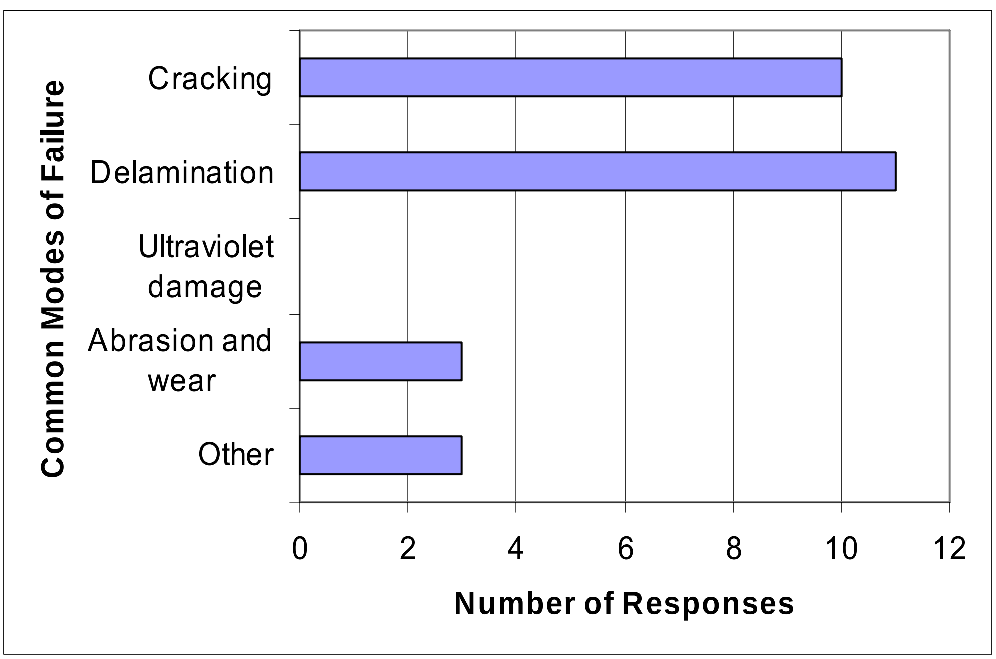


FIGURE 7.5 Common modes of failure.

have been contaminated with chloride and other chemicals often exhibit delamination problems within 15 to 20 years depending on the amount of traffic on the decks. The Wyoming DOT respondent reported delamination on surfaces treated with methyl-methacrylate within 1 year after placement.

None of the survey participants mentioned UV damage as a common source of failure, and only three states cited abrasion and wear as common modes of failure. The Nevada DOT respondent mentioned that polyester styrene overlays seem to lose skid resistance faster than regular concrete overlays.

Only three participants, namely the New York, North Dakota, and Ohio DOT respondents, marked “other” in response to this question; however, none of them specifically mentioned other types of commonly observed failures. The North Dakota DOT respondent indicated that current inspection protocols do not readily facilitate identification of failure modes.

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

Seventeen of the 20 survey participants provided responses to this question. The Idaho DOT respondent simply stated that applying surface treatments extends bridge deck service life. The Kansas DOT participant reported the use of surface treatments as a primary means of sealing extensive cracking on bridge decks. The New Jersey DOT reported that the use of overlays extends bridge deck service life and that crack sealers are employed to prevent chloride intrusion. Similarly, minimizing water intrusion is a key function of surface treatments used by the New Mexico DOT. The silicone-based treatments that the North Dakota DOT uses might help seal concrete from penetrates; however, the product does not seem to last for more than 2 years.

The Michigan DOT uses epoxy surface treatments, which are easy to mix and apply. The Missouri DOT respondent cited the use of epoxy-based and low-slump concrete to extend bridge deck life. The New York DOT respondent reported using surface treatments with quick cure times.

The Nevada DOT mainly uses polyester-styrene and epoxy overlays for surface treatments. The advantages of the polyester-styrene overlay reportedly include good long-term performance, quick on-site construction, the ability to place at low temperatures, and the use of common equipment; the disadvantages of this product include health and safety hazards associated with resins, a requirement to taper roadway grades into the overlay, fairly high cost, and temperature sensitivity. Also according to the Nevada DOT, the advantages of epoxy overlays include quick on-site construction, no requirement to taper the approach roadway, and no requirement for special equipment; the disadvantages include temperature sensitivity and a comparatively short service life.

The Ohio DOT typically utilizes a concrete or asphalt overlay to improve the wearing surface condition on existing structures. While the Ohio DOT would prefer to use concrete overlays, asphalt is frequently the best option due to project funding constraints, the condition of the bridge deck, and the expected life until deck replacement. The Ohio DOT respondent further commented that chemical treatments are applied by some districts as preventive maintenance but mostly as reactive maintenance when decks leaks. Construction specifications for new concrete bridge decks on interstate projects in Ohio require the contractor to apply surface treatments if spalling, scaling, or cracking is beyond expected limits.

The Pennsylvania DOT uses asphalt overlays because very smooth surfaces can be achieved; however, the asphalt often traps salt, which hastens deterioration of the surface. The Rhode Island DOT respondent stated that surface treatments often exhibit shrinkage cracks. The South Dakota DOT respondent explained that the advantages of concrete deck overlays include long-term performance and protection, improved ride quality, and extension of deck service life, while the only listed disadvantages include the project cost and construction time. Furthermore, the South Dakota DOT respondent commented that the advantages of membrane and asphalt systems include comparatively low cost and improved ride quality, while disadvantages include necessary maintenance due to inadequate durability and limited protection compared to a conventional concrete overlay. The South Dakota DOT respondent also mentioned that epoxy-based surface treatments are advantageous because of low cost, quick construction, and the ability to seal cracks; however, epoxy-based products apparently exhibit poor long-term performance and durability on decks in South Dakota.

The surface treatments that UDOT uses improve skid resistance and create a barrier to chloride penetration; however, UDOT struggles with ongoing maintenance issues. The Vermont DOT respondent explained that membranes applied to bridge decks in Vermont are expensive and are often applied under adverse conditions. The advantages of the types of surface treatments used by the Wisconsin DOT include extension of deck service life and removal of chloride-contaminated concrete, while the primary disadvantage is the requirement to close lanes to traffic during construction; surface treatments utilized by the Wisconsin DOT are reportedly characterized by high skid resistance and minimize deck crack-sealing maintenance work. Finally, the Wyoming DOT uses methyl-methacrylate overlays, which restore a tractive surface to the bridge deck and impede chloride contamination, but the respondent cited some significant problems with early delamination. Also, the tractive surface provided by this overlay may be fairly short-lived.

Question 13. Do you avoid using certain types or brands of surface treatments?

Six respondents answered “yes” to this question, including the Michigan, Nevada, New Jersey, Ohio, Rhode Island, and Utah DOT participants. The Michigan DOT respondent explained that the price and ease of installation are important factors in determining the types of surface treatments to use. The Nevada DOT does not use cement-based overlays, such as low-slump and latex-modified concrete, because those products take a comparatively long time to cure and do not reportedly perform well in low humidity; the low humidity causes the overlays to crack, which then requires deck sealing. The New Jersey DOT respondent explained that products with the potential to cause a loss of skid resistance are avoided. The Rhode Island DOT generally avoids latex-modified concrete overlays because “they have not worked for us in the past.” All of the products that UDOT permits are listed in a publication. To be included on this list, the product must be formally evaluated, which is a 3-year process.

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

Eleven survey participants responded “yes” to this question, including the Idaho, Illinois, New Jersey, New Mexico, New York, Ohio, Pennsylvania, Rhode Island, South Dakota, Utah, and Wisconsin DOTs. A majority of the respondents explained that their inspections are conducted on a bi-annual basis in accordance with the National Bridge Inventory (NBI) program requirements. In each case, inspectors specifically report on the condition of the wearing surface and the structural qualities of the deck.

The Ohio DOT is the only participating agency that conducts annual bridge inspections. The respondent explained that the purpose of the additional testing is to permit the use of inspection data for both safety and maintenance needs assessments. UDOT supplements NBI data with skid resistance measurements and chloride concentration tests usually performed through the UDOT Research Division. The Wisconsin DOT conducts chain-drag tests or infrared thermography tests on concrete bridge decks approximately every 5 years, with more heavily used bridges being evaluated on a more frequent basis.

Routine bridge inspection is the primary method of monitoring the condition of bridge structures over time. Computer programs such as PONTIS are also used by state DOTs to aid in tracking changes in bridge condition over time and optimizing agency resources.

7.4 SUMMARY

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. State DOTs reporting the use of bridge deck surface treatments utilize them as either a chloride barrier or a skid-resistant wearing course, or both. A few states apply surface treatments at regular intervals through time, ranging from every 5 years to every 25 years. Deck age and crack density are the most important factors considered by engineers in determining when to apply surface treatments. Early applications of surface treatments are most effective in maintaining low chloride concentrations. For example, 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 stable and ready to be bridged by the overlay material. Further research is needed to investigate optimum timing of surface treatment applications and to quantify the number of years subsequently added to the service life of a bridge deck.

Eleven of the 20 survey participants reported using an epoxy-based and/or an epoxy-mixture material, while only one state DOT indicated the use of purely urethane-based polymer overlay materials. In addition to using epoxy, some states reported the use of silicon-based sealers, methacrylates, low-slump concrete overlays, and asphalt overlays. Substrate preparation and overlay thickness are the most common construction specifications used for placement of surface treatments, although many states require a product representative to be present at the time the polymer overlay is applied. ASTM D 4263 may be used to determine whether the deck is adequately dry before application of a surface treatment.

Cracking and delamination are the most common modes of surface treatment failure; shrinkage cracking appears especially problematic. At least one state requires a 5-year performance guarantee from the overlay manufacturer against these distresses, 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.

Primary advantages of surface treatments include extension of deck service life, cracking sealing, reduced chloride penetration, enhanced skid resistance, quick construction, and good durability in many cases. Disadvantages include potential health and safety hazards associated with resins, a requirement to taper roadway grades into the overlay in some instances, fairly high costs for some products, and temperature sensitivity. A majority of the respondents explained that their inspections are conducted on a bi-annual basis in accordance with the NBI program requirements.

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 DOTs 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 require 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 survey 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 magnitude at the level of the steel reinforcement.

The survey results also indicate that epoxy-based products are used far more extensively than urethane products. Only one of the 19 state DOTs responding to the survey cited the use of purely urethane-based polymer materials, while nearly all of the other state DOTs reported the use of epoxy-based materials. Epoxy overlays consistently out-perform urethane-based overlays without any significant increase in cost or health risk. In addition to using epoxy, some state DOTs reported the use of silicon-based sealers and methacrylates.

Cracking and delamination were the most commonly reported modes of failure for polymer concrete surface treatments. At least one state DOT requires a 5-year performance guarantee from the overlay manufacturer against these distresses, and another state DOT 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 silane surface treatments, which 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 in the vicinity of the reinforcing steel. Further research is needed to investigate optimum timing of surface treatment applications and to quantify the number of years subsequently added to the service life of a bridge deck.

Finally, 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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