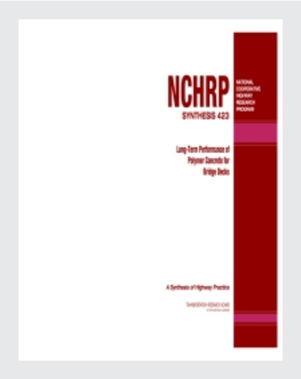

Long-Term Performance of Polymer Concrete for Bridge Decks

DETAILS

63 pages | | PAPERBACK
ISBN 978-0-309-14354-7 | DOI 10.17226/14623

AUTHORS

David W Fowler; David W Whitney; Transportation Research Board

NCHRP SYNTHESIS 423

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Long-Term Performance of Polymer Concrete for Bridge Decks

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 423

Long-Term Performance of Polymer Concrete for Bridge Decks

A Synthesis of Highway Practice

CONSULTANTS
DAVID W. FOWLER
and
DAVID W. WHITNEY
University of Texas–Austin

SUBSCRIBER CATEGORIES
Bridges and Other Structures • Highways • Maintenance and Preservation • Materials

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2011
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board of the National Academies, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

NCHRP SYNTHESIS 423

Project 20-05 (Topic 39-11)
ISSN 0547-5570
ISBN 978-0-309-14354-7
Library of Congress Control No. 2011936876

NOTICE

The project that is the subject of this report was a part of the National Co-operative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:
http://www.national-academies.org/trb/bookstore

Printed in the United States of America

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jon M. Williams
Program Director
Transportation Research Board

Thin polymer overlays (TPOs) consist of a polymer binder and aggregates with a thickness not exceeding 25 mm (1 in.). They have provided long-lasting wearing surfaces for bridge decks with many advantages, including adding very little dead load; very fast cure times; shallow depths that eliminate the need for raising approach slabs; ability to transition from overlaid lane to non-overlaid lane during construction; low permeability; and good frictional resistance. This study found that TPOs have become an accepted construction method for deck preservation, restoring surface friction and extending the lives of decks. When constructed properly on sound decks, TPOs should provide a service life of 20 or 25 years.

Information was gathered through literature review, a survey of all state transportation agencies, and selected interviews.

David W. Fowler and David W. Whitney, University of Texas at Austin, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

1 SUMMARY

3 CHAPTER ONE INTRODUCTION
Background, 3
Scope, 3
Major Definitions, 3
Methodology for Obtaining Information, 4
Report Organization, 4

6 CHAPTER TWO LITERATURE FINDINGS AND SPECIFICATIONS
Uses of Thin Polymer Overlays, 6
Pre-Overlay Evaluation, 6
Repairs, 7
Materials Used in Overlays, 7
Installation, 7
Quality Control Tests, 10
Test Methods, 11
Thin Polymer Overlay Field Sections, 11
Failures, 19
Stresses in Overlays, 20
Special Applications, 21
Service Life, 24
Warranties, 24
Relative Cost, 24
Specifications, 24

26 CHAPTER THREE PERFORMANCE OF OVERLAYS FROM SURVEYS AND INTERVIEWS
Scope of Surveys, 26
General Responses, 26
Overlay Cost, 26
Causes of Failures, 26
Specifications, 29
Materials, 30
Contractor Interviews, 30
Material Supplier Interviews, 31

32 CHAPTER FOUR PROVEN PRACTICES
Candidates for Overlays, 32
Overlay Types, 32
Materials, 32
Aggregates, 33
Qualification of Substrate, 34
Installation Methods, 36

39 CHAPTER FIVE REPAIR

40 CHAPTER SIX CONCLUSIONS
Research Needs, 40

41 REFERENCES

43 BIBLIOGRAPHY

47 GLOSSARY OF TERMS

49 APPENDIX A QUESTIONNAIRES

59 APPENDIX B STRESSES IN OVERLAYS

61 APPENDIX C WARRANTY AND PAYMENT BOND

LONG-TERM PERFORMANCE OF POLYMER CONCRETE FOR BRIDGE DECKS

SUMMARY

Thin polymer overlays (TPOs) consist of a polymer binder and aggregates with a thickness not exceeding 25 mm (1 in.). They have provided long-lasting wearing surfaces with many advantages, including very little dead load, very fast cure times, shallow depths that eliminate the need for raising approach slabs, ability to transition from overlaid lane to non-overlaid lane during construction, low permeability, and good frictional resistance.

TPOs were first used as single layers of coal tar epoxy broomed onto the concrete deck with fine aggregate broadcast onto the surface in the 1950s. In the 1960s, an oil-extended epoxy was used to improve the performance. Polyester-styrene resins and methyl methacrylate monomer systems were being installed in the mid-1970s using the broom-and-seed method. Premixed polymer concrete (PC) began to be used as overlays using screeds for placing and finishing. Some of the thicker, brittle layers delaminated owing to thermal incompatibility.

As the interest in TPOs increased in the 1980s, material suppliers began to develop resins specifically for these applications. Through a better understanding of the causes of delamination, construction techniques and materials improved, with a corresponding increase in TPO performance. One of the major causes of delamination, thermal incompatibility of polymers and concrete, was reduced significantly by the use of higher elongation and lower modulus resins.

The Transportation Research Board issued a problem statement, NCHRP Synthesis 25/Topic 39-11, *Performance of Thin Polymer Overlays for Bridge Decks*. The scope included collecting information on a variety of topics, including previous research and construction methods, performance based on field applications, primary factors that influence the performance, current construction guidelines, repair procedures, factors that influence performance of overlays, and successes and failures of TPOs. Information was to be gathered from state departments of transportation and Canadian provinces, a literature review, a survey of vendors, and selected interviews.

The literature contains many references to overlays, particularly in the late 1980s, 1990s, and early 2000s. It provides useful information on use of TPOs, pre-overlay evaluation, materials, installation, test methods, TPO field sections, failures, service life, cost, warranties, and special applications. Construction procedures, candidates for TPOs, and construction issues (substrate tests, repair, surface preparation, material handling and mixing, placement, finishing and curing, and quality control tests) were identified from the literature.

The survey responses, from 40 states and seven provinces, revealed that at least 2,400 TPOs have been constructed in the United States and Canada, a fourfold increase over the number installed through 1999. Seven states and three provinces that responded have not used TPOs. Nearly all states use epoxy resins, and only California indicated that it uses predominantly polyester-styrene in premixed overlays. Causes of failures were given. Several states provided specifications for TPOs.

Contractors interviewed were well experienced with TPO construction; they work on bridges in varying conditions of soundness. They discussed repair procedures, installation procedures, and problems encountered and provided recommendations for construction. The material suppliers had considerable experience with TPOs and provided their opinions on problems encountered and recommendations for improvement of materials applications.

From the literature and surveys, the factors that influence performance were identified as the (1) soundness of the substrate, (2) surface preparation, (3) compatibility of the overlay and substrate, (4) aggregates, (5) overlay thickness, (6) bridge girder flexibility, (7) environment, and (8) constructability and workmanship. Little information was found on overlay maintenance; some agencies replace delaminated TPOs with similar materials or even with hydraulic cement concrete. The chapter on proven practices covers best candidates for TPOs, overlay types, materials, qualification of substrate, installation methods, construction test methods, special applications, and warranties.

TPOs have become an accepted construction method for deck preservation, restoring surface friction and extending the lives of decks. The three overlay types, multilayer, slurry, and premixed, are used widely throughout the United States and Canada. These overlays give good performance when placed on decks that are in good condition and when constructed in accordance with established principles such as those specified in *Guide Specification for Polymer Concrete Bridge Deck Overlays*. When constructed properly on sound decks, TPOs could provide a service life of 20 or 25 years.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Polymer concrete (PC) overlays were first used in the 1950s as single layers of coal tar epoxy broomed onto the concrete substrate and seeded with fine aggregate. These overlays were not very impermeable, nor were they durable under traffic. In the 1960s, an oil-extended epoxy was used to improve the performance. By the mid-1970s, polyester-styrene resins and methyl methacrylate monomer systems were being placed using the broom-and-seed method (*1*). Premixed PC that was screeded in place began to be used. In many cases, the thicker, more brittle layers delaminated because of thermal incompatibility of the overlay and substrate.

Through increased attention to monomer and resin formulations and a better understanding of the causes of delamination and other distresses, the performance of thin polymer overlays (TPOs) has increased significantly. Considerable efforts have gone into improving the resistance to chemical and mechanical attack and into understanding the requirements for surface preparation, mixing and placing the PC, and in curing (*2*).

Initially, the reviews of TPOs were not favorable. For example, in 1984 Furr (*3*) stated concerning sand-filled epoxy TPOs, "these overlays generally have proved to be a poor solution to the surfacing and waterproofing problem." He went on to say that of 12 states, only one had found one epoxy that had performed well. However, since that time, the improvement in performance has been substantial, although some problems still exist. It is now understood that flexible resins used in thin layers with wear-resistant aggregates are essential in producing TPOs that are thermally compatible with the concrete decks and are long wearing (*3*). It was learned in this survey of states and provinces that most problems occur because of errors in workmanship.

The use of TPOs has increased significantly in recent years. Sprinkel (*4*) reports that before 1990, 139 TPOs had been placed. There was a threefold increase between 1990 and 1999, with 416 additional overlays having been placed. Considerable experience and data now permit more informed conclusions to be drawn relating to best practices for constructing TPOs.

SCOPE

In 2007, TRB issued a problem statement, NCHRP Topic 39-11, *Performance of Thin Polymer Overlays for Bridge Decks*. The scope of the topic included the following statement:

> Thin polymer overlays, which consist of a polymer binder; e.g., epoxies, polyesters, or methacrylates, and aggregates are constructed with a thickness of no more than 25 mm (1.0 in.). They have the advantages of (1) adding very little dead load; (2) very fast cure times; (3) shallow depths that eliminate need for raising approach slabs; (4) transition from overlaid lane to non-overlaid lane during construction; (5) low permeability; (6) long-lasting wearing surface; and (7) frictional resistance. Many thin polymer overlays have been installed and it is critically important to summarize their performance in one document.

Considerable performance history over the past 20 years is now available and the synthesis study collected information on a variety of topics: (1) previous research, specifications, and procedures on TPOs; (2) performance based on field applications; (3) the primary factors that influence the performance, including traffic, chemical contamination, alkali–silica reaction, corrosion, concrete strength, air content, moisture, environment including temperature and climate, use of tire chains and studs, methods of removing existing concrete, aggregate, surface preparation, material compatibility including substrate, treatments, and patching; (4) current construction guidelines related to surface preparation, mixing and placement, consolidation, finishing, and curing; (5) repair procedures; (6) factors that influence the performance of overlays, including life-cycle cost, benefits and costs, bridge deck condition, service life extension, and performance; and (7) successes and failures of TPOs, including reasons for both.

Information was gathered from state departments of transportation (DOTs) and Canadian provinces, a literature review, a survey of vendors, and selected interviews.

MAJOR DEFINITIONS

The focus of this report is TPOs. There are several important distinctions to be made. The overlays are noncementitious, that is, there is no hydraulic cement such as portland cement; the binder is a polymer. The overlays are thin, typically less than 1 in. in thickness and often 0.5 in. or less. The substrate is normally a portland cement concrete bridge deck, although in a few instances steel decks or concrete pavements have been used.

Definitions taken in part from *ACI 548.5R-96 Guide for Polymer Concrete Overlays* (*1*) are given in the Glossary at end of the report. A few of the more important definitions are presented in this section.

Epoxy resin—A resin that contains epoxy groups principally responsible for its polymerization.

Monomer—A small molecule from which much larger polymer molecules can be made, usually in liquid form for concrete applications.

Multiple-layer overlay—Two or more layers of polymer concrete bonded to concrete; normally each layer consists of an application of resin with aggregate broadcast into the surface.

Polymer—The product of polymerization, more commonly a rubber or resin consisting of large molecules formed by polymerization.

Polymer concrete (PC)—A composite material in which the aggregate is bound in a matrix with a polymer binder.

Premix overlay—The method of initially blending a polymer binder, with fine and coarse aggregate and fillers, if used, and then mixing until all particles are completely wetted. Once the composite has been mixed as required, it is transported and placed. The term applies to polymer concrete.

Resin—A natural or synthetic, solid or semisolid organic material of indefinite and often high molecular weight, with a tendency to flow under stress. It usually has a softening or melting range and usually fractures conchoidally.

Slurry overlay—Overlay applied by placing an application of resin or monomer followed by broadcasting aggregate onto the surface.

Thin polymer overlays (TPOs)—One or more layers of polymer concrete bonded to concrete, normally 1 in. or less in thickness.

METHODOLOGY FOR OBTAINING INFORMATION

Literature Review

A literature review was conducted that included the most likely sources of information on TPOs. The Transportation Reference Information System (TRIS) was a major source of information. Professor Yoshihiko Ohama of Nihon University in Japan has maintained a complete bibliography on concrete-polymer materials over the past several years, and his database, which was last updated in 2007, was used in this review (*5*). The proceedings of the International Congress in Polymers in Concrete were searched for information along with other conference proceedings that were potential sources of information.

The American Concrete Institute (ACI) has published many papers on TPOs in journals and in special publications. ACI Committee 548 Polymers in Concrete has also published several documents on TPOs including a *Guide for Polymer Concrete Overlays* (*1*) and a specification for epoxy TPO construction (*2*).

AASHTO has published *Guide Specifications for Polymer Concrete Bridge Deck Overlays*, which has been widely adopted, at least in part, by many agencies (*6*).

Survey of Transportation Agencies, Material Suppliers, and Contractors

Survey forms were developed and sent to state DOTs and Canadian provinces. Selected vendors and selected contractors that have had experience with TPOs were surveyed by telephone. The agency survey forms, contained in Appendix A, were e-mailed to agencies. Contractors and vendors were interviewed by telephone. Some follow-up telephone interviews with agencies were conducted to obtain additional information.

REPORT ORGANIZATION

The report is organized in the following manner:

- Chapter One—Introduction
- Chapter Two—Literature Findings and Specifications
- Chapter Three—Performance of Overlays from Surveys and Interviews
- Chapter Four—Proven Practices
- Chapter Five—Repair
- Chapter Six—Conclusions
- References
- Bibliography
- Glossary of Terms
- Appendix A: Questionnaires
- Appendix B: Stresses in Overlays
- Appendix C: Warranty and Payment Bond

The information obtained from the various sources was reviewed to obtain the background on the topics listed in the scope. The information was grouped into the subtopics used in the chapters. The factors that influence performance were derived from these sources. The best practices are a summary of the knowledge that has produced overlays that have performed well as reported by the states and provinces.

Little information on costs and repairs was obtained from the literature and from surveys and interviews. For this reason, these issues are addressed in only a cursory manner.

CHAPTER TWO

LITERATURE FINDINGS AND SPECIFICATIONS

A review of the literature that pertains to TPOs is presented. Thin polymer overlays consist of a polymer binder and aggregates with a thickness not exceeding 25 mm (1 in.).

USES OF THIN POLYMER OVERLAYS

Harper (*7*) observed that "epoxy polymer overlays are not a 'repair' for bridge decks. They are only a means of protecting a deck that is in fairly good condition but is at risk for chloride and water penetration." Based on the experience in Alberta, Carter (*8*) states that—

1. TPOs properly applied can provide service lives of up to 20 years, but that maintenance will be required if the surface is intended to remain free of defects.

2. TPOs can be used in high salt environments to extend the lives of existing bridges containing noncoated steel even if some corrosion has begun prior to repair.

3. TPOs are economically competitive with other repairs, especially when a minimum of repairs to the deck are required and a minimum of resin is used, that is, the overlay thickness is less than 10 mm (0.40 in.).

4. TPOs are more suited for preservation than for rehabilitation. Resins are too expensive to be used on excessively rough or deteriorated concrete surfaces because considerable material would be required to bring the surface to grade. They can be used to extend the service lives of dense concrete overlays that are extensively cracked or to prevent freezing and thawing damage to decks with inadequate entrained air void systems.

5. TPO installation requires specialized expertise. The primary failures observed in Alberta have been the result of workmanship or contractor-related errors.

6. Crack repairs are risky and are often a waste of money. Most nonworking, nonrepaired cracks will not reflect through TPO wearing surfaces within 5 years. Many working cracks will eventually reflect whether repaired or not.

7. Polymer wearing surfaces may lose toughness and ductility as they age under ultraviolet exposure. The application of a thin, asphaltic chip seal coat may be economically viable in order to extend the lives of TPOs by shielding them from ultraviolet exposure and abrasive wear.

Sprinkel (*4*) states that the bridges that are the most likely candidates for TPOs (1) "are those that are in need of a skid-resistance wearing and protective surface but have peak-hour traffic volumes that are so high that it is not practical to close a lane to apply the surface except during off-peak traffic periods" and (2) "are those in which increases in dead load, reductions in overhead clearance, and modifications to joints and drains must be held to a minimum."

Multiple-Layer Overlays

According to Sprinkel (*4*), multiple-layer overlays are best used on decks that have good ride quality because the overlays follow the contours of the deck surface. This is the result of the layers being of uniform thickness, which results in the overlays following the surface irregularities instead of bringing the surface to a uniform grade.

Slurry and Premixed

Decks that have many surface irregularities are the best candidates for slurry and premixed TPOs (*4*).

PRE-OVERLAY EVALUATION

The Missouri DOT performed an investigation of the cause of failures of the epoxy overlays that they had installed. Harper's (*7*) observations related to failures involving TPOs are as follows:

- Missouri recommends placing TPOs on decks that have less than 5% of the deck requiring repairs. It is important that decks be tested for delamination, chloride levels, and tensile strength of the concrete deck. Decks that require less than 5% of surface to be repaired have more likelihood of success.
- Many of the failures appeared to be a failure of the top surface of the concrete deck instead of the polymer.

Examinations of spalled material usually showed a layer of concrete beneath the epoxy PC.
- Decks that were rated higher before overlay placement performed better based on an inspection rating system for both the deck and overlay.
- Longer span bridges were more likely to have problems with overlays owing to the greater deflections that can cause deck or overlay cracking. More flexible epoxies are recommended for longer spans. Bridges with girders that were wide flange sections or post-tensioned I-beams had overlays with higher ratings than bridges with plate girders.

REPAIRS

Cracks

TPO contracts in Alberta in the period 1985 to 1987 required flexural cracks to be repaired (*8*). Flexural cracks were distinguished from shrinkage cracks by (1) straightness in contrast to shrinkage cracks, which tend to be more curved and randomly oriented; (2) location in negative moment region; and (3) presence of stains on the bottom of the bridge, which indicated that the cracks were full depth. The cracks were routed and filled with a flexible epoxy that was said to have "probably performed as designed until exposed to very low temperatures." In 1988, "band-aid" repairs were developed. These repairs involved debonding the wearing surface along the crack, strengthening the wearing surface with tensile reinforcement centered over the crack. One repaired bridge originally had about 600 lineal meters (2,000 ft) of flexural cracks and 6,000 lineal meters of shrinkage cracks; after 4 years, about 100 lineal meters (325 ft) of cracks have reflected through the TPO. Another repaired bridge had 3,000 lineal meters (10,000 ft) of crack repairs, and about 70% of the cracks have reflected through the TPO. Carter concludes that, "the extreme cold, as well as the flexibility and live load deflection of this deck, make crack repairs appear futile" (*8*).

Sprinkel (*4*) states that "large cracks should be filled ahead of time with a gravity fill polymer that is compatible with the overlay."

Concrete

It is important that concrete with chloride ion content greater than 0.77 kg/m^3 (1.3 lb/yd^3) at the level of reinforcing be removed and replaced before placing the overlay (*4*).

MATERIALS USED IN OVERLAYS

Resins

Typical resins are epoxy, polyester, and methacrylate (*4*). The curing time is a function of the type and amount of initiator or curing agent, curing temperature, and binder content. AASHTO *Guide Specifications* (*6*) show the minimum times for curing that have been successfully used for TPOs.

White and Montani (*9*) point out the importance of tensile elongation and note that polymers that have good tensile elongation at room temperature may have poor elongation at low temperatures. They recommend 20% elongation of the polymer at 40°F and 30% when tested at 73°F in accordance with ASTM D638 (*10*).

Gaul (*11*) reports on the use of epoxy asphalts over the previous 25 years. He describes the properties of epoxy asphalt and provides guidance on proper installation.

Aggregates

It is important that aggregates used in TPOs be dry (less than 0.2% moisture), angular-grained silica sand or basalt, and free from dirt, clay, asphalt, and other organic compounds. AASHTO *Guide Specifications* (*6*) give recommended gradings for multiple-layer, slurry, and premixed overlays.

Fontana et al. (*12*) indicate that an increase in aggregate moisture to 1% by weight can significantly decrease the strength of the PC from which it is made. They state that the addition of 1% silane coupling agent by weight of the monomer (methyl methacrylate) can significantly offset up to 1% moisture in the coarse aggregate in the reductions in strength and freezing and thawing that normally would be expected.

Polymer Concrete Application Rates

Typical PC application rates for the three different types of overlays are given in AASHTO *Guide Specifications* (*6*).

INSTALLATION

Surface Preparation

Surface preparation procedures need to be approved only when test patches, 0.3 m by 0.9 m (1 ft by 3 ft), constructed with approved materials are shown to have a minimum average tensile rupture strength of three tests per patch, based on the procedure in ACI 503R (*13*), of 1.7 MPa (250 psi) (*4*). If the failure in the concrete occurs at depths greater than 6.4 mm (0.25 in.) and at stresses less than 1.0 MPa (150 psi), it is important that the concrete be removed and replaced with higher quality concrete, followed by surface preparation and placement and testing of new test patches. When stresses at failure occur between 1 MPa (150 psi) and 1.7 MPa (250 psi), the overlay can be placed, but the engineer determines whether part or the entire base concrete needs to be replaced. A visual inspection needs to be made before the overlays are placed to ensure that the surface is properly prepared, dry, and free of dust or other contaminants.

Substrate Tensile Strength

The deck must have a minimum rupture strength of 1.0 MPa (150 psi) based on the test method in ACI 503R (*13*) or ASTM C1583 (*14*) to receive an overlay; otherwise, the concrete must be removed and replaced so that a sound substrate is available to bond to the TPO (*15*).

Repair of Substrate

The substrate concrete needs to be patched, and large cracks [greater than 1 mm (0.04 in.)] in width need to be repaired (*15*). It is important that concrete with chloride ion content greater than 0.77 kg/m^3 (1.3 lb/yd^3) at the level of the reinforcing steel be removed and replaced before placing the overlay (*16*, *17*).

Surface Cleaning

"The surface should be cleaned by shot blasting (Figure 1) and other approved cleaning practices to remove asphaltic material, oils, dirt, rubber, curing compounds, paint, carbonation, laitance, weak surface mortar, and other detrimental materials that may interfere with the bonding or curing of the overlay" (*15*). Along edges of the deck and other areas that cannot be cleaned by shot blasting, grit blasting might be used.

Test for Adequacy of Surface Preparation

The test method described in ACI 503R (*13*) and ASTM C1583 (*14*) could be used to determine whether the size of shot, flow of shot, traveling speed of machine, and number of passes are adequate to provide the required surface preparation to achieve a minimum tensile bond strength of 1.7 MPa (250 psi) or a failure area at a depth of 64 mm (0.25 in.) or more into the base concrete greater than 50% of the test area. The test result might be based on the average of three tests on an overlay test patch of at least 0.3 m by 0.9 m (1 ft by 3 ft). One test result could be obtained for each span or 418 m^2 (500 yd^2) of deck surface, whichever is the smaller area, as shown in Figure 2. The cleaning procedure could be approved if the test requirements are met for each test panel (*6*, *17*). Because the temperature of the overlay can affect the test result in that adhesion decreases at higher temperatures, the temperature of the overlay at the time of the test should be recorded (*17*).

FIGURE 2 Apparatus for performing pull-off test to evaluate surface preparation or overlay bond strength.

Methods of Application

It is important that TPOs be placed the same day that the surface is shot blasted to ensure cleanness. Areas of the deck

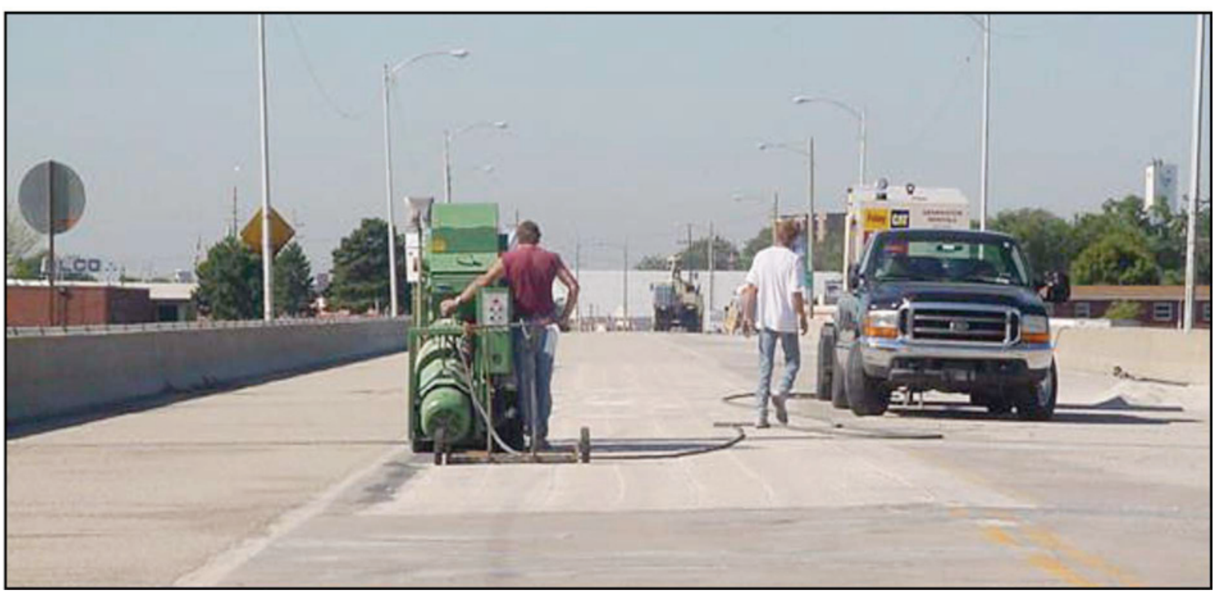

FIGURE 1 Shot-blast preparation of the surface.

that are not shot blasted the same day could be shot blasted again just prior to installing the overlay (*4*).

Multiple-Layer Overlays

Multiple-layer overlays are constructed by application of the binder (resin or monomer system) to the deck surface by spray, squeegee, or broom and broadcasting gap-graded aggregate to excess over the fresh binder-covered surface (Figure 3). After the binder has cured, the loose aggregate is removed from the deck and a second layer is applied. The first layer consists of approximately 1.1 kg/m^2 (2 lb/yd^2) of binder and 5.4 kg/m^2 (10 lb/yd^2) of aggregate. The second layer consists of approximately 2.2 kg/m^2 (4 lb/yd^2) of binder and 7.6 kg/m^2 (14 lb/yd^2) of aggregate. The resin content is approximately 25% by weight of the overlay. The thickness is about 6.4 mm (0.25 in.) (*15*).

FIGURE 3 Workers spraying resin followed by application of aggregates in multiple-layer TPO.

Slurry Overlays

Slurry overlays are constructed by applying a primer of monomer or resin system at an approximate rate of 0.41 kg/m^2 (0.75 lb/yd^2) followed by a slurry mixture of about 2.6 kg/m^2 (5 lb/yd^2) of binder, 3.8 kg/m^2 (7 lb/yd^2) of silica sand, and kg/m^2 (5.21 lb/yd^2) of silica flour. This slurry mix is applied with a gauge rake to ensure proper depth of placement (Figure 4). Gap-graded aggregate (as used in multiple-layer overlays) is broadcast onto the surface. A binder seal coat at 0.68 kg/m^2 (1.25 lb/yd^2) is applied. The binder content is approximately 24% by weight of the overlay (primer and seal coat). The thickness is about 7.9 mm (0.31 in) (*15*).

FIGURE 4 Using gauge rakes to control thickness of slurry overlay. (*Courtesy*: Virginia Center for Transportation Innovation and Research.)

Premixed Overlays

Premixed overlays are installed by mixing about 12% binder with the aggregates. A primer is usually applied to the surface at an approximate rate of 0.41 kg/m^2 (0.75 lb/yd^2) to improve the bond strength (Figure 5). The polymer concrete is placed and a vibratory screed is used to strike off and consolidate the PC (Figure 6). In some applications, continuous batching and paving equipment has been successfully used to place premixed PC (Figure 7). A suitable skid resistance can be achieved by placing grooves in the fresh PC (Figure 8) or by broadcasting aggregates onto the fresh PC surface (Figure 9). The thickness is about 13 mm (0.50 in.) (*15*).

FIGURE 5 Priming deck with initiated high-molecular-weight methacrylate prior to placement of PPC. (*Courtesy*: American Civil Constructors.)

FIGURE 6 Vibrating screed consolidates and strikes off PPC overlay. (*Courtesy*: Virginia Center for Transportation Innovation and Research.)

FIGURE 7 Metered mixing and placement of mixed polyester polymer concrete from mobile concrete batching plant. (*Courtesy*: Gomaco.)

FIGURE 8 Placement and finishing fresh PPC surface with modified laydown machine and conventional tining rake. (*Courtesy*: Gomaco.)

Dimmick (*18*) describes two methods of mixing and three methods for placing premixed TPOs. He suggests mixing in containers with electric power drills with paint paddle mixers or in drum mixers. For placement, he suggests the use of a power screed, a manual screed, or a static screed. He gives examples of each in his paper.

FIGURE 9 Equipment used to blow aggregates onto overlay surface.

QUALITY CONTROL TESTS

Quality control tests and required test results according to Sprinkel (*15*) are as follows:

Resin

It is important that resin or monomer be sampled at the rate of one sample for each 3,785 L (1,000 gal). The required viscosity, gel time, tensile elongation, and bond strength are shown in AASHTO *Guide Specifications* (*6*) along with the appropriate test method. Samples are to be accepted only when the required properties are furnished. The curing time is a function of the type and amount of initiator or curing agent, curing temperature, and binder content. AASHTO *Guide Specifications* (*6*) show the minimum times for curing that have been successfully used for TPOs.

Aggregate

An aggregate sample needs to be obtained for each 43,350 kg (100,000 lb) of aggregate used. The aggregate grading can be determined to be acceptable when meeting the grading shown in AASHTO *Guide Specifications* (*6*). Aggregates subject to wear would be silica or basalt and have a Mohs scale hardness of about 7.

Typically, DOTs specify noncarbonate aggregates or define aggregates with a specified acid insoluble residue (AI) minimum that ranges from 80% to 95% for coarse aggregates for long-term surface friction. The test method for AI is provided in *ASTM D3042-09 Standard Test Method for Insoluble Residue in Carbonate Aggregates* (*19*). This is the basis for all individual state DOT test methods. AASHTO does not have a listing for this test method. Some states, including Missouri, list New York State DOT Method 28 for AI.

Polymer Concrete

Specimens made from the furnished resin and aggregate need to be made and tested in accordance with the tests shown in AASHTO *Guide Specifications* (*6*). The test results should meet the minimum requirements in the table for the type of polymer used.

Gel Time

The gel time needs to be monitored to ensure that the requirements of AASHTO *Guide Specifications* (*6*) are met.

Application Rates

The application rates need to be monitored to ensure that they are in conformance with AASHTO *Guide Specifications* (*6*).

Curing

The minimum curing time before opening to traffic is given in AASHTO *Guide Specifications* (*6*); however, a compressive strength of 6.9 MPa (1,000 psi) based on field-cured cubes (ASTM C579, Method B) (*20*) might be obtained before opening to traffic (*6*).

TEST METHODS

Shrinkage

Many monomers and resins shrink during curing, particularly polyester-styrene and acrylics. Zalatimo (*21*) and Zalatimo and Fowler (*22*) developed a test method for measuring shrinkage, including the effect of relaxation. A 150-mm × 150-mm × 0.9-m (6-in. × 6-in. × 36-in.) beam is overlaid with the PC with the center portion unbonded to the concrete substrate by means of plastic sheets placed on the concrete surface. A measuring device with a 250-mm (10-in.) gauge length is placed into the fresh PC; at different times after the PC has initially cured, one end of the unbonded section is cut. Residual shrinkage stresses in the PC will cause the unbonded section to contract from the cut end. It has been shown that when the time of cutting is increased, the measured shrinkage is reduced. For most materials tested, including epoxies, polyester-urethane, and polyester-styrene, the shrinkage is generally nonexistent after 72 h, which indicates that relaxation has occurred.

Tensile Elongation

White and Montani (*9*) recommend that cured resins have a minimum of 20% elongation at 40°F and 30% when tested at 73°F in accordance with ASTM D638. The AASHTO *Guide Specifications* have the requirement of 30% to 80% tensile elongation for epoxy and polyesters (*6*).

Water Absorption

White and Montani (*9*) recommend that the water absorption in PC be limited to a maximum of 1% by weight when tested in accordance with ASTM D570 (*23*).

Abrasion

White and Montani (*9*) recommend that overlays be tested at 125°F in accordance with ASTM D4060 (1,000 g load at 1,000 cycles) (*24*) and maintain a wear index of less than 2.0.

Chloride Ion Penetration

White and Montani (*9*) recommend that when tested in accordance with AASHTO T277-07 (*25*) the "polymer and system in place shall be required to register zero coulombs in the test to ensure chloride resistance." The AASHTO *Guide Specifications* require that the permeability be a maximum of 100 coulombs at 28 days (*6*).

Evaluation of Bridge Decks

Carter (*8*) reports on the procedures used to evaluate many bridges. They were (1) ASTM C876 (*26*) for corrosion activity using a 1.2-m (4-ft) square grid pattern; (2) air permeability on 75-mm (3-in.) cores that were oven dried for 24 hours. (specimens were pressurized from the bottom surface using the American Petroleum Institute Recommended Practices 40 test method); (3) bond strength tests using 75-mm (3-in.) cores taken randomly; (4) ultraviolet exposure tests using ASTM D638 (*10*) for measuring tensile strength and elongation (samples were lightly sprayed with water each day); and (5) skid resistance tests done by a mobile skid trailer traveling at 64.4 km/h (40 mi/h).

THIN POLYMER OVERLAY FIELD SECTIONS

Many authors have reported results of TPO test sections, and some of the more significant tests are discussed in this section. In most cases, the information on the resins used did not include tensile elongation or modulus of elasticity; rather, the generic resin type was given, for example, epoxy, polyester-styrene, or methacrylate.

Ohio Bridge Deck, 1983

Dimmick (*18*) reports that a bridge deck in Ohio, constructed in 1962, had experienced transverse cracking and extensive wear. An epoxy TPO was selected primarily for the purpose of surface friction. The surface was shot blasted; because the pH exceeded 13, the surface was acid etched to reduce the pH to 9.2, although normally acid etching is not recommended for surface preparation. Cracks were not repaired. The surface was primed with neat epoxy. Polymer concrete consisting of silica sand and 10.5 (wt %) epoxy resin was batched in mixers and placed to a depth of 6 mm (0.25 in.). The surface was finished with a wood screed to provide transverse irregular ridges. The area overlaid was 1,642 m^2 (17,676 ft^2). After 10 years and 121 million vehicles, the surface was said to still have excellent anti-skid properties. About 2 m^2 (22 ft^2) of overlay had to be replaced because of delamination; it was not known whether the delamination occurred in the substrate or at the bond line.

Post-Tensioned Parking Garage

Post-tensioned slabs in a 6-year-old parking garage in Tennessee had experienced severe freezing and thawing as a result of an improper air void system (*27*). Tests on cores indicated concrete compressive strength of about 6,000 psi. Some deformed bars and post-tensioning tendons were corroded and exposed. The chloride ion content at a 12-mm (0.5-in.) depth was three times the corrosion threshold level of 0.77 kg/m^3 (1.3 lb/yd^3). Methyl methacrylate (MMA) PC was selected because of (1) the ability to place it in very thin applications, (2) the ability to place the material in a range of −7°C (20°F) to 38°C (100°F), and (3) short cure time that allowed the garage to remain open during repairs. The deteriorated concrete was chipped out and the corroded bars and tendons were exposed. The surface was sandblasted and then primed with MMA primer. Deep spalls were filled with MMA PC that used pea gravel. All of the negative moment regions received a 6-mm-thick (0.25-in.-thick) MMA PC overlay. Inspections were made at 1.5, 7, 10, and 13 years after repair. During the first inspection, very shallow 0.3-mm (0.012-in.) deep crazing cracks were observed in areas exposed to sunlight and were attributed to the trowel finishing that brought excess monomer to the surface, resulting in additional shrinkage. No spalling, cracking, or delamination was observed until the last inspection; at that time, some delamination associated with cracking in the surface was observed. Cracks over deformed bars and tendons were associated with continued corrosion of the bars and tendons. Apparently, all of the contaminated concrete around bars and tendons had not been removed and corrosion had continued at a slow rate. In areas where freezing and thawing had occurred and corrosion had not continued, the overlay performed well.

Epoxy Asphalt TPOs

The San Francisco–Oakland Bay Bridge was constructed in 1936, and ceramic tile embedded in mortar was used as permanent lane striping (*11*). In 1963 and 1964, the upper and lower decks were resurfaced to cover the ceramic tile striping with a PC made of coal tar epoxy binder and quartz beach sand. The binder was sprayed on the surface and the sand was broadcast onto the binder. By 1968, the sand had begun to polish and to be picked out, reducing the skid resistance, although the binder was in excellent condition. In 1971, 16 test sections using different resins and aggregates were installed. Epoxy asphalt and a combination of hard metagraywacke and soft, lightweight, synthetic aggregate were selected for the overlay. In 1976 and 1977, the upper and lower decks were resurfaced with 256 m^2 (2,760 ft^2) of 19-mm-thick (0.75-in.-thick) epoxy asphalt using conventional asphalt paving machines followed by compaction with rubber tired and steel drum rollers. In 1996, an inspection showed five types of distress: (1) small mechanical gouging depressions, (2) three locations of fire pitting owing to vehicular fires, (3) pot holes resulting from delamination of the lightweight concrete substrate or weak bond to the epoxy coal tar chip seal (approximately 93 m^2 or 1,000 ft^2), (4) joint crumbling that required six joints to be repaired, and (5) reduced skid resistance that had not been predicted by lab tests. Bond pull-off tests using ACI 503R-93 (*13*) with 50-mm (2-in.) diameter cores gave tensile bond strengths ranging from 0.84 to 2.45 MPa (122 to 356 psi). The performance was deemed a success for the 20-year life for a bridge experiencing 250,000 vehicles per day in both directions.

Gaul (*11*) gives a 25-year history of the use of epoxy asphalt, including properties, manufacture, methods of use, and list of applications.

Alberta Overlays

Initial Investigation

In an initial investigation, Carter (*8*) states that Alberta had waterproofed 66 bridges with TPOs. Many of the TPOs were placed on dense concrete overlays that were heavily cracked owing to long-term drying shrinkage. The cracks appeared to propagate each year when subjected to vehicle loads in cold weather. Half-cell (copper sulfate electrode) and chloride content testing were performed on many of the decks, and it was concluded that corrosion was continuing to develop and would likely reduce the service life and require a second major rehabilitation. An investigation of thin epoxy wearing surfaces installed by agency crews in the 1960s showed that some had performed well. Carter notes that on one bridge on which a coal tar epoxy overlay had been installed, 70% of the overlay was still intact and many of the failed areas appeared to have been caused by thermal incompatibility owing to an excessive thickness of epoxy having been applied.

Test Bridge

In 1984, a test bridge was selected and divided into eight equal sections of 139.4 m^2 (500 ft^2) to test some of the available membrane wearing surface systems, including some parking garage membrane systems. These softer, more flexible materials performed poorly on the bridge. One system composed of coal tar epoxy was seeded with a very hard (Mohs hardness of 9) brittle slag aggregate. The aggregate disintegrated under tire impact, leaving tiny holes in the membrane. After 6 years, most of the membrane had worn away. Two other sections using silica sand embedded in epoxy resins became highly polished because of the poor wear resistance of the sand. One of these systems exhibited some debonding that was attributed to the well-graded fine aggregate creating a brittle epoxy–aggregate composite material that performed differently than the deck when subjected to live load and thermal stresses. The most durable of the eight systems was a flexible epoxy that used a poorly graded basalt aggregate with a relatively high aluminum oxide content. It had the highest bond strength and the best electrical resistivity readings.

Description of TPOs

The TPOs applied after 1985 usually consisted of two layers plus a tie coat, resulting in an average thickness of 6 mm (0.25 in.) (*8*). No primer was used. Each layer consisted of liquid seeded with aggregate applied with squeegees and rollers to seal the deck surface. Excess aggregate was removed after the resin hardened. The tie coat consisted of a thin layer of resin used to seal pinholes and voids in the composite layer.

In 1988, six bridges with low traffic volume were repaired with a less expensive system that had only one seeded layer applied on a nonseeded primer. Permeability tests indicated better waterproofing than the system with two seeded layers and no primer (*8*).

In 1989, the two-layer system was changed by applying the tie coat first as a primer, followed by the two seeded layers. Three bridges were repaired by using a premixed PC that was screeded; the main advantage is the speed at which they can be placed on large bridges, resulting in labor savings and reduced closure time. A possible disadvantage is the possibility of entrapped air at the bond line, which would reduce bond strength (*8*).

Performance of 21 Bridges

Carter (*8*) reports on 21 TPOs of a total of more than 100 that had been placed in Alberta beginning in the 1960s. Typically, it was found that the failure of TPOs resulted "from the basic incompatibility of polymer concrete and portland cement concrete, manifested as debonding or shearing of the overlay from the concrete." Many of the bridges had been overlaid previously with dense concrete that developed numerous cracks. Many of the bridges, especially the ones with the largest spans, had steel superstructures that were more flexible and developed more cracking and also received more deicing salt than the average deck. In 1990, the accumulated damage to the TPOs was 0.6% of the total 22,052 m^2 (237,000 ft^2) installed on the 21 bridge decks between 1985 and 1987. By 1995, the failed surface area had increased to 2.0% at an average of 9 years. The original installation had a 5-year warranty, so that at an age of 5 years the contractor had repaired all of the original defects. The amount of defective surface area in 1995 included the total distress that had been repaired before and after the 5-year warranty repairs.

Thermal Incompatibility

One bridge that was overlaid in 1991 experienced 10% debonding in 2 years and 50% in 3 years (*8*). The failure involved shear failure of the dense concrete just below the bond line. The thickness was 15 mm, greater than normal; that also leads to increased stress owing to thermal changes. The initial strength of the polymer (the type of polymer was not given) was 25 MPa (3,600 psi), which was considerably higher than for other "well-performing resins that had been used in Alberta." The strength increased to 30 MPa (4,350 psi) when exposed to ultraviolet light. The tensile elongation of the polymer was found to have decreased significantly from its original 30%. It was concluded that thermal incompatibility with the substrate caused the failure because of loss of flexibility.

Aggregate

A bridge placed in 1990 used red basaltic aggregate on one side of the bridge and green trap rock on the other side (*8*). After 2 years, it was observed that more red aggregate was accumulating in the gutter lines of the deck than green aggregate. Further testing using cores indicated that five times as many empty sockets were left by red aggregate. The problem was attributed to the fact that the red aggregate was more rounded and had a lower fracture-face count. In addition, after 5 years of service, the amount of lost or debonded overlay was twice as much on the red side even though the overlays were placed at the same time by the same contractor. A study of other bridges that used the red, green, and a less frequently used black aggregate was conducted. It was found that under similar conditions of age and traffic, the red overlays were debonding 25 times more rapidly than the black overlays and 19 times more rapidly than the green ones. Stress–strain tests on cylinders using the same polymer and the three different aggregates showed that the polymer concrete made with the red aggregate could absorb only 70% as much energy (area under the stress–strain curve) than the other materials (*8*).

Contractor Experience

A study of 71 bridges for durability also evaluated the performance of contractors (*8*). The overlays constructed by the most experienced TPO contractors (i.e., those who had done the most work) were significantly more durable than those constructed by contractors with lesser amounts of installation experience.

Ability of TPOs to Protect Nondurable Concrete

TPOs were applied to several bridges with concrete decks of substandard quality and durability based on Carter's experience (*8*). One bridge deck had little entrained air, and the surface was badly scaled on one side after one winter of service. Another bridge had a wavy surface owing to hand screeding, and the cover over the steel varied "substantially." The bridge carried heavy traffic, received heavy applications of deicing salt, and had many freezing and thawing cycles. A third bridge had a 1972 overlay that had been placed with the expectation of providing 10 to 15 years of life. By 1986, the overlay was partially debonded and had moderate salt scaling. A single-layer TPO was placed with the goal of providing 10 years of service life. It was concluded that "the extension of deck service life resulting from the thin overlays at these inferior concrete sites appears to be from 5 to 12 years. Since the cost of deck or entire bridge placement is so much higher than the overlay cost, these polymer systems were successful in reducing life cycle costs." It was noted that the deck life was significantly reduced when a significant amount of reflective cracking was present in the concrete. "Apparently, since the polymer overlays did not effectively seal the wide, moving cracks, deck deterioration proceeded below the overlay in the cracked areas."

Effectiveness in Sealing Deck Cracks

Carter (*8*) notes that it is difficult to know which cracks are reflective cracks prior to installation of TPOs, and that it may be better to install the overlay and then repair the cracks later. In his opinion, even when crack repairs are made, they may last only 5 to 10 years, but the life of the overlay is likely to be 15 to 20 years (*8*). One bridge had about 1,500 m (5,000 ft) of cracks in 1985 before installing the overlay. About 185 m (600 ft) of "apparently actively moving cracks" were repaired by routing and using an epoxy caulking material. After 5 years, approximately 46 m (150 ft) of cracks had reflected through the overlay; after 10 years, it had increased to 215 m (700 ft). It was thought that ultraviolet radiation had caused the polymer to lose flexibility over time.

Thickness of TPOs in Cold Climates

Carter (*8*) notes that TPOs are more durable in Alberta when they are thin. The reduction in temperature [to as low as –40°C (–40°F)] causes the polymer to become more brittle at the same time that interfacial stresses are developing. The stress is proportional to the thickness of the polymer. Excessive thickness can lead to bond failures.

Repair of TPOs

Because the service life of TPOs is affected by ultraviolet radiation and traffic wear, Alberta began placing thin asphaltic chip coats over aging TPOs to renew their skid resistance and to extend the life of the overlay (*8*). Carter reported that 56 bridges have been treated using inexpensive chip coats; the results were satisfactory.

Virginia Multiple-Layer Overlays

Virginia has used many TPOs over the years, and Sprinkel (*16*) reported on 18 multiple-layer overlays and one single-layer overlay placed between 1981 and 1987. The binders for the multiple-layer overlays included four polyester-styrenes, one polyester amide alkyd, one MMA, three EP5-LV epoxies, and two flexible epoxies. A single-layer high-molecular-weight methacrylate overlay was installed. After all major spalls were repaired, the bridge decks were shot blasted, except cleaning with compressed air was used in the high-molecular-weight methacrylate single-layer overlay. The initiated and promoted resins were sprayed or broomed onto the clean surface, and before the resin gelled, aggregate was broadcast onto the surface. After curing, the excess sand was broomed or vacuumed off the surface. The additional layer or layers were applied in a similar manner. Three or four layers were applied for the polyesters; the epoxy overlays used only two layers. The high-molecular-weight methacrylate overlay had only one layer. The aggregate was clean, dry, angular silica sand.

Tensile Bond Strength

Virginia requires a tensile bond strength test, based on ACI 503R (*13*) or ASTM C1583 (*14*), to ensure that the installation procedure would give the target strength of 1.7 MPa (250 psi) or more. The contractor was required to install two layers of an overlay, 0.3 m by 0.9 m (1 ft by 3 ft), on each span or 167 m^2 (200 yd^2), whichever was the smaller area. Their experience indicated that a typical standard deviation was 0.27 MPa (40 psi), and average bond strength of 1.52 MPa (220 psi) was required for satisfactory performance. The tensile bond strengths were found to decrease with time. Initially, failures were in the concrete substrate, but with time the failures were in adhesion or near the bond line. In bridges on which traffic was allowed on the shot-blasted surface before overlay application, the initial bond strengths were low (*16*).

Shear Bond Strength

Guillotine shear strength tests were performed on cores taken from the bridge decks (*16*). Some cores were thermally cycled from −18°C to 38°C (0° to 100°F) three times each day. For some overlays, the thermal cycling gave good correlation with tensile bond strength test results from the field. It was concluded that environment had a greater effect on the bond strength for polyesters than for the epoxies, and that degradation of bond strength with time leads to delamination for some overlays within 10 years.

Rapid Chloride Permeability

All polyester and epoxy overlays displayed very low (100 to 1,000 coulombs) or negligible (<100 coulombs) permeability initially; the high-molecular-weight methacrylate overlay displayed low permeability (1,000 to 2,000 coulombs). After 1 year, the brittle polyester had a moderate permeability (2,000 to 4,000 coulombs). After 4 years, the stiffer epoxy had the lowest permeability, and after 5 years, the flexible had the lowest, both being in the very low category. After 100 thermal cycles in the laboratory, only the brittle polyester and the epoxies had a negligible permeability; the MMA, high molecular weight, and some of the other polyesters had low or moderate values (*16*)

Electrical Resistivity

Electrical resistivity tests (*28*) were performed to determine the presence and extent of microcracks. Only the flexible polyester had no significant cracks until 3 years after placement; all others had extensive cracking after 1 year or less. However, the permeability tests indicated that the other overlays were "providing significant protection against chloride penetration" (*16*).

Half-Cell Potential

Copper sulfate half-cell potential readings (*26*) indicated that only four small areas on four spans had a 90% corrosion probability. Over a 6-year period, the half-cell readings did not change significantly (*16*).

Skid Resistance

All overlays had adequate skid resistance at the time the overlays were installed, and the values are reported in Sprinkle (*16*). The overlays made with the more rigid epoxy showed a significant reduction in skid resistance after 1 year of service; the reduction was because these overlays used less resin and finer sand than the other overlays in the program. Virginia no longer uses this epoxy (*16*).

Wear

The most wear occurred in the travel lanes. The greatest wear occurred for the brittle polyester-styrene (2.5 mm or 0.10 in. in 5 years), but that rate is 23% of the wear reported for latex-modified concrete. The conclusion was that the overlays would likely delaminate or exhibit an unacceptable skid resistance before the overlays wear through (*16*).

Nineteen-Year Performance

Sprinkel (*15*) provides a summary of performance of TPOs on bridge decks in California, Michigan, Ohio, Virginia, and Washington. A summary of aggregate gradations for multiple layer, slurry, and premixed overlays is given; properties of epoxy, polyester, and methacrylate binders and PC are presented with the appropriate test method for each property; and typical polymer concrete application rates for the three types of application methods are given.

The 14 bridges were evaluated in 1991 and 1995. Three overlays, each constructed with multiple-layer epoxy, multiple-layer epoxy urethane, premixed polyester, and methacrylate slurry, and two overlays installed with multiple-layer polyester, were included in the evaluation. The overlays ranged in age from 6 to 19 years.

Tensile Bond Strength

The tensile bond test was a modified version of Virginia Test Method 92. This method is similar to ACI 503R (*13*) but differs by providing a swivel attachment to the cap and the top hook of the test device to minimize eccentricity. The results indicated little change in initial tensile bond strengths of more than 1.65 MPa (240 psi) for the multiple-layer epoxy, multiple-layer epoxy urethane, and the premixed polyester over the life of the overlays; the multiple-layer polyester overlays had lost considerable bond strength [from over 2.0 MPa (300 psi) to about 0.50 MPa (75 psi)] and were projected to fail within 10 years. There were insufficient data to evaluate the MMA slurry overlays (*15*).

Permeability

Permeability performance based on AASHTO T277-07 (25) tests in 1995 and from a previous project was given. The results indicated that the lowest permeability (<100 coulombs) was provided by the methacrylate slurry, and that negligible to very low permeability (<1,000 coulombs) was associated with the multiple-layer epoxy and epoxy urethane and the premixed polyester. Multiple-layer polyester had greater increases in permeability but was predicted to provide good protection for 10 years (*15*).

Skid Resistance

Based on ASTM E524 (*29*) (smooth tire), acceptable skid numbers (<33 coulombs) were being maintained for all overlays except MMA slurries, which were showing a downward trend (*15*).

Durability

Polymer concrete was tested for freezing and thawing in accordance with ASTM C666, Procedure A (*30*); modification by the addition of 2% sodium chloride to the water had shown a durability factor of over 90% after 300 cycles, considerably greater than the minimum factor of 60% generally accepted for concrete. Polymer concrete had good resistance to wear. Projections based on tensile bond strengths, permeability, and skid resistance, for the overlays, with the exception of the MMA slurry and multiple-layer polyester overlays, indicated a service life of at least 20 years (*15*).

Epoxy TPO Overlays

The advantages of epoxy TPOs were given, including excellent bond strength, unaffected by alkalinity of concrete, little shrinkage, low modulus, high strength-to-weight ratio, and not flammable. Epoxy PC consists of resin, hardener, and aggregates. Nabar and Mendis (*31*) provide a list of key projects using flexible epoxy binder that had been in service for 10 years. The authors provide a good summary of surface preparation, overlay application including multiple-layer method or slurry method, and curing quality assurance procedures, service life, trouble-shooting procedures, and loss of skid resistance.

Evaluation results of four bridges in Michigan, Ohio, Virginia, and Washington are given.

Fort Worth, Texas, Overlays

Zalatimo and Fowler (*22*) report on different resins used to construct small overlay test sections on two bridges in Fort Worth, Texas. One bridge used (1) high-molecular-weight methacrylate, (2) four hybrid polyester-urethanes (three low modulus and one high modulus), (3) experimental epoxy with a high modulus, and (4) two commercially available epoxies. The PC was batch mixed and placed in a 12-mm (0.5-in.) thickness with a vibrating screed. Additional aggregate was broadcast on the surface to obtain improved skid resistance. The second bridge used two polyester-urethanes, experimental polyester, and an experimental epoxy, which were applied as multiple-layer overlays over a high-molecular-weight methacrylate primer. Two layers were applied, resulting in a thickness of about 9 mm (0.375 in.). The overlays generally performed well, except that two of the hybrid resin overlays failed owing to the primer being allowed to pond and form a thick layer. Because of thermal stresses, it failed within the first couple of months. The 5-year evaluation found that most were in good condition, although some had polished on the surface owing to inadequate aggregate seeding for texture.

California I-80

Maass (*32*) reports that the Donner Pass section of I-80 in California that was overlaid in 1986 has performed well. In 1983, the section of highway carried an average daily traffic of 9,750 vehicles, of which 950 were trucks. The average annual rainfall is 1.54 m (61 in.) and the average snowfall is 10.4 m (410 in.). Two resins were used—one with a tensile strength of 17 MPa (2,500 psi) and a tensile elongation of 35%, and another that had a tensile strength of 55 MPa (8,000 psi) and a tensile elongation of 5%. The surface was shot blasted and primed with either high-molecular-weight methacrylate or an unsaturated diaromatic glycol fumerate. The aggregate was 12 mm (0.5 in.), with less than 25% crushed particles. The overlay was installed using a continuous screw-type mixer and a paving machine. Dry screenings were broadcast on the surface to provide improved skid resistance. The overlay was 3.6 mi in length and had a 19-mm (0.75-in.) thickness. Krauss (*33*) states that, "Over 25 bridge decks have been overlaid with polyester-styrene concrete overlays and all the overlays are performing well." He states that in 1988 there had been no delamination on any polyester-styrene concrete overlay placed by contract. No overlay since 1983 had shown signs of wear or cracking.

Several Epoxy TPOs

Two epoxy overlay test sections were reported by Dimmick (*34*).

Toll Booth Lanes

Portland cement and epoxy polymer concrete were tested side by side at toll booth lanes into Newark Airport in 1977. The portland cement had about 40 MPa (6,000) psi compressive strength. The epoxy concrete had 14% epoxy by weight. The surface was primed and the hand-mixed epoxy concrete was placed on portland cement concrete slabs to a depth of 0.16 mm (0.625 in.) in the wheel paths. After 6 years, the portland cement concrete was badly worn to a depth of 13 to 19 mm (0.5 to 0.75 in.) and had about 1 m^2 (10 ft^2) of deeper spalling. The portland cement concrete wore out after about 97 million vehicle passes. The epoxy polymer concrete had no surface defects and still had an excellent textured surface. After 15 years, the epoxy polymer concrete was still providing excellent skid resistance and had shown about 3-mm (0.12-in.) wear after 243 million vehicular passes. One small patch had to made, and a small gouge had occurred in the surface about 12 mm (0.5 in.) deep.

Bridge Deck Overlays for Skid Resistance

In 1983, the Ohio DOT found it necessary to overlay three bridges to obtain improved skid resistance during times of rain, snow, and ice. The substrate had transverse structural cracks, which exhibited spalling and grooves that were completely worn down in many places. The surface was shot blasted, the epoxy polymer concrete was mixed in drum mixers, and it was placed on a surface primed with neat epoxy to an average depth of 6 mm (0.25 in.). It was finished with a wood screed to provide good texture. The total area of overlay placed was 1,637 m^2 (17,676 ft^2). After 10 years, 120.8 million vehicles had passed over the overlay. It still had excellent skid resistance. Only 0.09 m^2 (1 ft^2) has had to be replaced; the cause of failure was unknown.

Washington Overlays

Three epoxy and two MMA TPOs were installed and monitored. For all overlays, the decks were shot blasted prior to placing the overlays. The epoxy overlays were placed using an epoxy primer, then a coat of epoxy followed by an application of aggregate. After curing, the excess aggregate was removed and an epoxy seal coat was applied. The MMA overlays used an MMA primer and a slurry application of MMA and aggregate with the thickness controlled using gauge rakes. Additional aggregate was broadcast on the surface. The results of the 10-year monitoring were reported in 1995 (*35*).

Tensile Bond Strength

The average initial tensile bond strength was 2 MPa (297 psi) for the epoxies, which was greater than the 1.72 MPa (250 psi) specified. The average for the MMA was only 1.45 MPa (211 psi). After 1 to 5 years of age for the overlays, follow-up testing was performed. For the epoxies, the average strength had reduced slightly to 1.89 MPa (274 psi), but for the MMA the strength had reduced to 0.98 MPa (143 psi).

Frictional Resistance

For epoxies, the initial average skid number was 70 but reduced to 20 after 7 years. For the MMA, the initial average reading was 40, and it reduced only slightly to 39 after 9 years.

Chloride Ion

The average permeability to chloride ion as measured by AASHTO T277-07 (*25*) was 0 for the MMA overlays and 3 coulombs for the epoxy overlays.

New York

In 1993, New York DOT performed a study of overlays that involved a survey of other states and an evaluation of its own TPOs that were 5 to 7 years old. It had placed three different resin systems: polyester, MMA, and flexible epoxy. New York DOT concluded that the newer resin systems "support optimism to suitability and durability." It was further concluded that the overlays in the state appear to meet expectations. New York DOT recommended the use of TPOs for only two applications: (1) for bridges where weight was critical such as moveable spans and (2) bridges for which extended delays would be intolerable, such as in urban areas (*36*).

Since 1999, New York DOT has installed 44 TPOs (*37*). Thirty-eight were epoxy, and one each was MMA, polyurea, polyester, polyurethane, and vinyl ester. One was not identified as to the resin type. The total area of bridges overlaid was 18,832 m^2 (202,632 ft^2).

In 2007, the Materials Bureau evaluated 15 of the TPOs. Among the findings were

- The MMA overlay was the only one of the 15 to have failed. It had several spalls with about 90% of the overlay remaining and 80% to 90% of the friction aggregates intact.
- The polyester overlay was in very good condition, with some polishing observed.
- The urethane overlay was in excellent condition.
- The 12 epoxy overlays were found to be performing acceptably although several distresses were noted:
  - Short crack in one;
  - One appeared to have been poorly installed and exhibited small spalls; 90% of the overlay was intact and 80% to 90% of the friction aggregate remained;
  - Two were very thin owing to wear or installation, with 75% to 95% of the overlay remaining;
  - One had small delaminations, with 90 to 95% of the overlay remaining; and
  - The other seven were in very good to excellent condition, with 90% or more of the overlay remaining.

New York DOT conducts friction tests annually and uses ground-penetrating radar to determine whether TPOs waterproof the decks and retard the corrosion rate. It has experimented with using one-coat overlays instead of two, sandblasting in place of shot blasting, and using boiler slag instead of the normally specified aggregates.

Alabama

Alabama placed four 6-mm (0.25-in.) polyurethane, twelve 9-mm (0.375-in.) polyester, two 19-mm (0.75-in.) low-modulus epoxy, and one 12- to 19-mm (0.5- to 0.75-in.) asphaltic-based Novachip overlays. The performance of the polyurethane was poor, the polyester was variable, the low-modulus epoxy was excellent after 8 years, and the Novachip was excellent after 3 years.

Montana

Four different overlays were installed on 13 bridges in Montana; two portland cement concrete, one acrylic modified concrete, and a low-modulus epoxy. On a single bridge, an MMA overlay was installed. Both the epoxy and the MMA exhibited limited cracking but no significant delamination or dramatic loss of surface roughness after 2 years. The evaluation period was not long enough to make a thorough assessment.

Louisiana

Four different epoxy TPOs were applied to a bridge in Louisiana in 1985 to evaluate their performance as friction surfaces primarily and as sealers secondarily. After

5 years, an evaluation showed the surface friction as measured by the British Portable Tester and ASTM E274 (*38*) skid trailer to be very good for two of the epoxies and less effective for the others. All remained bonded and resisted cracking (*17*).

Kansas

The Kansas Department of Transportation (KDOT) placed its first overlays in 1999. Four contractors placed approximately 100 linear feet (333 yd^2) each on the same bridge. The four materials, all epoxies, had similar properties. The bridge deck was shot blasted using International Concrete Repair Institute (ICRI) Concrete Surface Preparation (CSP) Standards 5 to 7 for the desired texture. Flint rock was used for the aggregate. In 2000, bond failure occurred in all four sections of overlays. The failure was determined to be caused by the presence of a bond breaker (said to be a byproduct of alcohol production) on the original concrete. Saw cuts were made outside the delaminated areas, and the contaminated concrete was removed by sandblasting and chipping. The overlays were replaced with the same materials and same procedures as used initially. After 9 years and approximately 21,000,000 vehicles, with 30% heavy trucks, no problems have been experienced. The skid coefficient was found to be 53 using a ribbed tire in 2003.

KDOT has placed more than 100 TPOs with the goal of minimizing water and chloride intrusion to preserve the structures. (In addition to the overlays placed by KDOT, four counties have placed 13 TPOs.) Some structures have had minimal spalling, which was repaired. Many have had delaminated silica fume or high-density concrete overlays, and because the surface had not failed, the decks were shot blasted before placing the TPOs. Where shallow delaminations had occurred, the loose concrete was removed, the area repaired, the entire deck was shot blasted, and the TPO placed. The intent of KDOT is to place the overlays on decks that are not seriously deteriorated to preserve the structure.

TPOs on three new bridge decks have been installed for different construction errors. One deck had concrete that exhibited high permeability and low density because of concrete consistency problems. Another had reduced cover because of a malfunction of the screed. A third had been constructed with a corrosion-inhibiting admixture, and extensive cracking in the deck occurred. The TPO was placed to seal the cracks. The first two bridges had TPOs applied using 50% greater amounts of epoxy than the normal overlay. The third used a standard two-coat system.

One new bridge was designed for a TPO to be applied before opening to traffic. The bridge is on a service road heavily trafficked by trucks hauling sand and salt and trucks accessing a KDOT shop. The previous bridge deck was found to have chloride in excess of 11 lb/yd^3, and the purpose of the overlay was to provide additional protection.

The popularity of the TPOs has resulted from the lower cost of the installation and traffic control because of much shorter periods of lane closures than for bonded cement overlays. Typically, for a silica fume overlay, the structure is closed overnight for 20 days and requires that temporary traffic signals be installed; in comparison, the TPO requires flaggers for only 5 days and is open overnight (*31*).

LaGuardia Airport, New York

The two runways at LaGuardia Airport in New York were constructed more than 30 years ago. Texture had been maintained by cutting grooves in the concrete surface. But eventually, it was found to be structurally unacceptable to cut away more of the section to reestablish the grooves. It was decided to place a TPO because of its projected service life and the reduced time required to place the overlay and return the runways to service. The two runways accommodate more than 1,400 aircraft daily.

Test sections were placed using epoxy and MMA. Two epoxy test sections were installed, one using the slurry method and the other using the broom-and-seed method. The slurry method consisted of mixing the aggregate and resin and placing the slurry in one operation. The broom-and-seed method consisted of placing a layer of resin and then broadcasting aggregate having a nominal size of 1/8 in. into the resin. Four applications were placed to obtain the required ½-in. overlay. Based on the test sections, the epoxy resin applied by the broom-and-seed method was selected. Visual inspection showed the epoxy slurry method and the MMA test sections did not have a uniform surface texture, with some areas having a glassy appearance. The broom-and-seed method provided a uniform surface with excellent frictional resistance.

The repair work was initiated and represented the first major runways to be overlaid with an epoxy TPO. The work was performed between 6 a.m. Saturday and 6 a.m. Monday, weather permitting. The surface was shot blasted to produce minimum bond strength of 200 psi, and bond tests were performed every weekend before application of resin to confirm that the substrate had adequate bond strength to achieve the specified strength. Bond tests were performed by bonding 100-mm × 100-mm (4-in. × 4-in.) steel plates to the concrete surface and pulling in direct tension in accordance with ACI 503R (*13*). The overlay was constructed by applying four applications of epoxy resin and aggregate.

Prior to opening the runways to traffic, bond tests were performed to determine whether the specified bond strength of 1.4 MPa (200 psi) was met. The specified strength was met every weekend after 9 hours of cure time. The bond strengths averaged 1.8 MPa (270 psi) for deck surface preparation and 2.6 MPa (390 psi) for the overlay bond strength for the project.

The Port Authority modified its contract requirements and bidding procedures in order to obtain the best possible wearing surface. Epoxy resins were tested for conformance to specifications prior to soliciting bids. Four resin suppliers were approved with no substitutions. The resin suppliers were then formally requested to select a contractor that could provide a joint warranty with them. The warranty required the contractor to repair any defects within 5 years of installation. The resin supplier was required to have a full-time representative on the site when work was being done. The purpose for the contract requirements was to provide the contractor and material supplier the incentive to take joint responsibility for the installation.

The contract required the finish surface to have a minimum surface friction number of 60 as determined by the British Pendulum Tester. The average friction number obtained for the project was 71. Grooves 6 mm × 6 mm (¼ in. × ¼ in.) were cut 37 mm (1.5 in.) apart, center to center, in the transverse direction several days after the overlays were placed. No complaints have been received from airlines for excessive rubber wear on tires.

The overlays were completed for one runway in 1998 and the other in 1999. The overlays have performed well, with only minor repairs required. Most of the delaminations occurred at structural expansion joints and at locations where the overlay was very thick, about 1 in. The airport management and the airlines have been pleased with the performance of the overlays (*39*).

Pennsylvania

Pennsylvania DOT installed three TPOs: premixed polyester, an epoxy multiple layer, and an epoxy urethane multiple layer, each on two separate bridge decks. The decks were rehabilitated after being evaluated for chloride ion content, corrosion activity using half-cell tests, and delamination using chain drag. Problems were encountered during construction with the premixed polyester resulting in a resin-rich mixture that made it susceptible to oxidation and ultraviolet light degradation. A 5-year evaluation indicated significant moderate spalling, cracking, and debonding in the polyester overlay. The two epoxy multiple-layer overlays provided good long-term performance as evidenced by the excellent protection against chloride and moisture intrusion. As a result of the performance, the use of epoxy and epoxy urethane multiple-layer TPOs was recommended for future use by Pennsylvania DOT (*39*).

FAILURES

Alberta

Lessons Learned from Failures

Carter (*8*) provides observations on lessons learned from TPOs installed in Alberta, but states that his comments may not always be in agreement with experiences in other areas.

1. Failures are usually the result of constructability rather than materials. If the in-place material is defective, it is usually because of improper proportioning or mixing. Using different colors for multicomponent systems would help reduce proportioning errors.

2. The moisture content of the deck is important in achieving good bond strength of the TPO to the deck. Some parts of the deck, including low areas, other areas that drain slowly, and gutters, dry slower owing to ponding. The moisture may prevent adequate bond strength development.

3. Deck repair patches made with portland cement concrete need to be wet cured to reduce shrinkage and subsequent debonding. The patches should be allowed to dry sufficiently to achieve good bond to the TPO. In Alberta, the maximum depth for mortar patches is 15 mm (0.67 in.) because deeper patches may develop cracks around the perimeter at low temperatures.

4. The more the surface is prepared and roughened, the greater the bond strength will be. Shot blasting provides a more uniformly prepared surface than does sandblasting.

5. In cold climates, thicker TPOs will fail faster than thinner ones because of the different thermal coefficients of expansion of the concrete and the PC.

6. Thin TPOs cannot be expected to provide a smooth surface on a rough deck surface. Deck patching must be done carefully to prevent the creation of a rough surface. Bumps in the surface of the TPO will shorten the life, particularly when snowplows are used.

7. Aggregate type and grading are important for wear resistance, flexibility, toughness, and crack-bridging ability of the wearing surface, particularly when high-modulus polymers are involved.

8. The method of seeding aggregate into the resin is important in preventing surface ripples, wicking,

high porosity, and resin-rich areas that are not thermally compatible with the concrete. It is important that the aggregate be allowed to spread out and fall downward into the resin, with the dust and fines carried off in the air. In hot weather, it is important that aggregate not be introduced too quickly; rather, it needs to be slowly and evenly built up on the surface until no wet spots are visible.

9. Static mixers and paddle mixers are not foolproof. The viscosity of the resin components are affected by temperature and hot or cold weather may affect the mixing process. Routine calibration checks must be made.

Case History of a Failure

Carter (*8*) reports that a bridge overlaid in 1985 had many problems even though only experienced contractors were allowed to bid for the job. The contractor provided a 5-year warranty, but problems occurred quickly. The surface preparation by the contractor was rejected twice; the final surface preparation was a compromise. The contractor did not notify the resin manufacturer until the job was well underway, the contractor's workmanship was poor, and there was little input from the manufacturer. The warm weather that lowered the viscosity of the resin combined with improper seeding methods resulted in a glassy, resin-rich surface that varied in thickness by as much as 6 mm (0.25 in.) across a 75-mm (3-in.) core. Water had infiltrated some of the resin drums. After 3 years, 180 m^2 (1936 ft^2) of surface had debonded, beginning in the first winter. Of the 180 m^2 that were repaired, 40 m^2 (430 ft^2) have since failed along with 60 m^2 of additional TPO.

Texas

Two short overlay test sections in Texas failed within a short time of installation because the high-molecular-weight methacrylate primer was allowed to pond near the edge of a sloping deck and form a thick film. The thick film had a very high coefficient of thermal expansion, and it delaminated over a large area, requiring replacement with an epoxy overlay (*22*).

Panama, Canal Zone

The Bridge of the Americas was overlaid with epoxy slurry TPO. High-molecular-weight methacrylate was used to seal the cracks on the bridge before installing the TPO. After 1 or 2 years, a considerable portion of the overlay had delaminated based on visual observations. Laboratory tests sought to duplicate the application. The initial tensile bond tests gave good strengths, but when they were performed after several months on the same specimens, the specimens that had been primed with the high-molecular-weight methacrylate had low bond strengths. Anecdotal experiences of others confirmed that some epoxies tend to lose bond with time when placed over a high-molecular-weight methacrylate.

STRESSES IN OVERLAYS

Analytical Method for Calculating Thermal Stresses

Choi et al. (*40*) present a method for calculating interfacial stresses and axial stresses in TPO overlays because of changes in temperature. The method assumes (1) that there are linearly elastic stresses in overlay and substrate, (2) that the effect of the very thin adhesive layer is negligible, and (3) that the composite beam (overlay and substrate concrete) is subjected to a uniform temperature change and the difference in the thermal coefficients for the overlay and concrete remain constant during the temperature change. The governing differential equations and solution are presented. The three types of stresses that can be determined from this analysis are the interfacial shear and normal stress and the axial stress in the overlay shown in Figure 10. The shear and normal stresses are maximized near the end or boundary, which can be the edge of the overlay, a crack or a joint, which explains why delamination always starts near one of these boundaries as shown in Figure 11. The axial stress in the overlay starts at zero stress at the boundary and within a short distance from the boundary reaches its maximum stress.

The stresses are shown to be a function of the ratio of the coefficient of thermal expansion of overlay to concrete, the temperature change, the ratio of overlay thickness to substrate thickness, and the ratio of modulus of elasticity of the overlay to the substrate. As each of these increases, the shear, normal, and axial stresses increase. Thus, overlays that are thinner and less stiff will produce smaller stresses with the same temperature change. Graphs are provided to simplify the determination of stresses, and examples are given to illustrate the method in Figures 12, 13, and 14. The graphs are developed for differential strain because of temperature change, $\Delta\varepsilon_T = 500 \times 10^{-6}$ in./in., and a given substrate modulus, $E_s = 4 \times 10^6$ psi. In the graphs, t_o is the overlay thickness, t_s is the substrate thickness, and E_o is the overlay modulus. $\Delta\varepsilon_T$ is the difference in the coefficients of thermal expansion for the two materials, overlay and substrate, times the change in temperature. The analytical values are compared with experimentally determined stresses. Examples are shown in Appendix B.

Letsch (*41*) shows measured stresses resulting from differential strains in the substrate and the overlay and indicates that curing, shrinkage, and thermal changes can result in stresses in the overlay and substrate. Strains were measured with a cracking frame.

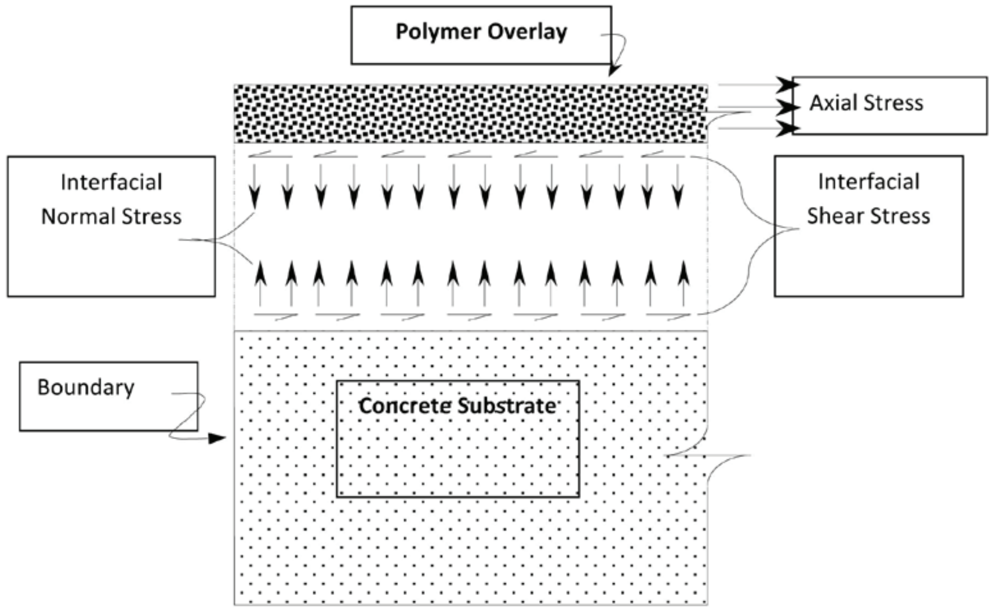

FIGURE 10 Stresses in overlays.

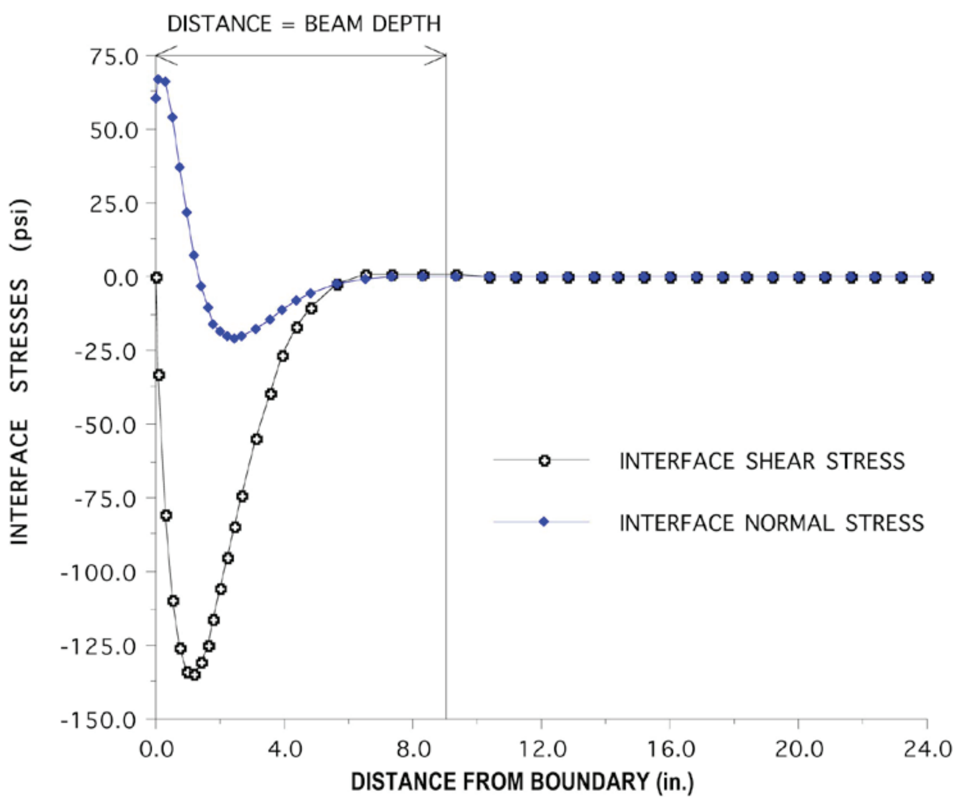

FIGURE 11 Shear and normal stresses near boundary (for normal stresses + = tension).

SPECIAL APPLICATIONS

Cathodic Protection

Cathodic protection overlays have been developed and used for bridges subject to or experiencing corrosion activity in the reinforcing steel. Fontana et al. (*12*) describe a cathodic protection TPO used to overlay a bridge in Virginia. Two resin systems were used on separate lanes: (1) modified vinyl ester and (2) polyester. Each was used with an aggregate consisting of 50% calcined coke breeze (an electrically conductive aggregate) and 50% silica sand. The surface was shot blasted, the primary anode system was installed, and the polymer concrete was placed and screeded to a 12-mm (0.5-in.) thickness.

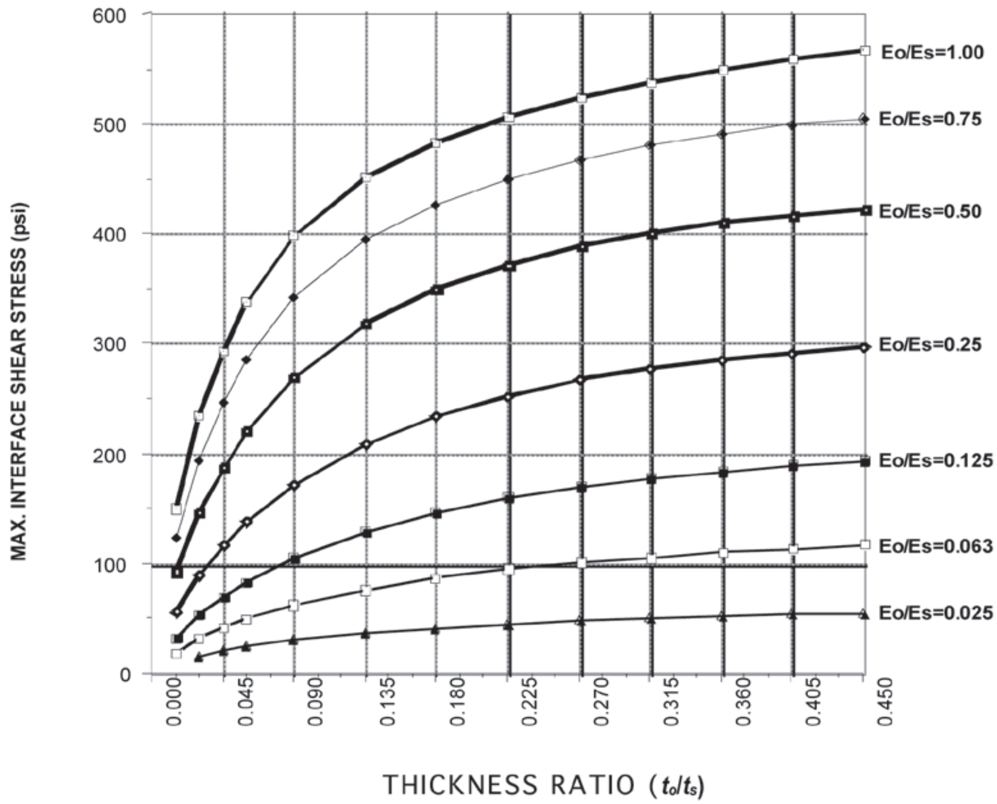

FIGURE 12 Shear stresses in overlays for various thickness and modulus ratios. (For assumed values of $\Delta\varepsilon_T = 500$ μ-in./in., $E_s = 4 \times 10^6$ psi.)

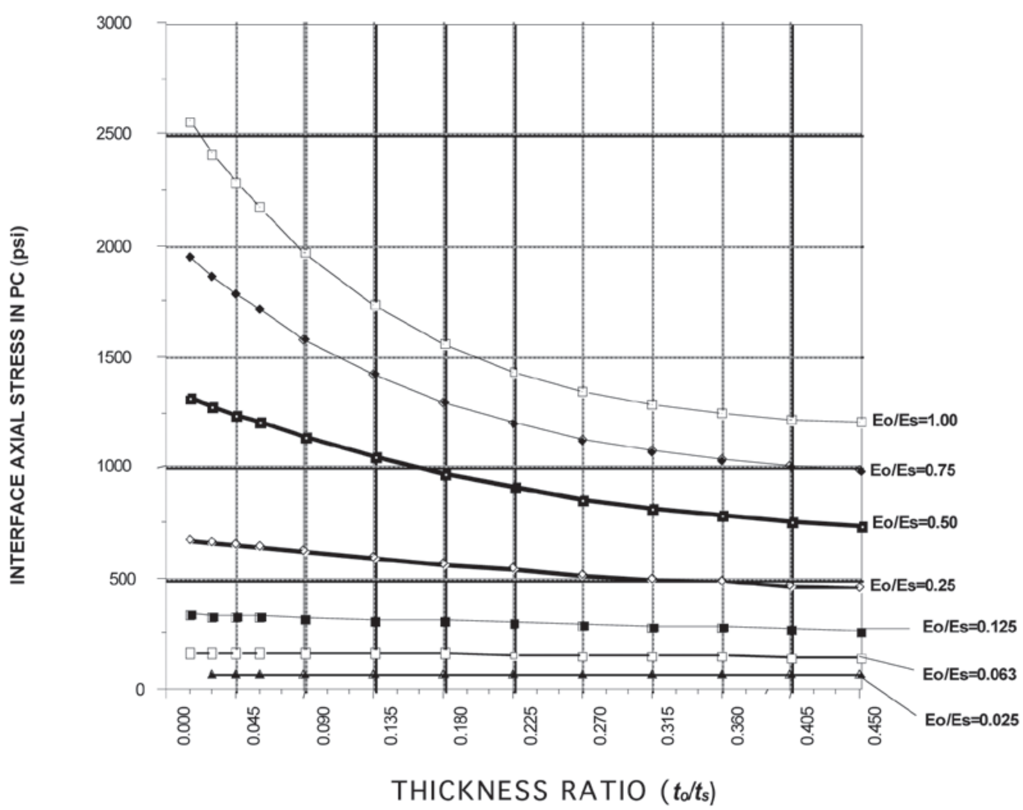

FIGURE 13 Normal stresses in overlays for various thickness and modulus ratios. (For assumed values of $\Delta\varepsilon_T = 500$ μ-in./in., $E_s = 4 \times 10^6$ psi.)

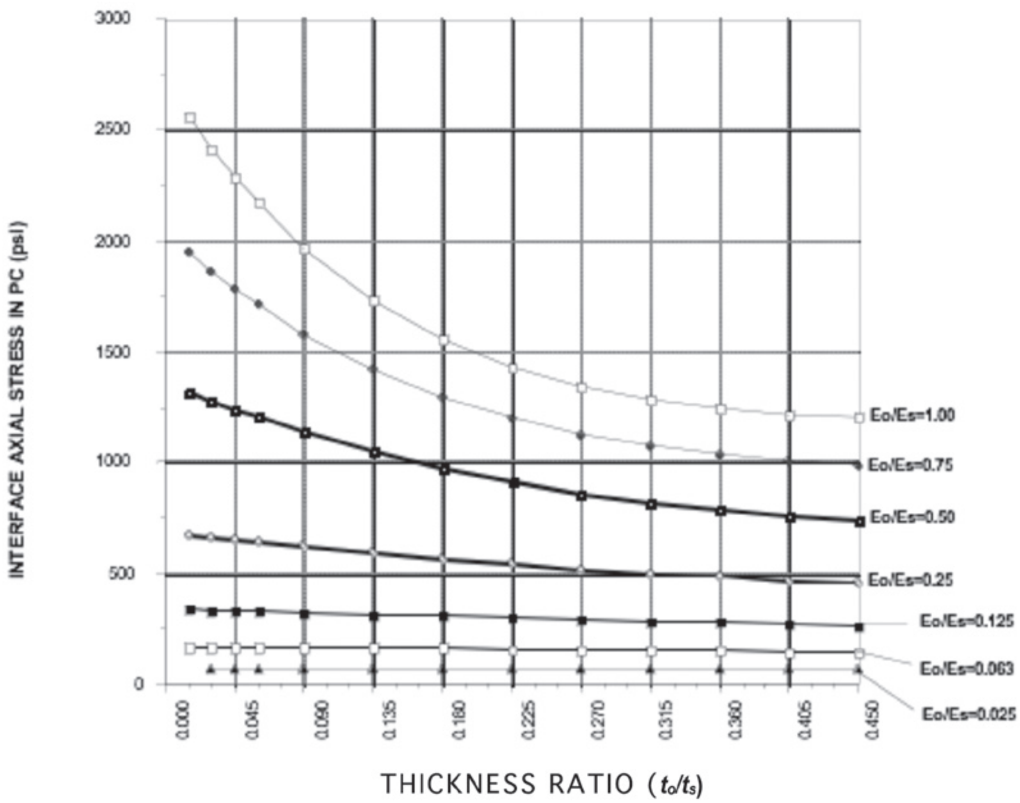

FIGURE 14 Axial stresses in overlays for various thickness and modulus ratios. (For assumed values of $\Delta\varepsilon_T$ = 500 μ-in./in., $E_s = 4 \times 10^6$ psi.)

About 25% of the first system had to be replaced because of delamination. A current of 1 mA/ft^2 was applied.

It has been shown that cathodic protection overlays can be sprayed on horizontal and vertical surfaces (*12*). A PC made of vinyl ester and about 60% by weight of calcined coke breeze can provide a non-sag material for overhead.

Wet Surfaces

Ahn and Fowler (*42*) found that the addition of zinc diacrylate, in the range of 5% to 15% by weight of MMA, resulted in an increase in tensile bond to wet concrete by up to 50% compared with no zinc diacrylate. The addition of the same amount to polyester-styrene also produced a very good increase in tensile bond, including smooth, wet surfaces. Calcium diacrylate worked much better with epoxies, giving up to 20% increase in strength. Although this has not been used in TPOs, it is a viable solution.

Deicing Overlays

Virginia Department of Transportation (VDOT) conducted an evaluation of a patented deicing overlay system designed to prevent frost formation and the bonding of ice and snow to the deck surface (*43*). The 9-mm-thick (3/8-in.-thick) overlay consists of epoxy binder and limestone aggregate that the manufacturer states acts like a rigid sponge that stores salt-brine deicing solution, which is released when needed. Silica or basalt aggregates that are typically used to construct TPOs do not have the required absorption. Four overlays were placed on bridge decks on I-81 in September and October 2005: two two-layer deicing overlays and two one-layer VDOT epoxy overlays. The overlays were treated approximately every 2 weeks with deicing salt brine at a nominal rate of 70.5 L per lane-kilometer (30 gal per lane-mile) using a spray bar. Four overlays were placed on Smart Road in September 2006: two two-layer deicing overlays and two two-layer epoxy overlays. The two deicing overlays were pretreated with salt brine at a rate of 70.5 L per lane-kilometer (30 gal per lane-mile). One of the epoxy overlays was pretreated at the same rate and the other was untreated (*43*).

I-81 Overlays

The aggregates used in the deicing overlays had significantly higher absorption (1.70%) compared with the quartz (0.72%) and basalt (0.45%) aggregates used in the epoxy overlays. The soundness loss for the deicing aggregates was much higher (6.0% to 21.6%) compared with the loss for the epoxy overlays (1.1% to 1.9%). It can be noted that the report indicated that the deicing overlay aggregates reported in this study are no longer being used.

Bond strength tests were performed in February 2006. The thicknesses for the deicing overlays were 12 mm (0.49 in.) and 11 mm (0.46 in.), whereas the epoxy overlays were 2.5 mm (0.10 in.). The bond strengths were 1.41 and 1.50 MPa (205 and 218 psi) for the deicing overlays and 1.59 and 1.89 MPa (230 and 274 psi) for the epoxy overlays. The permeabilities to chloride ion when tested in February 2006 were 23 and 246 coulombs for the deicing overlays and 1,226 and 1,367 for the epoxy overlays.

The bare tire skid numbers for travel lanes on the bare concrete were 27 and 28 in June 2004 before the deicing overlays were installed; in October 2005, after overlay installation, the skid numbers were 59 and 60. In December 2005, the numbers dropped to 46 and 53 for the deicing overlays. For the epoxy overlays, the skid numbers were 22 and 26 before overlay installation in June 2004. In the October after installation, the numbers were 57 and 49. No values were reported for December.

Inconclusive results were obtained for ice and melting snow performance on I-81 because insufficient ice and snow events had occurred at the time of the evaluation (*43*).

Smart Road Overlays

Permeability and bond tests were not reported for the Smart Road overlays. Skid tests were performed in November and December 2006 and January 2007. All skid numbers were 57 or higher.

Snow was applied artificially to the Smart Road overlays. Friction tests were performed on the pavements: 4 passes on dry surfaces, 8 with snow, 4 after the first plow, and 12 after the second plow. Five snow experiments using artificially applied snow and one using artificial “black ice” were conducted.

The results of the tests using artificial snow indicated that both deicing and epoxy overlays would improve the friction of bare, tined concrete pavements or bridge decks in the early stages of a snow storm before the snow removal equipment can arrive. However, no consistent conclusions could be drawn after the initial plowing for the snow and traffic conditions occurring during the tests. The difficulties encountered in obtaining a uniform coverage with “natural” quality snow and accurately defining the location of the friction measurements precluded more accurate comparisons of performance of the two overlay systems (*43*).

SERVICE LIFE

Sprinkel (*4*) states that projections suggest that, with the exception of the methacrylate slurry and the multiple-layer polyester overlays, TPOs constructed in accordance with AASHTO specifications (*6*) should have a service life of 25 years. Carter (*8*) states that TPOs properly applied can provide service lives of up to 20 years, but that maintenance will be required if the surface is intended to remain free of defects.

WARRANTIES

Alberta

In the Province of Alberta, each TPO contract requires a 5-year warranty signed by both the contractor and material supplier (*8*). Bankruptcy of either party leaves the other party wholly responsible. The warranty covers failure of the wearing surface exposed to normal traffic; it does not cover failures of the substrate. Repairs of distress that occur after the work was approved by the province are required to be made at the end of the 5-year period, except that large failures, defined as more than over 5% of the deck, must be repaired within 60 “good weather days” of notification, regardless of when the accumulated 5% distress developed. Carter (*8*) notes that this has happened only twice. Even with the warranty, the contractor’s work is subject to approval by the province, and the contractor is compensated only for work that has been approved.

LaGuardia Airport, New York

The warranty used in the construction of LaGuardia Airport is shown in Appendix C. The warranty was executed jointly by the material supplier and the contractor. The warranty required that the contractor repair any defects that occurred within 5 years of installation.

RELATIVE COST

Sprinkel (*4*) reports that the cost of epoxy overlays, based on 1994 and 1995 bid tabulations in Virginia, was 25% of the hydraulic cement concrete overlays based on total initial cost, and 36% if based on life-cycle cost assuming a 15-year life for the epoxy TPO and 30-year life for the hydraulic cement concrete. However, the life-cycle cost for the epoxy is even lower if a 25-year life is assumed.

Kansas DOT reported that the cost of milling and placement for TPOs between 2001 and 2008 was about 20% less than for silica fume overlays. Traffic control costs are much lower for TPOs because of the much shorter cure time (5 days versus 2 days) and the elimination of overnight lane closures. For a four-lane structure, traffic control for a TPO would be approximately 12% of that required for a silica fume overlay (*44*).

SPECIFICATIONS

National organizations have prepared three specifications for the installation of TPOs:

1. *Guide Specifications for Polymer Concrete Bridge Deck Overlays,* AASHTO-AGC-ARTBA Task Force 34, Washington, D.C., 1995 (*6*).

2. *Specification for Type EM (Epoxy Multi-Layer) Polymer Overlay for Bridge and Parking Garage Decks*, An ACI Standard, Reported by ACI Committee 548, ACI 548.8-07, American Concrete Institute, Farmington Hills, Mich., 2007 (*2*).

3. *Specification for Type ES (Epoxy Slurry) Polymer Overlay for Bridge and Parking Garage Decks*, An ACI Standard, Reported by ACI Committee 548, ACI 548.9-08, American Concrete Institute, Farmington, Hills, Mich., 2008 (*45*).

CHAPTER THREE

PERFORMANCE OF OVERLAYS FROM SURVEYS AND INTERVIEWS

This chapter reviews performance in the field based on information from agencies, contractors, and material suppliers.

SCOPE OF SURVEYS

Surveys were sent to all states and Canadian provinces. The questionnaires are in Appendix A. Each agency was asked to complete a general survey form ("Agency Questionnaire") and to complete a form for each TPO or group of TPOs ("Information on Each TPO"). If agency forces were used to install the overlay, they were asked to complete an "Agency-as-Installer Questionnaire." Few states completed the form for the individual TPOs. Follow-up telephone interviews were conducted with representatives from the agencies that had constructed the greatest number of TPOs. Materials suppliers and contractors identified by the agencies were then interviewed by telephone to obtain information.

GENERAL RESPONSES

Responses were received from 40 states and seven provinces. Seven states and three provinces reporting have never used TPOs. Table 1 summarizes the findings. The information includes

- Number of overlays placed. Approximately 2,400 TPOs have been installed by the states and 147 by the provinces reporting, a fourfold increase over the 555 reported to have been installed through 1999 (*4*). California has placed the most (520), but each of seven other states, Missouri, Virginia, New Mexico, Michigan, Ohio, Kansas, and Utah, and one province, Alberta, has placed 100 or more.
- Ohio and North Carolina reported the first use of TPOs in the 1970s. Four states (California, Missouri, Oregon, and Virginia) and Alberta began applying overlays in the 1980s.
- Three states (Florida, Iowa, and Montana) and two provinces (Alberta and British Columbia) no longer use TPOs. Florida indicated that it had installed 30 on segmental bridges but does not have deck problems; Iowa had installed one and indicated that it performed poorly; and Montana had installed 30 to 35, but stated that administrative problems made it too time consuming to enforce the specifications. Alberta has constructed 139 TPOs, with the last one placed in 1999, but plans to use no more in the future. Alberta experienced some problems with TPOs placed initially, but when those problems were resolved, the overlays performed well. Eventual problems with achieving adequate inspection and wet, rainy conditions in some parts of the province were reasons cited for discontinuing their use. British Columbia installed two but reported high cost and poor performance as reasons for no longer using them.
- Most of the states indicated more than one reason for the use of TPOs; improving skid resistance was the most often cited reason, with extending the life of the deck the next most cited. Other reasons included repairing spalled and cracked surfaces, restoring a uniform appearance, and waterproofing the deck.
- Nearly all states use epoxy resins. Many did not respond as to the construction type, but the majority of states that did indicated that multiple layer was the preferred method. California was an exception, having installed over 500 premixed polyester overlays. Other West Coast states also use premixed systems.
- The majority of states use contractors for installation, but 10 states use their own forces for at least some installations.
- New Mexico, Georgia, and LaGuardia Airport require warranties ranging from 1 to 10 years.
- Many states have specifications available.

OVERLAY COST

Three states reported overlay costs. Virginia reported a cost of $60/m^2 ($50/yd^2) for an epoxy multiple-layer TPO installed by a contractor in 2005, and Alaska reported a cost of $114/m^2 ($95/yd^2) for an epoxy-urethane TPO installed by a contractor in 2007. Kansas DOT reported that between 2001 and 2008 the cost of shot blasting and placement of TPOs averaged $66/m^2 ($55/yd^2).

TABLE 1
SUMMARY OF STATES AND PROVINCES SURVEY

State	No. Placed	First/Last Year	Future TPOs	Reasons for Use	TPO System	Installer	Warranty, Year	Failures	Specs Avail.	Comments
AK	2	2007	Yes	l, a, w	P PM	Agency	N/A	No	No	Excessive wear in tire lanes
AL	31	1992/1994	Yes	sf, l, a, s, w	Any	Agency	N/A	No	No	
AR	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
AZ	No state DOT TPOs									
CA	520	1983/2008	Yes	sf, l, s, w	P PM	Contract	N/A	Yes	Sent P PM, E ML	Snow chain rutting problems
CO	Used, but no information available									
CT	Not used									
DE	1	2007	Yes	l	E ML	N/A	N/A	No	No	Too expensive
FL	30	2000/2003	No	w	HMWM sealer	N/A	N/A	No	No	Protect cables in segmental bridges
GA	10	Mid-1990s/2007	Yes	sf, l, a	EU ML	Contract	10	N/A	Sent E ML	
HA	0	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	
IA	1	1986	No	Trial	N/A	N/A	N/A	N/A	No	Poor performance
ID	2	2003/2007	Yes	sf, l, w	E ML, EU ML	N/A	N/A	N/A	N/A	
IL	24	1996/2007	Yes	l, w	E ML	Contract	N/A	Yes	Sent E ML	
KS	100 +13[a]	1999/2009	Yes	w, l, s	E ML	Contract	None	1	E ML	Failed due to deck contamination
MD	1	2000	N/A	w	E ML	Agency	N/A	Small cracks	No	Worked pretty well
ME	1	1 bridge TPO DOT Installation								
MI	100s	1995/2007	Yes	sf, l, a, s	E ML	Contract, agency	N/A	Yes	Yes	Poor bond from poor surface prep
MS	No information available									
MN	5	2006/2007	Yes	sf, l, w	E ML	Agency	N/A	No	N/A	
MO	>300	1989/2007	Yes	sf, l, a, w	E ML, EU ML, E PM	Contract	N/A	Yes	Sent	
MT	35	1995/2000	No	N/A	N/A	Contract	N/A	Yes	No	Inspection process QC/QA difficulties
NC	50	1975/1990	Yes	w	E ML	Agency	N/A	Yes	No	
ND	Used, but no information available									
NE	0	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	
NH	2				EU ML	Contract	Yes	Yes		Improve skid resistance, life and look of bridge

Table 1 Continued on p.28

Table 1 Continued from p.27

State	No. Placed	First/Last Year	Future TPOs	Reasons for Use	TPO System	Installer	Warranty, Year	Failures	Specs Avail.	Comments
NJ	0	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	
NM	250	1995/2008	Yes	sf, l, a, s, w	E ML, EU ML	Contract, agency	5	Yes	Online	Inspection process QC/QA difficulties
NY	44	1999/2007	Yes	l, w	M PM, E ML, EU ML, P ML	Contract	N/A	Only one MMA	Sent	Wearing surface aggs
OH	147 + 15 +1[b]	1979/2006	Yes	l, s	E ML	Agency, polycarb	N/A	Yes	No	Over 100 failures in late '90s
OK	10	2003/2007	Yes	sf, l, w	E ML, EU ML	N/A	N/A	N/A	N/A	
OR	35	1981/2007	Yes	l, s, w	E ML, P PM, M PM	Contract	N/A	Yes	N/A	Mostly for traction
SC	Les Floyd, not used									
SD	0	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	
TN	3	2000/2005	Yes	sf, l, w	E ML	Contract	N/A	N/A	N/A	
TX	12	1998/2008	Yes	sf, l, a, s, w	E ML	Contract	N/A	N/A	N/A	
UT	100	2001/2007	Yes	sf, l, w	E ML	Contract	N/A	N/A	N/A	Too expensive
VA	300	1981/2008	Yes	sf, l, a, s, w	E ML, P ML, P PM, M PM	Contract, agency	N/A	N/A	Yes	Bridge deck preservation
WV	8	1997/2007	Yes	sf, l, w	E ML, U ML	N/A	N/A	N/A	N/A	
WY	61	1990/2005	Yes	sf, s	E ML	Contract, agency	N/A	Yes	Yes	Mostly for traction
Canadian Provinces										
AB	139	1984/1998	No	N/A	N/A	N/A	N/A	N/A	N/A	Poor performance, too expensive
BC	2	1990/1991	No	N/A	N/A	N/A	N/A	N/A	N/A	Poor performance, too expensive
MB	0	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	
NB	5	2005/2007	Yes	l, s, w	E ML	Agency	N/A	Yes	N/A	
NS	0	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	
NT	1	1991	Yes	s, w	E ML	Contract	N/A	N/A	Sent	
ON	0	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	Poor performance, too expensive

NOTE. sf = restore surface friction; l = extend life of deck, including additional cover; a = restore uniform appearance of deck surface; s = restore surface to previous spalled, cracked, and repaired deck; w = waterproof deck; P = polyester-styrene; E = epoxy; EU = epoxy urethane; HMWM = high-molecular-weight methacrylate; M = methacrylate (slurry); PM = premixed; ML = multiple lift; N/A = information not available from agency.

[b]147 by Ohio, 15 by counties, 1 by city. [a]100 by Kansas, 13 by counties.

CAUSES OF FAILURES

From the surveys, both written and telephone, causes of failures were identified and included the following:

- Deck condition—in many cases, overall condition of deck probably too poor to apply overlay;
- Repaired areas not sufficiently dry and/or not roughened;
- Inadequate surface preparation;
- Cool damp weather during installation;
- Deck too damp at time of overlay installation;
- Construction problems;
- Inadequate quality control; and
- Use of snow chains.

SPECIFICATIONS

Specifications were requested from agencies, and the states submitting specifications included the following:

California

Method of Testing for Determining Suitability of Materials for Overlayment and Repair of Portland Cement Concrete Pavement and Structures, California Test 551, Engineering Service Center, Department of Transportation, Sacramento, Feb. 2000, http://www.dot.ca.gov/hq/esc/ctms/pdf/CT_551.pdf.

www.dot.ca.gov/...structurespecs/.../UpdatedMetricSpecs/51-806_B07-02-09.doc.

www.dot.ca.gov/.../structurespecs/...04SPECS/.../51-806(51POVR0_R02-14-07.doc.

Prepare Concrete Bridge Deck Surface, Engineering Service Center, Department of Transportation, Sacramento, http://search.ca.gov/search?site=ca_dot&client=ca_dot&output=xml_no_dtd&proxystylesheet=ca_dot&q=Prepare+Concrete+Bridge+Deck+Surface&submit.x=13&submit.y=6.

Polyester Concrete Bridge Deck Surface, Engineering Service Center, Department of Transportation, State of California, Sacramento, http://www.kwikbondpolymers.com/product/application/sample_spec.pdf.

Georgia

Two-Part Epoxy-Urethane Co-Polymer Bridge Deck Overlay, Section 519, Department of Transportation, Georgia, Special Provision, Sep. 23, 2002.

Illinois

Bridge Deck Thin Polymer Overlay, Illinois Department of Transportation, Springfield, Jan. 1, 2007, http://www.dot.state.il.us/materials/polymeroverlaysystems.pdf.

Kansas

Multiple-Layer Polymer Concrete Overlay, www.ksdot.org/burConsMain/specprov/pdf/729.pdf; www.ksdot.org/burConsMain/specprov/2007/pdf/07-07013.pdf.

Michigan

Thin Epoxy Polymer Bridge Deck Overlay, Michigan Department of Transportation, Special Provision, Dec. 29, 2005, http://www.michigan.gov/documents/mdot/MDOT_Research_Report_RC1422_200642_7.pdf.

Missouri

Epoxy Resin Material, Section 623, Missouri Department of Transportation, http://www.modot.mo.gov/business/standards_and_specs/Sec1039.pdf.

Montana

http://www.mdt.mt.gov/publications/manuals.shtml.

New York

https://www.nysdot.gov/spec-repository/584.50----03.pdf;

https://www.nysdot.gov/spec-repository-us/584.40000006.pdf.

North Carolina

SBE Program Contracts (see the section on Epoxy Coating Systems), http://www.ncdot.org/doh/Operations/division1/BID_LISTINGS/10808683.pdf.

Ohio

Epoxy Waterproofing Overlay for Bridge Decks, Proposal Note 514, Ohio Department of Transportation, Sep. 24, 1992, http://www.ohiopavementselection.org/construction/OCA/Specs/SSandPN2002/pn5140402for2002.pdf.

Oregon

Section 00557—Premixed Polymer Concrete Pavement Overlays, http://www.oregon.gov/ODOT/HWY/SPECS/docs/08specials/Updates/01-14-10/SP557.pdf.

Texas

Multiple-Layer Polymer Concrete Overlay, ftp://ftp.dot.state.tx.us/publ/txdot-info/cmd/cserve/specs/2004/spec/ss4429.pdf; ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/1993/spec/es7675.pdf; ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/…/spec/ss4398.pdf.

Utah

www.dot.state.uut.us/main/uconower.gf?n=504434814209249743.

Virginia

http://www.aot.state.vt.us/conadmin/Document/Section%20900%20Items/THINPOLYMEROVERLAY.pdf.

Contact the California, New York, and Virginia DOTs for specifications through their websites.

MATERIALS

Resin Systems

Epoxies are preferred by states, with some states using epoxy-urethanes; specifications requiring a minimum tensile elongation of 30%. One company, however, supplies the majority of the polyester premix used in North America. One state specifies 20% tensile elongation, and one state specifies brand names of low-modulus epoxies. California uses polyesters and requires a minimum elongation of 35%.

CONTRACTOR INTERVIEWS

Nine contractors having considerable experience with TPOs were interviewed by telephone. The contractor questionnaires are in Appendix A. These nine contractors had installed hundreds of TPOs in many states.

Condition of Bridges

Most of the bridges on which they had installed TPOs ranged from sound to seriously deteriorated, but generally they were moderately distressed. Most bridges had been previously repaired, and at least four had repairs of the substrate performed as part of the TPO installation contract. One contractor said that 80% of his jobs have been on older bridges that had been repaired, and virtually all contracts involved some repair work before the TPO was installed. Another contractor said that 90% of the bridges he works on are deteriorated.

Repair Materials

Repair materials included polymer concrete, latex modified concrete, magnesium phosphate, proprietary fast-setting concretes, and high alumina cement concrete. One indicated that the California Department of Transportation specification requires a 72-hour cure for magnesium phosphate and 1 hour for high alumina cement. In another case, 3 days were required for fast-setting materials to cure before overlaying the repair.

Installation

Shot blasting was the cleaning method used on flat work; in some cases, grit blasting was used on curbs and gutters. It was indicated that if the shot clogs in the shot blaster, the deck is too damp and provides a good control. They repair just before installing the overlay. All of them installed epoxy multiple-layer TPOs; one also installed MMA slurry and premix, and the other installed deicing overlays. One contractor permits traffic on the first layer after it cures and then shot blasts the first layer the next day and immediately places the second layer. He uses 550 shot for the first application and 460 for the second. One performed mixing as specified, including a completely automated system using a mobile batching machine and modified asphalt paver. Another used concrete mixers, wheelbarrows, and screeds on rails.

Problems Encountered

Contractors encountered the following primary problems:

- Weather: rain or high or low temperatures;
- Cure times related to traffic openings: resin cured too slowly to open as required by contract;
- Quantities of materials: plans always indicate less than required;
- Day or night temperatures affect the work time and volume of materials that can be placed;
- Deck condition: decks are often in badly deteriorated condition; some DOTs assume that a polyester premixed TPO can restore a deteriorated deck with 18- to 150-mm (0.75- to 6-in.) premixed polyester TPO as needed to restore ride quality; the inevitable deterioration of the TPO is usually blamed on the contractor;
- Moisture in deck: excessive moisture reduces bond strength.

Recommendations

Contractor recommendations include that—

- Bidders be prequalified for TPO experience;
- Resin manufacturer's representative always be present, especially if warranty is required;

- Repairs be made using compatible polymer patching materials supplied or specified by the TPO manufacturer, which eliminates paying for traffic control twice and having to build in an extra 28 to 56 days to let the patches cure, dry, and outgas;
- Diamond grinding be specified for very rough decks to save on the cost of shot blasting and to minimize the resin consumption;
- A mandatory 4-hour curing period is too long in hot weather; 1 hour is often enough and can be verified by the impact hammer and/or screwdriver test; peak exotherm or maturity might also work to confirm the curing, especially for thicker overlays;
- The specifications requiring the airless spray application for high-molecular-weight methacrylate sealers and primers be eliminated because of the difficulty in keeping the spray guns calibrated; by the time the problem is discovered, considerable improperly mixed resin has been applied;
- TPO applications always be restricted to warm and dry periods; and
- Warranties for 5 years be required.

MATERIAL SUPPLIER INTERVIEWS

Seven material supplier representatives were interviewed by telephone. The questionnaires are in Appendix A. Two suppliers had been involved with approximately 1,000 TPOs and another two with hundreds each. The others, however, were involved in at least 10 bridges. Their companies primarily supply epoxy resin systems. One company, however, supplies the majority of the polyester premix systems used in North America. Collectively, they have worked in 13 or more states and Canada.

Problems Encountered

Material suppliers observed the following problems that may lead to poor performance of TPOs:

- Poor deck condition;
- Cracking and delamination of deck;
- Inadequate concrete cover on steel;
- Bidding followed by requirement that they must provide technical support on site; and
- Obtaining all three surface preparation requirements: clean, dry, and sound.

Recommendations

To improve the quality of TPOs, material suppliers recommend that—

- Technical representatives be trained;
- Manufacturer's representative be on site to oversee work;
- The deck be in good condition;
- Deck be clean and dry;
- Deck cleaning texture be specified as ICRI CSP 7, but can accept 6;
- Multiple-layer TPOs be used for epoxy systems;
- Minimum tensile elongation be 50% for epoxy systems;
- Aggregate have a Mohs hardness of 7;
- AASHTO Task Force 34 recommendations (*6*) be followed;
- For polyester systems specifications, have contractor make an investment in volumetric mixers with readouts and plural components, paving machine with automatic grade control, and shot-blasting equipment; and
- Specification must require experience.

CHAPTER FOUR

PROVEN PRACTICES

Based on the findings from the literature and the agency surveys, the following practices have been found to be useful. These are not intended to be specifications; rather, they summarize the important preservation methods that agencies/owners have found to produce long-lasting, durable TPOs.

CANDIDATES FOR OVERLAYS

Sprinkel (*15*) states that the bridges that are the most likely candidates "(1) are those that are in need of a skid-resistant wearing and protective surface but have peak-hour traffic volumes that are so high that it is not practical to close a lane to apply the surface, except during off-peak traffic periods" and (2) "are those in which increases in dead load, reductions in overhead clearance, and modifications to joints and drains must be held to a minimum."

Harper (*7*) concludes, "Epoxy polymer overlays are not a 'repair' for bridge decks. They are only a means of protecting a deck that is in fairly good condition but is at risk for chloride and water penetration. Decks that have more than 5 to 10% of area that is unsound have been found to continue to experience problems after the overlay is placed."

Sprinkel (*15*) states that projections suggest that, with the exception of the methacrylate slurry and the multiple-layer polyester overlays, TPOs constructed in accordance with AASHTO specifications (*6*) should have a service life of 25 years.

Carter (*8*) states that (1) TPOs properly applied can provide service lives of up to 20 years, but that maintenance will be required if the surface is intended to remain free of defects. (2) TPOs can be used in high-salt environments to extend the lives of existing bridges containing noncoated steel, even if some corrosion has begun prior to repair. (3) TPOs are economically competitive with other repairs, especially when a minimum of repairs to the deck are required and a minimum of resin is used; that is, the overlay thickness is less than 10 mm (0.40 in.). (4) TPOs are more suited for preventive maintenance than for rehabilitation. Resins are too expensive to be used on excessively rough or deteriorated concrete surfaces.

OVERLAY TYPES

The types and recommended uses for each are as follows:

Multiple-Layer Overlays

Multiple-layer overlays are best used on decks that have good ride quality because the overlays follow the contours of the deck surface (*15*).

Slurry and Premixed

Decks that have many surface irregularities are the best candidates for slurry and premixed TPOs (*15*).

MATERIALS

Binders

Many polymer-based binder systems have been developed for protecting bridge decks. Epoxies (including modified epoxy urethanes), polyester-styrenes, and MMAs have been the most widely used. Earliest attempts to seal decks from ingress of water and waterborne deicing chlorides with polymeric membranes emphasized the need for including aggregates to provide skid resistance in wet or freezing weather. To accommodate this need, three overlay methods evolved. The first, the multiple-layer method, emulated asphaltic seal coats, and the second, the premixed, as well as the third, slurries, emulated asphalt concrete overlays.

Multiple-Layer Overlay

The multiple-layer PC overlay is thinly applied and often used to seal the bridge deck while masking any unsightly repairs under a well-bonded, uniform, durable, skid-resistant cover. This method is often referred to as "broom-and-seed" because the method involves spreading the somewhat viscous resin system over the deck and then immediately seeding the surface with the aggregate. After the first application has set, a second broom-and-seed operation is performed and allowed to cure. It may be repeated again as needed or done only one time if adequate skid resistance or waterproofing can be achieved.

A binder system is required that has a viscosity sufficiently low to spread easily, and relatively thinly, over the deck, bonding well to the deck and to the aggregates that are dispersed into the surface. Additionally, the binder system must be low enough in solvents and nonpolymerizing chemicals to preclude pinholes or permeability. Finally, the cure system for the binder must provide adequate working time to apply the binder wherever needed and to adequately broadcast and bond the aggregate into the binder before becoming too viscous, and then curing relatively quickly. The recommended binder for multiple-layer overlays is epoxy.

Premixed Polymer Overlay

The premixed TPO is typically specified for thicker overlays, typically 75 mm (0.75 in.) and up, used for accommodating uneven or rough riding surfaces, or where the thicker, lower modulus polymer concrete can resist the stress and impact of tire chains. Epoxy and polyester-styrene are the recommended resins for premixed overlays.

The requirements of the binder for the premixed TPO are not necessarily different from the binders used in the multiple-layer system. However, because the premixed system incorporates the aggregates into the resin before placement on the deck, resin viscosity and rheology would permit a low percentage of resin while permitting good workability.

The premixed systems usually require a primer to ensure a good durable bond between the cohesive polymer matrix and the deck. For polyester-styrene resins, the primer is typically a high-molecular-weight methacrylate that penetrates into the concrete surface and provides for excellent mechanical bond to the concrete while providing chemical bonding to the overlay matrix. Additionally, the primer prevents long-term deterioration of the polyester at the concrete interface owing to alkaline attack when wet. Premixed systems are cohesive enough to be tined or screeded to provide more skid resistance. Aggregates are sometimes broadcast over the screeded surface to enhance the surface friction of the overlay.

Slurry Overlays

Like the premixed system, the slurry incorporates aggregates into the binder before placement on the deck, but the lower viscosities of their binders, such as epoxies and methacrylate, require a well-graded fine filler component to help support and more uniformly disperse the larger sand particles at the desired depth. They are normally thinner than premixes and slightly thicker than multiple-layer systems, somewhere between 6 and 12 mm (0.25 in. and 0.5 in.). They are frequently applied with a gauge rake and sprinkled with an angular aggregate.

Slurries also rely on a primer of the substrate before the placement of the overlay. Slurry systems usually require a seal coat to help bind the aggregate that is seeded over the surface for additional skid resistance. Epoxies and methacrylates are the recommended resins for slurry overlays.

Cured Properties

The cured binders need to possess certain properties to perform well in TPOs. These properties include high bond strength to concrete substrates and the embedded TPO aggregates, high tensile elongation, and a very low modulus of elasticity (compared with the concrete substrate) to offset the higher coefficients of thermal expansion. They must also exhibit very low permeability to water, as well as good resistance to tire abrasion, acid rain, concrete alkalinity, and ultraviolet exposure.

Commercially available binder systems for the TPOs include several types of polymers, including epoxies (modified with copolymers in some cases), styrenated unsaturated polyesters, vinyl esters, and polyurethanes. Table 2 lists properties for several of the binder systems that are used on bridges (*15*).

AGGREGATES

TPOs require clean, dry, hard aggregates, including angular silica sand, basalt, trap rock, or flint. Most contractors use prebagged aggregates supplied by the overlay material supplier to ensure that the aggregates will be free of dirt, dust, oils, and moisture, and will have the correct grading for the specific application. Known standard bag weights also make it easier to keep track of the aggregate application rate, although large bags can result in segregation and the possibility of the fines collecting in the bottom of the bags.

Multiple-Layer Aggregates

The aggregates typically specified for multiple-layer TPOs are hard (6 or higher for basalt and 7 or higher for other mineralogies on Mohs scale), angular, and tough (nonbrittle), and they are typically either single-sized or a gap-graded blend of several complementary sizes. Basalts (containing at least 10% aluminum oxide), calcined bauxite, some natural granites, and angular grained silica sand are all commonly used. Their size is usually very near a no. 8 sieve to keep the overlay thin, yet skid resistant.

Premixed Aggregates

The aggregates for a premixed system require a few smaller sizes to uniformly distribute, embed, and support the largest aggregates that provide durable surface friction. The aggregates used in the premixed systems tend to be well graded and more regularly shaped, like siliceous river pea gravel and natural river sand, because they pack more easily and

TABLE 2
POLYMERIC BINDER SYSTEMS FOR TPOs

Property	Epoxy	Polyester	Methacrylate	Test Method
Viscosity, Poise	7–25	1–5	11–13	ASTM D2393
Gel Time, Minutes	15–45	10–25	15–45	AASHTO T237
Tensile Strength (Binder) MPa @ 7 days	13.8–34.4 (2,000–5,000 psi)	13.8–34.4 (2,000–5,000 psi)	3.4–8.3 (500–1,200 psi)	ASTM D638
Tensile Elongation (Binder) % @ 7 days	30–80	30–80	100–200	ASTM D638
PC Compressive Strength, MPa @ 3 h	Min. 6.9 (1,000 psi)	Min. 6.9 (1,000 psi)	Min. 6.9 (1,000 psi)	ASTM C579
PC Compressive Strength, MPa @ 24 h	Min. 34.4 (5,000 psi)	Min. 34.4 (5,000 psi)	Min. 34.4 (5,000 psi)	ASTM C579
PC Tensile Bond Strength, MPa @ 24 h	Min. 1.7 (250 psi)	Min. 1.7 (250 psi)	Min. 1.7 (250 psi)	ASTM 1583
PC Cure Time @ 32°C (90°F), h[a]	2	2	2	ASTM C109
PC Cure Time @ 24°C (75°F), h[a]	3	3	3	ASTM C109
PC Cure Time @ 16°C (60°F), h[a]	6–8	5–6	4	ASTM C109

[a] Time required to obtain compressive strength = 6.9 MPa (1000 psi).
Source: Sprinkel (*15*).

help reduce the resin content. Topping aggregate, like the aggregates in the multiple-layer systems, however, must be angular, hard, and tough for long-term performance.

Slurry Aggregates

Similar to the premixed system, aggregates must be small and well graded. Additionally, a finely graded silica flour or other filler is introduced to help build the apparent viscosity or to add rheology and support the larger aggregates in the matrix.

Table 3 lists common gradings for some of the aggregate systems used for TPOs.

The durability and the skid resistance of TPOs are greatly affected by the relative volumes and distribution of the aggregates into the binder system. Also, some of the materials rely on a primer to ensure the best bond to the concrete substrate over time, and MMA slurry systems typically require a seal coat for better retention of the exposed friction aggregate course. Application rates for TPOs are listed in Table 4.

TABLE 3
TYPICAL AGGREGATE GRADINGS FOR TPOs
(Percentage Passing Sieve)

Sieve Size	Multiple-Layer Overlays	Slurries: Sand	Slurries: Fine Fillers	Premix Overlays
0.13				100
0.10				83–100
No. 4	100			62–82
No. 8	30–75			45–64
No. 16	0–5	100		27–50
No. 20		90–100		
No. 30	0–1	60–80		12–35
No. 40		5–15		
No. 50		0–5		6–20
No. 100				0–7
No. 140			100	
No. 200			98–100	0–3
No. 270			96–100	
No. 375			93–99	

Source: Sprinkel (*15*).

QUALIFICATION OF SUBSTRATE

Evaluation of Substrate

The deck is to be sounded for delamination, and the areas from which concrete is to be removed need to be clearly marked. The area needs to be evaluated for corrosion activity using the copper sulfate electrode method in accordance with ASTM C876 (*26*). It is important that the concrete in areas where the chloride content exceeds 0.77 kg/m^3 (1.3 lb/yd^3) be marked for removal. The concrete substrate should have a minimum tensile rupture strength of 1.0 MPa (150 psi) based on ACI 503R (*13*) or ASTM C1583 (*14*); otherwise, the concrete must be removed and replaced.

Repair

Concrete needs to be removed in areas determined by the evaluation of the substrate. It is important that vertical saw be made to a minimum depth of 25 mm (1 in.) with care taken

TABLE 4
APPLICATION RATES FOR TPO COMPONENTS

Overlay	Multiple-Layer Epoxy	Epoxy Slurry	Methacrylate Slurry	Premixed Polyester
Thickness, mm (in.)	6.4 (1/4)	7.5 (5/16)	7.6 (5/16)	19.1 (3/4)
Prime Coat, kg/m^2 (lb/yd^2)	None	1.1 0.14 1.2 (2.0 ± 0.3)	0.41 ± 0.14/-0 (0.8 ± 0.3)	0.41 ± 0.14/-0 (0.8 ± 0.3)
Layer 1 Resin, kg/m^2 (lb/yd^2)	1.1 ± 0.14 (2.0 ± 0.3)	6.0 ± 0.4 (9.8 ± 0.8)	2.7 ± 0.27 (5.0 ± 0.5)	5.29 ± 0.41 (9.8 ± 0.8)
Layer 1 Aggregate, kg/m^2 (lb/yd^2)	5.4 ± 0.54 (10.0 ± 1.0)	6.5 ± 0.5 (12.0 ± 1.0)	6.5 ± 0.54 (12.0 ± 1.0)	38.6 ± 0.54 (71.0 ± 1.0)
Layer 2 Resin, kg/m^2 (lb/yd^2)	2.2 ± 0.14 (4.1 ± 0.3)	None	None	None
Layer 2 Aggregate, kg/m^2 (lb/yd^2)	7.6 ± 0.54 (14.0 ± 1.0)	None	7.6 ± 2.7 (14.0 ± 0.5)	None
Seal Coat Resin, kg/m^2 (lb/yd^2)	None	None	0.68 ± 0.14/-0 (1.3 ± 0.3)	None
Approx. Resin Content, %	25	25	24	13

Source: Sprinkel (*15*).

not to cut reinforcing steel. Concrete needs to be removed in such a manner as to not weaken or crack the surrounding sound concrete. Chipping hammers heavier than 15 lb are not to be used. It is important that concrete be removed beneath the steel to a depth of 12 mm (0.5 in.) or three times the diameter of the largest size aggregate, whichever is greater, in areas where the steel is corroded or the chloride content exceeds 0.77 kg/m^3 (1.3 lb/yd^3) at the level of the steel. Final cleaning could be by shot blasting or grit blasting; shot blasting cannot be used for deep patches. The steel is be cleaned from corrosion scale and other contaminants.

Materials for repair are to be low shrinkage and applied in accordance with the manufacturer's instructions. The repair material is to be compatible with the resins used in the TPO. If a hydraulic cement repair material is used, it needs to dry for a minimum of 28 days before placing the TPO unless bond tests show that earlier application is acceptable. Latex-modified concrete repair materials need to be wet cured for 2 to 3 days before beginning the drying process. Grinding might be considered to remove rough or unlevel areas.

Cracks wider than 1 mm (0.04 in.) need to be filled with a gravity-fill resin that is compatible with the overlay primer or resin. It has been noted that an application of high-molecular-weight methacrylate for crack repair before installation of an epoxy TPO resulted in delamination of the (epoxy) overlay, and the reason was believed to be the incompatibility of the materials (*3*). ACI 548.8 (*2*) cautions against placing TPOs "over crack-fill materials that will affect the bonding or the curing of the overlay."

Moving cracks in the substrate will likely cause reflective cracking through the TPO. Synthetic fiber fabrics have been used over joints in segmental bridges, shown in Figure 15.

FIGURE 15 Fiber fabric applied previous to overlay over bridge joint.

Surface Preparation

The deck surface must be cleaned prior to placement of the TPO to remove all contaminants, including oil, grease, dirt, asphalt, paint, carbonation, weak surface mortar, curing compounds, and laitance. The surface is to be shot blasted the day of the placement, preferably just before overlay placement. A reasonable texture can be achieved by meeting the ICRI CSP 7 profile. Oil-free and moisture-free compressed air can be used to remove dust or debris just before application of the resin. The surface should be dry as determined by ASTM D4263 (*46*) modified to keep the plastic sheet in place a minimum of 2 hours. Some parts of the deck, including low areas and other areas that drain slowly, such as gutters, dry more slowly and need to be tested to be certain that the surface is sufficiently dry to receive the TPO.

The test for strength based on the test method in ACI 503R (*13*) should be used to determine whether the cleaning procedure, that is, size of shot, flow of shot, traveling speed of machine, and number of passes, is adequate to provide the required minimum tensile bond strength. Figure 16 shows the setup for the tensile bond strength on a test patch of the installed overlay. For tensile bond strength of 1.7 MPa (250 psi) or a failure at a depth of 6 mm (0.25 in.) or more into the concrete substrate, greater than 50% of the area is required. The result is based on the average of three tests on each test panel, which is normally at least 0.3 m by 0.9 m (1 ft by 3 ft). Because the test is temperature sensitive, the test cannot be performed above 27°C (80°F). One test result (three tests on one patch) is required for each span or 418 m^2 (500 ft^2) of deck surface, whichever is greater.

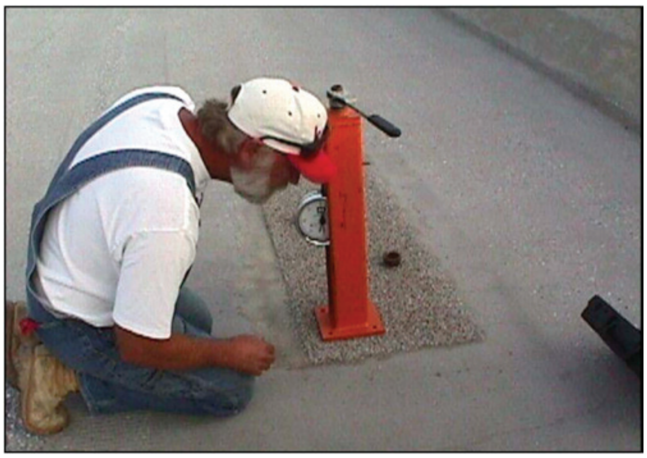

FIGURE 16 Pull-off test to determine suitability of surface preparation or bond strength of overlay.

INSTALLATION METHODS

Primers

Primers, if required by the manufacturer, should be compatible with the concrete repair materials and the first resin coat to be applied.

Multiple-Layer Overlays

Figures 17 and 18 show where binder (resin or monomer system) needs to be sprayed, squeegeed, or broomed on to the deck surface and followed by broadcasting gap-graded aggregate to excess over the surface. Figures 19–21 show hand applications, chip spreader, and salting truck for applying aggregates. The aggregate must be allowed to spread out and fall downward into the resin, with the dust and fines carried off in the air. In hot weather, aggregate should be slowly and evenly built up on the surface until no wet spots are visible but before the resin begins to gel. After the binder has cured, the loose aggregate is removed from the deck and a second layer is applied. The first layer consists of approximately 1.0 kg/m^2 (2 lb/yd^2) of binder and 5.4 kg/m^2 (10 lb/yd^2) of aggregate. The second layer consists of approximately 2.2 kg/m^2 (4 lb/yd^2) of binder and 7.6 kg/m^2 (14 lb/yd^2) of aggregate. The resin content is approximately 25% by weight of the overlay. The thickness is about 6.4 mm (0.25 in.)

FIGURE 17 Applying epoxy to deck for multiple-layer overlay.

FIGURE 18 Brooming epoxy over surface.

Slurry Overlays

For MMA, a primer of monomer or resin system should be applied at a rate of 0.41 ± 0.14 kg/m^2 (0.8 ± 0.3 lb/yd^2) fol-

FIGURE 19 Hand application of aggregates over resin.

FIGURE 20 Chip spreader application of aggregates.

FIGURE 21 Salting truck for applying aggregates over epoxy.

lowed by a slurry mixture of 2.7 ± 0.27 kg/m² (5 ± 0.5 lb/yd²) of binder and 6.5 ± 0.54 kg/m² (12 ± 1.0 lb/yd²) of manufactured-supplied filler. Gap-graded aggregate (as used in multiple-layer overlays) is broadcast onto the surface at a rate of 7.6 ± 0.27 kg/m² (14.0 ± 0.5 lb/yd²). A binder seal coat of 0.68 ± 0.14 kg/m² (1.3 ± 0.3 lb/yd²) is applied. The binder content is approximately 24% by weight of the overlay (primer and seal coat). The thickness is about 7.6 mm (0.31 in) (*6*).

Premixed Overlays

Approximately 12% binder should be mixed with the aggregates. A primer is usually applied to the surface at a rate of 0.41 ± 0.14 kg/m² (0.8 ± 0.3 lb/yd²) to improve the bond strength. The polymer concrete is placed and a vibratory screed is used to strike off and consolidate the PC. In some applications, continuous batching and paving equipment has been successfully used to place premixed PC. The thickness is about 19 mm (0.75 in.) The polymer concrete could be consolidated to a relative compaction of not less than 97% in accordance with California Test Method 551. Wood screeds can be used to obtain good surface texture in the form of transverse irregular ridges for premixed PC (*34*). A suitable skid resistance can be achieved by placing grooves in the fresh PC or by broadcasting aggregates onto the fresh PC surface (*15*). Figure 22 shows the finished surface of an overlay.

FIGURE 22 Finished overlay surface.

Material Handling, Mixing, and Placement Temperatures

Handling and Mixing

It is important that the handling and mixing of the resins and curing agents be performed in a safe manner that is accordance with the manufacturer's written recommendations. Illinois DOT requires that resins be stored in their original containers inside a heated warehouse in a dry area with temperatures maintained between 16°C (60°F) and 32°C (90°F) Workers directly exposed to the resins are to wear protective gloves and goggles. Material Safety Data Sheets should be prominently displayed at the storage site, as per the Illinois

2007 TPO specification. Hsu et al. (*47*) provide a summary of safety requirements for using chemicals for concrete-polymer materials.

Michigan DOT indicates that if the in-place material is defective, it is usually because of improper proportioning or mixing. Using different colors for multicomponent systems helps to reduce proportioning errors (*8*).

Missouri DOT has reported that an incorrect type of mixing paddle can lead to air bubbles in the epoxy, which results in pitting on the surface of the TPO. Harper (*7*) recommends that “jiffy” or “Sika” paddles be used.

Placement Temperatures

The temperature of placement is important. Not all DOTs specify a minimum temperature for placement; 10°C (50°F) to 16°C (60°F) is the range of minimum temperatures for epoxies reported by several DOTs. Some DOTs specify the same temperature for the deck and ambient; some use a slightly higher minimum temperature for the deck. Some DOTs specify the minimum temperature of the TPO components to be the same as the minimum ambient and/or deck temperature. North Carolina DOT recommends that the temperature be above 24°C (75°F).

Harper (*7*) suggests that for bridges with steep grades or with super elevations, an upper limit on temperature be provided to prevent the resin system from becoming too low in viscosity and ponding at the lowest elevation.

CHAPTER FIVE

REPAIR

TPO repairs generally proceed as follows:

- Sounding is normally conducted to find the extent of delamination.
- The perimeter of the distressed area of overlay is saw cut.
- The overlay inside the saw cut is removed using a small chipping hammer to minimize damage to the concrete substrate and surrounding overlay.
- The substrate surface is cleaned, usually by shot blasting.
- The same or similar overlay materials and application methods are used to replace the removed overlay (*44*).

In Alberta, aging TPOs subjected to wear and loss of skid resistance have been successfully treated by applying the asphaltic chip coats over the surfaces (*48*).

CHAPTER SIX

CONCLUSIONS

Thin polymer overlays (TPOs) have become a widely used construction method in North America for protecting bridge surfaces, restoring skid resistance, and a bridge preservation treatment for extending the lives of decks. The use of TPOs tripled from 1990 to 1999 and more than quadrupled from 1999 to 2008. More than half of the states and several of the Canadian provinces have used TPOs. AASHTO, the American Concrete Institute, and a number of states have developed specifications for the construction of TPOs.

Three types of overlays are widely used: multiple layer that consists of two or more layers of resin and aggregate; slurry that consists of a single layer of primer, resin, and aggregate followed by a seal coat; and premixed that uses resin and aggregate mixed in continuous batching machines or concrete mixers and placed on decks using screeds. The most common resins and monomers are epoxies, polyester-styrenes, methacrylates, and epoxy-urethanes. Most agencies use contractors to install TPOs, but some use their own forces.

TPOs give the best performance when applied to decks that are in good condition. TPOs must be constructed in accordance with established principles to provide good performance. The most important factors for the success of TPOs are—

- Sound, dry substrate that requires quality repair procedures;
- Adequate preparation to provide a clean, textured dry surface;
- Environment including dry and warm weather;
- Experienced applicator and good workmanship to ensure proper application of materials;
- Involvement of resin supplier or manufacturer to assist contractor in proper handling, mixing, and application of resins; and
- Thermal compatibility that requires low-modulus resins and compatibility of resins and repair materials.

TPOs have an important role in bridge maintenance and protection. They are particularly appropriate in high-traffic areas in which lane closures must be minimized and for structures that cannot accommodate significant increases in dead load. When constructed properly, TPOs can provide a service life of 20 to 25 years.

RESEARCH NEEDS

Research is needed to improve the performance and to extend the life of TPOs. Suggested areas of research include

- Development of resins, including those from recycled plastics, that will perform under extreme conditions, such as very low or very high temperatures, heavy traffic volumes, or heavy loads;
- Development of polymer concretes that will self-heal in the event of cracks and delamination;
- Development and validation of tests that will more accurately predict long-term performance of polymer concrete systems when used in a wide range of temperatures, heavy loads, and heavy traffic volumes;
- Improved analytical techniques to select material properties and thicknesses of TPOs to perform satisfactorily in the intended conditions; and
- Development of nondestructive test procedures that will accurately determine whether the condition of bridge decks is suitable for TPO application.

REFERENCES

1. *ACI 548.5R: Guide for Polymer Concrete Overlays,* American Concrete Institute, Farmington Hills, Mich., Jan. 1994, Reapproved 1998, 26 pp.
2. *ACI 548.8: Specification for Type EM (Epoxy Multi-Layer) Polymer Overlay for Bridge and Parking Garage Decks*, American Concrete Institute, Farmington Hills, Mich., Oct. 2007, 9 pp.
3. Furr, H.L., *Synthesis of Highway Practice 109: Highway Uses of Epoxy with Concrete*, Transportation Research Board, National Research Council, Washington, D.C., 1984, 68 pp.
4. Sprinkel, M.M., "Twenty-Five-Year Experience with Polymer Concrete Bridge Deck Overlays," *Polymers in Concrete: The First Thirty Years*, ACI Special Publication No. 214, 2003, pp. 51–62.
5. Ohama, Y., *Bibliography on Polymers in Concrete*, 3rd ed., International Congress on Polymers in Concrete, 2007.
6. AASHTO-AGC-ARTBA Task Force 34, *Guide Specification for Polymer Concrete Bridge Deck Overlays*, AASHTO, Washington, D.C., 1995.
7. Harper, J., *Investigations of Failures of Epoxy Polymer Overlays in Missouri*, Missouri Department of Transportation, Jefferson City, Nov. 2007, 22 pp.
8. Carter, P.D., "Thin Polymer Wearing Surfaces for Preventive Maintenance of Bridge Decks," *Polymer Concrete*, ACI Special Publication No. 137, 1993, pp. 29–48.
9. White, D. and R. Montani, "Thin-Bonded Polymer Concrete Overlays for Exposed Concrete Bridge Deck Protection and Maintenance," *In-Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 99–106.
10. *ASTM D638, Test Method for Tensile Properties of Plastics*, ASTM, West Conshohocken, Pa.
11. Gaul, R.W., "Epoxy Asphalt Concrete—A Polymer Concrete with 25 Years' Experience," *Properties and Uses of Polymers in Concrete*, ACI Special Publication No. 166, 1996, pp. 233–251.
12. Fontana, J.J., W. Reams, W. Scannell, and M.M. Sprinkel, *Electrically Conductive Polymer Concrete Overlay as Secondary Anode for Cathodic Protection*, FHWA-RD-90-005, Brookhaven National Laboratory, Upton, N.Y., May 1990, 61 pp.
13. *ACI 503R, Use of Epoxy Compounds with Concrete, Appendix A—Test Methods*, American Concrete Institute, Farmington Hills, Mich., Reapproved 2008, 28 pp.
14. *ASTM C1583, Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)*, ASTM, West Conshohocken, Pa.
15. Sprinkel, M.M., "Nineteen Year Performance of Polymer Concrete Bridge," *In-Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 42–74.
16. Sprinkel, M.M., "Performance of Multiple Layer Polymer Concrete Overlays on Bridge Decks," *Polymers in Concrete: Advances and Applications*, ACI Special Publication No. 116, 1989, pp. 61–95.
17. Sprinkel, M.M., "Polymer Concrete Bridge Overlays," *Transportation Research Record 1392*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 107–116.
18. Dimmick, F.E., Sr., "Premixed Epoxy Polymer Concrete Bridge Deck Overlays," *In-Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 146–171.
19. *ASTM D3042-09, Standard Test Method for Insoluble Residue in Carbonate Aggregates*, ASTM, West Conshohocken, Pa.
20. *ASTM C579, Standard Test Methods for Compressive Strength of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes*, ASTM, West Conshohocken, Pa.
21. Zalatimo, J.H., *Analysis, Design, Construction, and Durability of Polymer Concrete Overlays*, Ph.D. dissertation, University of Texas, Austin, 1993.
22. Zalatimo, J.H. and D.W. Fowler, "5-Year Performance of Overlays in Fort Worth, Texas," *In-Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 122–145.
23. *ASTM D570, Standard Test Method for Water Absorption of Plastics*, ASTM, West Conshohocken, Pa.
24. *ASTM D4060, Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser*, ASTM, West Conshohocken, Pa.
25. *AASHTO T277-07, Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*, AASHTO, Washington, D.C., 2007.
26. *ASTM C876, Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete*, ASTM, West Conshohocken, Pa.

27. Meinheit, D.F. and W.H. Riesterer, "Performance of Thin Methyl-Methacrylate Polymer Concrete (MMA) Overlay in a Post-Tensioned Parking Garage," *In-Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 18–41.

28. *ASTM D3633, Test Method for Electrical Resistivity of Membrane-Pavement Systems*, ASTM, West Conshohocken, Pa.

29. *ASTM E524, Standard Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests*, ASTM, West Conshohocken, Pa.

30. *ASTM C666, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*, ASTM, West Conshohocken, Pa.

31. Nabar, S. and P. Mendis, "Experience with Epoxy Polymer Concrete Bridge Deck Thin Overlays in Service for Over 10 Years," *In-Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 1–17.

32. Maass, J.E., "I-80—It's Almost a Decade," *Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 172–179.

33. Krauss, P.D., "Status of Polyester-Styrene Resin Concrete Bridge Deck and Highway Overlays in California," *43rd Annual Conference SPI Composites Institute Inc.*, Feb. 1–5, 1988.

34. Dimmick, F.E., Sr., "15-Year Tracking Study: Comparing Epoxy Polymer Concrete to Portland Cement Concrete Applied on Slab-on-Grade and Bridge Decks," *Properties and Uses of Polymers in Concrete*, ACI Special Publication No. 166, 1996, pp. 211–231.

35. Wilson, D.L. and E.H. Henley, *Thin Polymer Bridge Deck Overlays: WSDOT's 10 Year Evaluation*, WA-RD 374.1, Washington State Department of Transportation, Lacey, Feb. 1995, 100 pp. [Online]. Available: http://www.wsdot.wa.gov/research/reports/fullreports/374.1.pdf.

36. Doody, M.E., and R. Morgan, *Polymer-Concrete Bridge-Deck Overlays*, FHWA/NY/SR-93/110, Engineering Research and Development Bureau, State Campus, Albany, N.Y., June 1993, 48 pp. [Online]. Available: http://ntl.bts.gov/lib/21000/21100/21137/PB99100349.pdf.

37. New York State Department of Transportation (NYSDOT), *Field Trip Report on Thin Polymer Overlays*, NYSDOT, Albany, Unpublished report, 2007.

38. *ASTM E274, Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire*, ASTM, West Conshohocken, Pa.

39. Bognacki, Casimir, "LaGuardia Airport Polymer Concrete Overlay," Port Authority of New York and New Jersey, 1998.

40. Choi, D., D.W. Fowler, and D.L. Wheat, "Thermal Stresses in Polymer Concrete Overlays," *Properties and Uses of Polymers in Concrete*, ACI Special Publication No. 166, 1996, pp. 93–122.

41. Letsch, R.H., "Polymer Mortar Overlay—Measurement of Stresses," *ICPIC '87: The Production Performance and Potential of Polymers in Concrete*, 5th International Congress, Brighton, England, Sep. 22–24, 1987, pp. 119–126.

42. Ahn, N. and D.W. Fowler, "Effects of Metallic Monomers on the Bond Strength of Polymer Concrete to Wet Substrates," *9th International Congress on Polymers in Concrete: ICPIC '98*, Bologna, Italy, Sep. 14–18, 1998, pp. 199–216.

43. Sprinkel, M.M., D.S. Roosevelt, G.W. Flintsch, E. Izeppi, and D.W. Mokarem, *Evaluation of the Cargill Safelane™ Surface Overlay,* VTRC 09-R8, Virginia Transportation Research Council, Charlottesville, Jan. 2009.

44. Meggers, D., Unpublished report, Kansas Department of Transportation, Topeka, 2009.

45. *Specification for Type ES (Epoxy Slurry) Polymer Overlay for Bridge and Parking Garage Decks*, ACI Standard, Reported by ACI Committee 548, ACI 548.9-08, American Concrete Institute, Farmington, Hills, Mich., 2008.

46. *ASTM D4263, Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method*, ASTM, West Conshohocken, Pa.

47. Hsu, H., D.W. Fowler, M. Miller, and D.R. Paul, *An Investigation of the Use of Polymer-Concrete Overlays for Bridge Decks*, FHWA/TX-79/36+114-7, CFHR 3-9-71-114-7, Center for Highway Research, The University of Texas at Austin, March 1979, 146 pp.

48. Carter, P.D., "A Procedure for Determining Performance of Thin Polymer Overlays on Alberta Bridge Decks," *In-Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 107–121.

BIBLIOGRAPHY

Ahn, N. and D.W. Fowler, "The Effects of Metallic Monomers on the Mechanical Properties of Polymer Concrete Made with Wet Aggregates," *Proceedings of the Tenth International Congress on Polymers in Concrete*, Honolulu, Hawaii, May 21–25, 2001.

Alexanderson, J., "Polymer Cement Concrete for Industrial Floors," *Polymers in Concrete: Third International Congress on Polymers in Concrete Vol. I* (pre-prints), Koriyama, Japan, May 13–15, 1981, pp. 358–371.

Arellano, J.L., *Polymer Concrete Overlays for Bridge Decks*, FHWA-PA-87-030+83-29, Pennsylvania Department of Transportation, Harrisburg, June 1988, 16 pp.

Chamberlin, W.P. and R.E. Weyers, "Protection and Rehabilitation Treatments for Concrete Bridge Components: Status and Service Life Opinions of Highway Agencies," *Transportation Research Record No. 1304*, Transportation Research Board, National Research Council, Washington, D.C., 1991, pp. 114–121.

Ciappa, A., P. Racz, and D. Micheletto, "A New Polymer Concrete for Repair and Renovation of Airport Pavements," *ICPIC VIII International Congress on Polymers in Concrete Proceedings*, Oostende, Belgium, July 3–5, 1995, pp. 503–508.

Dinitz, A.M. and R. Ferri, "Polymer Concrete (MMA) for Bridge Rehabilitation Applications," *Polymer Concrete: Uses, Materials, and Properties*, ACI Special Publication No. 89, 1985, pp. 141–159.

DePuy, G.W. and C.E. Selander, "Polymer Concrete—Trials and Tribulations," *Second International Congress on Polymers in Concrete,* Austin, Tex., Oct. 25–27, 1978, pp. 461–482.

Depuy, G.W. and F.E. Dimmick, Sr., "Polymer Concrete Overlays for Repair and Protection of Concrete Surfaces," *Proceedings of the International Workshop on Concrete Repair and the 4th Southern African Conference on Polymers in Concrete*, Johannesburg, South Africa, June 21–23, 2000, pp. 165–173.

Depuy, G.W. and F.E. Dimmick, Sr., "Polymer Concrete Overlays for the Repair and Protection of Concrete," *Proceedings of the Tenth International Congress on Polymers in Concrete*, Honolulu, Hawaii, May 21–25, 2001.

Depuy, G.W. and F.E. Dimmick, Sr., "Polymer Concrete Overlays for the Repair and Protection of Concrete," *Polymers in Concrete: The First Thirty Years*, ACI Special Publication No. 214, 2003, pp. 139–150.

Fairweather, V., "Filling the Cracks," *Civil Engineering*, Vol. 56, No. 10, Nov. 2006, pp. 20–23.

Fontana, J.J. and R. Webster, "Thin, Sand-Filled, Resin Overlays," *Second International Congress on Polymers in Concrete*, Austin, Tex., Oct. 25–27, 1978, pp. 89–104.

Fontana, J.J. and J. Bartholomew, "Use of Concrete Polymer Materials in the Transportation Industry," *Applications of Polymer Concrete*, ACI Special Publication No. 69, 1981, pp. 21–43.

Fontana, J.J., "Electrically Conductive Polymer Concrete Coating," *Polymer Modified Concrete*, ACI Special Publication No. 99, 1987, pp. 31–50.

Fontana, J.J. and P. Mendis, "Installation of an Insulating Polymer Concrete Overlay for Dike Insulation at Long Island Lighting Company's LNG Storage Facility," *Polymers in Concrete: Advances and Applications*, ACI Special Publication No. 116, 1989, pp. 145–156.

Fontana, J.J., W. Reams, and D. Elling, "Electrically Conductive Polymer Concrete Overlay Installed in Pulaski, VA," *Polymers in Concrete: Advances and Applications*, ACI Special Publication No. 116, 1989, pp. 157–175.

Fowler, D.W., "Sealing Pavement Cracks with High Molecular Weight Methacrylates," *ICPIC/IBRACON Working Papers*, Salvador, Bahia, Brazil, Oct. 17–20, 1993.

Fowler, D.W., "PC Materials, Properties and Applications," *ICPIC Workshop on Polymers in Concrete for Central Europe: Proceedings*, Bled, Slovenia, Sep. 10–12, 1996, pp. 37–45.

Fowler, D.W., "Current Status of Polymer Concrete in the U.S.," *IXth International Congress on Polymers in Concrete: ICPIC '98*, Bologna, Italy, Sep. 14–18, 1998, pp. 37–44.

Fowler, D.W., D. Choi, J. Zalatimo, and D.L. Wheat, "Stresses in PC Overlays Due to Thermal Changes," *Proceedings of the Tenth International Congress on Polymers in Concrete*, Honolulu, Hawaii, May 21–25, 2001.

Fowler, D.W. and G.W. Depuy, "Status of Concrete Polymer Materials in the United States," *ICPIC VIII International Congress on Polymers in Concrete Proceedings*, Oostende, Belgium, July 3–5, 1995, pp. 67–73.

Fowler, D.W. and D.L. Wheat, "Polymer Concrete Floor and Bridge Overlays," *Polymers in Concrete 1992: Proceedings of the Second Southern African Conference*, Johannesburg, South Africa, Apr. 23–24, 1992, pp. 208–218.

Fowler, D.W., and D.L. Wheat, "Polymer Concrete Floor and Bridge Overlays," *Polymers in Concrete: 7th International Congress on Polymers in Concrete*, Moscow, Russia, Sep. 22–25, 1992, pp. 58–68.

Fowler, D.W. and D.L. Wheat, "Polymer Concrete Floor and Bridge Overlays," *ICPIC/IBRACON Working Papers*, Salvador, Bahia, Brazil, Oct. 17–20, 1993.

Garbacz, A., L. Czarnecki, and E. J.Garboczi, "Ultrasonic Assessment of Adhesion Between Polymer Composites and Concrete Substrate," *Proceedings of the Tenth International Congress on Polymers in Concrete*, Honolulu, Hawaii, May 21–25, 2001.

Gierloff, M., "Resin Dispersion Modified Concretes Under Traffic Simulation in the Federal Institute for Testing Materials, Berlin," *Polymers in Concrete: Third International Congress on Polymers in Concrete Vol. I* (preprints), Koriyama, Japan, May 13–15, 1981 pp. 288–308.

Ignoul, S., F. Van Rickstal, and D. Van Gemert, "Blistering of Epoxy Industrial Floor on Concrete Substrate: Phenomena and Case Study," *11th International Congress on Polymers in Concrete*, Berlin, Germany, June 2–4, 2004, pp. 393–400.

Hsu, H., *An Investigation of the Use of Polymer-Concrete Overlays for Bridge Decks*, Master's thesis, University of Texas, Austin, 1979.

Husquinet, C., "Strategic Approach for Repair," *ICPIC VIII International Congress on Polymers in Concrete Proceedings*, Oostende, Belgium, July 3–5, 1995, pp. 131–135.

International Concrete Repair Institute (ICRI), *Guide for Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Membranes*, ICRI, Farmington Hills, Mich., 1996.

Knight, M.L., G.S. Wilson, W.J. Seger, and S. Mahadevan, "Overlay Types Used as Preventive Maintenance on TN Bridge Decks," *Transportation Research Record: Journal of the Transportation Research Board, No. 1866*, Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 79–84.

Koyanagi, W., et al., "Structural Behavior of Unsaturated Polyester Resin Concrete Slabs," *Polymers in Concrete: Proceedings of the 6th International Congress*, Shanghai, China, Sep. 24–27, 1990, pp. 405–410.

Kranenberg, H., "Worldwide Applications of Polymer Concrete," *Polymers in Concrete: Proceedings of the 6th International Congress*, Shanghai, China, Sep. 24–27, 1990, pp. 60–64.

Krauss, P.D., "Bridge Deck Repair Using Polymers," *ICPIC Working Papers: North American Workshop*, San Francisco, Calif., Sep. 24–27, 1991.

Krauss, P.D., *New Materials and Techniques for the Rehabilitation of Portland Cement Concrete*, FHWA/CA/TL-85/16, Office of Transportation Laboratory, California Department of Transportation, Sacramento, Oct. 1985, 272 pp.

Krauss, P.D. and L. Ferroni, *New Bridge Deck Rehabilitation Techniques Being Implemented in California Utilizing Polymers*, California Department of Transportation, Sacramento, 1986.

Leskovar, I., "Use of PMC and PC in Repair of Some Concrete Structures in Slovenia," *ICPIC Workshop on Polymers in Concrete for Central Europe: Proceedings*, Bled, Slovenia, Sep. 10–12, 1996, pp. 153–159.

Letsch, R., "Blistering of Polymer Overlays on Concrete," *Third Southern African Conference on Polymer in Concrete*, Johannesburg, South Africa, July 15–17, 1997, pp. 151–156.

Maass, J., "How Polyester Polymer Concrete Highway Bridge Deck Overlays Became 'State of the Art'," *Polymers in Concrete: The First Thirty Years*, ACI Special Publication No. 214, 2003, pp. 39–50.

Maggenti, R., L. Ferroni, and J.L. DeVilbiss, "Polyester Polymer Concrete in Bridge Deck Overlays," *Proceedings of the Tenth International Congress on Polymers in Concrete*, Honolulu, Hawaii, May 21–25, 2001.

Maximov, Yu. V., G.K Soloviov, and V.P. Trambevetsky, "Polymer Concretes on Methylmethacrylate Base Hardened Under Sub-Zero Temperatures," *IXth International Congress on Polymers in Concrete: ICPIC '98*, Bologna, Italy, Sep. 14–18, 1998, pp. 589–592.

Mendis, P., "Polymer Concrete Overlays and Applications," *ICPIC '87: The Production Performance & Potential of Polymers in Concrete*, 5th International Congress, Brighton, England, Sep. 22–24, 1987, pp. 53–57.

Munn, W.D., "Teflon-lined Paver Places Polymer Concrete Surface," *Highway and Heavy Construction*, Vol. 132, No. 4, Apr. 1989, pp. 54.

Murray, M.A., "Polymers, the Versatile Materials for the Repair, Rehabilitation, and Protection of the Infrastructure," *IXth International Congress on Polymers in Concrete:* ICPIC '98, Bologna, Italy, Sep. 14–18, 1998, pp. 447–453.

Omata, F., M. Kawakami, M. Kagaya, and H. Tokuda, "Abrasion Characteristics of MMA Resin Mortar Overlaid on a Pavement in a Cold Environment," *Place Performance of Polymer Concrete Overlays*, ACI Special Publication No. 169, 1997, pp. 180–198.

Orentlicher, L.P. and W.J. Loganina, "Maintenance Reliability of Coverings Dependent on the Structure of the Sublayer," *Polymers in Concrete: Proceedings of the 6th International Congress*, Shanghai, China, Sep. 24–27, 1990, pp. 330–336.

Ottman, R.E., "High Molecular Weight Methacrylates for Portland Cement Concrete Crack Repair and Sealing," *ICPIC Working Papers: North American Workshop*, San Francisco, Calif., Sep. 24–27, 1991.

Persichetti, B., "Safe in Snow," *Bridges*, Vol. 9, No. 6, Nov., 2006, pp. 20–23 [Online]. Available: http://www.cargill-safelane.com/documents/2_1_07gobridgesstory1.pdf.

Peschke, H.J., "Stress and Stain Analysis Between Cementitious Concrete and Polymer Concrete," *Polymers in Concrete: Third International Congress on Polymers in Concrete Vol. I* (pre-prints), Koriyama, Japan, May 13–15, 1981, pp. 437–449.

Rebeiz, K.S. and A.P. Craft, "Polymer Concrete Using Coal Fly Ash," *Journal of Energy Engineering*, Vol. 128, No. 3, Dec. 2002, pp. 62–73.

Riesterer, W., "Polymer Concrete Applications in New Construction and Rehabilitating Old Structures of Railroad Operations," *Polymers in Concrete: Third International Congress on Polymers in Concrete Vol. I* (pre-prints), Koriyama, Japan, May 13–15, 1981, pp. 644–656.

Selander, C.E., "Recent Applications of Concrete Polymer Materials," *Polymers in Concrete: Third International Congress on Polymers in Concrete Vol. I* (pre-prints), Koriyama, Japan, May 13–15, 1981, pp. 68–87.

Shahrooz, B.M., et al., *Bond Characteristics of Overlays Placed over Bridge Decks Sealed with HMWM or Epoxy*, Report UC-CII 98/02, Cincinnati Infrastructure Institute, Cincinnati, Ohio, July 1998, 202 pp. [Online]. Available: Location: http://ntl.bts.gov/lib/21000/21700/21778/PB99140865.pdf.

Shivasharan, S.M., "Polymer Coatings," *Polymers in Concrete: Third International Congress on Polymers in Concrete Vol. II* (pre-prints), Koriyama, Japan, May 13–15, 1981, pp. 1347–1363.

Sommer, H., "Wear-Resistance of Resin-Bound Mortar to Studded Tyres," *Proceedings of the First International Congress on Polymer Concrete*, Great Britain, May 5–7, 1975, pp. 323–337.

Sprinkel, M.M., "Thermal Compatibility of Thin Polymer Concrete Overlays," *Transportation Research Record 899*, Transportation Research Board, National Research Council, Washington, D.C., 1983, pp. 64–73.

Sprinkel, M.M., "Thin Polymer Concrete Overlays for Bridge Deck Protection," *Transportation Research Record 950*, Transportation Research Board, National Research Council, Washington, D.C., 1984, pp. 193–201.

Sprinkel, M.M., "FHWA Value Engineering Study of Bridge Deck Maintenance, Repair and Protection," *FHWA-TS-90-041*, Office of Implementation, Federal Highway Administration, McLean, Va., Aug. 1990.

Sprinkel, M.M., "Polymer Concrete Bridge Overlays," *ICPIC Working Papers: North American Workshop*, San Francisco, Calif., Sep. 24–27, 1991.

Sprinkel, M.M., "Rapid Techniques for the Repair and Protection of Bridge Decks," *Transportation Research Record 1304*, Transportation Research Board, National Research Council, Transportation Research Board, Washington, D.C., 1991, pp. 75–86.

Sprinkel, M.M., R.E. Weyers, B.D. Prowell, and M. Verster, "Concrete Bridge Protection, Repair, and Rehabilitation Relative to Reinforcement Corrosion: A Methods Application Manual," *SHRP-5-360*, Strategic Highway Research Program, Washington, D.C., Oct. 1993.

Sprinkel, M.M., *Guide Specifications for Polymer Concrete Bridge Deck Overlay*, AASHTO, Washington, D.C., Oct. 1995.

Sprinkel, M.M., "Repair and Protection of Concrete Bridge Decks," *Proceedings NCMEC*, San Francisco, Calif., June 16, 1995.

Sprinkel, M.M., "Performance Review of Polymer Concrete Bridge Overlays," *Concrete Repair Bulletin*, May/June 1996, pp. 10–14.

Sprinkel, M.M., "Polymer Concrete Bridge Overlays," International Symposium on Polymers in Concrete, Composite Fabrications Association, Orlando, Fla., Oct. 28, 1997.

Sprinkel, M.M., "Polymer Concrete Bridge Deck Overlays," International Symposium on Polymers in Concrete, Composite Fabrications Association, Chicago, Ill., Oct. 28, 1999.

Sprinkel, M.M., "Polymer Concretes, Adhesives and Sealers," *Transportation in the New Millennium*, Transportation Research Board, National Research Council, Washington, D.C., 2000, 2 pp.

Sprinkel, M.M., "Maintenance of Concrete Bridges," *Transportation Research Record: Journal of the Transportation Research Board, No. 1749*, Transportation Research Board of the National Academies, Washington D.C., 2001, pp. 60–63.

Sprinkel, M.M., *Thin Bonded Overlays and Surface Lamination Projects for Pavements and Bridge Decks*, Federal Highway Administration, Washington, D.C., Feb. 2001.

Sprinkel, M.M., "Twenty-Five Year Experience with Polymer Concrete Bridge Deck Overlays," *Proceedings of the International Congress on Polymers in Concrete*, Honolulu, Hawaii, May 21–24, 2001.

Sprinkel, M.M., "Protection and Repair of Bridge Decks," *Proceedings Concrete Repair Mexico*, Mexico City, Sep. 11–12, 2002.

Sprinkel, M.M., "Deck Protection Systems for Post-Tensioned Segmental Concrete Bridges," *Abstracts and Summaries of 2003 Convention Presentations*, Dallas, Tex., Nov. 3–4, 2003, American Segmental Bridge Institute, Phoenix, Ariz., 2003.

Staynes, B.W. and T.A. Willway, "The Composite Behavior and Delamination of Thin Surface Overlays and Repairs—Identification and Measurement of Controlling Parameters," *ICPIC '87: The Production Performance & Potential of Polymers in Concrete*, 5th ICPIC International Congress, Brighton, England, Sep. 22–24, 1987, pp. 301–304.

Stirmer, N. and V. Ukrainczyk, "Response of Industrial Floor to Impact Loading," *11th International Congress on Polymers in Concrete*, Berlin, Germany, June 2–4, 2004, pp. 383–392.

Tu, L. and D. Kruger, "Epoxy Resins Used in Civil Engineering," *ICPIC VIII International Congress on Polymers in Concrete Proceedings*, Oostende, Belgium, July 3–5, 1995, pp. 125–130.

Ukrainczyk, V., "Polymer Modified Cement Mortar Overlays and Patches," *ICPIC Workshop on Polymers in Concrete for Central Europe: Proceedings*, Bled, Slovenia, Sep. 10–12, 1996, pp. 143–149.

Van Gemert, D. and A. Beldens, "Highway and Industrial Floor Foundation Repair and Consolidation," *ICPIC Workshop on Polymers in Concrete for Central Europe: Proceedings*, Bled, Slovenia, Sep. 10–12, 1996, pp. 161–169.

Watanabe, Y., K. Tsuchida, H. Arita, and M. Koga, "Methyl Methacrylate Based Polymer Concrete Used for Repairing Hydraulic Structures," *Polymers in Concrete: Proceedings of the 6th International Congress*, Shanghai, China, Sep. 24–27, 1990, pp. 622–629.

Whitney, D., D.W. Fowler, and D. Zollinger, "Best Methods for Spall Repair in Concrete Pavements," *XIIth International Congress on Polymers in Concrete*, Chuncheon, Korea, Sep. 27–28, 2007, pp. 673–684.

Zajc, A. and J. Korla, "Freeze–Thaw Resistance w/ and w/o De-Icing Salts of Polymer Cement Concrete," *ICPIC VIII International Congress on Polymers in Concrete Proceedings*, Oostende, Belgium, July 3–5, 1995, pp. 245–250.

Zajc, A., "Central European Applications," *ICPIC Workshop on Polymers in Concrete for Central Europe: Proceedings*, Bled, Slovenia, Sep. 10–12, 1996, pp. 23–24.

Zalatimo, J.H. and D.W. Fowler, "Measurement of Shrinkage-Induced Stress in Polymer Concrete Overlays," *Properties and Uses of Polymers in Concrete*, ACI Special Publication No. 166, 1996, pp. 37–59.

GLOSSARY OF TERMS

Accelerator—See *Initiator.*

Catalyst—See *Initiator.*

Cross-linking agent—Bifunctional or polyfunctional monomer whose addition to a polymer system increases the rigidity, resistance to solvents, and softening point of the polymer.

Curing agent—See *Initiator* and *Hardener.*

Epoxy resin—A resin that contains or did contain epoxy groups principally responsible for its polymerization.

Flash point—The lowest temperature at which the vapor of a combustible liquid can be made to ignite momentarily in air.

Glass transition temperature (Tg)—The temperature at which an amorphous material (such as glass or a high polymer) changes from a brittle, vitreous state to a plastic state.

Hardener—The chemical component added to epoxy resins that causes the resin to harden or cure.

Inhibitor—Free-radical scavengers added to monomers to react with and deactivate the free radicals in growing polymer chains, and to act as antioxidants to prevent polymerization by oxidation product reaction during monomer storage.

Initiator—Agent that initiates growth of polymer chains by decomposing into free radicals that actually start the chain's growth; often incorrectly called a catalyst.

Microcracks—Small, numerous, noncritical cracks that can develop in hardened concrete in the matrix and at matrix–aggregate interfaces both prior to the concrete receiving external loads or during loading.

Monomer—A small molecule from which much larger polymer molecules can be made; usually in liquid form for concrete applications.

Monomer depletion—The loss of monomer because of evaporation from the surface of hardened concrete prior to the polymerization process associated with the production of polymer-impregnated concrete.

Multiple-layer overlay—Two or more layers of polymer concrete bonded to concrete; normally each layer consists of an application of resin with aggregate broadcast into the surface.

Plasticizer—Chemical additions to monomers to improve the flexibility of inherently brittle polymers.

Polymer—The product of polymerization, more commonly a rubber or resin consisting of large molecules formed by polymerization.

Polymerization—The reaction in which two or more molecules of the same substance combine to form a compound containing the same elements, and in the same proportions, but of high molecular weight, from which the original substance can be regenerated, in some cases only with extreme difficulty.

Polymer concrete (PC)—A composite material in which the aggregate is bound in a matrix with a polymer binder.

Porosity—The ratio, usually expressed as a percentage, of the volume of voids in a material to the total volume of the material, including the voids.

Premix placement—The method of initially blending a polymer binder, with fine and coarse aggregate and fillers, if used, and then mixing until all particles are completely wetted. Once the composite has been mixed as required, it is transported and placed. Term applies to polymer concrete.

Prepackaged polymer concrete—Polymer concretes whose individual components (that is, monomer or resin, fillers, and aggregates) are premeasured and packaged by the manufacturer for a prescribed sequence of introduction into the mixing process.

Promoted-catalytic method—A polymerization method that uses promoters or accelerators to cause the decomposition of organic peroxide initiators, and subsequent release of free radicals that allow polymerization to take place at ambient temperature without the need for an external source of energy.

Promoter—See *Initiator.*

Resin—A natural or synthetic, solid, or semisolid organic material of indefinite and often high molecular weight, with a tendency to flow under stress. It usually has a softening or melting range and usually fractures conchoidally.

Shelf life—Maximum interval during which a material may be stored and remain in a usable and safe condition.

Silane coupling agent—Silicon compounds having the general formula (HO)3SiR were R is an organic group compatible with thermoplastic or thermosetting resins. They are used to enhance the chemical bond of organic polymers to inorganic materials such as sand, rock, glass, and metals.

Slurry overlay—Overlay applied by placing an application of resin or monomer followed by broadcasting aggregate onto the surface.

Solvent—A liquid capable of dissolving another substance.

Thermal-catalytic method—A polymerization method that uses chemical initiators that are dissolved in the monomer before introducing the mixture into the concrete. The subsequent application of external heat then causes the polymerization to occur at a rapid rate.

Thermosetting—Term applied to synthetic resins that solidify or set on heating or curing and cannot be remelted.

Thin polymer overlays (TPOs)—One or more layers of polymer concrete bonded to concrete, normally 1 in. or less in thickness.

Viscosity—Friction within a liquid owing to mutual adherence of its particles. Low-viscosity liquid monomers flow more easily into the pores of concrete at ambient temperatures and pressures than do high-viscosity monomers.

APPENDIX A

Questionnaires

1. NCHRP SYNTHESIS 39-11: PERFORMANCE OF THIN POLYMER OVERLAYS FOR BRIDGE DECKS

Introduction/Background: The National Cooperative Highway Research Program (NCHRP) has requested that a synthesis of polymer overlays for concrete bridge decks be conducted. Thin polymer overlays (TPOs), also referred to as polymer concrete or polymer mortar overlays, which consist of a polymer binder; e.g., epoxies, polyesters, or methacrylates, and aggregates are constructed with a thickness of no more than 1.0 in. They have the advantages of (1) adding very little dead load; (2) very fast cure times; (3) shallow depths that eliminate need for raising approach slabs; (4) transition from overlaid lane to non-overlaid lane during construction; (5) low permeability, (6) long-lasting wearing surface; and (7) frictional resistance. Many TPOs have been installed and it is critically important to summarize their performance in one document.

The intent of this synthesis is to summarize the history and performance of thin polymer overlays over the past 20 years and specifically:

- Summarize the research, specifications, and procedures
- Summarize the performance data based on field applications
- Determine the primary factors that influence the performance of these overlays

Your assistance in responding to this questionnaire is very important to the success of this effort to produce the most accurate and complete synthesis possible. We are asking you to complete the **Agency Questionnaire** below. As well, there is an attached **TPO Questionnaire** asking for information on specific TPOs you have completed. If your agency used its own forces to install a TPO, there are some additional questions on this questionnaire relating to **Agency-as-Installer**.

These questionnaires can be completed on-line. Please save and email back the completed questionnaires to **David Whitney**, whose email address is below.

We particularly appreciate any comments you may have. **Please provide any unpublished reports or documents that you may have related to TPOs.** Please feel free to contact either of us if you have any questions or comments that you would like to discuss:

David W. Fowler
Professor
University of Texas at Austin
dwf@mail.utexas.edu
512 232 2575

David W. Whitney
Manager, Construction Materials Research Lab
University of Texas at Austin
dpwhitney@mail.utexas.edu
512 471 4529

Thin Polymer Overlays

AGENCY QUESTIONNAIRE

1. In which state are you employed?

2. Your name:______________________Phone:________________ Email: _______________________

3. What is your organization?

   ☐ State DOT

   ☐ Other public transportation agency

4. Has your agency constructed one or more thin polymer overlays (TPO)?
   (See the cover letter for a more complete description of TPO.)

   ☐ Yes (Please continue to question 5.)

   ☐ No (If no, you are finished with the survey. Your time and attention are sincerely appreciated. Please send the form back to the email address at the end of the questionnaire.)

5. In what year did you construct your first TPO?

6. How many TPOs has your agency constructed? (Normally one TPO is defined as one bridge; if more than one type TPO is used on a bridge, each type would be a separate TPO.)

7. What was the last year that you constructed a TPO?

8. Do you plan to construct TPOs in the future?

   ☐ Yes

   ☐ No—If no, skip to question 12.

9. For what reasons will you construct TPOs (check all that apply)?

   ☐ To improve skid resistance.

   ☐ To extend life of deck.

   ☐ To surface bridge deck that has been repaired due to spalling or cracking.

   ☐ To provide a uniform surface for appearance.

   ☐ To waterproof the deck.

10. What resin systems will you specify?

11. What method of installation will you specify?

12. If you do not plan to construct additional TPOs, please indicate the reason:

    ☐ Too expensive

    ☐ Poor performance

    ☐ Other (please indicate):

    Please indicate why TPOs were used originally.

Please save and email back the completed questionnaire to **David Whitney**, dpwhitney@mail.utexas.edu.

For specific TPO projects you have completed, we most appreciate you filling out the TPO questionnaire, also attached to the transmittal email.

2. QUESTIONNAIRE TO AGENCIES

Information on each TPO

Please complete the following questions for each TPO your agency has constructed. This can be accomplished by copying the following questionnaire and filling it in as many times as needed. We request that you complete one of the following questionnaires for each different TPO if possible. We need to determine the performance of different polymer systems on different types of bridge decks subjected to different environmental conditions during application and during the life of the TPO. If you are not able to provide information on each TPO, please provide as much information as possible. Feel free to call us if you would like to discuss the information.

Information on original bridge deck

13. State in which TPO is located:

14. Bridge reference name/number/location: ____________ Year constructed ____________

15. Bridge structure: ☐ Prestressed girders ☐ Prestressed box beams ☐ Steel beams
    ☐ Other (describe): ____________________________

16. Substrate was ☐ concrete ☐ steel (If steel go to question 23.)

17. Deck concrete actual compressive strength________ psi or NA ☐

18. Coarse aggregate in deck concrete:
    ☐ Limestone ☐ Silica gravel ☐ Basalt
    ☐ Other

19. Fine aggregate in deck concrete:
    ☐ Silica sand ☐ Limestone fines
    ☐ Other

20. Actual air content: in original deck concrete

    % or NA ☐

21. Condition of deck at time of TPO placement (check all that apply):
    ☐ Sound, no spalls ☐ Low surface friction
    ☐ Corrosion: ☐ Less than 10% of area ☐ 10–25% of area ☐ Over 25%
    ☐ Delaminated: ☐ Less than 10% of area ☐ 10–25% of area ☐ Over 25%
    ☐ Alkali-silica/alkali-carbonate reaction distress: ☐ Yes ☐ No

22. Deicing salt application: ☐ None ☐ Moderate ☐ Heavy ☐ Magnesium chloride

23. Prior deck repairs: ☐ No ☐ Yes If yes, briefly describe

Polymer overlay:

24. Year installed:

25. Was bridge kept in service during TPO installation? ☐ yes ☐ no

26. Contractor contact information

    Please send Questionnaire B to them, or check the box , if you prefer that we send it to him. Researchers send? ☐

27. Number of lanes: ____________ Length:_________ ft. Area of TPO: _________ sq. yd.

28. Nominal thickness: _______ in.

29. Monomer/resin system: ☐ Acrylic; ☐ Epoxy; ☐ Polyester ☐ Other:

30. Resin supplier: _____________________

31. Aggregate type: ____________________

Environment at time of placement:

32. Moisture: ☐ Dry for previous 2 weeks; ☐ Rain during previous 2 weeks;

    ☐ Rain during previous 3 days. ☐ Other:

33. Air Temperature: ☐ Below 50°F ☐ 50 to 70°F ☐ 70 to 85°F

    ☐ Over 85°F

34. Surface preparation: ☐ Sand blast ☐ Shot blast ☐ Milling ☐ Hydro blast

    ☐ Other:

35. Approximate depth removed: ______ in.

Application method:

36. Monomer/resin system mixing method: ☐ Hand ☐ In line mixing

37. Method of application:

    ☐ Resin system mixed and sprayed on deck followed by broadcasting aggregate

    ☐ Resin system mixed and poured on deck followed by broadcasting aggregate

    ☐ Resin system and aggregate premixed and applied to deck

    ☐ Other:

38. Thickness control:
    - ☐ Gauge rakes used to control thickness
    - ☐ Screed guides used with screed or paver to control thickness
    - ☐ Self-leveling (notched squeegees, brooms or rollers used to spread polymer)

39. Number of layers:

40. Curing method: ☐ Ambient conditions ☐ Insulating blankets
    ☐ Other:

41. Original cost: $ __________ /sq. yd.

Other information

42. Estimated additional TPO life prior to significant repairs or removal:____________years

43. Do you have original specifications: ☐ Yes ☐ No

    If yes, please attach a copy of the construction specifications.

44. Describe any problems/spalling/cracking and repairs that have been made in the TPO.

    If you have reports on the TPO installation and/or evaluation please attach.

45. The purpose of the overlay for this bridge was (check all that apply):
    - ☐ Restore frictional resistance. (If so, please give the change in frictional resistance, before and after TPO, if known.)
    - ☐ Provide impermeable surface on sound deck
    - ☐ Provide impermeable surface on deteriorated deck which has been repaired
    - ☐ Restore surface on steel deck
    - ☐ Other: ____

46. Please indicate any recommended changes in your specifications.

Please save your completed form and email back to David Whitney at dpwhitney@mail.utexas.edu. Thank you for your time in this survey. If your agency was an installer on this TPO, please complete the following questions.

Agency-as-Installer Questions

For agencies whose own forces have performed TPO installations, please complete the following questions for each TPO your local agency forces have installed. This can be accomplished by copying the following questionnaire and filling it in as many times as needed. We request that you complete one of the following questionnaires for each different TPO if possible. We need to determine the performance of different polymer systems on different types of bridge decks subjected to different environmental conditions during application and during the life of the TPO. If you are not able to provide information on each TPO, please provide as much information as possible. Feel free to call us if you would like to discuss the information.

47. Name of unit: ____________________ Your name: ____________________

48. Unit's location: ____

49. Phone: ____________________________ Email: __________________________

50. Name/location of bridge: ____

51. Owner: ____

52. Substrate was ☐ concrete ☐ steel (If steel, go to question 10.)

53. Condition of bridge at time of placement:

    ☐ Sound condition ☐ Minor spalling/cracking ☐ Moderate spalling/cracking.

54. Had bridge been previously repaired? ☐ Yes ☐ No

55. Did you perform substrate repairs as part of the overlay project? ☐ Yes ☐ No.

    If "yes," what type of repair material was used?

56. Surface preparation: ☐ sand blast ☐ shot blast ☐ milling ☐ hydro blast

    ☐ Other: ____

57. Overlay application:

    Resin/monomer system: ____

    Mixing method: ____

    Application method: ____

    Number of layers: __________________ Thickness: ____________________ in.

    Type of aggregate: ____

    Method of finishing: ____

    Curing method: __________________ Ambient temperature ____________ °F

58. Problems encountered: ____

59. Recommended changes in specifications/procedures:

Please save your completed form and email back to David Whitney at dpwhitney@mail.utexas.edu. Thank you for your time in this survey.

3. CONTRACTOR QUESTIONNAIRE

NCHRP Synthesis 39-11: Performance of Thin Polymer Overlays for Bridge Decks

Introduction/Background: The National Cooperative Highway Research Program (NCHRP) has requested that a synthesis of polymer overlays for concrete bridge decks be conducted. Thin polymer overlays (TPOs), also referred to as polymer concrete or polymer mortar overlays, which consist of a polymer binder; e.g., epoxies, polyesters, or methacrylates, and aggregates are constructed with a thickness of no more than 1.0 in. They have the advantages of (1) adding very little dead load; (2) very fast cure times; (3) shallow depths that eliminate need for raising approach slabs; (4) transition from overlaid lane to non-overlaid lane during construction; (5) low permeability, (6) long-lasting wearing surface; and (7) frictional resistance. Many TPOs have been installed and it is critically important to summarize their performance in one document.

The intent of this synthesis is to summarize the history and performance of thin polymer overlays over the past 20 years and specifically:

- Summarize the research, specifications, and procedures
- Summarize the performance data based on field applications
- Determine the primary factors that influence the performance of these overlays

Your assistance in responding to this questionnaire is very important to the success of this effort to produce the most accurate and complete synthesis possible. As a contractor, we are asking you to complete the **attached questionnaire**. We particularly appreciate any comments you may have **and would request that you provide any reports or documents that you may have related to TPOs.** Please feel free to contact either of us if you have any questions or comments that you would like to discuss:

David W. Fowler
Professor
University of Texas at Austin
dwf@mail.utexas.edu
512 232 2575

David W. Whitney
Manager, Construction Materials
Research Lab
University of Texas at Austin
dpwhitney@mail.utexas.edu
512 471 4529

Contractor Questionnaire

Please complete the following questions for each TPO you have installed. This can be accomplished by copying the following questionnaire and filling it in as many times as needed. We request that you complete one of the following questionnaires for each different TPO if possible. We need to determine the performance of different polymer systems on different types of bridge decks subjected to different environmental conditions during application and during the life of the TPO. If you are not able to provide information on each TPO, please provide as much information as possible. Feel free to call us if you would like to discuss the information.

1. Name of firm:_______________ Your name:__________________________

2. Location: __________________

3. Phone:______________________ E-mail: _____________________________

4. Name/location of bridge:_____

5. Owner: ___________________

6. Substrate was ☐ concrete ☐ steel (If steel, go to question 10.)

7. Condition of bridge at time of placement:

   ☐ Sound condition ☐ Minor spalling/cracking ☐ Moderate spalling/cracking.

8. Had bridge been previously repaired? ☐ Yes ☐ No

9. Did you perform repairs as part of your contract? ☐ Yes ☐ No

   If "yes," what type of repair material was used?

10. Surface preparation: ☐ sand blast ☐ shot blast ☐ milling ☐ hydro blast

    Other: ____________________

11. Overlay application:

    Resin/monomer system: ____

    Mixing method: ____

    Application method:____

    Number of layers:___________ Thickness: ________________________ in.

    Type of aggregate: ____

    Method of finishing:____

    Curing method: ____________ Ambient temperature ________________ °F

12. Problems encountered:

13. Recommended changes in specifications/procedures:

Please save your completed form and email back to David Whitney at dpwhitney@mail.utexas.edu. Thank you for your time in this survey.

4. MATERIAL SUPPLIER QUESTIONNAIRE

NCHRP Synthesis 39-11: Performance of Thin Polymer Overlays for Bridge Decks

Introduction/Background: The National Cooperative Highway Research Program (NCHRP) has requested that a synthesis of polymer overlays for concrete bridge decks be conducted. Thin polymer overlays (TPOs), also referred to as polymer concrete or polymer mortar overlays, which consist of a polymer binder; e.g., epoxies, polyesters, or methacrylates, and aggregates are constructed with a thickness of no more than 1.0 in. They have the advantages of (1) adding very little dead load; (2) very fast cure times; (3) shallow depths that eliminate need for raising approach slabs; (4) transition from overlaid lane to non-overlaid lane during construction; (5) low permeability, (6) long-lasting wearing surface; and (7) frictional resistance. Many TPOs have been installed and it is critically important to summarize their performance in one document.

The intent of this synthesis is to summarize the history and performance of thin polymer overlays over the past 20 years and specifically:

- Summarize the research, specifications, and procedures
- Summarize the performance data based on field applications
- Determine the primary factors that influence the performance of these overlays

Your assistance in responding to this questionnaire is very important to the success of this effort to produce the most accurate and complete synthesis possible. As a material supplier, we are asking you to complete the **attached questionnaire**. We particularly appreciate any comments you may have **and request that you provide any reports or documents that you**

may have related to TPOs. Please feel free to contact either of us if you have any questions or comments that you would like to discuss:

David W. Fowler
Professor
University of Texas at Austin
dwf@mail.utexas.edu
512 232 2575

David W. Whitney
Manager, Construction Materials Research Lab
University of Texas at Austin
dpwhitney@mail.utexas.edu
512 471 4529

4. Material Supplier Questionnaire

Your name:____________________ Company: ____________________

Phone: ____________________ E-mail: ____________________

How many years have you supplied resins?____________________

Provide information on each resin system you furnish for TPOs:

Resin No. 1:

Type: ☐ Epoxy ☐ Acrylic ☐ P/S ☐ Other: ____________________

Viscosity @ 75°F ______________ cps

Tensile elongation (ASTM D638) __ %

Gel time ____________________ min. and cure time ____________ min @ 75°F

Is cured polymer breathable (allows moisture vapor out of concrete)?

☐ Yes ☐ No

Date first installed as TPO:

Approximately how many bridges?

States used:

Resin No. 2:

Type: ☐ Epoxy ☐ Acrylic ☐ P/S ☐ Other: ____________________

Viscosity @ 75°F ______________ cps

Tensile elongation (ASTM D638) __ %

Gel time ____________________ min. and cure time ____________ min @ 75°F

Is cured polymer breathable (allows moisture vapor out of concrete)?

☐ Yes ☐ No

Date first installed as TPO:

Approximately how many bridges?

States used:

Please save your completed form and email back to David Whitney at dpwhitney@mail.utexas.edu. Thank you for your time in this survey.

APPENDIX B

Stresses In Overlays

Reference: Choi, D., D.W. Fowler, and D.L. Wheat, "Thermal Stresses in Polymer Concrete Overlays," *Properties and Uses of Polymers in Concrete*, ACI Special Publication No. 166, 1996, pp. 93–122.

This reference provides a method for analytically predicting the stresses in TPOs because of temperature changes. The method is facilitated by the graphs that are shown in chapter two, Figures 12, 13, and 14, respectively, for shear, normal and axial stresses. It should be noted that the stresses in these graphs are for one-way or beam elements; for overlays that are two-way elements, the stresses must be multiplied by $1/(1-\mu_o)$, where μ_o is the coefficient of thermal expansion of the overlay.

EXAMPLE: TPO with moderate thickness and low-modulus epoxy resin

The following properties are assumed:

Overlay thickness, $t_o = 0.40$ in. Overlay modulus, $E_o = 100{,}000$ psi

Substrate thickness, $t_s = 8.0$ in. Substrate modulus, $E_s = 4{,}000{,}000$ psi

Overlay thermal coefficient, $\alpha_o = 15 \times 10^{-6}$ in./in./°F

Substrate thermal coefficient, $\alpha_s = 6 \times 10^{-6}$ in./in./°F

Overlay Poisson's ratio, $\mu_o = 0.25$ Temperature drop, $\Delta T = 35$°F

Differential strain between overlay and substrate, $\Delta\varepsilon_T = (\alpha_o - \alpha_s)\,\Delta T$

$\Delta\varepsilon_T = (15 - 6) \times 10^{-6}$ in./in./°F × 35°F = 315 in./in.

Because the stresses shown in chapter two, Figures 12, 13, and 14 are based on $\Delta\varepsilon_T = 500$ in./in., the stresses from the graphs must be multiplied by the ratio of 315/500 = 0.63. Because the graphs were developed for beam elements and the overlay is a two-way system, the stresses must be multiplied by

$1/(1 - \mu_o) = 1/(1 - 0.25) = 1.33$.

From chapter two, Figures 11, 12, and 13, for $t_o/t_s = 0.05$ and $E_o/E_s = 0.025$, find stresses and multiply by modification factors:

Shear stress = 27 psi × 0.63 × 1.33 = 23 psi,

Normal stress = 20 psi × 0.63 × 1.33 = 17 psi,

Axial stress = 76 psi × 0.63 × 1.33 = 64 psi.

EXAMPLE: TPO with greater thickness and high-modulus epoxy resin

The following properties are assumed:

Overlay thickness, $t_o = 1.0$ in. Overlay modulus, $E_o = 2{,}000{,}000$ psi

Substrate thickness, $t_s = 8.0$ in. Substrate modulus, $E_s = 4{,}000{,}000$ psi

Overlay thermal coefficient, $\alpha_o = 12.5 \times 10^{-6}$ in./in./°F

Substrate thermal coefficient, $\alpha_c = 5.5 \times 10\text{-}6$ in./in./°F

Overlay Poisson's ratio, $\mu_o = 0.22$ Temperature drop, $\Delta T = 35°F$

Differential strain between overlay and substrate, $\Delta\varepsilon_T = (\alpha_o - \alpha_s)\,\Delta T$

$\Delta\varepsilon_T = (12.5 – 5.5) \times 10\text{-}6$ in./in./°F × 35°F = 245 in./in.

Because the stresses shown in chapter two, Figures 12, 13, and 14 are based on $\Delta\varepsilon_T = 500$ in./in., the stresses from the graphs must be multiplied by the ratio of 245/500 = 0.49. Because the graphs were developed for beam elements and the overlay is a two-way system, the stresses must be multiplied by

$1/(1 - \mu_o) = 1/(1 - 0.22) = 1.28$.

From chapter two, Figures 12, 13, and 14, for $t_o/t_s = 0.05$ and $E_o/E_s = 0.5$, find stresses and multiply by modification factors:

Shear stress = 309 psi × 0.49 × 1.28 = 194 psi,

Normal stress = 154 psi × 0.49 × 1.28 = 97 psi,

Axial stress = 1070 psi × 0.49 × 1.28 = 672 psi.

Discussion

The two examples illustrate the very significant effect that using high-modulus, thick overlays has on the stresses produced compared with using thinner, low-modulus overlays. These stresses should be compared with the bond strength, shear strength, and the tensile strengths for the overlay as determined by lab tests. The strengths should be divided by an appropriate factor of safety.

APPENDIX C

Warranty And Payment Bond

The manufacturer of the epoxy binder and the Contractor shall jointly and severally furnish a bond for the faithful performance of all obligations imposed upon each by the clauses hereof entitled "Manufacturer's Warranty" and "Contractor's Warranty" and also for the payment of all lawful claims of subcontractors, material men, and workmen arising out of the performance of each such Warranty. Such bond shall be in the form bound herewith entitled "Warranty and Payment Bond," shall be in a penal sum equal to the Lump Sum compensation inserted in the Form of Contract clause entitled "General Agreement" and such bond shall be signed by one or more sureties* satisfactory to the Authority. The bond may be executed on a separate copy of such form not physically attached to this Contract booklet. In any case, both the form of bond bound herewith and any unattached executed copy thereof shall form a part of this Form of Contract as though herein set forth in full.

Submit such bond to the Authority with the Proposal.

* Sureties must be corporations (commonly known as "surety companies"), authorized to do business as sureties in the state(s) in which the construction site is located, whose names appear on the current list of the Treasury Department of the United States in effect at the time of submission of the Warranty and Payment Bond to the Authority as acceptable as sureties to the Treasury Department. In addition, the aggregate underwriting limitations on any one risk as set forth in the aforementioned list of the Treasury Department of the sureties shall equal or exceed the penal sum of the Warranty and Payment Bond.

MANUFACTURER'S WARRANTY

WHEREAS, ______ Name of Manufacturer† ______, Address ______
Telephone ______, FAX ______
manufactured the epoxy binder for Authority Contract LGA-124.058, entitled "La Guardia Airport Wearing Course Installation on Runway Decks"; a copy of said Contract is hereby made a part of this warranty as though set forth in full; and

WHEREAS, the above-named entity has agreed to warrant the Work as such term is defined in Contract LGA-124.058 to the Port Authority of New York and New Jersey, to preserve the performance of the Work against any degradation of performance from the requirements of said Contract during the term of said Contract and for a period of five (5) years from the date of issuance of the Certificate of Final Completion for Contract LGA-124.058; and

WHEREAS, the above-named entity agrees to repair the Work in the event of any degradation of performance of the Work as specified in 3.03 of the Section of the Specifications for Contract LGA-124.058, entitled "Epoxy Overlay," as determined solely by the Manager, La Guardia Airport, and further agrees to commence repair within three (3) calendar days of notification from such Manager of the necessity for such repair and perform such repair operations continuously between the hours of midnight and 6:00 a.m., seven days a week (weather permitting), 365 days per year until completion of each such repair to the satisfaction of the Manager, La Guardia Airport; and

WHEREAS, the above-named entity agrees that no exclusion to this Warranty shall be made for any reason whatsoever; and

WHEREAS, this Warranty shall be deemed to have been made by the above-named entity pursuant to the requirements of Contract LGA-124.058, and with the full knowledge that it would become a part of the records of the Authority and that the Authority will rely on its truth and accuracy in awarding Contract LGA-124.058; and

WHEREAS, the above-named entity agrees to insure its financial viability for the term of Contract LGA-124.058 and the Warranty period thereafter in accordance with the clause of Contract LGA-124.058 entitled "Warranty and Payment Bond";

NOW, THEREFORE, the above-named entity hereby warrants the Work as such term is defined in Contract LGA-124.058, jointly and severally with any other entity which executes a Warranty for the Port Authority of New York and New Jersey with respect to Contract LGA-124.058, jointly and severally with any other entity which executes a Warranty to the Port Authority of New York and New Jersey with respect to Contract LGA-124.058;

IN WITNESS THEREOF, the above-named entity has caused this instrument to be executed by a duly authorized officer.

____

(Type or print name of Manufacturer)

By: ______________________________

(Signature of officer of Manufacturer)

____

(Type or print name of officer of Manufacturer)

____

(Type or print title of officer of Manufacturer)

____

(Type or print date)

† Insert Manufacturer's name. If a corporation, give state of incorporation, using the phrase, "a corporation organized under the laws of the State of ______ ."
If a partnership, give full names of partners, using also the phrase, "co-partners doing business under the firm name of ______ ."
If an individual using a trade name, give individual name, using also the phrase, "an individual doing business under the trade name of ______ ."

CONTRACTOR'S WARRANTY

WHEREAS,____________________(Name of Contractor)‡________________, Address __________________,
Telephone ____,
FAX ____, entered into a Contract in writing with the Authority, a copy of which is hereby made a part of this warranty as though set forth in full and which is designated Contract LGA-124.058 entitled "La Guardia Airport Wearing Course Installation on Runway Decks"; and

WHEREAS, the above-named entity has agreed to warrant the Work as such term is defined in Contract LGA-124.058 to the Port Authority of New York and New Jersey, to preserve the performance of the Work against any degradation of performance from the requirements of said Contract during the term of said Contract and for a period of five (5) years from the date of issuance of the Certificate of Final Completion for Contract LGA-124.058; and

WHEREAS, the above-named entity agrees to repair the Work in the event of any degradation of performance of the Work as specified in 3.03 of the Section of the Specifications for Contract LGA-124.058, entitled "Epoxy Overlay," as determined solely by the Manager, La Guardia Airport, and further agrees to commence repair within three (3) calendar days of notification from such Manager of the necessity for such repair and perform such repair operations continuously between the hours of midnight and 6:00 a.m., seven days a week (weather permitting), 365 days per year, until completion of each such repair to the satisfaction of the Manager, La Guardia Airport; and

WHEREAS, the above-named entity agrees that no exclusion to this Warranty shall be made for any reason whatsoever; and

WHEREAS, this Warranty shall be deemed to have been made by the Contractor pursuant to the requirements of Contract LGA-124.058, and with the full knowledge that it would become a part of the records of the Authority and that the Authority will rely on its truth and accuracy in awarding Contract LGA-124.058; and

WHEREAS, the above-named entity agrees to insure its financial viability for the term of Contract LGA-124.058 and the Warranty period thereafter in accordance with the clause of Contract LGA-124.058 entitled "Warranty and Payment Bond";

NOW, THEREFORE, the above-named entity hereby warrants the Work as such term is defined in Contract LGA-124.058 jointly and severally with any other entity which executed a Warranty to the Port Authority of New York and New Jersey with respect to Contract LGA-124.058;

IN WITNESS THEREOF, the above-named entity has caused this instrument to be executed by a duly authorized officer.

____

(Type or print name of Contractor)

By: ____

(Signature of officer of Contractor)

____

(Type or print name of officer of Contractor)

____

(Type or print title of officer of Contractor)

____

(Type or print date)

‡ Insert Manufacturer's name. If a corporation, give state of incorporation, using the phrase, "a corporation organized under the laws of the State of ________ ."
If a partnership, give full names of partners, using also the phrase, "co-partners doing business under the firm name of ______________________________ ."
If an individual using a trade name, give individual name, using also the phrase, "an individual doing business under the trade name of ________________ ."
If a joint venture, insert name as appropriate for one participant of the joint venture on this page and attach and complete an additional page in the same form as spears on this page for each other participant as required.

Abbreviations used without definition in TRB Publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETY-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

TRANSPORTATION RESEARCH BOARD
500 Fifth Street, N.W.
Washington, D.C. 20001

ADDRESS SERVICE REQUESTED

THE NATIONAL ACADEMIES™

Advisers to the Nation on Science, Engineering, and Medicine

The nation turns to the National Academies—National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council—for independent, objective advice on issues that affect people's lives worldwide.

www.national-academies.org

ISBN: 978-0-309-14354-7

90000

9 780309 143547