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SUPERIORITY & CONSTRUCTABILITY OF FIBROUS ADDITIVES FOR BRIDGE DECK OVERLAYS

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16. Abstract

Concrete overlays are highly susceptible to cracking due to the large surface area that is exposed to drying, the low water to cement ratio, the environmental exposure and loading conditions, the reflected cracks the underlying bridge deck, and the small thickness of the overlay. This research project investigated the potential benefits of synthetic fibrous additives with regard to the performance of bridge deck concrete overlays. Determining practical dosages and types of synthetic fibers that have the ability to enhance overlay performance, while maintaining convenient constructability without complications during mixing and finishing, was a major mission of this research. The project also outlined critical issues essential for successful and durable overlay applications with minimal cracking and delaminations. Various micro- and macro-fiber combinations were added to the fibrous overlay mixtures, resulting in 13 fibrous mix designs (nine LMC, two MSC, and two FAC). An extensive experimental laboratory program was then conducted to evaluate the major performance characteristics of each overlay mix design in terms of workability and finishability, compressive and flexural strengths, shrinkage, toughness, permeability, and bond strength. For further evaluation of the constructability of fibrous overlay—taking into consideration actual field conditions—demonstration bridges were selected and received fibrous overlays through actual IDOT contracts. Life-cycle cost analyses were also conducted to assess potential savings from incorporating fibrous additives within the concrete overlays. This research is pioneering in terms of using fibrous FAC overlay, which could be a potentially sustainable overlay system for preserving bridge decks with lower cost and minimized adverse environmental impact.

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EXECUTIVE SUMMARY

Protective overlays on bridge decks help prevent penetration of chloride into the decks resulting from heavy application of deicers and consequent corrosion and deterioration problems. The overlay also provides wear resistance and good riding quality. The current practices by many U.S. transportation agencies require new bridges to receive a protective overlay system. In addition, of the 600,000-plus bridges in the United States, many are in critical need of a new overlay system as part of a comprehensive rehabilitation program.

Maintaining adequate functionality for a bridge deck throughout its service life requires an overlay with superior performance characteristics. Latex-modified concrete (LMC) and microsilica concrete (MSC) are the most common types of bridge deck concrete overlays. Concrete overlays have low permeability and good performance properties. However, in many projects, cracks in LMC and MSC overlays were noticed shortly after installation despite the use of mix designs with verified performance and strict quality control and assurance practices. These cracks could be attributed to one or a combination of factors including the large surface area that is exposed to drying (i.e., high plastic and drying shrinkage), the low water to cement ratio (i.e., minimal bleeding water to prevent plastic shrinkage), effects of environmental exposure (i.e., application of deicers, freeze–thaw cycles, and temperature variations), effects of the loading conditions (i.e., wear and tear due to live load and impact), influence of the cracks and deterioration in the underlying bridge deck, and the thickness of the overlay, which is typically only 2¼ in. These factors impose a critical stress condition in the thin overlay and bond interface, which causes common cracking and delaminations.

Accordingly, it was recognized that there is a need to enhance the performance of concrete overlays. A potential method is to incorporate discontinuous synthetic fibers within the overlay mix design. Synthetic fibers are noncorrosive, alkali resistant, simple to apply, and typically added in small quantities due to their low density. Therefore, a substantial number of uniformly distributed fibers are added. A few studies have been conducted to investigate the influence of fibers on the performance of bridge deck concrete overlays. Although some potential advantages were noticed, the studies were limited to laboratory investigations and did not address critical issues such as the optimum fiber content that can enhance performance without jeopardizing the constructability of the overlay.

This research project investigated the potential benefits of synthetic fibrous additives with regard to the performance of bridge deck concrete overlays. The benefits include minimizing shrinkage cracking and providing toughness and post-cracking residual strength, thus increasing resistance to cracking. Illinois Department of Transportation (IDOT) concrete overlays typically achieve 12 to 20 years of service life; however, it would be more economical if the use of fibrous additives could extend the service life of IDOT overlays. Determining practical dosages and types of synthetic fibers that have the ability to enhance overlay performance, while maintaining convenient constructability without complications during mixing and finishing, was a major mission of this research. The project also outlined critical issues essential for successful and durable overlay applications with minimal cracking and delaminations. To assess the involved parameters and factors, a 3-year systematic research program was implemented through extensive laboratory investigations and field demonstrations.

The scope of this research project included ten major tasks. Initially, the relevant literature and practices of U.S. transportation agencies were reviewed to identify reasons for cracking and to learn from any previous experience with using fibrous additives in concrete overlays. Then, target performance criteria were established to design LMC, MSC, and a

newly proposed fly ash concrete (FAC) overlay mixtures, in accordance with IDOT guidelines and requirements. After that, different types and dosages of synthetic fibers were selected based on the findings of the literature review and after careful review of the technical data sheets of various fiber companies. Seven representative fiber types were identified including micro- and macro-fibers. Various fiber contents including a single macro-fiber type and a combination of macro- and micro-types were added to the fibrous overlay mixtures, resulting in 13 fibrous mix designs (nine LMC, two MSC, and two FAC).

An extensive experimental laboratory program was then conducted to evaluate the major performance characteristics of each overlay mix design in terms of workability and finishability, compressive and flexural strengths, shrinkage, toughness, permeability, and bond strength. Analyses of the test results were conducted, and recommendations of fibrous additives were drawn accordingly. For further evaluation of the constructability of fibrous overlay—taking into consideration actual field conditions—demonstration bridges were selected and received fibrous overlays through actual IDOT contracts. Life-cycle cost analyses were also conducted to assess potential savings from incorporating fibrous additives within the concrete overlays.

Based on the results and findings of this project, the total recommended synthetic fiber content is 3 lb/yd^3. Fiber contents greater than 3 lb/yd^3 result in serious constructability issues such as fiber balling and clumping during the placing and finishing procedures. The results showed very promising benefits of fibrous additives on the performance of concrete overlays. The major notable performance enhancements include significant reduction in the drying shrinkage, adding post-cracking residual strength, and providing internal confinement, resulting in a slight increase in the flexural strength and improved compression failure mode. For mixtures with similar total fiber content, the workability and finishability were better when macro- and micro-fibers were combined, compared with use of a single macro-fiber. The mesh-type configuration of synthetic macro-fibers showed complications during the mixing and finishing processes. The workability of the fibrous LMC overlay mixtures was better than the workability of the companion fibrous MSC and FAC. The drying shrinkage strains of the LMC mixtures were significantly higher than the companion MSC and FAC mixtures due to the short moist-curing period of the LMC. However, the high drying shrinkage strain of the LMC is usually balanced by the inherent flexibility provided by latex polymerization. At the end of the specified curing period for each overlay type, the compressive and flexural strengths of the studied LMC, MSC, and FAC mixtures exceeded the 14-day requirement of 4000 psi and 675 psi, respectively. The use of hydro-demolition for deck surface preparation resulted in strong adhesion between the overlay and the deck.

This research is pioneering in terms of using fibrous FAC overlay, which could be a potentially sustainable overlay system for preserving bridge decks with lower cost and minimized adverse environmental impact. The use of fly ash in the FAC mix design complies with one of the major sustainability goals of minimizing adverse environmental impact of fly ash disposal and CO_2 emissions resulting from the reduced amount of cement. The performance characteristics of the proposed FAC overlay mix design were quite comparable to the performance of the LMC and MSC, except for the coulomb permeability (low permeability class for the FAC compared with very low permeability class for the LMC and MSC).

It is expected that the encouraging findings of this project will demonstrate (to IDOT and other U.S. highway agencies) the potential benefits of using fibrous concrete overlays. Fibrous additives and overlay type can be selected by a transportation agency based on the nature and importance of the project and the availability of local overlay contractors to minimize the cost.

CONTENTS

CHAPTER 1 RESEARCH DESCRIPTION

1.1 INTRODUCTION

The high cost to repair a large number of deteriorated bridge decks in the United States dictates an optimum protection strategy. Protective overlays prevent the penetration of chloride ions resulting from intensified application of deicers and consequent corrosion and deterioration in bridge decks. A protective overlay also reduces wear and provides good riding quality. Keeping a bridge deck system in excellent performance condition and free of cracking and deterioration by using overlays with superior performance characteristics is more cost effective than using conventional overlays. Cementitious bridge deck overlays have had limited success due to concerns about initial cost, constructability, and relative performance compared to hot-mix asphalt (HMA) overlays. Previous experience with concrete overlays, in general, showed that in many cases, they showed severe cracking and delaminations within a few years after construction. Consequently, additional research is needed to outline critical issues related to successful and durable application of cementitious bridge deck overlays.

Latex-modified concrete (LMC) and microsilica concrete (MSC) are the most well-known types of bridge deck concrete overlay and have a typical thickness of 2¼ in. These overlay types are favorable due to their low permeability and high performance strength and durability aspects, which provide optimum protection to the underlying bridge deck. However, many studies showed that cracks in LMC and MSC overlays were noticed shortly after installation, although high-quality control and assurance practices (QC/QA) were imposed. These cracks were attributed to the large surface area of the overlay that is exposed to drying, the low water to cement ratio, and the small typical thickness. These factors impose a very critical stress condition in the thin overlays and at the bond interface with the underlying bridge deck, which causes common cracking.

A potential procedure to the cracking problems in concrete overlays is to incorporate discontinuous synthetic fibers within their mix designs to prevent early age cracking and add toughness and crack-arresting characteristics. Synthetic fibers are typically added in small quantities without the need to modify the mix design proportions. In addition, because of their low specific gravity and very small diameters, a substantial number of single fibers are added for such small weights, resulting in a homogeneous fiber distribution. Furthermore, synthetic fibers (typically polypropylene or nylon-based fibers) have high strength properties and are alkali resistant. Few studies evaluated the influence of fibers on the performance of concrete overlays, especially in LMCs. Although some potential advantages were recorded, the studies lacked critical parameters such as identifying the optimum fiber content that will provide balance between performance and constructability. Also, the previous studies did not consider the wide range of fiber types and the possibility of using fiber combinations.

1.2 OBJECTIVES

The principal objectives of this research project were to (1) systematically and reliably evaluate the potential advantages of incorporating synthetic fibers within the mix designs of bridge deck concrete overlays and (2) outline critical issues essential for successful and durable overlay applications with minimal cracking and delaminations. Additionally, a fibrous concrete overlay must be constructable without complications during mixing and finishing. The study also investigated the potential use of fly ash concrete (FAC) as a new overlay system and included a life-cycle cost analysis of the potential savings when utilizing fibrous concrete overlay instead of plain overlay.

1.3 SCOPE

To accomplish the research objectives, the following major tasks were carried out over a 3-year period (January 2009–December 2011):

- Task 1: Review relevant literature and examination of the practices of U.S. DOTs
- Task 2: Establish target performance criteria
- Task 3: Design LMC, MSC, and FAC overlay mixtures without fibrous additives
- Task 4: Select different types of fibrous additives
- Task 5: Proportion LMC, MSC, and FAC overlay mixtures with fibrous additives
- Task 6: Evaluate the mixtures' performance characteristics
- Task 7: Analyze test results and recommend fibrous additives
- Task 8: Install selected fibrous overlays on demonstration bridges
- Task 9: Conduct life-cycle cost analysis
- Task 10: Submit final report

1.4 RELEVANT STUDIES

The majority of the available studies regarding bridge deck concrete overlays were reviewed. The reviewed studies consisted of technical papers and reports, experience and observations of U.S. DOTs, and information obtained from fiber companies and overlay suppliers.

It is important to recognize that it was not until 2002 that states realized the importance of surface preparation in concrete overlay performance. The majority of the reported cracking problems and delaminations in concrete overlays before 2002 can be attributed primarily to poor bonding with the underlying bridge deck. With the use of hydro-demolition as a deck surface preparation method, this problem has been resolved and optimum bonding is typically achieved. Therefore, the focus of this research is on the states' practices over the past 10 years and what states are doing with fibers today. A summary of the findings of the studies before 2002 can be found in Issa (2004) and Alhassan (2007).

A limited number of studies on the use of fibrous additives in concrete overlays are documented in the existing literature. Issa (2004) conducted a research project funded by IDOT to develop overlay materials for the new Mississippi River bridge. The findings of that research project were also published in several refereed publications (Issa, Alhassan, and Shabila 2007, 2008; Alhassan and Issa 2008, 2010). The synthetic fiber type evaluated was a macro-type polypropylene fiber (1.55 in. long), and the recommended dosage for both LMC and MSC overlays was 5 lb/yd^3. The company that produces this fiber type recommends a minimum dosage of 4 lb/yd^3 if residual strength greater than 20% of the modulus of rupture is needed.

For the Dan Ryan project, Chicago, Illinois, MSC overlay with the macro-type polypropylene fiber was selected. The Dan Ryan project included two contracts. The first contract (number 62580) was let on November 18, 2005, Item 78.This contract included 14 structures on the NB FAI 90/94 from 15th Street to 28th Street. The quantity of the installed fibrous MSC overlay was 98,764 yd^2. The fiber content was initially specified at 4 lb/yd^3 and then revised to 3 lb/yd^3 in the field. The numbers of the included structures were 016-0137, 1047, 1059, 1070, 1110, 1111, 1112, 1113, 1114, 1115, 1116, 1117, 1118, and 1140. The second contract (number 6258) was let on August 4, 2006, Item 1P. This contract included eight structures on SB FAI 90/94 from 15thStreet to 28th Street. The quantity of the installed fibrous MSC overlay was 102,774 yd^2. The fiber content was specified at 3 lb/yd^3. The numbers of the included structures were 016-0137, 1050, 1062, 1110, 1112, 1114, 1116, and 1117. Trial batches were used to determine the amount and loading procedure of the fibers. A 24 ft × 12 ft × 2½ in. demonstration pour location was formed by the contractor finishers. The demonstration was witnessed by Dan Tiltges (IDOT Materials-Mixture Control) as well as representatives of the overlay contractor, concrete suppliers, and the fiber producer. The following is an excerpt from the report prepared by Dan Tiltges on May 24, 2006:

> The results of this trial batch were similar to the previous two except no strength specimens were made. As for surface quality of the concrete, fibers at 4 lb/yd^3 seem to make for a non-uniform finish. On the jobsite, finishers are unable to use a Bidwell burlap drag as well as a long magnesium bow float. These two finishing procedures pulled up large amounts of fibers to the surface. Also at 4 lb/yd^3 it seems there is a greater potential for the balling of fibers in concrete since none or very few were seen during the first two pours at 2.5 lb/yd^3. The smaller aggregate in the microsilica mix may be incapable of breaking up clumps of fibers when added at 4 lb/yd^3. If on future pours balling of fibers becomes present, IDOT construction should document the amount found for each truck per pour. Some truck mixers also may be unable to properly mix fibers into concrete and these trucks should not be allowed back onto jobsite.

In the case of LMC overlay, due to its short working time (15–30 minutes), mobile mixers must be used. This requires a special procedure to feed the fibers within the LMC overlay mixture. In the MSC and FAC overlays, the fibers can be added at the plant because ready-mixed concrete trucks are used. In 2007, a study was conducted by Issa et al. (Issa, Alhassan, and Ramos 2007) where alkali-resistant glass fibers (ARGF) were added to cast LMC overlay using a mobile mixer. This fiber type is manufactured in rolls that can be adapted to a fiber feeder system. The feeder system chops the fibers at ¾ in. length and distributes them within the LMC through a pipe under pressurized air. There are two limitations with the system: (1) only one type of fiber can be adapted to the system, and (2) the maximum fiber content that can be fed to the mix using this system is around 2 lb/yd^3. This seems to be low, especially when considering that the specific gravity of the ARGF is 2.6. The study showed that, although this low-volume fraction did not provide any significant residual strength, it helped reduce shrinkage of the LMC (Issa, Alhassan, and Ramos 2007).

In 1994, a research project was initiated by the South Dakota Department of Transportation (SDDOT) to study the use of 3M's polyolefin fibers (nonmetallic, fiber-reinforced concrete, NMFRC) in several applications (Ramakrishnan and Santhosh 2000). One application incorporated these fibers in the bridge deck overlay concrete for the structure at Exit 212 over I-90 (I-90/US83). As a result of the 1994 study, it was found that the fiber deck overlay performed favorably. Therefore, because of the fibers' ability to greatly enhance the concrete's structural properties, the SSDOT decided to include these fibers in the deck overlay concrete for the two severely deteriorated bridge decks at Exit 32 on I-90 (I-90/SD79). The department hoped that the overlays would extend the life of these decks for 7 years from the time of construction (to about 2004). As a result of the study of the fiber concrete bridge deck overlays, which were constructed in 1997, it was recommended that fiber concrete overlays be considered not only on badly deteriorated bridge decks but on a case-by-case basis for all bridges (Ramakrishnan and Santhosh 2000).

1.4.2 Survey Summary

The practices of various U.S. transportation agencies in terms of using fibrous additives within concrete overlays were surveyed. The mailed survey and the responses received are provided in Appendix A. There were a total of 28 responses to the survey: 26 submitted by U.S. DOT representatives and two submitted by representatives from Canada. Two states had multiple responses; the response with more input was used.

The survey showed that none of the states that responded are using fibrous LMC in their overlays, although previous trial experiments with fibrous LMC received overall good feedback. The service life of the LMC overlays was estimated to be 20 to 40 years.

Few states used MSC with fibers. Michigan has used nonmetallic synthetic fibers within the MSC overlays on more than 1000 projects. The fibrous mixtures showed good overall performance. The service life was estimated to be 10 to15 years. There was no agreement among the five states who responded to the question about best overlay type with fibers. Michigan chose MSC over LMC. Delaware and Virginia recommend fibers at low dosages. Kansas did not see any advantage from the fibers in their trial project. Oregon and Alberta recommended the use of steel fibers. Several commenters indicated interest in the current research as a source of additional information as they consider the possible use of nonmetallic fibers in their overlay mixtures.

The responses about the cost of LMC and MSC overlays had a wide range of values, with inconsistent values in many cases; therefore, no conclusions could be drawn. Accordingly, for the life-cycle cost analysis in the current project, the cost of the LMC and MSC overlays that had been installed in Illinois were obtained and used.

CHAPTER 2 MIX DESIGNS AND PERFORMANCE CRITERIA

2.1 INGREDIENTS AND MINIMUM PERFORMANCE REQUIREMENTS

The IDOT specifications (IDOT 2007, 2009) require the following minimum units of measure and performance requirements for bridge deck concrete overlays:

- **Bridge Deck LMC Overlay:** The LMC overlay mix design shall contain 658 lb/yd^3 Type I portland cement, 24.5 gal/yd^3 latex admixture, coarse aggregate between 42% and 50% by weight (mass) of total aggregate, and 157 lb/yd^3 maximum water content including the free moisture on the aggregates but not including the water in the latex admixture. The LMC overlay mixture shall have a slump between 3 and 6 in. measured after 5 minutes from discharge, 7% maximum air content, and water to cement ratio (w/c) between 0.30 and 0.40 considering all the nonsolids in the latex admixture as part of the total water (typically between 46% and 52%). Water reducers and air-entraining admixtures are prohibited. The latex in the LMC acts as plasticizing agent in the fresh state, and when polymerized, it provides membrane around the concrete particles, which is responsible for providing low-permeable concrete and inherent flexibility for freeze and thaw resistance.
- **Bridge Deck MSC Overlay:** The MSC mix design shall contain 565 lb/yd^3 Type I portland cement, 33 lb/yd^3 microsilica solids, 0.37 to 0.41 water to cementitious materials ratio (w/cm) (including water in the slurry), and 0.88 to 0.92 mortar factor (MF). When fibers are added, the upper limit of the MF criterion can be increased to 0.99. Water reducers and air-entraining admixtures are allowed to achieve 3 to 6 in. slump and 5% to 8% air content.
- **Bridge Deck FAC Overlay:** At the beginning of this project, there were no IDOT provisions for the FAC overlay mix design. Therefore, the research team and the IDOT bridge office established tentative guidelines for the FAC overlay mix design for this study. The tentative guidelines state that when fly ash is used, the amount of cement replaced shall be 15% by weight (mass) at a replacement ratio of 1.5:1, regardless of the type of fly ash used. The FAC mix design should contain 455 to 515 lb/yd^3 Type I portland cement, 140 to 150 lb/yd^3 Class C fly ash, 0.37 to 0.39 w/cm, and 0.88 to 0.92 MF. When fibers are added, the upper limit of the MF criterion can be increased to 0.99. Water reducers and air-entraining admixtures are allowed to achieve 3 to 6 in. slump and 5% to 8% air content. It is important to note that these tentative guidelines do not compare with current IDOT provisions for the FAC overlay mix design, nor do they compare with the FAC overlay mix design used in one of the demonstration projects listed in Chapter 4.
- **Minimum Performance Requirements:** For the three overlay types, IDOT specifications require 4000 psi and 675 psi minimum compressive and flexural strengths at 14 days, respectively, and direct tensile bond strength greater than 175 psi before opening the overlay to traffic. Crack-free overlay is also a target objective, especially under the influence of plastic and drying shrinkage. Also, construction of the fibrous overlay in terms of mixing, placing, and finishing must be practical, without fiber clumping or balling problems.

2.2 PLAIN MIX DESIGNS

Based on the above requirements, the LMC, MSC, and FAC mix designs shown in Tables 2.1 through 2.3 are proportioned. Type I portland cement is used in all mix designs along with coarse and fine aggregates from the same source and approved by IDOT. The maximum coarse aggregate size is 3/8 in. The cement content in the LMC mix design is equal to the total cementitious material (CM) content in the FAC mix design. The total CM content in the MSC mix design is about 10% lower than the LMC and FAC mix designs. Low water to cementitious materials ratio (w/cm) was used for all mixtures, which make them a particular category of high-performance concrete. The mix designs are based on saturated surface dry condition of the fine and coarse aggregates with specific gravities of 2.65. According to the latex manufacturer, the latex contains 52% water and 48% solids, which is considered in the w/c. The anticipated air contents in the three overlay mix designs were considered in the volumetric proportioning. In the MF calculation, the void content within the coarse aggregate was assumed to be 40%. The plasticizing agents in the MSC and FAC mix designs included water reducer added initially to achieve about 1.5 in. slump and followed by superplasticizer to achieve the required slump, in accordance with IDOT specifications. The MSC and FAC mix designs have the same coarse aggregate content and almost the same w/cm ratio.

Table 2.1. LMC Overlay Mix Design

Ingredient	Quantity/yd^3
Air content	5%
Type I portland cement	658 lb
Fine aggregate	1390 lb
Coarse aggregate	1390 lb
Styrene butadiene latex	24.5 gal
Water	135lb
w/c ratio	0.37
Mortar factor (MF)	1.34

Table 2.2. MSC Overlay Mix Design

Ingredient	Quantity/yd^3
Air content	6.5%
Type I portland cement	425 lb
Slag	145 lb
Microsilica solids	33 lb
Fine aggregate	1340 lb
Coarse aggregate	1690 lb
Water	230 lb
w/cm ratio	0.38
Mortar factor (MF)	0.99

Table 2.3. FAC Overlay Mix Design*

Ingredient	Quantity/yd^3
Air content	6.5%
Type I portland cement	515 lb
Class C fly ash	140 lb
Fine aggregate	1260 lb
Coarse aggregate	1690 lb
Water	240 lb
w/cm ratio	0.37
Mortar factor (MF)	0.99

*This is the FAC mix selected for the study, but it does not match the specifications in Appendix B because there were not IDOT specifications for this mix design at the onset of this study.

2.3 FIBROUS MIX DESIGNS

2.3.1 Selection of the Fibrous Additives

The intent of adding fibers to the bridge deck concrete overlays was to minimize cracking and provide a crack-arresting mechanism that would result in residual strength and control of crack widths to a hairline scale. However, the addition of fibers should not lead to adverse effects on the workability and constructability of the overlay. Therefore, the fiber type and dosage have to be optimized so that the intended advantages are achieved while maintaining adequate constructability of the concrete overlay. As experienced by IDOT, bridge deck concrete overlays with fiber contents greater than 3 lb/yd^3 of polypropylene-type fibers are hard to finish due to fiber clumping and balling problems. Consequently, the total fiber content within each overlay mix was limited to 3 lb/yd^3.

To select fiber types with potential benefits, the technical supporting engineers and technical data sheets of selected fiber companies were consulted. The experiences of concrete suppliers in Illinois and Indiana were also considered. The key aspects considered in the fiber selection were (1) ability to minimize plastic and early drying shrinkage cracking, (2) ability to add toughness and residual strength, and (3) dosage of the fiber to ensure constructability of the fibrous overlay. Based on these considerations and previous experience documented in literature, seven synthetic micro- and macro-fiber types were selected. Their brand names are omitted to avoid commercialization. Table 2.4 shows the major properties of the selected fiber types as provided by the manufacturers, while Figure 2.1 contains pictures of the fiber types.

Table 2.4. Major Properties of the Selected Fiber Types

Fiber	Type	Configuration	Length	S.G.	Elastic Modulus	Tensile Strength	Durability
ARGF*	Macro-type glass fiber	Monofilament	¾ in. (19 mm)	2.68	10,000 ksi (69 GPa)	250 ksi (1,720 MPa)	Alkali resistant
SX	Macro-type polyolefin fiber	Monofilament	1.55 in. (40 mm)	0.92	1,378 ksi (9.5 GPa)	90 ksi (620 MPa)	High alkali, acid, and salt resistance
GF	Micro-type 100% virgin	Collated-fibrillated	¾ in. (19 mm)	0.91	500 ksi (3.45 GPa)	90 ksi (620 MPa)	
GMF	Ultrathin micro-type 100% virgin	Resin-bundled monofilament	¾ in. (19 mm)	0.91	500 ksi (3.45 GPa)	90 ksi (620 MPa)	
NXL	Macro-type polyolefin fiber	Collated-fibrillated	1½ in. (38 mm)	0.91	—	90–100 ksi (620-690 MPa)	Chemically stable
RF	Macro-type poly-vinyl alcohol (PVA) fiber	Monofilament	1.18 in. (30 mm)	1.3	—	130.5 ksi (900 MPa)	
RSC	Micro-type polyvinyl alcohol (PVA) fiber	Resin-bundled monofilament	1.18 in. (30 mm)	1.3	—	203 ksi (1,400 MPa)	

*Fabricated in 40-lb rolls and through a special feeder system adaptive to any volumetric truck, including mobile mixers, the fibers are chopped at ¾-in. length and uniformly distributed to the concrete. Currently, the maximum dosage that can be added is around 2 lb/yd^3. Industry can adapt equipment to achieve desired dosage rates.

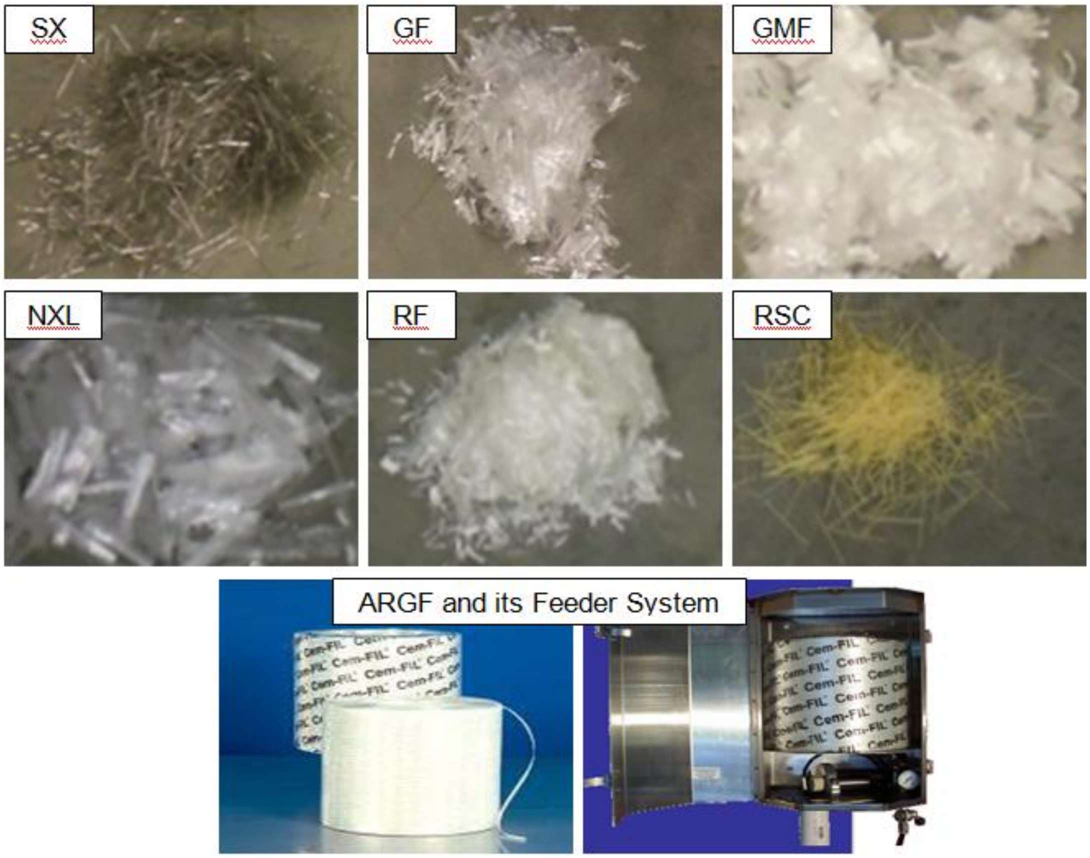

Figure 2.1. Pictures of the seven selected fiber types described in Table 2.4.

2.3.2 Proportioning of the Overlay Mixtures with Fibrous Additives

As outlined previously, IDOT's experience with the fiber content revealed that concrete overlay mixtures with fibers ratios greater than 3 lb/yd^3 of polypropylene type fibers are hard to place and finish, as documented in the recent Dan Ryan overlay project. The volumetric fraction of the fibers is relatively small within the mix design; however, it affects the performance and constructability significantly. Fibers are generally classified into two categories: macro-fibers and micro-fibers. Macro-fibers are sometimes referred to as structural fibers and are intended to carry load and therefore are used to replace traditional reinforcement in certain nonstructural applications as well as minimize and/or eliminate both early and late age cracking. Typical lengths for macro-fibers are greater than or equal to 1.5 in. Micro-fibers are generally utilized to minimize early age cracking. This category of fibers is generally classified according to length, although sometimes the diameter and/or aspect ratio are considered. Therefore, some mixtures were proportioned with single fiber type, while others included a combination of macro- and micro-fiber types, as shown in Table 2.5.

The selected combinations of fibers take into consideration the recommended percentages by each producer for each type of fiber for economic and constructability considerations. A total of 13 fibrous mix designs (nine LMC, two MSC, and two FAC) were proportioned. In the designations used for the fibrous mix designs, the numbers and letters after the mix type represent the fiber types and dosages in lb/yd^3. For example, LMC-3SX indicates LMC with 3 lb/yd^3 of SX, and LMC-2SX+1GF indicates LMC with 2 lb/yd^3 of SX plus 1 lb/yd^3 of GF. The plain mixtures were used as base mixtures for the fibrous mixtures.

The macro- and micro-fibers that are supplied by the same manufacturers are combined within the same mix design.

Table 2.5. Fibrous Mix Designs

Mix Type	Mix Designation	Fiber Type	Ratio
LMC	LMC-Plain	Plain	No fiber
	LMC-2ARGF	ARGF	2.0 lb/yd^3
	LMC-3SX	SX	3.0 lb/yd^3
	LMC-2SX+1GF	SX+GF	2.0 lb/yd^3+1.0 lb/yd^3
	LMC-2SX+0.5GF		2.0 lb/yd^3+0.5 lb/yd^3
	LMC-2SX+1GMF	SX+GMF	2.0 lb/yd^3+ 1.0 lb/yd^3
	LMC-2SX+0.5GMF		2.0 lb/yd^3+ 0.5 lb/yd^3
	LMC-2RF+1RSC	RF+RSC	2.0 lb/yd^3+ 1.0 lb/yd^3
	LMC-3NXL	NXL	3.0 lb/yd^3
	LMC-2NXL+1RSC	NXL+RSC	2.0 lb/yd^3+ 1.0 lb/yd^3
MSC	MSC-2SX+1GF	SX+GF	2.0 lb/yd^3+ 1.0 lb/yd^3
	MSC-3NXL	NXL	3.0 lb/yd^3
FAC	FAC-2SX+1GF	SX+GF	2.0 lb/yd^3+ 1.0 lb/yd^3
	FAC-3NXL	NXL	3.0 lb/yd^3

2.4 MIXING AND CURING OF TEST SPECIMENS

Trial batches were constructed from each overlay mix type (LMC, MSC, and FAC) without fibers to verify the fresh concrete properties, primarily in terms of slump and air content. In addition, the trial batches were important to gain confidence about the adequacy of the latex content in the LMC mix design and to show the research team the allowable working time before the latex starts to polymerize. Stationary drum-type lab mixers were used. The batch size was 3 ft^3. After calibrating the plain mix designs, new batches were made from a typical fibrous mixture to check on the uniformity and consistency of fiber distribution. The fibers were manually distributed within the mixer, and the fibrous mixture was discharged after it had been ensured that the fibers were uniformly distributed within the mixture.

Following the trial batches, several batches were made from each mix design to cast the required number of test specimens. All the specimens were cast in accordance with the relevant ASTM standards (ASTM 2008). Consistency, uniformity of fiber distribution, and finishing ability were recorded. The specimens were covered with wet burlap and plastic sheets for 24 hr before being demolded and moist-cured in a standard moisture room, in accordance with to IDOT requirements. The LMC overlay mixtures were moist-cured for 2 days followed by 2 days of air-curing in the lab environment. The MSC and FAC overlay mixtures were moist-cured for 7 days. The specimens were considered moist-cured for 1 day while in the molds.

A similar mixing procedure was followed for all mixtures of the same overlay type to maintain consistency. The coarse aggregate was introduced first to the mixer, followed by the fine aggregates. The aggregates were dry mixed for approximately 3 minutes. The cement was then added, followed by the supplementary cementitious materials, if any. The materials were then mixed with approximately 50% of the mixing water. The rest of the water was then added gradually. For the LMC mixtures, the latex was added before the remaining water. For the MSC and FAC mixtures, the water reducer was added to the water to bring the slump to about 1.5 in., after which superplasticizer and air-entraining admixture were added to achieve the required slump and air content. The final step was to manually and carefully introduce the fibers to ensure uniform distribution as expected from a typical dispensing system. Additionally, the mixtures were mixed for about 3 minutes after introducing the fibers to ensure homogeneous fiber distribution. The concrete was then discharged, the plastic properties were measured, and the required specimens were prepared.

2.5 PERFORMANCE EVALUATION TESTS

Specimens were prepared for evaluating the key performance characteristics of the 14 overlay mixtures in terms of compressive and flexural strengths, shrinkage, permeability, toughness, and bond strength.

- Compression tests were conducted for the LMC overlay mixtures at 4, 7, 14, and 28 days, in accordance with ASTM C39. For the MSC and FAC mixtures, the compression tests were conducted at 3, 7, 14, and 28 days, in accordance with ASTM C39.Two to three cylinders of 6 × 12 in. were tested at each testing age for each mix type.
- Flexure tests were conducted for the LMC overlay mixtures at 4, 7, 14, and 28 days, in accordance with ASTM C293. For the MSC and FAC mixtures, the compression tests were conducted at 3, 7, 14, and 28 days, in accordance with ASTM C293. Beams of 6 × 6 × 21 in. and 6 × 6 × 36 in. were used. The latter beam size allows for performing two flexure tests per each specimen. Two or three breaks were made at each testing age for each mixture type.
- Unrestrained drying shrinkage tests were conducted for each mix type using three prisms of 3 × 3 × 11¼ in., and the shrinkage measurements were taken over a 1-year period, in accordance with ASTM C157.
- Rapid chloride permeability tests were conducted for each mix type, in accordance with ASTM C1202. Three cylinders of 4 × 8 in. were cast from each mix type, and then discs of 4 × 2 in. were saw-cut from each cylinder.
- Toughness and post-cracking residual strength evaluation were conducted for selected fibrous mixtures, in accordance with ASTM C1609/C1609M, “Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading).” Two or three beams of 6 × 6 × 21 in. were tested when the compressive strength was in the range of 4000 to 5000 psi.
- Direct tensile bond strength tests were conducted for typical plain and fibrous overlay mixtures at various ages, in accordance with ASTM C1583. To this, eight reinforced-concrete slab segments (2.5 ft × 2.5 ft × 8 in.) were cast using a fly ash concrete mix design with 515 lb/yd^3 Type I cement, 140 lb/yd^3 Class C fly ash, 0.40 w/cm, 1810 lb/yd^3 coarse aggregate of a maximum aggregate size of 1 in., and 1100 lb/yd^3 sand. The slump, air content, and unit weight were 6 in., 6.75%, and 144 pcf, respectively. The 28-day compressive and flexural strength were 6430 psi and 790 psi,

respectively. The slabs were moist-cured for 28 days with wet burlap covered with plastic sheets, followed by air-curing in the lab environment for about 4 months. The intent was to ensure that the majority of the drying shrinkage had already occurred. The surfaces of the slabs were then prepared using hydro-demolition before receiving the selected plain and fibrous overlay mixtures. Figure 2.2 shows some of the steps taken in preparing and curing test specimens.

Figure 2.2. Preparation and curing of test specimens (not all steps shown).

CHAPTER 3 RESULTS AND ANALYSIS

This chapter presents the laboratory test results for the various LMC, MSC, and FAC overlay mixtures. Several articles based on the findings of this research project were published in various refereed journals and at conferences (Alhassan 2010; Alhassan and Ashur 2010, 2011a, 2011b).

3.1 LATEX-MODIFIED CONCRETE OVERLAY

Many U.S. DOTs use LMC overlays as a corrosion protection strategy for bridge decks. The major benefit of incorporating latex within the LMC mix design is a reduction in the permeability through polymerization of the latex, leading to formation of a membrane around the hydration products. In addition, the LMC overlay adheres strongly to the underlying bridge deck slab and has inherent flexibility due to the formed membrane, which is beneficial for freeze and thaw resistance without the need for air entrainment. The latex also acts as a plasticizing agent that provides good workability, even for low w/c ratios.

Nevertheless, the latex imposes constructability limitations that increase the initial installation cost of the LMC overlay. The latex starts to polymerize within a short time—typically between 15 and 30 min, depending on air temperature, humidity, and wind speed. This dictates use of mobile mixers to install the LMC overlay; ready-mixed concrete trucks are not an option. In spite of these limitations, the LMC overlay is a high-quality and durable product and can be open to traffic after 4 days from the installation. Therefore, it is an effective product when considering its life-cycle cost.

3.1.1 Fresh Concrete Properties

With the w/c of 0.37, the slump for all the LMC mixtures, measured after 5 minutes from discharge, ranged from 4 to 6 in. Within the tested fiber types, the reduction in the slump for the LMC mixtures was minimal. The air content values were stable, around 5% to 6%. Unit weight values were around 143 pcf.

Table 3.1 shows the measured fresh concrete properties for a typical batch from each mix design. All of the fibrous LMC mixtures were constructed without complications during mixing and finishing, except LMC-3NXL and LMC-2NXL+1RSC. In those two mixtures, a portion of the added dosage of NXL fiber remained in the mixer after discharge, and fiber floating occurred during finishing of the cylinders and beams (Figure 3.1). This was attributed to the length and mesh-type configuration of NXL fiber (see Table 2.4). This problem was less pronounced in the LMC-2NXL+1RSC than in the LMC-3NXL, since former had lower NXL content.

Table 3. 2 summarizes the workability and finishability observations for each fiber combination within the LMC mixtures. In general, the constructability, including workability and finishability, of the fibrous mixtures with a combination of macro- and micro-type fibers was more favorable than the fibrous mixtures with one type of macro-fiber. Within the fiber types and dosages evaluated, the reduction in the slump was about 1 in. compared to the LMC plain mixture. The slump for all the fibrous LMC mixtures ranged from 4.5 to 6 in. Therefore, no adjustment to the w/c ratio was required. Also, the air contents in the fibrous mixtures were stable, as in the plain mixture (around 5%).

Table 3.1. Fresh Concrete Properties for a Typical Batch from Each LMC Overlay Mixture

Property	LMC Plain	LMC-2ARGF	LMC-3SX	LMC-2SX +1GF	LMC-2SX +0.5GF	LMC-2SX +1GMF	LMC-2SX +0.5GMF	LMC-3NXL	LMC-2RF +1RSC	LMC-2NXL +1RSC
Slump, in.	6	6	5	5.25	5.5	5	4.75	4.5	5.5	5
Air content, %	5.1	5	4.9	5	4.9	4.8	4.8	4.8	5	4.9
Unit weight, pcf	144	144	143	143.5	143.2	143.4	144	143	143.6	144

Figure 3.1. Portion of NXL fiber floated on the surface of the cylinders.

Table 3.2. Workability and Finishability of Fibrous Additives in LMC Mixtures

Fiber Combination	Workability	Finishing	Overall Constructability
2ARGF	Easy to mix, place, and compact. No fiber remains in the mixer.	Easy to finish. No clumping or balling.	Easy
3SX	Adequate to mix, place, and compact. Minimal fiber remains in the mixer.	Adequate to finish. Few clumps, no balling.	Appropriate
2SX+1GF	Adequate to mix, place, and compact. Minimal fiber remains in the mixer.	Adequate to finish. Minor clumps, no balling.	Appropriate
2SX+0.5GF	Adequate to mix, place, and compact. Minimal fiber remains in the mixer.	Adequate to finish. Minor clumps, no balling.	Appropriate
2SX+1GMF	Adequate to mix, place, and compact. Minimal fiber remains in the mixer.	Adequate to finish. Minor clumps, no balling.	Appropriate
2SX+0.5GMF	Adequate to mix, place, and compact. Minimal fiber remains in the mixer.	Adequate to finish. Minor clumps, no balling.	Appropriate
3NXL	Hard to mix, place, and compact. Much fiber remains in the mixer.	Not adequate to finish. Major clumps.	Poor
2RF+1RSC	Adequate to mix, place, and compact. Minimal fiber remains in the mixer.	Adequate to finish. Minor clumps, no balling.	Appropriate
2NXL+1RSC	Hard to mix, place, and compact. Much fiber remains in the mixer.	Not easy to finish. Major clumps.	Not appropriate

3.1.2 Compressive and Flexural Strengths

Compression tests were conducted on 6 × 12 in. specimens, in accordance with ASTM C39. Table 3.3 shows the compression test results for all LMC mixtures at various ages. The average results were based on testing 2 or 3 specimens with coefficients of variation less than 3%.

The 4-day compressive strengths for all LMC mixtures were much greater than the 4000 psi required by IDOT specifications at 14 days. At 14 days, all mixtures achieved compressive strength greater than 6000 psi. The results also showed insignificant variation in the compressive strengths of the fibrous mixtures that had proportions similar to those of the plain mixture except for the fibers. To perform a meaningful evaluation of the effect of fibrous additives on compressive strength, the average compressive strengths of all fibrous LMC mixtures were compared to the average compressive strength of the plain LMC mixture. The difference was –1% at 4 and 28 days, 2% at 7 days, and 5% at 14 days. This slight difference is insignificant and showed that the fibrous additives used in the mixtures evidently did not reduce the compressive strength of the LMC overlay. However, the failure modes of the compression test specimens revealed significant advantage for the fibrous additives. As shown in Figure 3.2, the fibrous LMC specimens remained intact after failure due to the internal confinement provided by the fibers, while the plain LMC specimens crushed at ultimate strength. The internal confinement benefit was not pronounced in the LMC-2ARGF specimens due to the low volumetric ratio of fibers (ARGF has a specific gravity of 2.6 compared to 0.91 and 1.3 for the polypropylene and PVA fibers, respectively).

Flexural tests were conducted on 6 × 6 × 21 in. and/or 6 × 6 × 36 in. specimens, in accordance with ASTM C293. Table 3.4 shows the average flexural strength test results for all mixtures at various ages. The average results were based on testing 2 or 3 specimens with a coefficient of variation less than 3%. All of the LMC mixtures achieved flexural strengths at 4 days much greater than 675 psi, which is required by IDOT at 14 days. Insignificant variation in the flexural strengths of the fibrous mixtures was noticed since they had proportions similar to the plain mixture except for the fibers. The enhancement of flexural strength provided by fibrous additives was obvious. As shown in Table 3.4, all fibrous mixtures achieved higher flexural strengths than the plain mixture at all ages. The increase was between 7% and 11%. Providing favorable compression failure mode and increasing the flexural strength are significant enhancements to the performance of LMC overlays.

Table 3.3. Compressive Strength Test Results for the LMC Overlay Mixtures (psi)

Testing Age (Days)	LMC Plain	LMC-2ARGF	LMC-3SX	LMC-2SX +1GF	LMC-2SX +0.5GF	LMC-2SX +1GMF	LMC-2SX +0.5GMF	LMC-3NXL	LMC-2RF +1RSC	LMC-2NXL +1RSC
4	5230	5760	5450	5060	4600	4920	4890	4920	4810	5100
	5060	5450	5380	4910	4820	4970	5270	4800	4880	5270
	5130	5590	5400	5000	4950	5110	4940	4830	4900	5210
Average	**5140**	**5600**	**5410**	**4990**	**4790**	**5000**	**5030**	**4850**	**4860**	**5190**
7	5710	6160	6280	5240	5300	5420	5560	5500	6170	5720
	5470	6230	6180	5180	5130	5620	5500	5500	6000	5680
	5600	6220	6200	5270	5180	5770	5620	—	6130	5790
Average	**5590**	**6200**	**6220**	**5230**	**5200**	**5600**	**5560**	**5500**	**6100**	**5730**
14	6200	6750	6830	6350	5900	6400	6210	6000	6370	6540
	5930	6830	6540	6360	5990	6600	6510	6190	6290	6230
	6050	6760	6620	—	6110	6570	6280	6140	6300	6370
Average	**6060**	**6780**	**6660**	**6350**	**6000**	**6520**	**6330**	**6110**	**6320**	**6380**
28	7000	7080	7140	6690	6630	7080	7050	7030	7030	6940
	6940	6950	7030	6590	6480	7090	7000	6950	7100	7020
	7120	6980	7070	6760	6520	—	7160	6940	7000	7050
Average	**7020**	**7000**	**7080**	**6680**	**6540**	**7080**	**7070**	**6970**	**7040**	**7000**

Figure 3.2. Failure modes of fibrous LMC (left four) and the plain LMC (right).

Table 3.4. Flexural Strength Test Results for the LMC Overlay Mixtures

Testing Age (Days)	LMC Plain	LMC-2ARGF	LMC-3SX	LMC-2SX +1GF	LMC-2SX +0.5GF	LMC-2SX +1GMF	LMC-2SX +0.5GMF	LMC-3NXL	LMC-2RF +1RSC	LMC-2NXL +1RSC
4	780	810	880	850	840	840	880	790	800	820
	780	800	880	860	840	850	890	820	810	830
	—	—	—	850	—	—	—	800	—	—
Average	**780**	**800**	**880**	**850**	**840**	**840**	**880**	**800**	**800**	**820**
7	770	820	920	860	870	880	910	800	850	870
	790	820	930	870	870	880	900	810	840	870
	—	—	—	—	—	—	—	—	—	—
Average	**780**	**820**	**920**	**860**	**870**	**880**	**900**	**800**	**840**	**870**
14	850	900	950	900	860	880	930	930	900	880
	850	910	960	900	870	890	950	930	930	890
	—	—	—	—	860	—	950	—	910	—
Average	**850**	**900**	**950**	**900**	**860**	**880**	**940**	**930**	**910**	**880**
28	910	1070	1040	950	1010	1000	1000	1000	1040	940
	910	1050	1050	950	1040	990	1070	1020	1050	950
	920	1090	1040	960	1020	990	1020	990	1050	940
Average	**910**	**1070**	**1040**	**950**	**1020**	**990**	**1030**	**1000**	**1050**	**940**

3.1.3 Drying Shrinkage

Figure 3.3 shows the shrinkage test prisms and the mechanical dial indicator used for measuring length, in accordance with ASTM C157. Figures 3.4 through 3.13 show the shrinkage-time responses of the plain and fibrous LMC overlay mixtures. Overall, the shrinkage strains of the plain and fibrous LMC mixtures were high. This can be attributed to two major factors: (1) the LMC overlay mixtures are wet-cured for only 2 days, and (2) the LMC overlay mixtures have high mortar content. These results may explain the high susceptibility of the LMC overlays to cracking at early age. Figure 3.14 shows the shrinkage-time responses of the plain and fibrous LMC overlay mixtures. Specifically, the fibrous mixtures experienced lower drying shrinkage than the plain mixture. The reduction was prominent after about 4 days and became significant therafter. In general, the two different fibrous mixtures of the same overlay type experienced comparable drying shrinkage strains. The average of the shrinkage strains of the fibrous LMC mixtures was approximately 17% lower than the plain LMC mixture at both 28 and 90 days. The reductions in the shrinkage strains confirm that the added dosages of the different fiber types are very advantageous in reducing the drying shrinkage and consequent cracking of the LMC overlays.

Figure 3.3. Shrinkage test prisms and mechanical dial indicator.

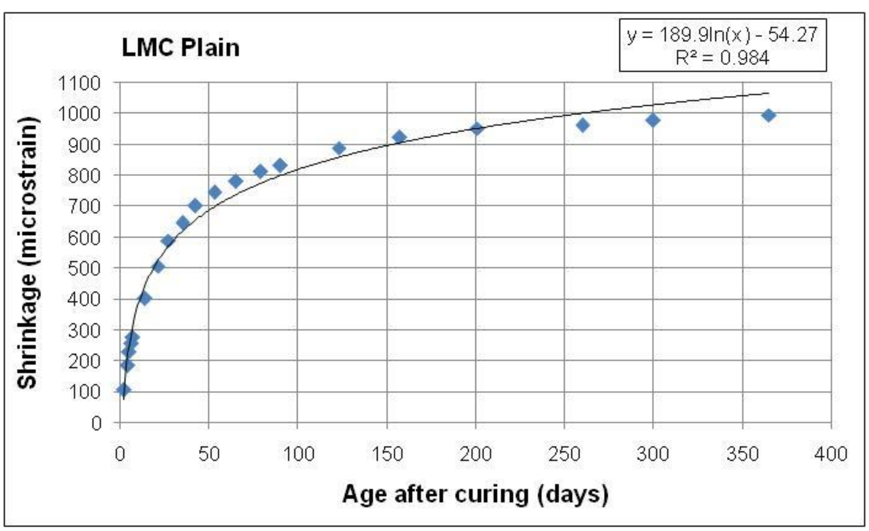

Figure 3.4. Shrinkage-time response of the LMC plain mixture.

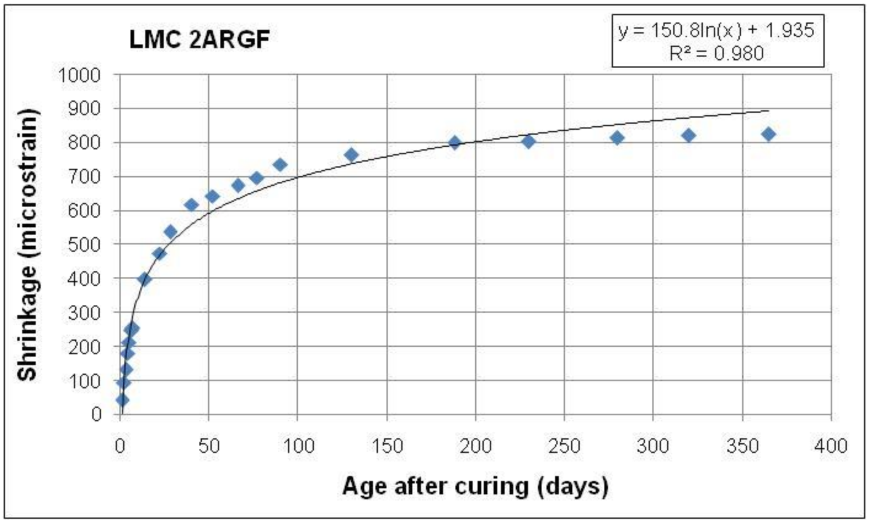

Figure 3.5. Shrinkage-time response of the LMC-2ARGF mixture.

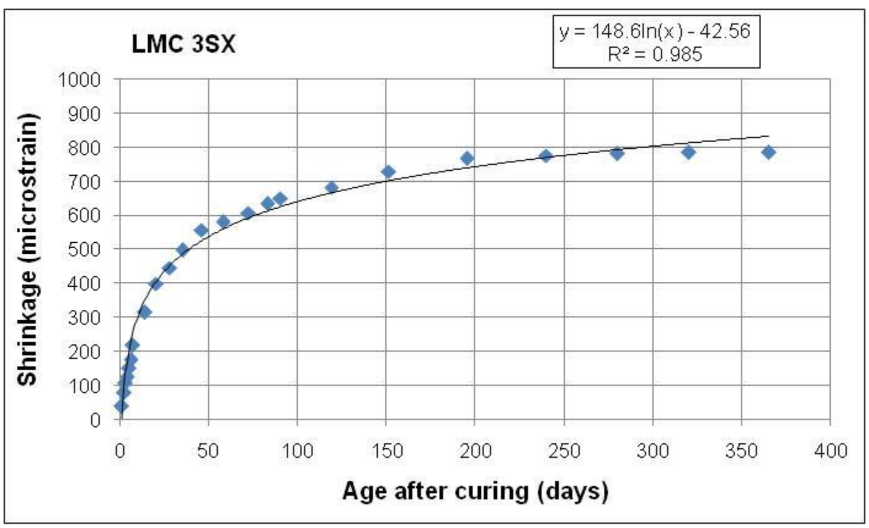

Figure 3.6. Shrinkage-time response of the LMC-3SX mixture.

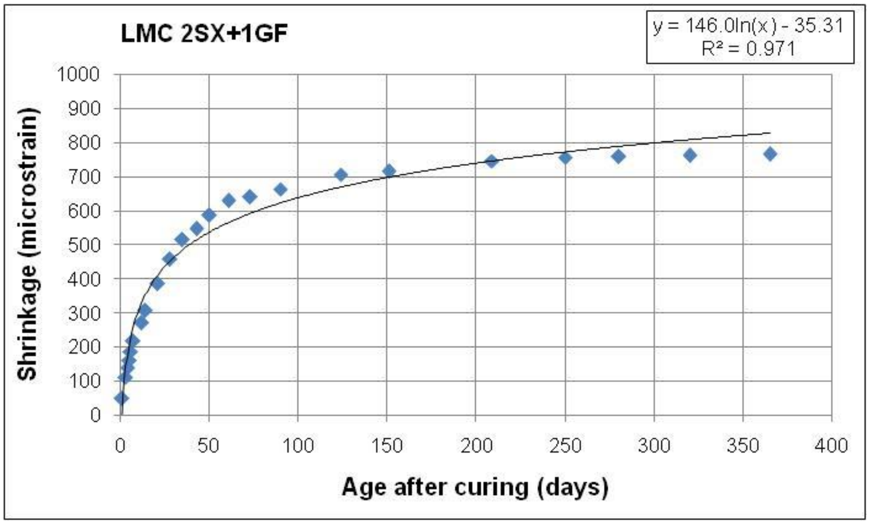

Figure 3.7. Shrinkage-time response of the LMC-2SX+1GF mixture.

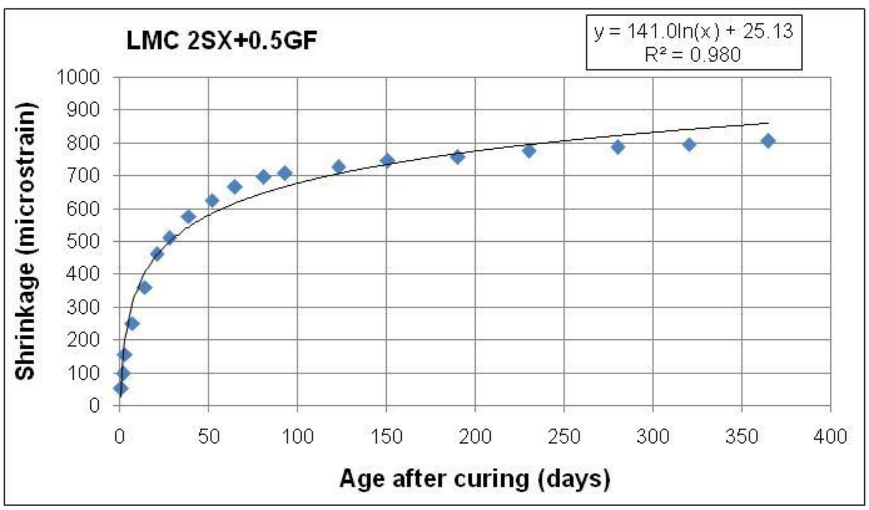

Figure 3.8. Shrinkage-time response of the LMC-2SX+0.5GF mixture.

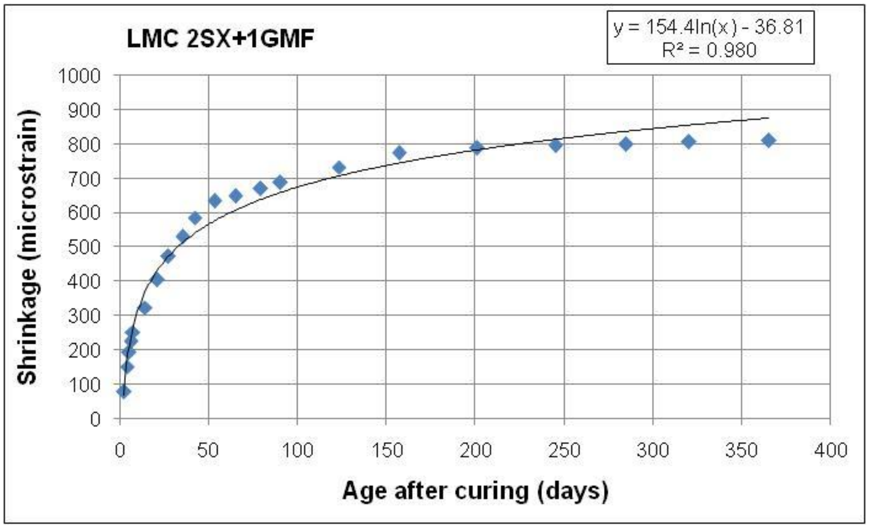

Figure 3.9. Shrinkage-time response of the LMC-2SX+1GMF mixture.

Figure 3.10. Shrinkage-time response of the LMC-2SX+0.5GMF mixture.

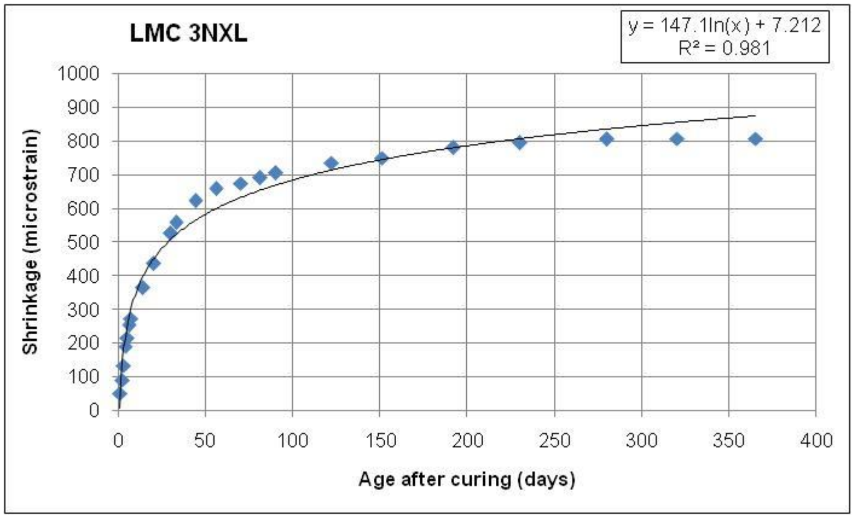

Figure 3.11. Shrinkage-time response of the LMC-3NXL mixture.

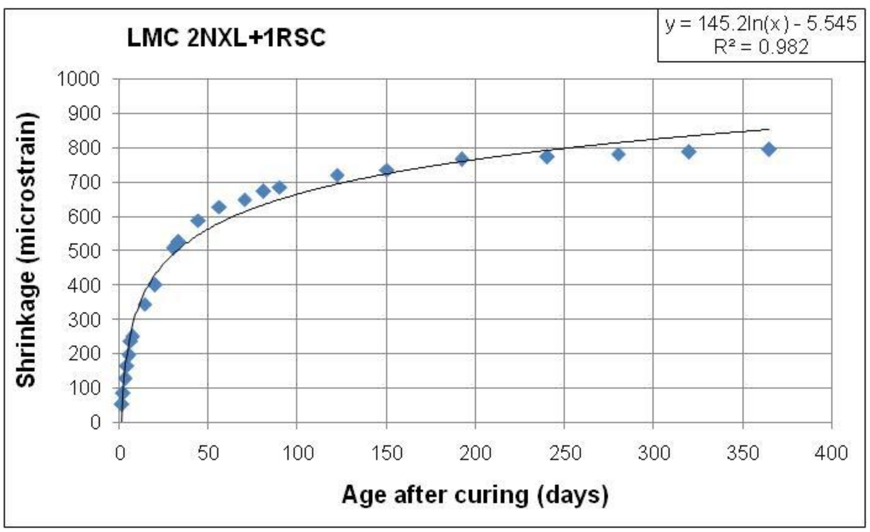

Figure 3.12. Shrinkage-time response of the LMC-2NXL+1RSC mixture.

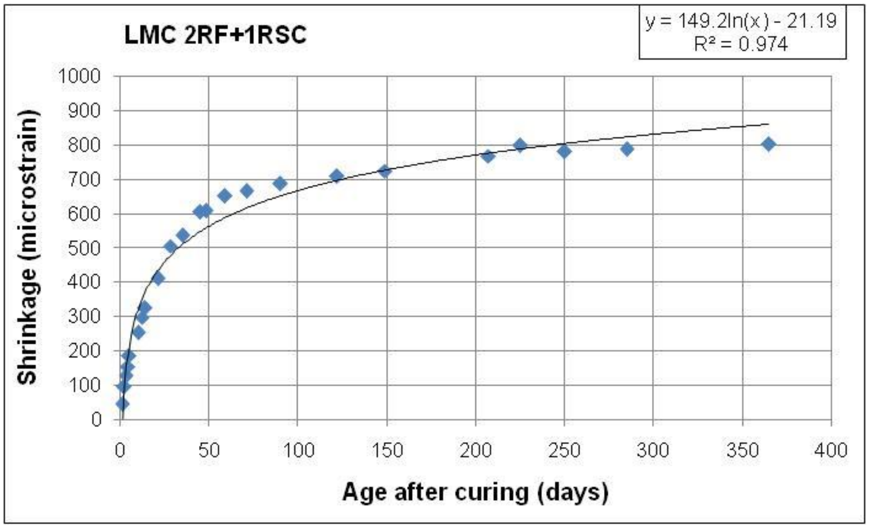

Figure 3.13. Shrinkage-time response of the LMC-2RF+1GF mixture.

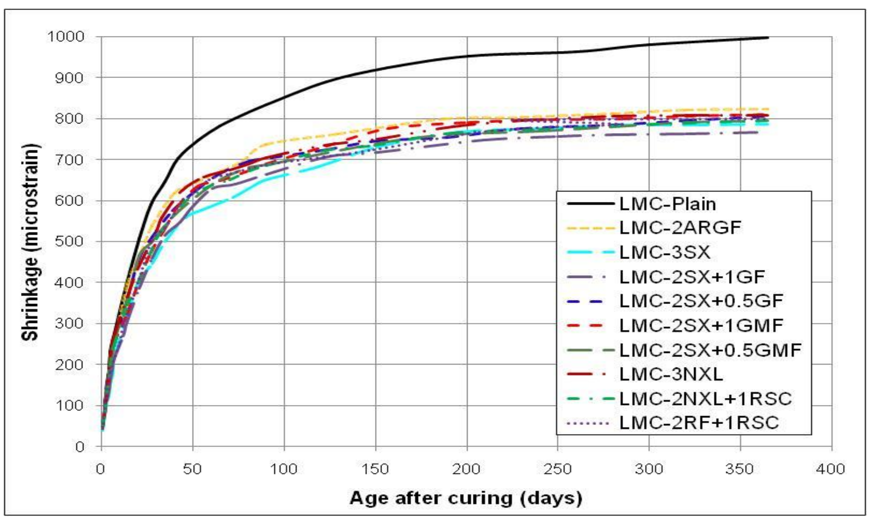

Figure 3.14. Shrinkage-time response of all LMC mixtures.

3.1.4 Coulomb Permeability

Rapid chloride permeability tests were conducted in accordance with ASTM C1202, which entails the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This method relies on the results from a test in which electrical current passes through a concrete specimen during a 6-hour exposure period. The interpretation is that the larger the coulomb value, or the charge transferred during the test, the greater the permeability of the specimen. As required by ASTM C1202, the saw-cut 4 × 2 in. discs were conditioned properly prior to testing. Once the conditioning was completed, the specimens were placed in special cells and were connected to the testing apparatus. The obtained average coulomb values and the corresponding permeability classes as defined by ASTM C1202 are shown in Table 3.5.

The permeability classes for all of the plain and fibrous LMC mixtures were very low. The very low permeability class of LMC overlays is the dominant reason for their use on bridge decks. It is evident that the fibrous additives that were evaluated did not reduce the permeability of the LMC. Although there is debate about the accuracy of ASTM C1202, the results obtained in this study for a large number of test specimens were very consistent and fell within typical values for LMC overlays. Such consistency and accuracy of test results indicate that ASTM C1202 is an appropriate and very effective method for rapid indication of concrete permeability if the specified procedure is followed carefully. Inconsistent results may occur for certain concrete types, especially those with high permeability. Figure 3.15 shows the rapid chloride permeability testing apparatus and conditioning of the test specimens.

Table 3.5. Rapid Chloride Permeability Test Results for the LMC Overlay Mixtures

Disc No.	LMC Plain	LMC-2ARGF	LMC-3SX	LMC-2SX +1GF	LMC-2SX +0.5GF	LMC-2SX +1GMF	LMC-2SX +0.5GMF	LMC-3NXL	LMC-2RF +1RSC	LMC-2NXL +1RSC
1	624	589	655	570	620	578	556	521	509	546
2	566	597	215	633	489	501	569	547	574	627
3	433	423	622	611	811	628	945	378	599	656
Avg.	541	536	497	604	640	569	690	482	561	610
Class	All mixtures have very low permeability class, in accordance with ASTM C1202									

Figure 3.15. Rapid chloride permeability test and conditioning of the specimens.

3.1.5 Direct Tensile Bond Strength

The surfaces of the full-depth slab segments were prepared using hydro-demolition. This technology uses a robot connected to a control unit with a power and water source. The water is applied to the concrete surface at a very high pressure (14,000 psi) and at a

30° angle. The robot cuts a strip approximately 4 in. wide along the surface of the slab segment and automatically shifts to the next strip until the entire surface is completed. The speed of cutting can be adjusted for the intended application. The intent is to expose the coarse aggregate and remove the weak concrete at the surface. If the entire cover of the slab is deteriorated, the cutting can be done slowly to remove all the weak concrete cover and expose the reinforcing steel bars. Figure 3.16 shows the hydro-demolition robot and a typical prepared slab segment.

Figure 3.16. Casting and hydro-demolition surface preparation of the slab segments.

The slab segments were divided into two groups. The first group consisted of four segments used to test the bond strengths at 7 and 28 days for typical LMC, MSC, and FAC overlay mixtures using IDOT-approved testing equipment. The first segment of this group was fully overlaid with LMC-2SX+1GF and used as a calibration specimen for performing the bond strength tests. The other three segments were divided in half to allow placement of two overlay types per each segment. One segment received LMC plain and LMC-3SX; one segment received MSC plain and MSC-2SX+1GF; and the third segment received FAC plain and FAC-2SX+1GF. Three cores were drilled in each overlay type through the entire overlay thickness and about 1 in. through the underlying slab. Steel discs, 3 in. in diameter and 1 in. thick, were glued to the surfaces of the prepared cores using a special epoxy.

The direct tensile bond strength test results are shown in Table 3-6. The bond strength results of the three cores exceeded 300 psi at 7 days, which exceed the target value at 28 days. The results are very encouraging and show that bond strength develops over time as the concrete matures. Figure 3.17 shows the bond strength equipment and typical pulled cores used for the tests. The variation in bond strength among the three cores at the same testing age was attributed to the sensitivity of this test to the depth of coring and to the occurrence of any eccentricity while pulling the cores, as well as to the rate of pulling.

Table 3.6. Direct Tensile Bond Strength Test Results for the LMC Overlay Mixtures.

Testing Age	Core No.	LMC-Plain	LMC-3SX	LMC-2SX+1GF
7 days	1	388^{BI}	404^{BI}	305^{BI}
	2	302^{DI}	364^{BI}	321^{BI}
	3	354^{DI}	380^{BI}	308^{BI}
28 days	1	483^{BC}	439^{BI}	353^{DI}
	2	521^{BC}	486^{BC}	404^{BI}
	3	429^{BC}	511^{BC}	465^{BI}

BI: failure at the bond interface; DI: failure at the disk interface; BC: failure in the base concrete.

Figure 3.17. Direct tensile bond strength test.

The second group of slab specimens included four segments, each fully overlaid with one overlay type (plain LMC, LMC-2SX+1GF, MSC-2SX+1GF, and FAC-2SX+1GF). Those four segments had been sitting outside the Structures and Materials Laboratory at Indiana–Purdue University Fort Wayne (IPFW) since January 20, 2010. The intent was to monitor their long-term performance under exposure to actual weathering conditions and drying shrinkage. This group of slab segments included plain and fibrous LMC overlays to evaluate the advantage of the fibrous additives in terms of cracking resistance at short- and long-term ages. The group also included the three overlay types (LMC, MSC, and FAC) with identical fibrous additives to allow comparison. Figure 3.18 shows pictures of the four segments taken on November 2, 2011, after approximately 2 years from sitting in the open environment. The segments, which were inspected frequently, did not show any cracking or delaminations. A major observation was that the edges of the segments were prone to cracking, which was pronounced in the plain LMC overlay, as shown in Figure 3.19. This issue will require more observation time to draw direct conclusions, but it can be considered good evidence for the advantages of fibrous additives in preventing and minimizing cracking, especially near the critical regions where stress concentrations exist. Figure 3.19 also shows the preferred distribution of the fibers that prevented the initiation of signs of potential cracking.

Figure 3.18. Four segments in an open environment (plain LMC, LMC-2SX+1GF, MSC-2SX+1GF, and FAC-2SX+1GF).

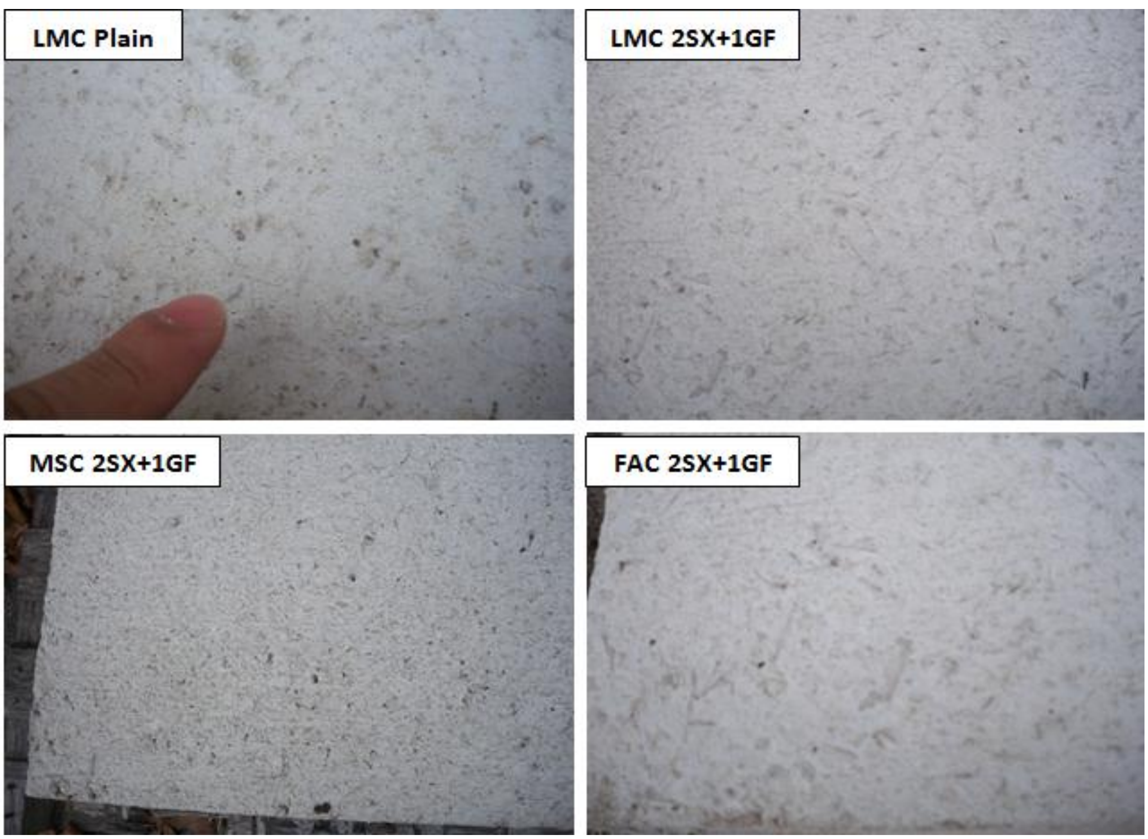

Figure 3.19. Close-up view of the surfaces of the segments around the edges after 2 years of sitting outside the lab in an open environment.

3.1.6 Flexural Performance and Residual Strength

Flexural performance tests were conducted for representative fibrous LMC mixtures, in accordance with ASTM C1609. IDOT is concerned about whether 20% residual strength is achievable at practical dosages of fibrous additives that are constructable yet do not present complications during mixing and finishing. It was agreed to perform the flexural performance tests when the compressive strength was between 4000 and 5000 psi. Calibration tests were conducted to ensure that the servo-controlled testing machine and transducer arrangement met the strict testing protocol of ASTM C1609, especially in terms of loading rate and type. For a 6 × 6 × 21 in. beam, ASTM C1609 requires that the rate of increase of net deflection be within the range 0.06 to 0.12 mm/min until a net deflection of 0.75 mm is reached, whereupon the rate of increase of net deflection be within the range 0.06 to 0.24 mm/min until completion of the test. Figure 3.20 shows the servo-controlled testing machine, transducer arrangement, and cracking of a beam during testing.

Figures 3.21 through 3.23 show the flexural performance test results for LMC-3SX, LMC-2SX+1GF, and LMC-RF+1RSC, respectively. Table 3.7 summarizes the residual strength results for the three overlay types. The obtained results are the average of three specimens. The residual strengths (f^{D}_{150}) of LMC-3SX and LMC-2SX+1GF were 78 psi and 52 psi, respectively. LMC-3SX achieved higher residual strength since it had 33% higher content of SX macro-type fiber that was 1.55 in. long and specifically fabricated to provide structural benefits such as crack arresting and residual strength. GF fiber type is a micro-type fiber and is not expected to provide residual strength; however, it has benefits during the plastic concrete state, as explained earlier. The achieved residual strengths were about 13% and 8% of the corresponding modulus of rupture for each mixture. These results reveal that 20% residual strength is impractical for bridge deck overlays with 3 lb/yd^3 synthetic fibrous additives. It is more reasonable to achieve a residual strength of 78 psi or 52 psi and maintain practical constructability than to aim for high residual strength and reduce constructability. It should be noted that LMC-3SX was tested at 3 days and at 14 days at different compressive strengths, as shown in Figure 3.21. Very similar post-cracking performance was achieved.

Figure 3.20. Testing machine, transducer arrangement, and cracking of a beam during ASTM C1609 toughness test.

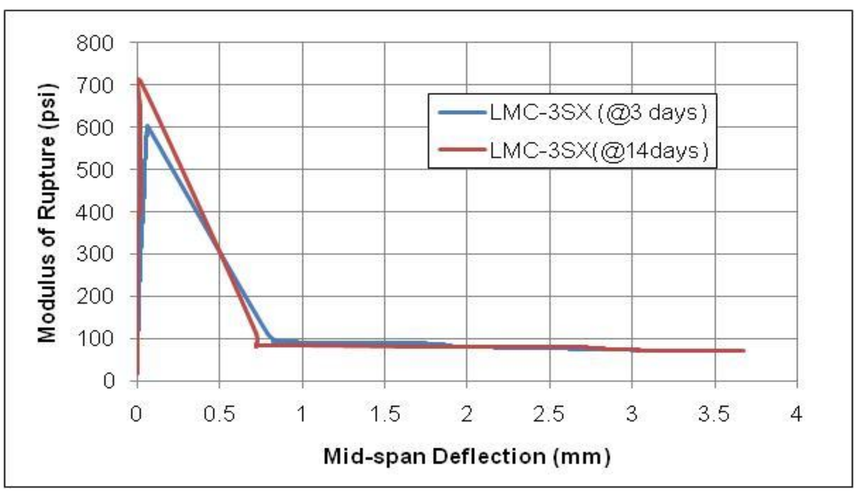

Figure 3.21. ASTM C1609 toughness test results of LMC-3SX.

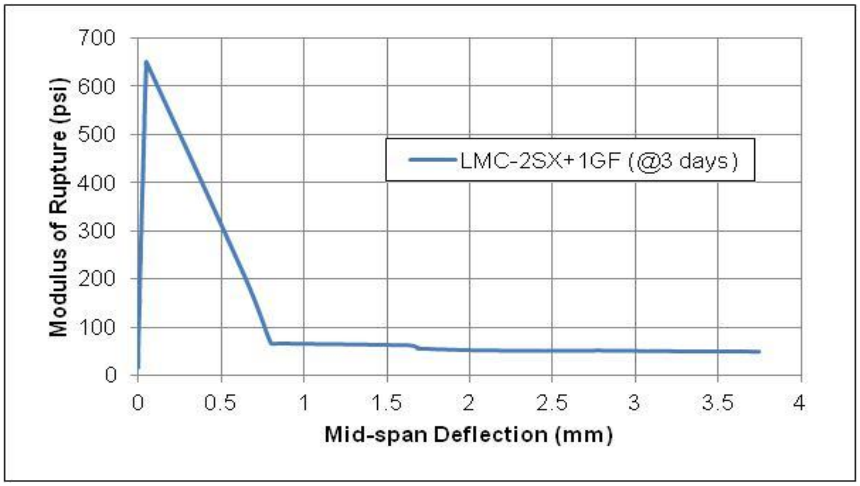

Figure 3.22. ASTM C1609 toughness test results of LMC-2SX+1GF.

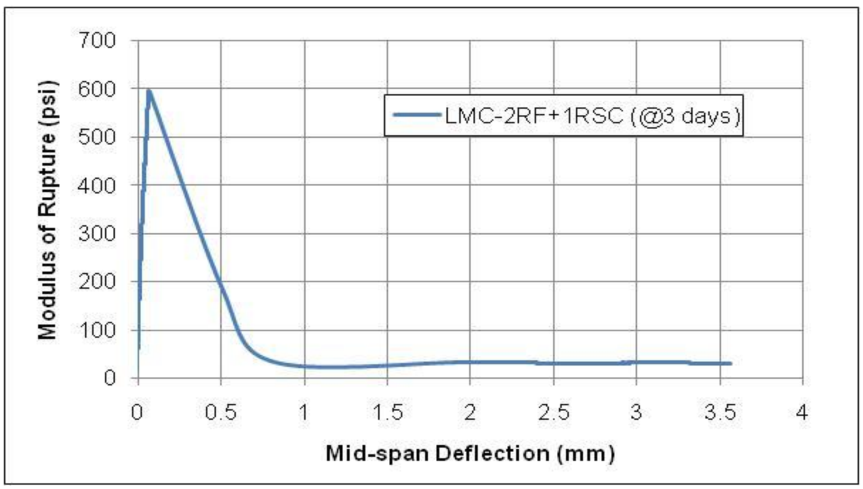

Figure 3.23. ASTM C1609 toughness test results of LMC 2RF+1RSC.

Table 3.7. Summary of Residual Strength Results for Fibrous LMC Overlay Mixtures

Mix Design	Compressive Strength, psi	Modulus of Rupture, psi	Residual Strength, psi	Residual Strength, % of the Modulus of Rupture
LMC-3SX	4420	600	78	13
	6660	715	78	10.9
LMC-2SX+1GF	4600	650	52	8
LMC-2RF+1RSC	4330	600	40	6.7

3.2 MICROSILICA CONCRETE OVERLAY

The rationale for using MSC overlay is attributed to its low permeability—the result of adding silica fume to the mix design. However, many U.S. DOTs, including IDOT, reported cracking and delamination problems in MSC overlays at early ages. These critical problems typically reduce the intended service life of MSC overlays. The frequent early age cracking and consequent delaminations of the MSC overlays are attributed to high early shrinkage as a result of the low w/cm of the mix design and the addition of silica fume. The very fine silica fume particles, typically 100 times finer than the cement particles, have a high surface ratio that demands more water for hydration. This results in high early drying shrinkage and high potential for cracking since the tensile strength of the overlay is still small. Plastic shrinkage cracking is also very possible since the w/cm is already small and there is not enough bleed water to prevent the problem. Accordingly, adding fibers seems to be essential to improve the MSC overlay's resistance to cracking. The required dosage of fibers can be added to the ready-mixed concrete trucks along with the other ingredients. The investigated MSC overlay mix design in this research project (see Table 2.2) was used in the Dan Ryan project (Section 1.4 of this report contains details for the Dan Ryan project). The performance characteristics of the MSC mix design were evaluated in this study using two synthetic fiber combinations (see Table 2.5).

3.2.1 Fresh Concrete Properties

Table 3.8 shows fresh concrete properties for typical batches of the fibrous MSC overlay mixtures. To achieve slump and air content in the range of 5½ to 8½ in. and 5% to 8%, respectively, the plastic concrete properties were calibrated before the fibrous additives were incorporated into the mixes. This was achieved by adding a mid-range water reducer and superplasticizer. The mid-range water reducer was added first to achieve around 1.5 in. slump followed by the superplasticizer to achieve the target slump value. Consistency and uniformity of the fiber distribution throughout the mixtures as well as finishability of the specimens were observed. Within the fiber dosages used, the reduction in the slump after the addition of fibers was not significant (around 1 in.).The fibrous MSC overlay mixtures included coarse aggregate content significantly higher than the LMC overlay mixtures. Accordingly, their workability and finishability were of slightly lower quality than the companion LMC mixtures with similar fibrous additives. As was the case for LMC-3NXL (see Table 3.2), the workability and finishability of MSC-3NXL overlay mixture were poor. In addition, it was hard to achieve the required air content within the fibrous MSC overlay mixtures. The air contents for typical batches from the fibrous MSC mixtures were 5% and 4.6%, as shown in Table 3.8. Typical unit weight values were 147and 148 pcf.

Table 3.8. Fresh Concrete Properties for a Typical Batch from Each MSC Overlay Mixture

Property	MSC-2SX+1GF	MSC-3NXL
Slump, in.	5.25	5.0
Air content, %	5.0	4.6
Unit weight, pcf	147	148
Workability	Adequate to mix, place, and compact. Minimal fiber remains in the mixer.	Hard to mix, place, and compact. Many fiber remains in the mixer.
Finishing	Adequate to finish. Few clumps, no balling.	Not adequate to finish. Many clumps.
Overall constructability	Appropriate	Poor

3.2.2 Compressive and Flexural Strengths

The compressive and flexural strengths for the plain MSC mixture were not tested as part of this study. However, it is believed that the comparison between the fibrous and plain LMC mixtures also applies to the plain and fibrous MSC overlay mixtures in terms of the effect of the fibrous additives on compressive and flexural strengths. The fibrous MSC overlay mixtures showed very high compressive strengths (Table 3.9), significantly exceeding the typical requirement of 4000 psi at 14 days. The high coarse aggregate content is one of the major factors that resulted in the very high compressive strengths of the fibrous MSC mixtures. In terms of flexural strength, the fibrous MSC overlay mixtures also showed very high values—significantly more than the 675 psi required at 14 days. As shown in Table 3.9, the fibrous MSC overlay mixtures achieved the required compressive and flexural strength values at 3 days. The strength results were comparable for both types of fibrous MSC overlay mixtures. It is important to mention that the total CM content in the MSC overlay mixtures is 603 lb/yd^3, which is approximately 8% lower than the CM content in the LMC and FAC overlay mixtures.

Table 3.9. Compressive and Flexural Strengths Test Results for the MSC Overlay Mixtures

Testing Age (Days)	MSC-2SX+1GF		MSC-3NXL	
	Compressive Strength, psi	Flexural Strength, psi	Compressive Strength, psi	Flexural Strength, psi
3	5180	900	5100	830
	5280	910	5110	840
	5230	900	—	830
Average	**5230**	**900**	**5100**	**830**
7	7920	1070	7240	1090
	8190	1020	7450	1200
	8060	1080	7390	—
Average	**8050**	**1050**	**7360**	**1190**
14	9300	900	8970	910
	9060	910	9040	910
	9210	900	9050	900
Average	**9180**	**900**	**9020**	**900**
28	9950	1110	9940	1050
	9870	1100	9650	1020
	9890	1080	9720	—
Average	**9900**	**1090**	**9770**	**1030**

3.2.3 Drying Shrinkage

The average shrinkage strains of the fibrous MSC overlay mixtures were approximately 17% and 13% lower than the companion plain MSC overlay mixture at 28 days and 90 days, respectively (Figures 3.24 through 3.26). The reductions in the shrinkage strains are significant and confirm that the added dosages of the different fiber types are very advantageous in reducing the drying shrinkage of MSC concrete overlays.The two fibrous MSC overlay types showed almost similar shrinkage-time responses. In contrast to the comparable LMC overlay mixtures, the LMC overlay mixtures experienced higher shrinkage than the MSC overlay mixtures. This is primarily attributed to the specified moist-curing periods for both types of overlays: 2 days for the LMC and 7 days for the MSC. Another major factor is that the MSC overlay mix design included more coarse aggregates than the LMC overlay mix design and had lower CM content. However, the higher shrinkage of the LMC overlay mixtures is typically balanced by its high extensibility due to the flexible membrane formed by the latex polymerization.

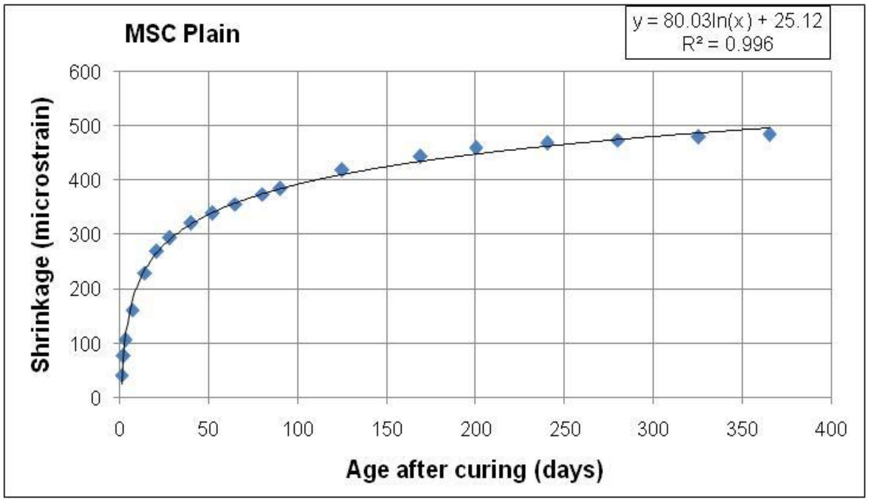

Figure 3.24. Shrinkage-time response of the plain MSC mixture.

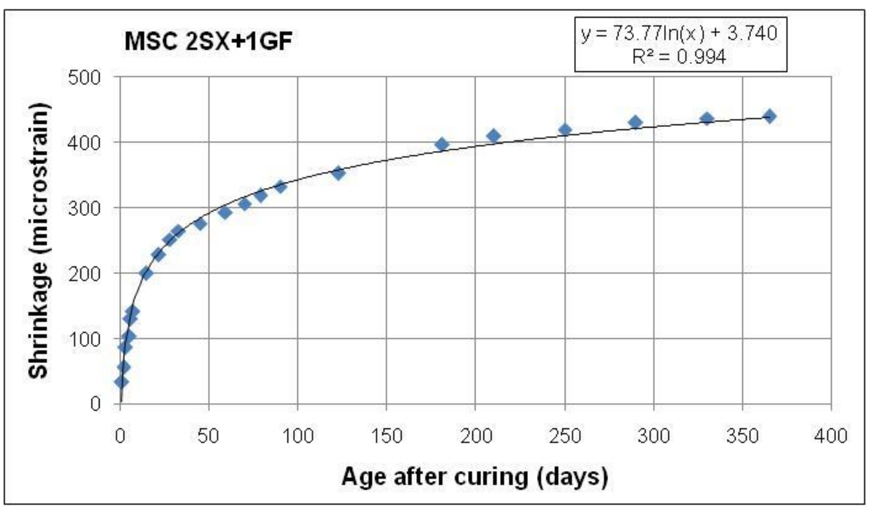

Figure 3.25. Shrinkage-time response of the MSC-2SX+1GF mixture.

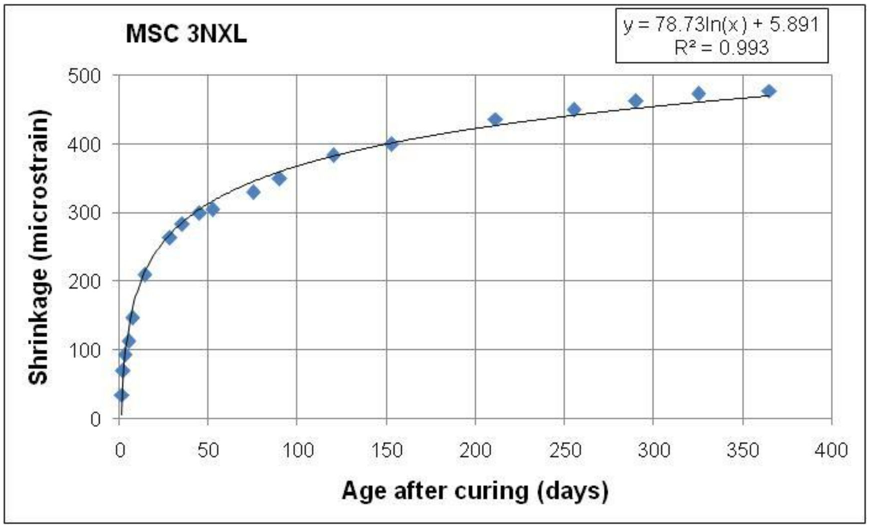

Figure 3.26. Shrinkage-time response of the MSC-3NXL mixture.

3.2.4 Coulomb Permeability

The average coulomb values of the two fibrous MSC overlay mixtures and the associated permeability classes as defined by ASTM C1202 are shown in Table 3.10. As anticipated, the permeability classes for both mixtures were very low. As mentioned earlier, the low permeability of the MSC overlay is the major reason for its use as a bridge deck concrete overlay. The results for each overlay type were consistent. The coulomb values obtained from the permeability test for MSC-2SX+1GF were slightly lower than the values obtained for MSC-3NXL.

Table 3.10. Rapid Chloride Permeability Test Results for the MSC Overlay Mixtures

Specimen No.	MSC-2SX+1GF	MSC-3NXL
1	404	569
2	431	629
3	372	704
Average	402	634
Class	Very Low	

3.2.5 Direct Tensile Bond Strength

Section 3.1.5 outlined the procedure for testing the bond strength of selected overlay types, including plain MSC and MSC-2SX+1GF.The direct tensile bond strength test results are shown in Table 3.11. The bond strength results of the three cores exceeded 300 psi at 7 days, which exceed the target value at 28 days. The results showed that bond strength develops with time as the concrete matures. Most important, the fibers did not adversely affect bond strength, as shown by the finding that bond strengths of the plain and fibrous MSC overlay specimens were comparable and exceeded the target value.

The slab segment that was overlaid with fibrous MSC-2SX+1GF and kept in the open environment since January 20, 2010, did not show any signs of cracking or delaminations. Section 3.1.5 of this chapter provides additional information and figures that show the surface of this overlay type.

Table 3.11. Direct Tensile Bond Strength Test
Results for the MSC Overlay Mixtures

Testing Age	Core No.	MSC Plain	MSC-2SX+1GF
7 days	1	413^{BI}	366^{BI}
	2	420^{BI}	331^{DI}
	3	457^{BC}	433^{BC}
28 days	1	333^{DI}	400^{DI}
	2	410^{DI}	352^{DI}
	3	398^{DI}	345^{DI}

BI: failure at the bond interface; DI: failure at the disk interface; BC: failure in the base concrete.

3.2.6 Flexural Performance and Residual Strength

Details of the flexural performance test in terms of the testing machine, testing protocol, and instrumentation of the specimens are explained in Section 3.1.6 of this chapter. Figure 3.27 shows the flexural performance test results of the MSC-2SX+1GF overlay mixture. Three beams were tested at 3 days and three beams were tested at 14 days. The averages of the three specimens are plotted in Figure 3.27. Table 3.12 summarizes the residual strength results. The results show a very slight difference in flexural performance and residual strength at both ages. The residual strengths (f^{D}_{150}) corresponding to a mid-span deflection of 3 mm are approximately 55 psi at both ages. Higher fiber contents for relatively thin pours may compromise constructability and finishability of the overlay.

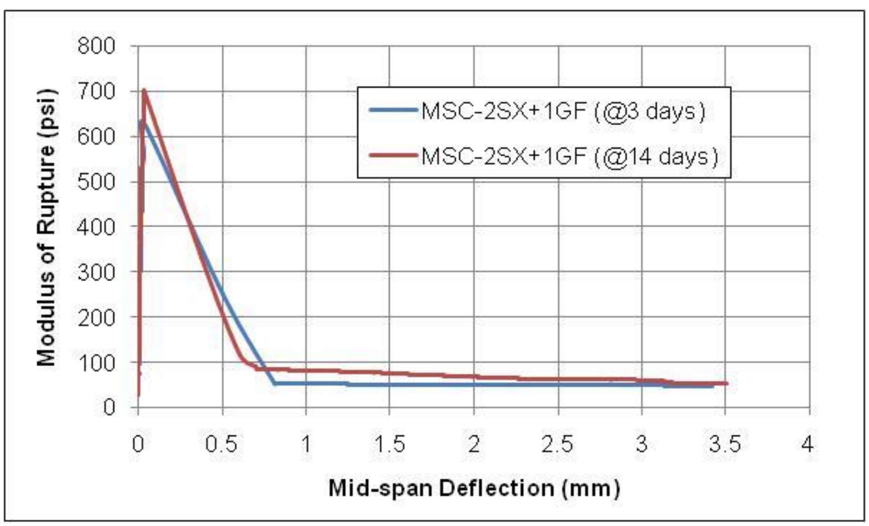

Figure 3.27. ASTM C1609 toughness test results of MSC-2SX+1GF.

Table 3.12. Summary of Residual Strength Results for MSC-2SX+1GF

Mix Design	Compressive Strength, psi	Modulus of Rupture, psi	Residual Strength, psi	Residual Strength, % of the Modulus of Rupture
MSC-2SX+1GF	4900	630	53	8.4
	9180	705	55	7.8

3.3 FLY ASH CONCRETE OVERLAY

In this project, the feasibility of using fibrous fly ash concrete (FAC) overlay was explored. The intent was to provide a new overlay system that is comparable to the MSC overlay system in terms of performance but is significantly cheaper. Two synthetic fiber combinations with the same plain FAC overlay mix design as a control mixture were (see Tables 2.3 and 2.5). The test involved evaluating the major performance characteristics of fibrous FAC overlay mixtures and comparing them to companion MSC and LMC overlay mixtures with similar synthetic fiber combinations.

3.3.1 Fresh Concrete Properties

Table 3.13 shows the fresh concrete properties for typical batches of the fibrous FAC overlay mixtures. The target plastic concrete properties were similar to those of the MSC overlay requirements. As in the MSC overlay mixtures, the plastic concrete properties were calibrated before adding the fibers to achieve a slump and air content in the range of 5½ to 8½ in. and 5% to 8%, respectively. Plasticizers and air-entraining admixtures were added to achieve these requirements. A mid-range water reducer was added first to achieve around 1.5 in. slump followed by a superplasticizer to achieve the target slump value. Consistency and uniformity of the fiber distribution throughout the mixtures, as well as finishability of the specimens, were observed. For the fiber dosages used, the reduction in slump after the addition of fibers was not significant (around 1 in.). The fibrous FAC overlay mixtures included coarse aggregate content similar to that of the MSC overlay mixtures but significantly higher than used in the LMC overlay mixtures. Accordingly, their workability and finishability were of slightly lower quality than the companion LMC mixtures of similar fibrous additives. As was the case for LMC-3NXL and MSC-3NXL, the workability and finishability of FAC-3NXL overlay mixture were poor. In addition, it was hard to achieve the required air content within the fibrous FAC overlay mixtures. The air contents for typical batches from the fibrous FAC mixtures were 5.5% and 4.9%, as shown in Table 3.13. Typical unit weight values were 146 and 147 pcf.

Table 3.13. Fresh Concrete Properties for a Typical Batch from Each FAC Overlay Mixture

Property	FAC-2SX+1GF	FAC-3NXL
Slump, in.	5.5	5.0
Air Content, %	5.5	4.9
Unit Weight, pcf	146	147
Workability	Adequate to mix, place, and compact. Minimal fiber remains in the mixer.	Hard to mix, place, and compact. Many fiber remains in the mixer.
Finishing	Adequate to finish. Few clumps, no balling.	Not adequate to finish. Many clumps.
Overall Constructability	Appropriate	Poor

3.3.2 Compressive and Flexural Strengths

The fibrous FAC mixtures showed very high compressive and flexural strengths that were comparable to the companion MSC overlay mixtures. As shown in Table 3.14, at 3 days the compressive strength was around 6000 psi and around 10,000 psi at 28 days. The flexural strength was around 900 psi at 3 days and 1000 psi at 28 days. It is interesting to observe that although the FAC overlay mix includes 20% fly ash, the early age strength was high. This observation is important since previous experience shows that adding fly ash to the concrete may reduce its early age strength. The results show that the FAC overlay mixtures can easily meet the 14-day compressive and flexural strengths criteria at 3 days. However, IDOT specifications require 7 days of moist-curing for the FAC overlay due to concerns about the drying shrinkage concerns. The very high compressive strengths of the fibrous FAC mixtures are attributed to the high coarse aggregate content and low w/cm ratio. Compressive strengths of the FAC fibrous mixtures were slightly higher than the companion MSC fibrous mixtures, which could be attributed to the fact that FAC mixtures have a higher total CM content and slightly lower w/cm ratio. In terms of flexural strength, the fibrous FAC and MSC overlay mixtures had comparable results that were slightly higher than the companion LMC fibrous mixtures. The strength results were comparable for both types of fibrous FAC overlay mixtures.

Table 3.14. Compressive and Flexural Strengths
Test Results for the FAC Mixtures

Testing Age (Days)	FAC-2SX+1GF		FAC-3NXL	
	Compressive Strength, psi	Flexural Strength, psi	Compressive Strength, psi	Flexural Strength, psi
3	5850	820	5950	910
	5920	820	5980	910
	—	—	—	—
Average	**5880**	**820**	**5960**	**910**
7	7600	1060	7970	1120
	7700	1080	8210	1080
	7660	1030	8020	1110
Average	**7650**	**1050**	**8060**	**1100**
14	9470	970	9530	910
	9680	940	9900	930
	9500	950	9750	900
Average	**9530**	**950**	**9720**	**910**
28	10,250	1150	10,210	1030
	10,060	1160	10,480	1010
	10,200	—	—	—
Average	**10,170**	**1150**	**10,340**	**1020**

3.3.3 Drying Shrinkage

The shrinkage-time responses of the fibrous FAC overlay mixtures and the control plain FAC overlay mixture were monitored over a 1-year period. The shrinkage strains of the plain and fibrous FAC mixtures were considered low and within the target values; however, the fibrous FAC mixtures experienced approximately 8% lower shrinkage than the plain FAC mixture at 28 days and 16% lower at 90 days (Figures 3.28 through 3.30). The reduction in the shrinkage strains is significant and confirms that the fibrous additives reduce the drying shrinkage of concrete overlays.Similar trends were also observed for the MSC and LMC overlay mixers.Comparing the shrinkage strains of the various overlay types shows that the LMC overlay mixtures experienced higher shrinkage than the MSC and FAC overlay mixtures. As mentioned earlier, this is attributed mainly to the fact that the LMC mixtures were moist-cured for 2 days only, while the MSC and FAC mixtures were moist-cured for 7 days. In addition, the MSC and FAC mixtures included more coarse aggregates and less CM content than the LMC mixtures. The plain and fibrous FAC mixtures showed approximately 30% higher shrinkage strains than the companion MSC mixtures, although both had similar coarse aggregate content and w/cm ratios (MSC mixtures had just a 3% higher w/cm ratio than the FAC mixtures). This is attributed to the higher total CM ratio in the FAC mixtures (658 lb/yd^3 compared to 603 lb/yd^3 in the MSC). Another factor could be the difference in the supplementary CM type and content between the FAC and MSC mixtures.

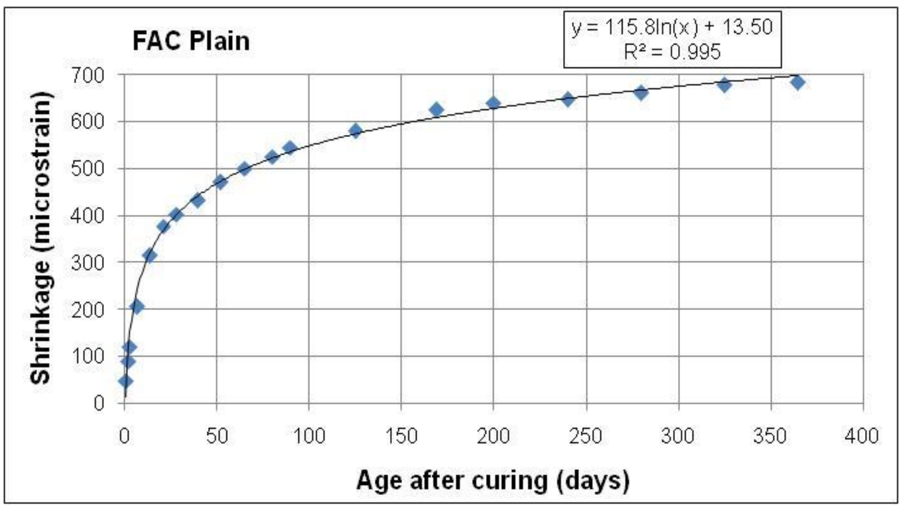

Figure 3.28. Shrinkage-time response of the plain FAC mixture.

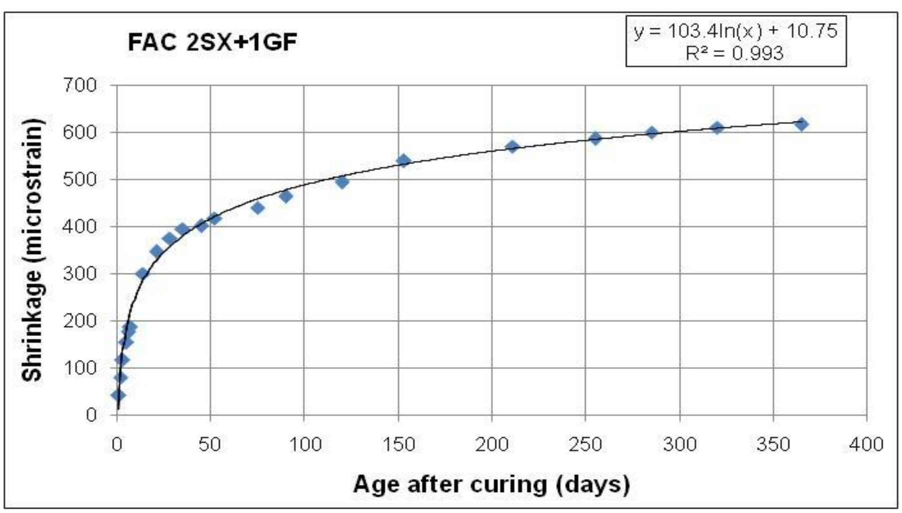

Figure 3.29. Shrinkage-time response of the MSC-2SX+1GF mixture.

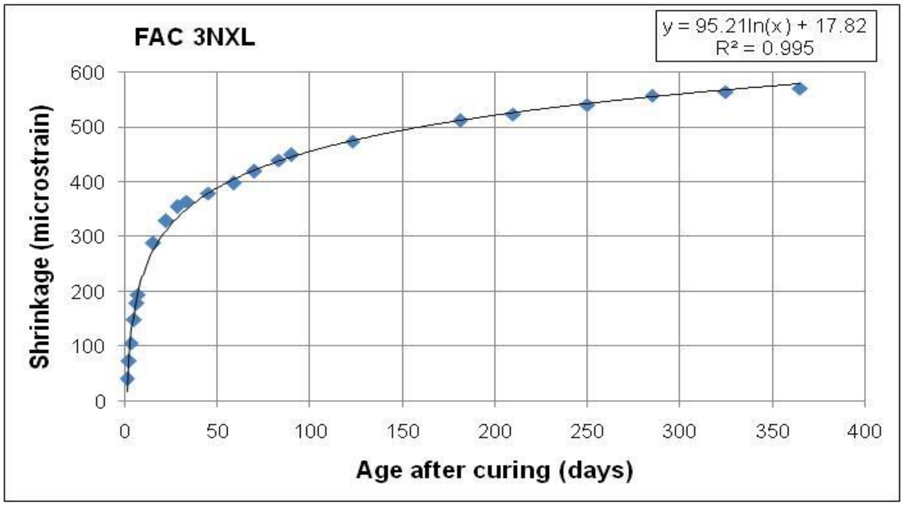

Figure 3.30. Shrinkage-time response of the MSC-3NXL mixture.

3.3.4 Coulomb Permeability

The average coulomb values of the two fibrous FAC overlay mixtures and the associated permeability classes as defined by ASTM C1202 are shown in Table 3.15. The coulomb values were higher than the companion MSC and LMC mixtures, and the corresponding permeability was higher. However, the permeability class is low for the fibrous FAC mixtures, which can be considered adequate for preserving bridge decks. The coulomb values from the permeability test for both fibrous FAC mixtures were comparable. As was the case in the LMC and MSC overlay mixtures, the coulomb values were consistent for the three specimens from each mixture type.

There is a concern about the validity of rapid chloride permeability test results when fly ash is added to concrete. Therefore, additional specimens from four different mix designs were sent to Purdue University–West Lafayette Materials Laboratory for further permeability testing as part of a pooled-fund research involving the Federal Highway Administration (FHWA), various states, and IDOT. The study is titled “Evaluation of Test Methods for Permeability (Transport) and Development of Performance Guidelines for Durability,” Project No. TPF-5 (179). The four mix designs were plain LMC, LMC-2SX+1GMF, MSC-2SX+1GF, and FAC-2SX+1GF. Five or six specimens were sent from each mix design. The tests conducted were rapid chloride penetration, conductivity, rapid chloride migration, porosity, oxygen diffusion, oxygen permeability, sorption, migration cell, and drying. The additional testing may provide further information on the differences in permeability among the mix designs. Information on the test methods and results obtained at Purdue University–West Lafayette can be obtained from IDOT, Division of Highways, Bureau of Materials and Physical Research, Springfield, Illinois.

Table 3.15. Rapid Chloride Permeability Test Results for the FAC Overlay Mixtures

Specimen No.	FAC-2SX+1GF	FAC-3NXL
1	1935	1586
2	1449	1512
3	1517	1638
Average	1634	1579
Class	Low	

3.3.5 Direct Tensile Bond Strength

Direct tensile bond strength tests were conducted for plain FAC and FAC-2SX+1GF.The direct tensile bond strength test results are shown in Table 3.16. The bond strength results of the three cores exceeded 300 psi at 7 days, although the test failures were at the disk interface not at the bond interface. The results show that bond strength develops with time as the concrete matures and that the fibers did not adversely affect the bond strength, as the bond strengths of the plain and fibrous FAC overlay specimens were comparable. The bond strength test results followed a similar trend as seen for the LMC and MSC overlay mixtures, which can be attributed to adequacy of the surface preparation of the full-depth slab segments as well as the appropriateness of the mix designs and installation procedure of the various overlay types.

The slab segment that was overlaid with fibrous FAC-2SX+1GF and kept in the open environment since January 20, 2010, did not show any signs of cracking or delaminations. Section 3.1.5 of this chapter includes additional information and figures that show the surface of this overlay type.

Table 3.16. Direct Tensile Bond Strength Test Results for the FAC Overlay Mixtures

Testing Age	Core No.	FAC Plain	FAC-2SX+1GF
7 days	1	391^{DI}	321^{DI}
	2	302^{DI}	312^{DI}
	3	343^{DI}	353^{DI}
28 days	1	429^{BC}	375^{DI}
	2	399^{DI}	464^{BC}
	3	421^{DI}	486^{BC}

BI: failure at the bond interface; DI: failure at the disk interface; BC: failure in the base concrete.

3.3.6 Flexural Performance and Residual Strength

Figure 3.31 shows the flexural performance of the FAC-2SX+1GF overlay mixture. The graph in Figure 3.31 is the average of the results obtained for three beams, all tested at 3 days. Table 3.17 summarizes the residual strength results. The residual strength (f^{D}_{150}) corresponding to a mid-span deflection of 3 mm is approximately 60 psi. The results are very comparable to the obtained residual strength for MSC-2SX+1GF and LMC-2SX+1GF. Those three different overlay mix types had similar fiber combinations. Since all of them experienced almost similar residual strength, it can be stated that the use of 2 lb/yd^3 of the macro-type fiber SX combined with 1 lb/yd^3 of the micro-type fiber GF will provide a residual strength of approximately 60 psi. As mentioned earlier, this fiber combination is practical in terms of constructability, as was demonstrated in this project. A higher dosage of the macro-fiber SX will result in a higher residual strength; however, the use of more than 3 lb/yd^3 of SX in bridge deck concrete overlays that are just 2¼ in. thick may result in constructability problems.

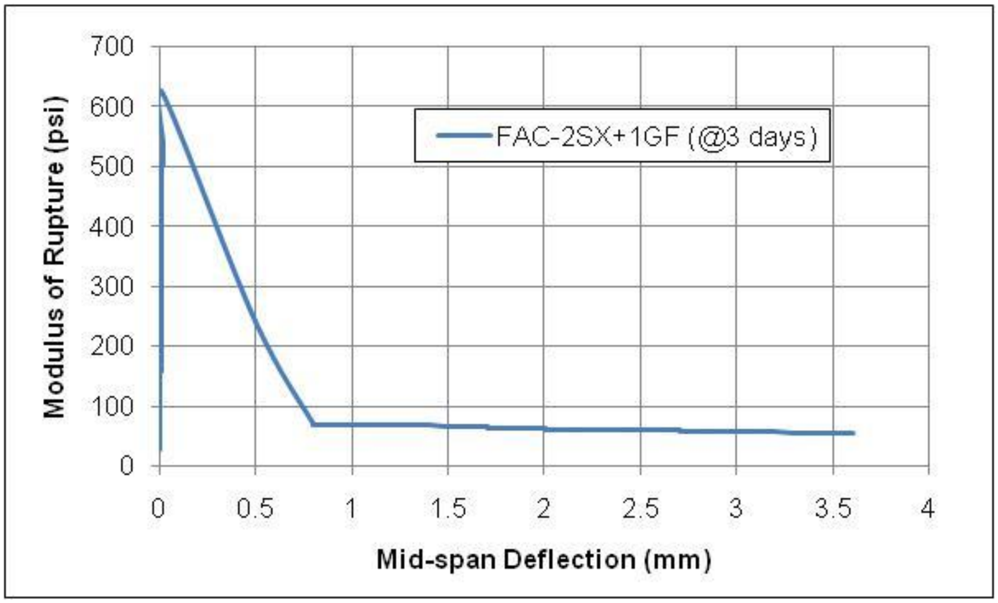

Figure 3.31. ASTM C1609 toughness test results of FAC-2SX+1GF.

Table 3.17. Summary of the Residual Strength Results for FAC-2SX+1GF

Mix Design	Compressive Strength, psi	Modulus of Rupture, psi	Residual Strength, psi	Residual Strength, % of the Modulus of Rupture
FAC-2SX+1GF	4780	620	60	9.7

CHAPTER 4 FIELD DEMONSTRATION AND COST ANALYSIS

4.1 FIELD DEMONSTRATION

This task was undertaken to evaluate the constructability of selected fibrous overlays. In addition, the demonstration projects will allow for long-term evaluation of the performance of fibrous concrete overlays under actual exposure conditions.

4.1.1 Fibrous LMC Overlay, Irving Park Road over EJ&E RR Bridge

The bridge at the intersection of Irving Park Road over EJ&E RR, Chicago, Illinois, received fibrous and plain LMC overlays on August 6 and 9, 2010, respectively. The IDOT structure number of this bridge is 016-0948. The original superstructure of the bridge was built in 1986 with a bare deck and no overlay. The general contractor of the project was Martam Construction, Inc. The IDOT representatives who witnessed installation of the overlays were Gary Kowalski (chair of the TRP of the research project), Christopher Haydel (RE), Abdul Dahhan, Julie Beran, and Robert Nies. Suleiman Ashur (co- PI. for this research project) represented the research team. The IDOT contract number is 60H80.

Fibrous LMC overlay (LMC with fiber-type ARGF) was installed on the westbound lane of the bridge, as shown in Figure 4.1. The eastbound lane received plain LMC overlay. The contractor was able to add approximately 2.4 lb/yd^3 of ARGF. The reason for selecting this fibrous LMC overlay mixture is that ARGF is currently the only fiber that can be added to the LMC into a mobile mixer. Each stage of the overlay was 142.3 ft long × 22 ft wide, with a total overlay width of 44 ft. The old deck surface was prepared using hydro-demolition to remove only the upper weak layer of concrete. Mobile volumetric trucks supplied with special fiber feeder systems that cut the fiber into ¾-in. sections prior to mixing were used to install the fibrous LMC overlay. Prior to the installation, the prepared deck surface was dampened for about 24 hours to fully saturate the upper concrete layer of the bridge deck. Just before placing the concrete overlay, the excess water at the deck surface was dried. Sufficient contractor crews were available for placement of the overlay, finishing, and curing procedures. Curing started as soon as possible, in accordance with IDOT standards. The fibrous LMC overlay was wet-cured for 2 days followed by 2 days of air-dry curing.

The roadway/bridge was completely closed on July 26, 2010, to begin the work on the deck slab repair, replacement of bridge expansion joints, and the overlay. The roadway was then completely opened (both sides) to traffic on August 16, 2010. This 3-week closure allowed IDOT to perform all repair work on the bridge. The roadway was opened to traffic after both sides of the overlay had achieved the IDOT-required compressive strength of 4000 psi (achieved at 3 days for both overlay types); the bridge deck grooving and permanent pavement markings were also in place. For bridge grooving, a series of grooves were cut into the overlay perpendicular to the centerline at ¾-in. center-to-center spacing, 1/8 in. wide, and 3/16 ± 1/16 in. deep. This work was performed by a machine with a series of saw blades calibrated to IDOT standards. The cost of the plain LMC overlay for this project was $\$63/yd^2$. The additional cost for the fibrous additives in the LMC overlay was $\$14/yd^3$, which is approximately equivalent to $\$0.88/yd^2$.

Specimens were taken by the research team and IDOT to test the compressive and flexural strengths at 14 days and to test the coulomb permeability. The results of the tests conducted at Purdue University–Fort Wayne (IPFW) and IDOT are shown in Tables 4.1 and 4.2, respectively. The results show that the fibrous and plain LMC mixtures met the IDOT strength criteria at 14 days. The difference in the strength results between the fibrous and plain LMC mixtures was attributed to the difference in the amount of water added. According to the proportions sheet that was supplied by the contractor, the w/c ratio for the plain LMC was lower than the fibrous LMC overlay mixture. Figures 4. 2 through 4.12 show the various stages of the overlay construction.

The fibrous and plain LMC overlays were visually inspected by the research team and two bridge inspectors from IDOT on July 11, 2011, after 1 year in service. The condition of both overlays was found to be excellent, without any visible hairline cracks. Figure 4.13 shows pictures taken during the inspection. The last picture to the right in Figure 4.13 shows visible cracks around the transverse joints, which received different concrete than the overlay. Such cracks, which ranged from hairline to a few millimeters at these locations, could lead to potential cracks in the overlay in the future.

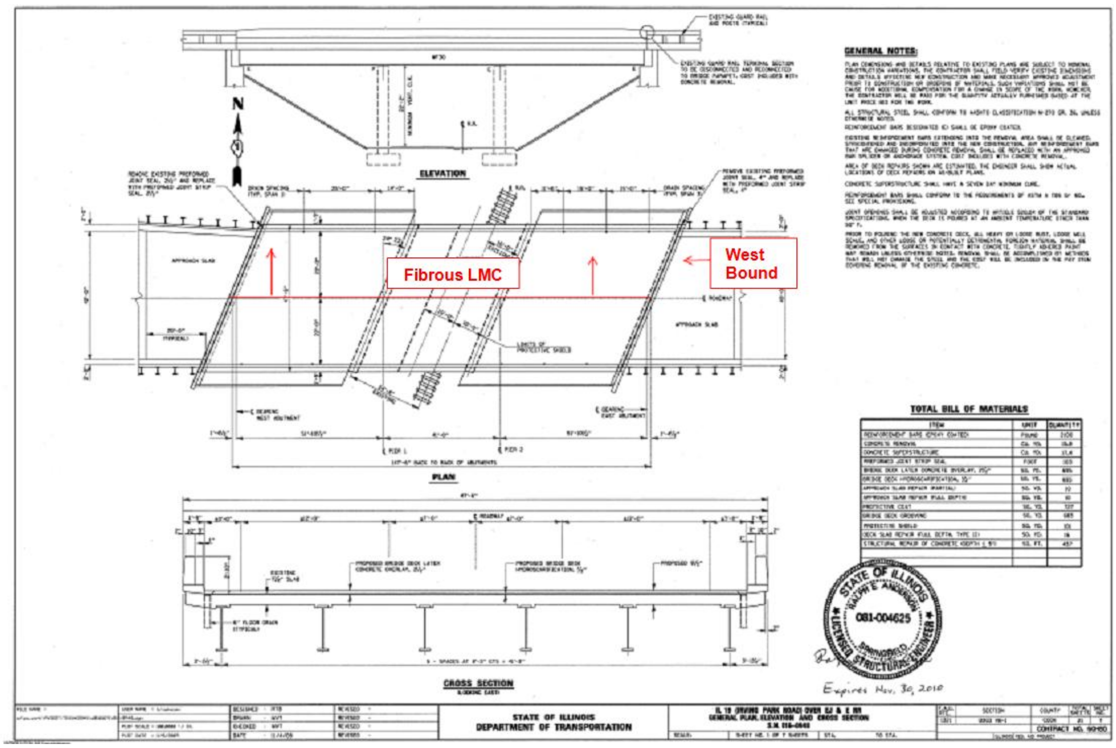

Figure 4.1. Irving Park Road over EJ&E RR, SN 016-0948, Contract 60H80m, let 01/15/2010, item 225 (latex overlay with fibers on the westbound lane).

Table 4.1. Results of the Tests Conducted at IPFW for the LMC Overlays

Property	Specimen No.	Fibrous LMC	Plain LMC
Compressive strength at 14 days (psi)	1	4780	5590
	2	4690	6000
	3	4630	5960
	Average	**4700***	**5850***
Flexural strength at 14 days (psi)	1	1040	1360
	2	1140	1270
	3	1100	1300
	Average	**1190***	**1310***
Coulomb permeability at 56 days (coulombs)	1	804	848
	2	914	756
	3	866	780
	Average	**860***	**795***
	Class	**Very low**	

*****The w/c ratio for the plain LMC is lower than that of the fibrous LMC mixture.

Table 4.2. Results of the Tests Conducted by IDOT for the LMC Overlays

Compressive	Fibrous LMC	Plain LMC
4 days	4500	4615
7 days	5030	5755
14 days	5840	6050

Figure 4.2. Construction site with the contractor and IDOT crews (LMC overlay).

Figure 4.3. Prepared bridge deck surface using hydro-demolition (in some locations, the epoxy-coated steel bars were exposed as shown, and touch-up coating was then applied).

Figure 4.4. Fiber feeder system adapted to the mobile trucks.

Figure 4.5. Calibration of the mobile mixer.

Figure 4.6. Blowing the chopped fibers into the LMC using a pipe under pressurized air.

Figure 4.7. Removal of the plastic sheets that were used to keep the prepared slab surface dampened prior to installation of the overlay, starting from the transverse joints.

Figure 4.8. Quality-control practices and preparation of the LMC overlay test specimens.

Figure 4.9. Finishing practices of the fibrous LMC overlay.

Figure 4.10. Removal of any fiber clumping during the finishing of the LMC overlay (clumping was noticed on rare occasions—probably only two times).

Figure 4.11. Finished surface of the fibrous LMC overlay ready for the stamp.

Figure 4.12. Laying down the cotton mats for curing of the LMC overlay.

Figure 4.13. Pictures taken during the inspection of the plain and fibrous LMC overlays after 1 year in service.

4.1.2 Fibrous FAC Overlay, IL106 Pike County Bridge

The bridge on Illinois Route 106 over the Sny River, Pike County (west of Hull), Illinois, received fibrous FAC overlay on the westbound lane on June 29, 2011, as shown in Figure 4.14. Plain FAC overlay was installed on the eastbound lane on August 3, 2011.The IDOT representatives who witnessed the installation of the fibrous FAC overlay (stage 1) were Gary Kowalski (chair of the TRP of the research project), Jerry Robbins (RE), Greg Heckel, John Sestak, Laura Shanley, and Solomon Wab-Lumor. Students Jacob Allen and Nicholas Fenton represented the IPFW research team.

The information reported in this section pertains to the fibrous FAC overlay, which is part of the scope of the research project. The bridge was built in 1965. The bridge is 91 ft, 6 in. × 46 ft, 10½ in., with a driving surface (44 ft, 5 in. wide) staged down the centerline of the bridge (where the overlay was installed). The joints were rehabbed in 1997 and the deck was bare, with no existing overlay. The IDOT structure number of the bridge is 075-0024. The contractor's name is Freesen, a division of United Contractors Midwest. The IDOT contract number is 72D44.

The mixture design proportions were not identical to the FAC mix design shown in Table 2.3 of this report. The mixture design proportions were 455 lb/yd^3 Type I portland cement, 150 lb/yd^3 Class C fly ash, 257 lb water (w/cm = 0.42),1853 lb/yd^3 coarse aggregate, and 1099 lb/yd^3 fine aggregate. The mix design materials were from IDOT-approved sources. The fiber type used in FAC overlay was a macro-fiber from an IDOT-approved list of fibers, with a dosage of 3 lb/yd^3.Ready-mixed concrete trucks were used for installation of the fibrous FAC overlay. The fibers were added at the plant. The unopened fiber bags were added to the truck mixer before batching. Each bag had 3 lb of fibers, and the bag dissolved in the concrete. The following was included in the project specifications as Note 3 (see Appendix B of this report):

When specified on the plans, synthetic fibers shall be added to the concrete and mixed per the manufacturer's recommendations. The fibers shall be from the "Approved List of Synthetic Fibers" except the maximum length of fiber shall be 1.75 inches (45 mm). Synthetic fibers shall be added at a rate of 3.0 lb/yd^3 (1.8 kg/m^3). A 2 yd^3 (1.5 m^3) trial batch shall be performed to evaluate the mixture for strength and other properties. Samples for testing will be done by the Department. The trial batch shall be placed in a 12 × 12 ft (3.6 × 3.6 m) slab or other configuration approved by the Engineer to evaluate the mixture for fiber clumping, ease of placement, and finishing. Based on the trial batch, the Department has the option to reduce the weight (mass) of fibers to be added to the concrete mixture.

According to the contractor and to IDOT, everything was adequate during the test slab.

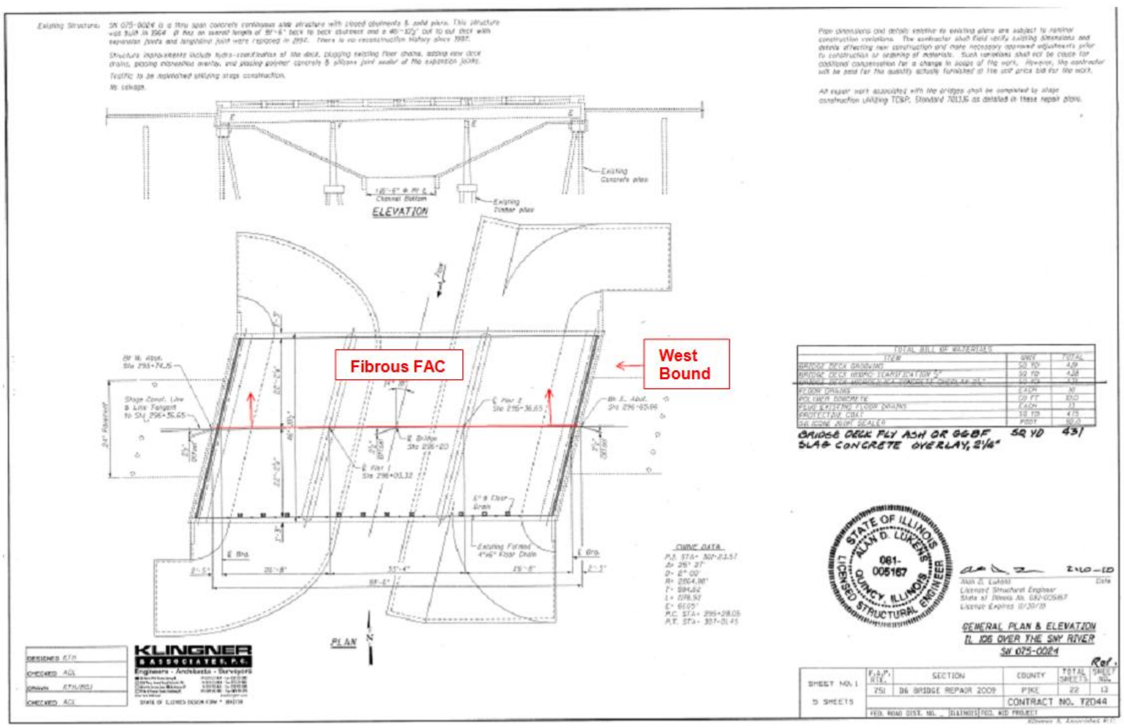

Figure 4.14. IL106 over the Sny River, SN 075-0024, Contract 72D44, let 01/21/2011, item 143 (fly ash overlay with fibers on the westbound lane).

Five concrete loads were mixed at the plant using five different ready-mixed concrete trucks and sent to the field to cast the fibrous FAC overlay. The fresh properties were measured initially at the plant and again at the construction site. The results are reported in Table 4.3. As shown in that table, the first truck was rejected because it arrived late and the concrete was too old to work with. For the second truck, the plant was not working properly, so it was impossible to know how much additives were in the mixture. Only 3 yd^3 of the 6 yd^3 were used; the remaining half of the load was rejected. The prepared test specimens were taken from load 3. The plant and field fresh concrete properties show general agreement. The differences were attributed to the difference in the air temperatures and the long drive from the plant to the field, which was around 45 minutes. Also, water and admixtures were added to some trucks at the bridge site to achieve the required slump and air values.

The old deck surface was prepared using hydro-demolition to remove the upper weak layer of concrete. Prior to the installation, the prepared deck surface was dampened for about 24 hours to fully saturate the upper concrete layer of the bridge deck. Just before placing the overlay, the excess water at the deck surface was dried. Sufficient contractor crews were available for the placing, finishing, and curing procedures. Curing started as soon as possible, in accordance with IDOT standards. The bridge was open to traffic 7 days after the overlay installation, which is the required curing period for the FAC overlay. For bridge grooving, a series of grooves were cut into the overlay perpendicular to the centerline at ¾-in. center-to-center spacing, 1/8 in. wide, and 3/16 ± 1/16 in. deep. This work was performed by a machine with a series of saw blades calibrated to IDOT standards. The cost of the FAC overlay with and without fibers was not representative of the expected cost of that overlay since it was just one item in the overall project. The lowest overall bidder had been awarded the contract.

Table 4.3. Fresh Concrete Properties for the Fibrous FAC Overlay Batches

Truck #	Test Location	Fresh Concrete Properties			
		Air Temp. (°F)	Concrete Temp. (°F)	Slump (in.)	Air (%)
1	The first truck was rejected because it arrived too late; therefore, the concrete was too old to work with.				
2	Plant	74.9	77	2.25	7.5
	Field	89	86	3.75	6.3
3	Plant	77.5	84.5	2.75	5.4
	Field	89	88	4	6.6
4	Plant	81	78.9	3.5	6.2
	Field	89	79	3	6.0
5	Plant	81.8	80	5.25	7.3
	Field	89	82	8	6.7

Specimens from the fibrous FAC overlay project were taken by the research team and IDOT to test compressive strength, flexural strength, residual strength, and permeability. Table 4.3 shows the plastic concrete properties measured at the plant and at the bridge site. The fresh concrete properties clearly illustrate the important of enforcing strict QC/QA practices. The first truck was rejected because it arrived late; half of the second truck's load was also rejected. After that, the process continued smoothly.

The compressive and flexural strength results are shown in Table 4.4. The results show that the compressive and flexural strengths of the fibrous FAC overlay mix design exceeded IDOT criteria at 14 days. The coulomb permeability was 1750, which is in the low class. Figure 4.15 shows the toughness test results. The residual strength corresponding to mid-span deflection of 3 mm was approximately 70 psi (12% of the modulus of rupture). Figures 4.16 through 4.20 show the various stages of the overlay construction. However, it should be noted that there are reservations about the suitability of ASTM C1202 for concrete mix designs with fly ash.

The overlay was visually inspected by the RE after curing and before the lane was opened to traffic (1 week from the installation). There were no cracks at any location, including at the east end where load #2 (the first half was used and the second half was rejected) was placed. According to the RE: "One thing I did notice from talking to the finishers, when the mix is very fresh and still very moist, the fibers seem to grab onto the finishing float. I did observe one area where it looked like this happened near the middle of the pour. The finisher said it worked better if he could let the mix begin to set up a little before he used the float."

Figure 4.21 shows pictures taken by the RE just before opening the fibrous FAC to traffic at the end of the curing period. The top left picture shows a good broomed finish with some fibers showing. The top right picture shows a broomed finish with some fibers showing and some wrinkles from the cotton blanket. The bottom left picture shows an area where the contractor tried to broom the surface too early, and the fibers wanted to grab the broom. The bottom right picture shows an area where the contractor may have laid the blankets on too early (fibers are showing, but not the broomed finish).

Table 4.4. Test Results of Fibrous FAC Overlay

Property	Age	Specimen No.	Tests at IPFW	Tests at IDOT
Compressive strength	7 Days	1	—	5022
		2	—	4421
		2	—	—
		Average	—	**4721**
	14 Days	1	6100	> 5305
		2	6420	> 5305
		3	6030	—
		Average	**6180**	**> 5305***
	28 Days	1	6590	6090
		2	6410	6140
		3	6300	—
		Average	**6430**	**6115**
Flexural strength	14 Days	1	592	—
		2	589	—
		3	595	—
		Average	**592**	—
	28 Days	1	800	—
		2	810	—
		3	800	—
		Average	**805**	—
Coulomb permeability at 56 days (coulombs)	56 Days	1	1690	—
		2	1836	—
		3	1720	—
		Average	**1750**	—
		Class	**Low**	—

*The testing machine was stopped at this stress level before breaking the specimen.

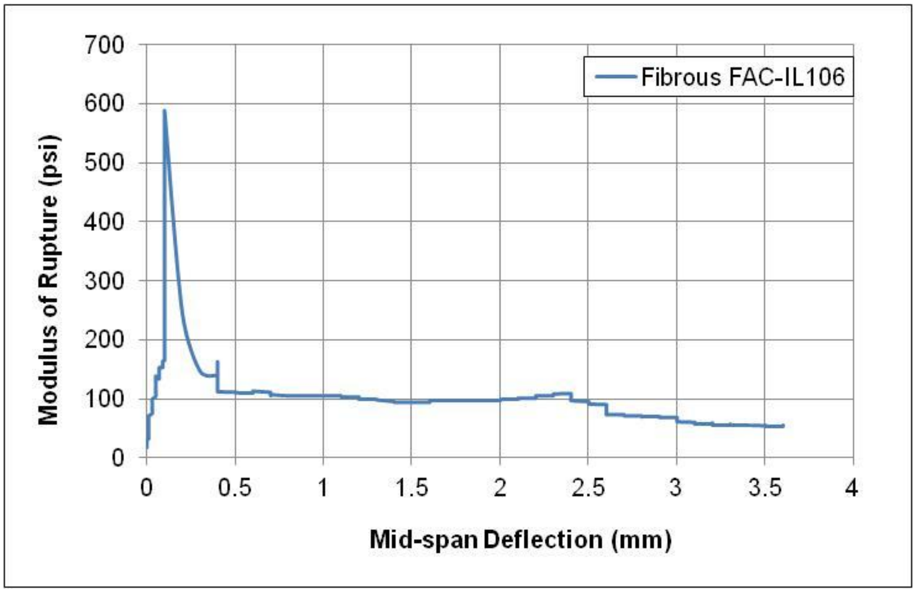

Figure 4.15. ASTM C1609 toughness test results of the fibrous FAC overlay.

Figure 4.16. Prepared bridge deck surface using hydro-demolition (in some locations, the slab was severely deteriorated, which required exposing the steel rebars).

Figure 4.17. Placement of the fibrous FAC overlay.

Figure 4.18. Finishing of the fibrous FAC overlay.

Figure 4.19. Quality control and preparation of the fibrous FAC test specimens.

Figure 4.20. Laying down the cotton mats for curing of the fibrous FAC overlay.

Figure 4.21. Pictures taken by the RE just before opening the fibrous FAC to traffic at the end of the curing period (1 week after the installation).

4.2 COST ANALYSIS

The intent of this task was to assess the potential life-cycle cost savings that might be obtained from incorporating fibrous additives within the concrete overlays. Comparison was also made between the life-cycle cost of the LMC and MSC overlays. The LMC and MSC overlays installed by IDOT during the period of 2005–2011 were acquired along with the quantities and unit cost, as shown in Table 4.5. Figure 4.22 shows the quantities installed each year, as well as the unit cost of the overlays. The majority of the installed overlays had a 2¼-in. thickness, but a few had higher thickness; however, the cost of the thicker overlays was comparable to the cost of the typical 2¼-in. overlays.

Table 4.5. Quantity and Cost of the Overlays Installed by IDOT from 2005–2011

Overlay Type		Year of Installation							Annual Average
		2005	2006	2007	2008	2009	2010	2011	
MSC	Quantity ($\times 10^3$ yd^2)	120.1	121.9	30.5	0.46	40.4	8.4	12.8	58.67
	Total cost ($\times 10^3$\$)	7,334	7,518	2,424	53	1,980	4,933	837	3,583
	Unit cost (\$/yd^2)	61.07	61.67	79.55	114	49	58.4	65.2	61*
LMC	Quantity ($\times 10^3 yd^2$)	1.7	3.2	21.5	20.4	65.5	103	31.1	35.2
	Total cost ($\times 10^3$\$)	161	205	1,795	1,618	3,700	7,686	1,935	2,443
	Unit cost (\$/yd^2)	93.64	64.59	83.41	79.38	56.45	74.54	62.26	69*

* Weighted average.

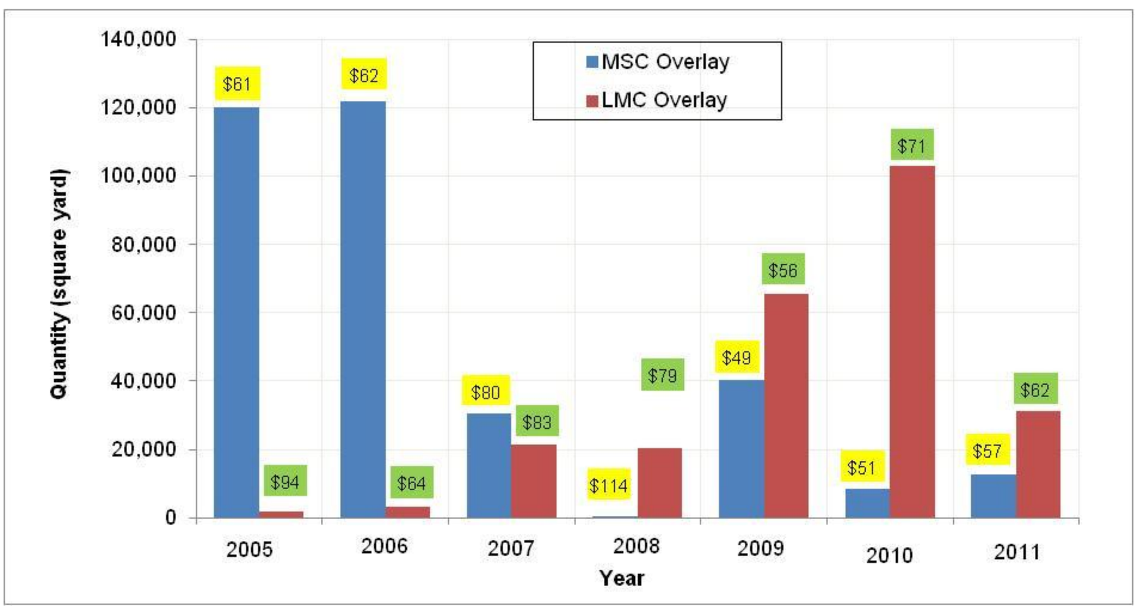

Figure 4.22. Quantity and unit cost of IDOT MSC and LMC overlays over 7-year period.

For this research, life-cycle cost analysis (LCCA) was defined as the process of identifying the total economic worth or cost of a bridge deck overlay over its complete life cycle or the duration of the period of study, whichever is shorter. Specifically, LCCA was conducted to assess the direct total costs associated with constructing and maintaining an overlay system. Information gleaned from LCCA is particularly important for planning a new overlay project and evaluating different alternatives. The quantities and unit costs presented in Table 4.5 were considered in the LCCA. The cost of the LMC and MSC overlays installed by IDOT during the period of 2005–2011 was \$657,174 yd^2 (\$246,495 yd^2 LMC and \$410,677 yd^2 MSC), with an average annual quantity of 93,882 yd^2 (35,214 yd^2 LMC and 58,668 yd^2 MSC). The weighted averages of the unit costs of the installed LMC and MSC overlays were \$69 and \$61, respectively. The total cost of concrete overlays during the period of 2005–2011 was approximately \$42 million (annual cost approximately \$6 million).

It is generally accepted (as can be seen in the survey results in Appendix A) that LMC overlays have longer service life than MSC overlays mainly due to their better bonding with the bridge deck. IDOT concrete overlays typically achieve 12 to 20 years of service life, according to the Bureau of Bridges and Structures Therefore, in the LCCA, the service lives of the LMC and MSC overlays were taken as 20 years and 15 years, respectively. It is important to recognize that the better performance of the LMC is reflected in its longer service life.

The FHWA recommends use of a real discount rate (i) in the range of 3% to 5% (Lamptey et al. 2005). In the LCCA conducted for this project, i was assumed to be 5%. Table 4.6 shows the results of the LCCA for 100 yd^3. The least common multiple was used for evaluation of the alternatives. The results show that the life-cycle cost of the plain LMC overlay is more economical than the plain MSC overlay by about 5.8%. A typical cash flow diagram of the LCCA (plain LMC and plain MSC overlays) is shown in Figure 4.23.

The fibers add approximately \$1/yd^2 to the cost of the overlay. To account for potential life-cycle cost savings as a result of potential increase of the service life of concrete overlays by the fibrous additives, a sensitivity analysis was conducted. The results (Figure 4.24) show that if the fibrous additives increase the service life by 1 year, the life-cycle cost savings for the LMC and MSC overlays would be 1.4% and 2.7% from the cost of plain overlays, respectively. If the increase is 5 years, the life-cycle cost savings for the LMC and MSC overlays would be 10.3% and 15.3% from the cost of the plain overlays, respectively. Another important point is that if the fibrous additives were not to extend the service life of concrete overlays, the addition to the initial cost would be just \$1/yd^2. This is considered a minor increase in the initial cost if the chance of success in concrete overlays will be improved.

A major factor not reflected in the LCCA (Table 4.6) is that the LMC overlay can be open to traffic sooner than the MSC and FAC overlays. This could be a huge savings in some projects, especially when fast-track construction is a major issue. A study by Kendall et al. concluded that “traffic delay caused by construction comprises 91% of total costs” for two alternative designs (2008, p. 214).

A sensitivity analysis is presented to reflect the impact of user cost shown in Table 4.7. The time to open the LMC overlay to traffic was assumed to be 5 days, and the time to open the MSC overlay to traffic was assumed to be 8 days (1 day is added to the typical curing period of each overlay type to account for deck surface preparation). If these numbers were implemented in the LCCA as shown in Table 4.7, the life-cycle cost of the LMC would be much lower than the MSC overlay cost. Therefore, the authors recommend the use of LMC overlay whenever possible, especially for new and heavy-traffic bridges, unless its cost is dramatically affected by unusual factors such as lack of local contractors. The use of MSC overlays may be justified in certain regions; however, the newly proposed FAC overlay could be used as a replacement to the MSC overlay, with significant reduction expected in the cost and comparable service life.

Table 4.6. LCCA of the Plain LMC and MSC

Item	Plain	
	LMC	MSC
Unit Cost	$69	$61
Total Cost of 100 yd^2	$6,900	$6,100
Service Life (n)	20	15
Analysis Life	60	60
Analysis Cycle	3	4
Agency Cost (Annuity)	$554	$588
Savings per 100 yd^2	$34 (5.8%)	

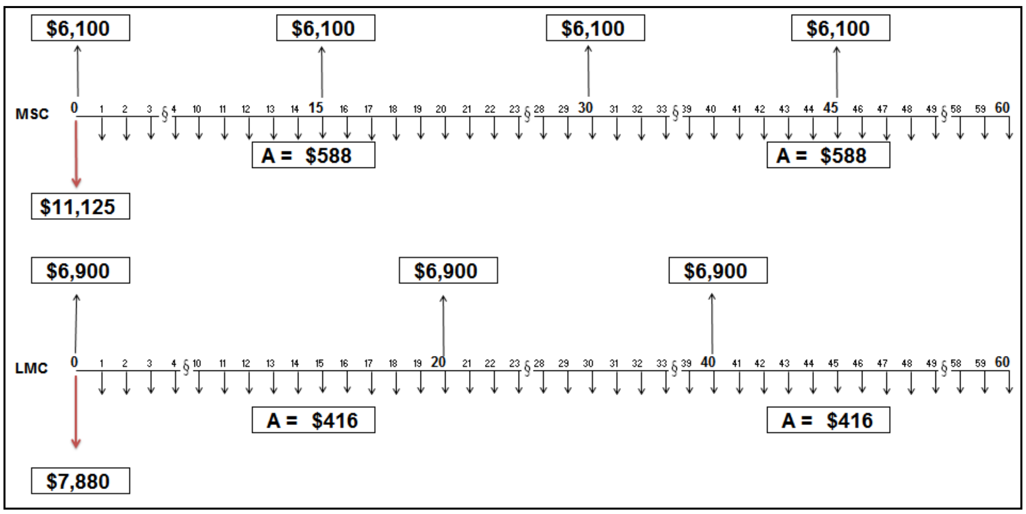

Figure 4.23. Typical cash flow diagram of LCCA (plain LMC and plain MSC overlays).

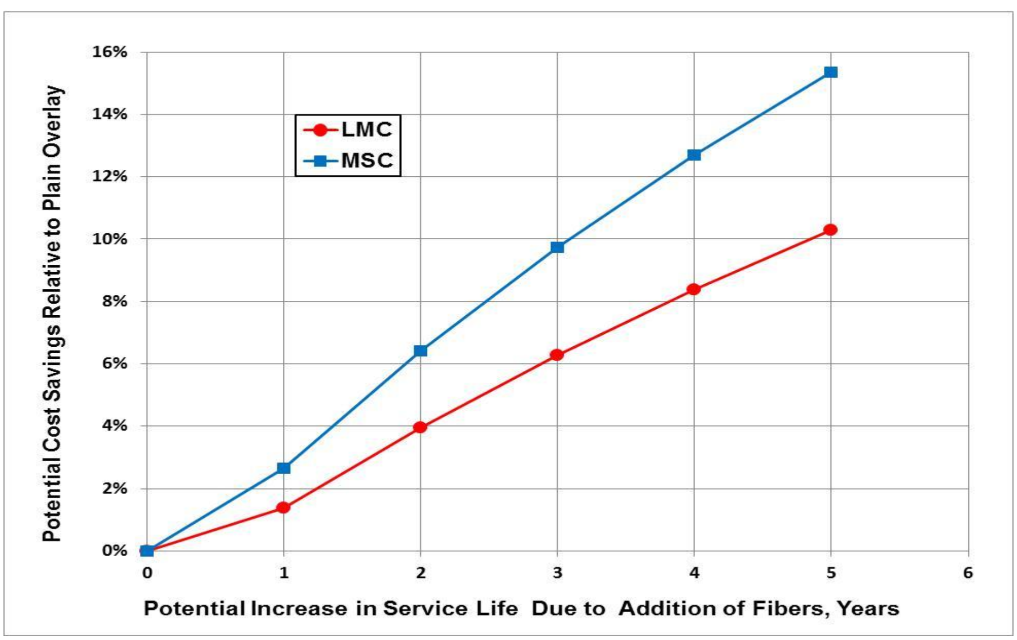

Figure 4.24. Potential cost saving from addition of fibers to concrete overlays.

Table 4.7. LCCA of the Plain and Fibrous LMC and MSC (User Cost Is Considered)

% of the Total Cost	Plain			Fibrous		
	LMC	MSC	% Savings	LMC	MSC	% Savings
0%	$554	$588	6%	$497	$498	0%
5%	$570	$617	8%	$512	$522	2%
10%	$587	$646	9%	$528	$547	4%
15%	$604	$676	11%	$543	$572	5%
20%	$620	$705	12%	$559	$597	6%
25%	$637	$735	13%	$574	$622	8%
30%	$654	$764	14%	$590	$647	9%
35%	$670	$793	16%	$605	$672	10%
40%	$687	$823	17%	$621	$697	11%
45%	$704	$852	17%	$636	$721	12%

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations detailed in this chapter are based primarily on the results and findings of this research project. The conclusions and recommendations are grouped under the major topics of importance.

5.1 FIBROUS ADDITIVES

- Total synthetic fiber content (polypropylene and nylon types) of 3 lb/yd^3 is recommended for bridge deck concrete overlays. Because of the thin concrete overlay, fiber contents greater than 3 lb/yd^3 may result in critical constructability issues such as fiber balling and clumping during mixing, placing, and finishing. Higher dosages of synthetic fibers must be justified through a trial batch and demonstration pad to verify their constructability in concrete overlays.
- For a similar total fiber content, the workability and finishability were slightly better when combining macro- and micro-fibers compared with a single macro-fiber type; however, the residual strength was lower.
- Within the upper recommended limit of 3 lb/yd^3, the results showed the following influence of the fibrous additives on the performance (i.e., improved resistance to cracking and delaminations) of concrete overlays:
  - Reducing the drying shrinkage (between 10% and 15%).
  - Adding post-cracking residual strength between 50 and 75 psi, depending on the percentage of macro-fibers used.
  - Providing internal confinement, resulting in a slight increase in the flexural strength (between 5% and 10%) and improved compression failure mode.
  - No adverse effects on the compressive strength, permeability, and bond strength.
- Macro-fibers with mesh-type configurations are not recommended for concrete overlays because they resulted in complications during mixing and finishing. Micro-fibers with mesh-type configurations did not show similar complications.
- The maximum recommended length of macro-fibers is1.75 in., and the minimum recommended length of micro-fibers is 0.75 in.
- Before using the fibrous concrete overlay mixture, it is recommended to perform a 2-yd^3 trial batch to evaluate the mixture for strength and other properties. The trial batch must be placed in a 12 × 12 ft slab or other configuration approved by the engineer to evaluate the mixture for fiber clumping, ease of placement, and finishing. Based on the trial batch, the department has the option to reduce the weight of fibers to be added to the concrete mixture.
- The workability and finishability of the fibrous LMC overlay mixtures was better than the companion fibrous MSC and FAC due to the higher mortar factor of the LMC compared with the MSC and FAC.
- A majority of the commercially available synthetic fibrous additives can be easily incorporated within the FAC and MSC overlay mix designs due to the use of ready-mixed concrete trucks.
- A special fiber feeder system is required in the LMC overlay due to the use of volumetric mobile mixers. Currently, one type of synthetic fibers (alkali-resistant glass fiber) can be added at a dosage between 2 and 2.4 lb/yd^3. Other fiber feeder systems are currently available in the market and can be used to incorporate other types of synthetic fibers within the LMC overlay; however, they have not yet been tried.

5.2 OVERLAY MIX DESIGNS AND PERFORMANCE CHARACTERISTICS

- IDOT specifications and requirements for the LMC, MSC, and FAC mix designs are adequate in terms of meeting the required fresh concrete properties and minimum performance requirements. Because of their demonstrated excellent performance characteristics, the mix designs (shown in Tables 2.1, 2.2, and 2.3) can serve as example mixtures for the three overlay types.
- In specifications for future IDOT concrete overlay projects, it is recommended to state the required fiber type and content(macro/micro) from IDOT's approved list of synthetic fibers (no brand name). As a quality check on the selected fiber type and content, it is recommended to require a minimum residual strength of 50 to 75 psi measured, in accordance with ASTM C1609.The 50-psi residual strength is recommended when 2 lb/yd^3 of synthetic macro-fibers plus 1lb/yd^3 of synthetic micro-fibers are specified for the project. The 75 psi residual strength is recommended when 3 lb/yd^3 of synthetic macro-fibers is specified for the project.
- All of the fibrous LMC, MSC, and FAC overlay mixtures had high performance strength properties; however, the MSC and FAC mixtures achieved significantly higher strength properties than the LMC with a similar fiber combination and w/cm ratio.
- The drying shrinkage strains of the LMC mixtures were significantly higher than the companion MSC and FAC mixtures due to the short moist-curing period of the LMC. However, the high drying shrinkage strains of the LMC are usually balanced by the inherent flexibility provided by latex polymerization.
- The permeability classes of the fibrous overlay mixtures were comparable with the companion plain mixtures, indicating that the fibrous additives did not jeopardize the permeability of concrete overlays.
- Enforcing strict QC/QA practices is a key element for successful overlay construction. As observed in the two demonstration projects, many things can go wrong when there are no QC/QA practices.

5.3 DECK SURFACE PREPARATION

- The condition of the underlying bridge deck slab surface is one of the major factors in the severe cracking and delaminations of concrete overlays that sometimes occur at very early age. Therefore, correct surface preparation is important for proper and strong adhesion of the overlay to the base and to the overall longevity of the overlay. Optimum bond can only be achieved if the weak concrete at the top surface of the slab is completely removed. In many locations, the entire reinforcing steel system was exposed since the surrounding concrete was completely disintegrated.

5.4 NEWLY PROPOSED FAC OVERLAY

- The performance characteristics of the newly proposed fibrous FAC overlay mix design exceed IDOT requirements for concrete overlays and can be considered quite comparable to the performance of the MSC except in terms of coulomb permeability (very low class for the LMC and MSC compared to low class for the FAC, in accordance with ASTM C1202)
- This research is pioneering in terms of using fibrous FAC overlay. Considering its performance characteristics (which exceed IDOT criteria for concrete overlays), low cost, and replacement of 20% to 25% of the cement with fly ash, the proposed FAC overlay is considered a new sustainable bridge deck concrete overlay system. The use of fly ash in the FAC overlay mix design is in compliance with one of the major

sustainability considerations in terms of minimizing adverse environmental impact (disposal of fly ash and reducing CO_2 emissions by lowering the cement content).

5.5 LIFE-CYCLE COST AND OPTIMUM OVERLAY SYSTEM

- Based on analysis of the IDOT overlay projects installed during the period of 2005–2011, the life-cycle cost of the plain LMC overlay is lower than the life-cycle cost of the plain MSC overlay when initial installation costs and the service lives are considered.
- If user costs from construction traffic delays are considered, the life-cycle cost of the plain LMC overlay will be much lower than the plain MSC overlay. The initial cost will also be lower since the required curing time of the LMC overlay is 4 days but is 7 days for the MSC overlay. The potential savings could be large in some projects, especially when fast-track construction is a major issue.
- The fibrous additives slightly increase the initial installation cost of concrete overlays (less than $\$1/yd^2$). Based on the sensitivity analysis shown in Figure 4.24 there could be a life-cycle cost saving for just a 1-year potential increase in the service life of concrete overlays. Therefore, fibrous additives are recommended for concrete overlays.
- The results of this project showed that the LMC overlay can develop 3000 psi compressive strength and bond strength above 175 psi at 2 days, which is the required wet-curing period for LMC overlays. Therefore, it might be possible to open the LMC overlay to traffic 2 or 3 days after installation. However, it is necessary to verify the strength criteria of the LMC overlay before opening it to traffic.
- The proposed fibrous FAC overlay can be used as a new overlay system with performance characteristics that exceed IDOT criteria and with significant expected reductions in the cost.

This project found some advantages for incorporating fibrous additives within bridge deck concrete overlays in terms of performance enhancement and potential life-cycle cost savings—and without significant increase in initial installation cost. Recommendations were made in this chapter regarding the type and content of fibrous additives as well as the optimum overlay system.

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APPENDIX A SURVEY

Dear State DOT,

We are conducting a survey pertaining to a research project entitled “Superiority and Constructability of Fibrous Additives for Bridge Deck Overlays” funded by Illinois Department of Transportation (IDOT) through the Illinois Center for Transportation (ICT).

The principal objective of this research study is to evaluate the advantages that the fibrous additives can add to the performance of bridge deck concrete overlays in terms of minimizing shrinkage cracking and providing crack arresting mechanism. At the same time, the fibrous concrete overlay must be constructible without complications.

As part of this project, the research team is charged with surveying the practices and experience of selected DOTs and researchers who have experimented with bridge deck concrete overlays with synthetic fibers (none-metallic fibers). Your completion of the attached survey is very valuable to this research and highly appreciated.

Please fill the attached survey and email the completed survey to alhassan@engr.ipfw.edu. Alternatively you can fill the survey on the web by accessing the following link: State DOT Survey. Please note that your participation is voluntary.

In case you have question or need further information, please contact either Dr. Mohammad Alhassan at Alhassan@engr.ipfw.edu or by phone at (708) 843-1885 or Dr. Suleiman Ashur by email at ashurs@ipfw.edu or by phone at (260) 481-6080.

Sincerely,

Drs. Alhassan and Ashur

State DOT Survey on Advantages of Fibrous Additives on Performance of Bridge Deck Concrete Overlays

Project Name: Superiority and Constructability of Fibrous Additives for Bridge Deck Overlays

Sponsor: Illinois Center for Transportation ICT/IDOT Project 27-57

Investigators: PI: Dr. Mohammad Alhassan
Co-PI: Dr. Suleiman Ashur

Address: Engineering Department
Indiana-Purdue University Fort Wayne (IPFW)
2101 E. Coliseum Blvd, ET 327A
Fort Wayne, IN 46805

State DOT Name: ____________________

Respondent Name: ____________________

Position of the Respondent: ____________________

Contact Information: Phone: ____________________

Email: ____________________

I) Background

1) Does your agency use synthetic fibers (non-metallic) in Latex-Modified Concrete(LMC) overlays? a) Yes b) No

2) Approximately, how many fibrous LMC overlays have been used in your state? ___overlays

3) Does your agency use synthetic fibers (non-metallic) in Micro-Silica Concrete (MSC) overlays? a) Yes b) No

4) Approximately, how many fibrous MSC overlays have been used in your state? ___ overlays

II) Overlay Mix Design

A copy of the standard overlay mixes (LMC & MSC) used at your state is highly appreciated.

III) Fiber Usage in Overlays

1) If your agency uses/used synthetic (non-metallic) fibers in LMC and/or MSC overlays, then please fill the table below:

	Brand Name	Dosage (lb/cy)	Overlay Type
A)	________	________	________
B)	________	________	________
C)	________	________	________
D)	________	________	________

2) Please indicate your observation when using synthetic fiber (non-metallic) in LMC overlays:

Observation	Frequent	Average	Rare	Never
1) Mix easily constructible				
2) Occurrence of fiber balling				
3) Occurrence of fiber floating				
4) Reduction in early age cracking				
5) Better overall performance				

3) Please indicate your observation when using synthetic fiber (non-metallic) in MSC overlays:

Observation	Frequent	Average	Rare	Never
1) Mix easily constructible				
2) Occurrence of fiber balling				
3) Occurrence of fiber floating				
4) Reduction in early age cracking				
5) Better overall performance				

4) Please indicate the best overlay type along with the fiber type and dosage that you believe was easily constructible and has optimum performance?

____

____

5) Nearly, what is the service life for the LMC overlays? ________________ Years

6) Nearly, what is the service life for the MSC overlays? ________________ Years

7) Please provide any information about the cost of the LMC overlays:

- Average Cost per square foot is $ ________________; or
- Average Cost per cubic yard is $ ________________
- The above cost includes the fibers? a) Yes b) No

8) Please provide any information about the cost of the MSC overlays:

- Average Cost per square foot is $ ________________; or
- Average Cost per cubic yard is $ ________________
- The above cost includes the fibers? a) Yes b) No

9) Any further comments are appreciated (please attach additional papers with your comments)

Thank you so much for your and support for this research.

Received Responses

There were a total of 28 responses to the survey: 26 submitted by USDOT's representatives and two filled by representatives from Canada. Two states have multiple responses and the response with more input was selected. The following is a summary of the responses:

I) Latex-Modified Concrete (LMC)

1) None of the 28 states and provinces has used fibers in their LMC overlays.
2) None of the 28 states and provinces had fibrous LMC overlay. However, Oregon DOT has used it on trial project and Oklahoma DOT indicated that one of their contracts has used it on a few projects but it is not their normal practice.
3) Oregon DOT indicated that using non-metallic synthetic fiber in LMC overlays has the following characteristics based on their trial project:
    a. The mix is moderately constructible.
    b. Rarely occurrence of fiber balling and floating in the mix.
    c. An average reduction in early age cracking.
    d. Most of the time it has a good overall performance.
4) The service life for LMC overlays were reported to be between 20-40 years. Some States indicated an average of 20 years only.
5) Excluding Michigan, the average costs per square foot vary from $11.06 psf in Missouri to $100 psf in Washington State DOT. Washington State and Maryland DOTs indicated an average of $20 psf without the cost of the fiber. Michigan DOT, however, indicated a cost of $325 psf without the fiber. Other states indicated the cost to be between $800-$1,500 pcy with and without the fiber.

II) Micro-Silica Concrete (MSC)

1) Only four states (Delaware, Illinois, Kansas, and Michigan) are using non-metallic synthetic fibers in MSC overlays.
2) Only three states (Delaware (20), Michigan (1000+), and Virginia (2)) have non-metallic synthetic fibers MSC overlays. In addition, Oregon used it on trial project, Kansas on three experimental projects, and Missouri used patches in one bridge only. Alberta used steel fiber with high performance mix of Silica Fumes/Fly ash on about 160 overlays.
3) Delaware, Kansas, Oregon, Virginia and Michigan DOTs indicated that using non-metallic synthetic fiber in MSC overlays mix has the following overall characteristics:
    a. It has an average constructability (i.e. moderately constructible) with expectation of Virginia DOT. It indicated that the mix is not usually easily constructible due to some fiber clumping and balling problems.
    b. The mix rarely has an occurrence of fiber balling and floating with exception of Delaware DOT. It indicated that the mix has moderate presence of balling and floating.
    c. The reduction in early age cracking is moderate with expectation of Virginia DOT (VDOT). It indicated that the mix rarely contribute to reduction in early age cracking.
    d. The mix is frequently has a good overall performance with expectation of VDOT and Oregon DOT. VDOT indicated that the mix rarely has a good overall performance. However, Oregon DOT observed that this mix is frequently good overall performance.
4) The service life for MSC overlays were reported to be between 15-30 years. Some States indicated that they have only been doing them for 15 years, and none has failed yet.

5) The average costs per square foot vary from $4.0 in New York to $12 in Oregon DOT without the fiber. In Delaware the cost was $15 with the fiber. OR $200 in MI and Delaware per CY and between $1000-$1,200 per CY in Alberta and VDOT with and without the fiber.

Best Overlay Type

Five states responded to the question regarding the best overlay type along with the fiber type and dosage that the respondent believes it was easily constructible and has optimum performance. Michigan DOT indicated that Silica Fume modified concrete overlays appear to be more easily constructible than latex modified concrete overlays. Delaware used 1.5 lbs fibers per cubic yard without problems. VDOT recommended the use of Polypropylene fibers at low dosage because it was easily constructed. However VDOT indicated that Polyolefin fibers at high dosages were almost impossible to construct. Kansas DOT did not see a significant improvement in the use of fibers. Oregon DOT recommends the use of steel fibers at 1% by weight and MSC. Alberta recommended the use of steel fiber as well.

III) Fiber Usage in Overlays

The following is a summary of responses on the usage of non-metallic synthetic fibers in LMC and MSC overlays:

State DOT	Brand Name	Dosage	Overlay Type
Alberta	Wiremix W50	60 kg/m^3	HPC - micro silica
	Novocon XR	60 kg/m^3	HPC - micro silica
Kansas	WR Grace	5 lb/cy	Silica Fume
	Fiber Mesh	3 lb/cy	Silica Fume
Oregon	Novamesh 950	7.5 lb/cy	MSC

The following table summarize the comment provided by several state DOTs.

Colorado DOT	CDOT used fibers in the concrete overlays on a few projects, but never adopted the routine use of fibrous additives. We have however been quite interested in exploring the benefits of fibrous additives further. We are consequently quite interested in your study. In the few projects where they were used by CDOT the fibers were added at the project site and there were some problems with balling of the fibers and surface finishing.
Maryland	The average unit cost provided for LMC overlays does not include costs associated with construction staging, maintenance of traffic, and other items.
Utah DOT	UDOT does not do fibrous concrete overlays on their bridge decks but I would be very interested in getting the results of this research.
New Mexico	Have gotten away from using LMC overlays.
Washington State DOT	Our inquiries indicated problems with distribution of the fibers in the mix, which would be more of a problem state wide.

Iowa DOT	Iowa DOT uses either Class O Portland Cement or Class HPC-O High Performance Concrete overlays. The Class O is our dense concrete mix which we have used for many years (maximum slump of 1") and the HPC is a new mix (slump 1 to 3"). In the past we had a latex modified mix but it was rarely used so we have eliminated it from our standard specifications. We have tried non-metallic fibers in pavement overlays with some success. However, the fibers are only effective in controlling the width and movement of the cracking, enhancing the durability of very thin overlays (2 to 3"). Cracking is not prevented or reduced. It essentially keeps the overlay from rubblizing when it starts to fail and holds the pieces together until a repair can be made. We generally found that they were not cost effective for pavement overlays over 3" thick since the failure of those overlays was less likely to spall out. With regard to our thin bridge deck overlays, there may be some benefit to using them, but we rarely see debonding of the overlay until well into the service life of the overlay (over 20 years).
Michigan Department of Transportation	The use of fibers does not make up for poor curing practices. To prevent deck cracking, proper curing procedures MUST be followed.
Missouri Department of Transportation	Submitted survey earlier with no contact information on it. Please disregard it and don't use in your survey. This is MoDOT's official answers to this survey.
Nebraska Department of Roads	NDOR currently does not use fibers in any concrete.
Virginia DOT	We have 3 reports dealing with Route 60 bridge deck overlays which were 7% silica fume and 3 types of fibers: steel, polyolefin and polypropylene: 1. Interim report VTRC 99-IR4 http://vtrc.virginiadot.org/PubDetails.aspx?PubNo=99-IR4 2. Final report VTRC 01-R1 http://vtrc.virginiadot.org/PubDetails.aspx?id=296415 3. Evaluation after 10 years: VTRC 09-R13 http://vtrc.virginiadot.org/PubDetails.aspx?PubNo=09-R13 They are available at the VTRC web site.
Alberta Transportation	Research on Alberta FRSF overlays: SERVICE LIFE OF BRIDGE DECK REPAIRS IN ALBERTA, Western Bridge Engineers Seminar 2007 PERFORMANCE OF ALBERTA INFRASTRUCTURE AND TRANSPORTATION FIBRE REINFORCED OVERLAYS, CSCE Small and Medium Span Bridge Conference 2006, Paul D. Carter, David J. Besuyen.
Ministry of Transportation Ontario	We have used macro structural fiber in flexible link deck slabs.

APPENDIX B TYPICAL IDOT OVERLAY SPECIFICATIONS

BRIDGE DECK LATEX CONCRETE OVERLAY
Effective: May 15, 1995
Revised: May 11, 2009

This work shall consist of the preparation of the existing concrete bridge deck and the construction of a latex overlay to the specified thickness. The minimum thickness of the overlay shall be 2 1/4 in. (60 mm).

Materials. Materials shall meet the following Articles of Section 1000:

Item	Section
(a) Latex/Portland Cement Concrete (Note 1) (Note 2)	1020
(b) Grout (Note 3)	
(c) Packaged Rapid Hardening Mortar or Concrete	1018
(d) Concrete Curing Materials	1022.02

Note 1: This item shall include the initial onsite technical assistance of the supplier of the latex admixture. Further technical assistance shall be available at the request of the Engineer. Any cement found to be incompatible in any respect for the latex overlay shall be removed from the work immediately and replaced with compatible cement at the Contractor's expense.

The latex admixture shall be a uniform, homogeneous, non-toxic, film-forming, polymeric emulsion in water to which all stabilizers have been added at the point of manufacture. The latex admixture shall not contain any chlorides and shall contain 46 to 49 percent solids.

The Contractor shall submit a manufacturer's certification that the latex emulsion meets the requirements of FHWA Research Report RD-78-35, Chapter VI. The certificate shall include the date of manufacture of the latex admixture, batch or lot number, quantity represented, manufacturer's name, and the location of the manufacturing plant. The latex emulsion shall be sampled and tested in accordance with RD-78-35, Chapter VII, Certification Program.

The latex admixture shall be packaged and stored in containers and storage facilities which will protect the material from freezing and from temperatures above 85°F (30°C). Additionally, the material shall not be stored in direct sunlight and shall be shaded when stored outside of buildings during moderate temperatures.

Note 2: Cement shall be Type I portland cement. Fine aggregate shall be natural sand and the coarse aggregate shall be crushed stone or crushed gravel. The gradation of the coarse aggregates shall be CA 13, CA 14 or CA 16.

Note 3: Grout. The grout for bonding new concrete to old concrete shall be proportioned by weight(mass) and mixed at the job site, or it may be ready-mixed if agitated while at the job site. The bonding grout shall consist of one part portland cement and two parts sand, mixed with sufficient water to form a slurry. The bonding grout shall have a consistency allowing it to be scrubbed onto the prepared surface with a stiff brush or broom leaving a thin, uniform coating that will not run or puddle in low spots. Grout that cannot be easily and evenly applied or has lost its consistency may be rejected by the Engineer. Grout that is more than two hours old shall not be used.

At the option of the Contractor the grout may be applied by mechanical applicators. If this option is chosen, the sand shall be eliminated from the grout mix.

Mixture Design. The latex concrete shall contain the following approximate units of measure or volumes per cubic yard (cubic meter):

Type I Portland Cement	658 lb. (390 kg)
Latex Admixture	24.5 gal (121.3 L)
Coarse Aggregate	42 to 50 percent by weight(mass) of total aggregate
Water (including free moisture on the fine and coarse aggregates)	157 lb. (93.1 kg) maximum

No air entraining admixtures shall be added to the mix.

This mix design is based on a specific gravity of 2.65 for both the fine and the coarse aggregates. The mix will be adjusted by the Engineer to compensate for aggregate specific gravity and moisture.

The latex concrete shall meet the following requirements:

Slump shall be according to Article 1020.07 and 1020.12: 3 to 6 in. (75 to 150 mm)

Air Content shall be according to Article 1020.08 and 1020.12:7 percent maximum

Water-cement ratio (considering all the nonsolids in the latex admixture as part of the total water)	0.30 to 0.40
Compressive Strength (14 days)	4000 psi (27,500 kPa) minimum
Flexural Strength (14 days)	675 psi (4,650 kPa)

Equipment: The equipment used shall be subject to the approval of the Engineer and shall meet the following requirements:

(a) Surface Preparation Equipment. Surface preparation equipment shall be according to the applicable portions of Section 1100 and the following:

(1) Sawing Equipment. Sawing equipment shall be a concrete saw capable of sawing concrete to the specified depth.

(2) Mechanical Blast Cleaning Equipment. Mechanical blast cleaning may be performed by high-pressure waterblasting or shotblasting. Mechanical blast cleaning equipment shall be capable of removing weak concrete at the surface, including the microfractured concrete surface layer remaining as a result of mechanical scarification, and shall have oil traps.

Mechanical high-pressure waterblasting equipment shall be mounted on a wheeled carriage and shall include multiple nozzles mounted on a rotating assembly. The distance between the nozzles and the deck surface shall be kept constant and the wheels shall maintain contact with the deck surface during operation.

(3) Hand-Held Blast Cleaning Equipment. Blast cleaning using hand-held equipment may be performed by high-pressure waterblasting or abrasive blasting. Hand-held blast cleaning equipment shall have oil traps.

Hand-held high-pressure waterblasting equipment that is used in areas inaccessible to mechanical blast cleaning equipment shall have a minimum pressure of 7000 psi (48 MPa).

(4) Mechanical Scarifying Equipment. Scarifying equipment shall be a power-operated, mechanical scarifier capable of uniformly scarifying or removing the old concrete surface and new patches to the depths required in a satisfactory manner. Other types of removal devices may be used if their operation is suitable and they can be demonstrated to the satisfaction of the Engineer.

(5) Hydro-Scarification Equipment. The hydro-scarification equipment shall consist of filtering and pumping units operating with a computerized, self-propelled robotic machine with gauges and settings that can be easily verified. The equipment shall use potable water according to Section 1002. Operation of the equipment shall be performed and supervised by qualified personnel certified by the equipment manufacturer. Evidence of certification shall be presented to the Engineer. The equipment shall be capable of removing concrete to the specified depth and be capable of removing rust and old concrete particles from exposed reinforcement bars. The hydro-scarification equipment shall be calibrated before being used and shall operate at a uniform pressure sufficient to remove the specified depth of concrete in a timely manner.

(6) Vacuum Cleanup Equipment. The equipment shall be equipped with fugitive dust control devices capable of removing wet debris and water all in the same pass. Vacuum equipment shall also be capable of washing the deck with pressurized water prior to the vacuum operation to dislodge all debris and slurry from the deck surface.

(7) Power-Driven Hand Tools. Power-driven hand tools will be permitted including jackhammers lighter than the nominal 45 lb. (20 kg) class. Jackhammers or

chipping hammers shall not be operated at an angle in excess of 45 degrees measured from the surface of the slab.

(b) Pull-off Test Equipment. Equipment used to perform pull-off testing shall be either approved by the Engineer, or obtained from one of the following approved sources:

James Equipment
007 Bond Tester
800-426-6500

Germann Instruments, Inc.
BOND-TEST Pull-off System
847-329-9999

SDS Company
DYNA Pull-off Tester
805-238-3229

Pull-off test equipment shall include all miscellaneous equipment and materials to perform the test and clean the equipment, as indicated in the Illinois Test procedure 304 and 305 “Pull-off Test (Surface or Overlay Method)”. Prior to the start of testing, the Contractor shall submit to the Engineer a technical data sheet and material safety data sheet for the epoxy used to perform the testing. For solvents used to clean the equipment, a material safety data sheet shall be submitted.

(c) Concrete Equipment: A mobile Portland cement concrete plant shall be used for Latex Concrete and shall be according to Articles 1020.12, 1103.04 and the following:

(1) The device for proportioning water shall be accurate within one percent.
(2) The mixer shall be a self-contained, mobile, continuous mixer used in conjunction with volumetric proportioning.
(3) The mixer shall be calibrated prior to every placement of material or as directed by the Engineer.

(d) Finishing Equipment. Finishing equipment shall be according to Article 503.03.

(e) Mechanical Fogging Equipment. Mechanical fogging equipment shall be according to 1103.17 (k).

Construction Requirements: Sidewalks, curbs, drains, reinforcement and/or existing transverse and longitudinal joints which are to remain in place shall be protected from damage during scarification and cleaning operations. All damage caused by the Contractor shall be corrected, at the Contractor’s expense, to the satisfaction of the Engineer.

The Contractor shall control the runoff water generated by the various construction activities in such a manner as to minimize, to the maximum extent practicable, the discharge of construction debris into adjacent waters, and shall properly dispose of the solids generated according to Article 202.03. Runoff water will not be allowed to constitute a hazard on adjacent or underlying roadways, waterways, drainage areas or railroads nor be allowed to erode existing slopes.

(a) Deck Preparation:

(1) Bridge Deck Scarification. The scarification work shall consist of removing the designated concrete deck surface using mechanical or hydro-scarifying equipment as specified. The areas designated shall be scarified uniformly to the depth as specified on the plans. In areas of the deck not accessible to the scarifying equipment, power-driven hand tools will be permitted. Power driven hand tools shall be used for removal around areas to remain in place.

A trial section on the existing deck surface will be designated by the Engineer to demonstrate that the equipment, personnel and methods of operation are capable of producing results satisfactory to the Engineer. The trial section will consist of approximately 30 sq. ft. (3 sq. m).

Once the settings for the equipment are established, they shall not be changed without the permission of the Engineer. The removal shall be verified, as necessary, at least every 16 ft. (5 m) along the cutting path. If sound concrete is being removed below the desired depth, the equipment shall be reset or recalibrated.

If the use of hydro-scarification equipment is specified, the Contractor may use mechanical scarification equipment to remove an initial depth of concrete provided that the last 1/4 in. (6 mm) of removal is accomplished with hydro-scarification equipment. If the Contractor's use of mechanical scarifying equipment results in exposing, snagging, or dislodging the top mat of reinforcing steel, the scarifying shall be stopped immediately and the remaining removal shall be accomplished using the hydro-scarification equipment. All damage to the existing reinforcement resulting from the Contractor's operation shall be repaired or replaced at the Contractor's expense as directed by the Engineer. Replacement shall include the removal of any additional concrete required to position or splice the new reinforcing steel. Undercutting of exposed reinforcement bars shall only be as required to replace or repair damaged or corroded reinforcement. Repairs to existing reinforcement shall be according to the Special Provision for "Deck Slab Repair".

After hydro-scarification the deck shall be vacuum cleaned in a timely manner before the water and debris are allowed to dry and re-solidify to the deck. The uses of alternative cleaning and debris removal methods to minimize driving heavy vacuum equipment over exposed deck reinforcement may be used subject to the approval of the Engineer.

(2) Deck Patching. After bridge deck scarification, all designated patching, except as note below, shall be completed according to the Special Provision for "Deck Slab Repair". All full depth patching shall be completed prior to final surface preparation. When hydro-scarification is specified, partial depth patches may be fill with overlay material at the time of overlay placement.

All patches placed prior to overlay placement shall be struck off and then roughened with a suitable stiff bristled broom or wire brush to provide a rough texture designed to promote bonding of the overlay. Hand finishing of the patch surface shall be kept to a minimum to prevent overworking of the surface.

After scarification, the deck shall be thoroughly cleaned of broken concrete and other debris. The Engineer will sound the scarified deck and all remaining unsound areas will be marked for additional removal and/or repairs as applicable. If the bottom mat of reinforcement is exposed, that area shall be defined as a full depth repair.

In areas where hydro-scarification is specified, No separate payment for partial depth patching will be made regardless of whether it was detailed in the plans or not. Just prior to performing hydro-scarification, the deck shall be sounded, with unsound areas marked on the deck to assist the hydro-scarification process in performing the partial depth removal simultaneously with the hydro-scarification operation. If in the opinion of the Engineer additional removal is required after the hydro-scarification process, which could not have been anticipated or accounted for by normal modifications to the scarification process (such as modifying the dwell time or Nozzle pressure), such removal shall be paid for according to Article 109.04. Any removal required or made below the specified depth for scarification of the bridge deck, which does not result in full depth patching, shall be filled with the overlay material at the time of the overlay placement.

(3) Final Surface Preparation. Final surface preparation shall consist of the operation of mechanical blast cleaning equipment to remove any weak concrete at the surface, including the microfractured concrete surface layer remaining as a result of mechanical scarification. Any areas determined by the Engineer to be inaccessible to mechanical equipment shall be thoroughly blast cleaned with hand-held equipment. When hydro-scarification equipment is used for concrete removal, the deck surface need not be blast cleaned with mechanical equipment unless the spoils from the scarification operation are allowed to dry and re-solidify on the deck surface.

Final surface preparation shall also include the cleaning of all dust, debris, and concrete fines from the deck surface including vertical faces of curbs, previously placed adjacent overlays, barrier walls up to a height of 1 in. (25 mm) above the overlay, depressions, and beneath reinforcement bars. Hand-held high-pressure waterblasting equipment shall be used for this operation.

If mechanical scarification is used to produce the final deck surface texture, surface pull-off testing will be required. After the final surface preparation has been completed and before placement of the overlay, the prepared deck surface will be tested by the Engineer according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”. The Contractor shall provide the test equipment.

a. Start-up Testing. Prior to the first overlay placement, the Engineer will evaluate the blast cleaning method. The start-up area shall be a minimum of 600 sq. ft. (56 sq. m). After the area has been prepared, six random test locations will be determined by the Engineer, and tested according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”.

   The average of the six tests shall be a minimum of 175 psi (1,207 kPa) and each individual test shall have a minimum strength of 160 psi (1,103 kPa). If the criteria are not met, the Contractor shall adjust the blast cleaning method. Start-up testing will be repeated until satisfactory results are attained.

   Once an acceptable surface preparation method is established, it shall be continued for the balance of the work. The Contractor may, with the permission of the Engineer, change the surface preparation method, in which case, additional start-up testing will be required.

b. Lot Testing. After start-up testing has been completed, the following testing frequency will be used. For each structure, each stage will be divided into lots of not more than 4500 sq. ft. (420 sq. m). Three random test locations will be determined by the Engineer for each lot, and tested according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”.

   The average of the three tests shall be a minimum of 175 psi (1,207 kPa) and each individual test shall have a minimum strength of 160 psi (1,103 kPa). In the case of a failing individual test or a failing average of three tests, the Engineer will determine the area that requires additional surface preparation by the Contractor. Additional test locations will be determined by the Engineer.

In addition to start-up and lot testing, the Department may require surface pull-off testing of areas inaccessible to mechanical blast cleaning equipment and blast cleaned with hand-held equipment. The Engineer shall determine each test location, and each individual test shall have a minimum strength of 175 psi (1,207 kPa).

Exposed reinforcement bars shall be free of dirt, detrimental scale, paint, oil, and other foreign substances which may reduce bond with the concrete. A tight non-scaling coating of rust is not considered objectionable. Loose, scaling rust shall be removed by rubbing with burlap, wire brushing, blast cleaning or other methods approved by the Engineer. All loose reinforcement bars, as determined by the Engineer, shall be retied at the Contractor's expense.

All dust, concrete fines, debris, including water, resulting from the surface preparation shall be confined and shall be immediately and thoroughly removed from all areas of accumulation. If concrete placement does not follow immediately after the final cleaning, the area shall be carefully protected with well-anchored white polyethylene sheeting.

(b) Pre-placement Procedure. Prior to placing the overlay, the Engineer will inspect the deck surface. All contaminated areas shall be blast cleaned again at the Contractor's expense.

Before placing the overlay, the finishing machine shall be operated over the full length of bridge segment to be overlaid to check support rails for deflection and confirm the minimum overlay thickness. All necessary adjustments shall be made and another check performed, unless otherwise directed by the Engineer.

(c) Placement Procedure: Concrete placement shall be according to Article 503.07 and the following:

(1) Bonding Methods. The Contractor shall prepare the deck prior to overlay placement by one of the following methods unless restricted as specified on the plans:

a. Grout Method. The deck shall be cleaned to the satisfaction of the Engineer and shall be thoroughly wetted and maintained in a dampened condition for at least 12 hours before placement of the grout is started. Any excess water shall be removed by compressed air or by vacuuming prior to grout placement. Water shall not be applied to the deck surface within one hour before or at any time during placement of the grout. Immediately before placing the overlay mixture, the exposed area shall be thoroughly covered with a thin layer of grout. The grout shall be thoroughly scrubbed into the surface. All vertical as well as horizontal surfaces shall receive a thorough, even coating. The rate of grout placement shall be limited so the brushed grout does not dry out before it is covered with the concrete.

Grout that is allowed to become dry and chalky shall be blast cleaned and replaced at the Contractor's expense. No concrete shall be placed over dry grout.

b. Direct Bond Method. The deck shall be cleaned to the satisfaction of the Engineer and shall be thoroughly wetted and maintained in a dampened condition with water for at least 12 hours before placement of the overlay. Any excess water shall be removed by compressed air or by vacuuming prior to the beginning of overlay placement. Water shall not be applied to the deck surface within one hour before or at any time during placement of the overlay.

(2) Overlay Placement. Placement of the concrete shall be a continuous operation throughout the pour. The overlay shall be placed as close to its final position as possible and then mechanically consolidated and screeded to final grade. All fogging, finishing, and texturing shall be according to Article 503.16.

Internal vibration will be required along edges, adjacent to bulkheads, and where the overlay thickness exceeds 3 in. (75 mm). Internal vibration along the longitudinal edges of a pour will be required with a minimum of 2 hand-held

vibrators, one on each edge of the pour. Hand finishing will be required along the edges of the pour and shall be done from sidewalks, curbs or work bridges. A construction dam or bulkhead shall be installed in case of a delay of 30 minutes or more in the concrete placement operation.
All construction joints shall be formed. When required by the Engineer the previously placed overlay shall be sawed full-depth to a straight and vertical edge before fresh concrete is placed. The Engineer will determine the extent of the removal. When longitudinal joints are not shown on the plans, the locations shall be subject to approval by the Engineer and shall not be located in the wheel paths.

The Contractor shall stencil the date of construction (month and year) and the letters LX into the overlay before it takes its final set. The stencil shall be located in a conspicuous location, as determined by the Engineer, for each stage of construction. This location shall be outside of the grooving where possible and within 3 ft. (1 m) of an abutment joint. The characters shall be 3 to 4 in. (75 mm to 100 mm) in height, 1/4 in. (5 mm) in depth and face the centerline of the roadway.

(3) Limitations of Operations:

(a) Weather Limitations. Temperature control for concrete placement shall be according to 1020.14(b). The concrete protection from low air temperatures during the curing period shall be according to Article 1020.13(d). Concrete shall not be placed when rain is expected during the working period. If night placement is required, illumination and placement procedures will be subject to the approval of the Engineer. No additional compensation will be allowed if night work is required.

(b) Other Limitations. Mobile concrete mixers, truck mixers, concrete pumps, or other heavy equipment will not be permitted on any portion of the deck where the top reinforcing mat has been exposed. Conveyors, buggy ramps and pump piping shall be installed in a way that will not displace undercut reinforcement bars. Air compressors may be operated on the deck only if located directly over a pier and supported off undercut reinforcement bars. Compressors will not be allowed to travel over undercut reinforcement bars.

Concrete removal may proceed during final cleaning and concrete placement on adjacent portions of the deck, provided the removal does not interfere in any way with the cleaning or placement operations.

If water or contaminants from the hydro-scarification flow into the area of final cleaning or concrete placement, hydro-scarification shall be suspended until the concrete has been placed and has cured a minimum of 24 hours. No concrete shall be removed within 6 ft. (1.8 m) of a newly-placed overlay until the concrete has obtained a minimum compressive strength of 3000 psi (20,700 kPa) or flexural strength of 600 psi (4,150 kPa).

(4) Curing.
Curing. The minimum curing time shall be 48 hours of wet cure followed by 48 hours of dry cure. The wet cure shall be according to Article 1020.13(a)(5) Wetted Cotton Mat Method except that the cotton mats may be pre-dampened to minimize adhesion of the cotton mats to the overlay. Excess water shall not be allowed to drip from the cotton mats onto the overlay during placement of the mats. After the wet cure is completed all layers of covering materials shall be removed to allow for the dry cure.

If the ambient temperature falls below 50°F (10°C) during either the wet or dry curing periods, the time below 50°F (10°C) will not be included in the 96 hour curing period. If there is sufficient rain to wet the surface of the overlay for more than one hour of the dry cure period, the wet time will not be included in the 48 hour dry cure period.

(5) Opening to Traffic.
No traffic or construction equipment will be permitted on the overlay until after the specified cure period and the concrete has obtained a minimum compressive strength of 4000 psi (27,500 kPa) or flexural strength of 675 psi (4,650 kPa) unless permitted by the Engineer.

(6) Overlay Testing. The Engineer reserves the right to conduct pull-off tests on the overlay to determine if any areas are not bonded to the underlying concrete, and at a time determined by the Engineer. The overlay will be tested according to the Illinois Test procedure 305 "Pull-off Test (Overlay Method)", and the Contractor shall provide the test equipment. Each individual test shall have a minimum strength of 150 psi (1,034 kPa). Unacceptable test results will require removal and replacement of the overlay at the Contractor's expense, and the locations will be determined by the Engineer. When removing portions of an overlay, the saw cut shall be a minimum depth of 1 in. (25 mm).

If the overlay is to remain in place, all core holes due to testing shall be filled with a rapid set mortar or concrete. Only enough water to permit placement and consolidation by rodding shall be used, and the material shall be struck-off flush with the adjacent material.

For a rapid set mortar mixture, one part packaged rapid set cement shall be combined with two parts fine aggregate, by volume; or a packaged rapid set mortar shall be used. For a rapid set concrete mixture, a packaged rapid set mortar shall be combined with coarse aggregate according to the manufacturer's instructions; or a packaged rapid set concrete shall be used. Mixing of a rapid set mortar or concrete shall be according to the manufacturer's instructions.

<u>Method of Measurement</u>. The areas of mechanical and/or hydro scarification on the bridge deck will be measured for payment in square yards (square meters). No additional payment will be made for multiple passes of the equipment required to achieve the specified scarification depth.

The concrete overlay will be measured for payment in square yards (square meters).

When Bridge Deck Hydro-Scarification is specified, the additional concrete placed with the overlay, required to fill all depressions below the specified thickness will be measured for payment in cubic yards (cubic meters). The volume will be determined by subtracting the theoretical volume of the overlay from the ticketed volume of overlay delivered minus the volume estimated by the Engineer left in the last truck at the end of the overlay placement. The theoretical cubic yard (cubic meter) quantity for the overlay will be determined by multiplying the plan surface area of the overlay times the specified thickness of the overlay.

Basis of Payment. Concrete scarification of the bridge deck using mechanical scarification equipment will be paid for at the contract unit price per square yard (square meter) for CONCRETE BRIDGE DECK SCARIFICATION of the depth specified. Concrete scarification of the bridge deck using hydro-scarification equipment will be paid for at the contract unit price per square yard (square meter) for BRIDGE DECK HYDRO-SCARIFICATION of the depth specified.

Latex concrete overlay will be paid for at the contract unit price per square yard (square meter) for BRIDGE DECK LATEX CONCRETE OVERLAY, of the thickness specified. When hydro-scarification is specified, the additional volume of overlay required to fill all depressions below the specified thickness will be paid for at the Contractor’s actual material cost for the latex concrete per cubic yard (cubic meter) plus 15 percent.

When mechanical scarification is specified, additional partial depth patches poured monolithically with the overlay will be paid for at the contract unit price bid per square yard (square meter) for DECK SLAB REPAIR (PARTIAL).

When the Engineer conducts pull-off tests on the overlay and they are acceptable, Contractor expenses incurred due to testing and for filling core holes will be paid according to Article 109.04. Unacceptable pull-off tests will be at the Contractor’s expense.

When specified on the plans, the Contractor has the option of choosing the type of overlay. The options will be limited to those specified in the plans and will be paid for at the contract unit price per square yard (square meter) for BRIDGE DECK CONCRETE OVERLAY OPTION, of the thickness specified.

Overlay material placed off the deck in abutment back walls, and/or other locations will not be measured for payment but will be included in the pay item involved.

BRIDGE DECK FLY ASH OR GROUND GRANULATED BLAST-FURNACE SLAG CONCRETE OVERLAY WITH SYNTHETIC FIBERS

Effective: September 30, 2010

Description. This work shall consist of the preparation of the existing concrete bridge deck and the construction of a fly ash or ground granulated blast-furnace (GGBF) slag concrete overlay to the specified thickness. The minimum thickness of the overlay shall be 2 1/4 in. (60 mm).

Materials. Materials shall meet the requirements of the following Articles of Section 1000:

Item	Article/Section
(a) Portland Cement Concrete (Note 1)	1020
(b) Grout (Note 2)	
(c) Packaged Rapid Hardening Mortar or Concrete	1018
(d) Synthetic Fibers (Note 3)	

Note 1: The bridge deck concrete overlay shall meet the requirements for Class BS concrete (portland cement shall be used with either a fly ash or GGBF slag replacement). The fly ash or GGBF slag shall replace 25 percent by weight (mass) of the portland cement at a replacement ratio of 1:1. A 2 cu yd (1.5 cu m) trial batch shall be performed to verify the mix design will meet strength requirements. Refer to Note 3.

Note 2: Grout. The grout for bonding new concrete to old concrete shall be proportioned by weight(mass) and mixed at the job site, or it may be ready-mixed if agitated while at the job site. The bonding grout shall consist of one part portland cement and two parts sand, mixed with sufficient water to form a slurry. The bonding grout shall have a consistency allowing it to be scrubbed onto the prepared surface with a stiff brush or broom leaving a thin, uniform coating that will not run or puddle in low spots. Grout that cannot be easily and evenly applied or has lost its consistency may be rejected by the Engineer. Grout that is more than one hour old shall not be used.
At the option of the Contractor the grout may be applied by mechanical applicators. If this option is chosen, the sand shall be eliminated from the grout mix.

Note 3: When specified on the plans, synthetic fibers shall be added to the concrete and mixed per the manufacturer's recommendation. The fibers shall be from the "Approved List of Synthetic Fibers" except the maximum length of the fiber shall be 1.75 inches (45 mm). Synthetic fibers shall be added at a rate of 3.0 lbs/cu yd (1.8 kg/cu m). A 2 cu yd (1.5 cu m) trial batch shall be performed to evaluate the mixture for strength and other properties. Samples for testing will be done by the Department. The trial batch shall be placed in a 12 ft. X 12 ft. (3.6 m X 3.6 m) slab or other configuration approved by the Engineer to evaluate the mixture for fiber clumping, ease of placement, and finishing. Based on the trial batch, the Department has the option to reduce the weight (mass) of fibers to be added to the concrete mixture.

Equipment: The equipment used shall be subject to the approval of the Engineer and shall meet the following requirements:

(a) Surface Preparation Equipment. Surface preparation equipment shall be according to the applicable portions of Section 1100 and the following:

(1) Sawing Equipment. Sawing equipment shall be a concrete saw capable of sawing concrete to the specified depth.

(2) Mechanical Blast Cleaning Equipment. Mechanical blast cleaning may be performed by high-pressure waterblasting or shotblasting. Mechanical blast cleaning equipment shall be capable of removing weak concrete at the surface, including the microfractured concrete surface layer remaining as a result of mechanical scarification, and shall have oil traps.

Mechanical high-pressure waterblasting equipment shall be mounted on a wheeled carriage and shall include multiple nozzles mounted on a rotating assembly. The distance between the nozzles and the deck surface shall be kept constant and the wheels shall maintain contact with the deck surface during operation.

(3) Hand-Held Blast Cleaning Equipment. Blast cleaning using hand-held equipment may be performed by high-pressure waterblasting or abrasive blasting. Hand-held blast cleaning equipment shall have oil traps.

Hand-held high-pressure waterblasting equipment that is used in areas inaccessible to mechanical blast cleaning equipment shall have a minimum pressure of 7,000 psi (48 MPa).

(4) Mechanical Scarifying Equipment. Scarifying equipment shall be a power-operated, mechanical scarifier capable of uniformly scarifying or removing the old concrete surface and new patches to the depths required in a satisfactory manner. Other types of removal devices may be used if their operation is suitable and they can be demonstrated to the satisfaction of the Engineer.

(5) Hydro-Scarification Equipment. The hydro-scarification equipment shall consist of filtering and pumping units operating with a computerized, self-propelled robotic machine with gauges and settings that can be easily verified. The equipment shall use potable water according to Section 1002. Operation of the equipment shall be performed and supervised by qualified personnel certified by the equipment manufacturer. Evidence of certification shall be presented to the Engineer. The equipment shall be capable of removing concrete to the specified depth and be capable of removing rust and old concrete particles from exposed reinforcement bars. The hydro-scarification equipment shall be calibrated before being used and shall operate at a uniform pressure sufficient to remove the specified depth of concrete in a timely manner.

(6) Vacuum Cleanup Equipment. The equipment shall be equipped with fugitive dust control devices capable of removing wet debris and water all in the same pass. Vacuum equipment shall also be capable of washing the deck with pressurized water prior to the vacuum operation to dislodge all debris and slurry from the deck surface.

(7) Power-Driven Hand Tools. Power-driven hand tools will be permitted including jackhammers lighter than the nominal 45 lb. (20 kg) class. Jackhammers or chipping hammers shall not be operated at an angle in excess of 45 degrees measured from the surface of the slab.

(b) Pull-off Test Equipment. Equipment used to perform pull-off testing shall be either approved by the Engineer, or obtained from one of the following approved sources:

James Equipment
007 Bond Tester
800-426-6500

Germann Instruments, Inc.
BOND-TEST Pull-off System
847-329-9999

SDS Company
DYNA Pull-off Tester
805-238-3229

Pull-off test equipment shall include all miscellaneous equipment and materials to perform the test and clean the equipment, as indicated in the Illinois Test Procedures 304 and 305 “Pull-off Test (Surface or Overlay Method)”. Prior to the start of testing, the Contractor shall submit to the Engineer a technical data sheet and material safety data sheet for the epoxy used to perform the testing. For solvents used to clean the equipment, a material safety data sheet shall be submitted.

(c) Concrete Equipment. Equipment for proportioning and mixing the concrete shall be according to Article 1020.03.

(d) Finishing Equipment. Finishing equipment shall be according to Article 503.03.

(e) Mechanical Fogging Equipment. Mechanical fogging equipment shall be according to 1103.17 (k)

<u>Construction Requirements:</u> Sidewalks, curbs, drains, reinforcement and/or existing transverse and longitudinal joints which are to remain in place shall be protected from damage during scarification and cleaning operations. All damage caused by the Contractor shall be corrected, at the Contractor’s expense, to the satisfaction of the Engineer.

The Contractor shall control the runoff water generated by the various construction activities in such a manner as to minimize, to the maximum extent practicable, the discharge of construction debris into adjacent waters, and shall properly dispose of the solids generated according to Article 202.03. Runoff water will not be allowed to constitute a hazard on adjacent or underlying roadways, waterways, drainage areas or railroads nor be allowed to erode existing slopes.

(a) Deck Preparation:

(1) Bridge Deck Scarification. The scarification work shall consist of removing the designated concrete deck surface using mechanical or hydro-scarifying equipment as specified. The areas designated shall be scarified uniformly to the depth as specified on the plans. In areas of the deck not accessible to the scarifying equipment, power-driven hand tools will be permitted. Power driven hand tools shall be used for removal around areas to remain in place.

A trial section on the existing deck surface will be designated by the Engineer to demonstrate that the equipment, personnel and methods of operation are capable of producing results satisfactory to the Engineer. The trial section will consist of approximately 30 sq. ft. (3 sq. m).

Once the settings for the equipment are established, they shall not be changed without the permission of the Engineer. The removal shall be verified, as necessary, at least every 16 ft. (5 m) along the cutting path. If sound concrete is being removed below the desired depth, the equipment shall be reset or recalibrated.

If the use of hydro-scarification equipment is specified, the Contractor may use mechanical scarification equipment to remove an initial depth of concrete provided that the last 1/4 in. (6 mm) of removal is accomplished with hydro-scarification equipment. If the Contractor’s use of mechanical scarifying equipment results in exposing, snagging, or dislodging the top mat of reinforcing steel, the scarifying shall be stopped immediately and the remaining removal shall be accomplished using the hydro-scarification equipment. All damage to the existing reinforcement resulting from the Contractor’s operation shall be repaired or replaced at the Contractor’s expense as directed by the Engineer. Replacement shall include the removal of any additional concrete required to position or splice the new reinforcing steel. Undercutting of exposed reinforcement bars shall only be as required to replace or repair damaged or corroded reinforcement. Repairs to existing reinforcement shall be according to the Special Provision for “Deck Slab Repair”.

After hydro-scarification the deck shall be vacuum cleaned in a timely manner before the water and debris are allowed to dry and re-solidify to the deck. The uses of alternative cleaning and debris removal methods to minimize driving heavy vacuum equipment over exposed deck reinforcement may be used subject to the approval of the Engineer.

(3) Deck Patching. After bridge deck scarification, all designated patching, except as note below, shall be completed according to the Special Provision for "Deck Slab Repair”. All full depth patching shall be completed prior to final surface preparation. When mechanical scarification is specified, partial depth patches may be filled with overlay material at the time of overlay placement.

All patches placed prior to overlay placement shall be struck off and then roughened with a suitable stiff bristled broom or wire brush to provide a rough texture designed to promote bonding of the overlay. Hand finishing of the patch surface shall be kept to a minimum to prevent overworking of the surface.

After scarification, the deck shall be thoroughly cleaned of broken concrete and other debris. The Engineer will sound the scarified deck and all remaining unsound areas will be marked for additional removal and/or repairs as applicable. If the bottom mat of reinforcement is exposed, that area shall be defined as a full depth repair.

In areas where hydro-scarification is specified, No separate payment for partial depth patching will be made regardless of whether it was detailed in the plans or not. Just prior to performing hydro-scarification, the deck shall be sounded, with unsound areas marked on the deck to assist the hydro-scarification process in performing the partial depth removal simultaneously with the hydro-scarification operation. If in the opinion of the Engineer additional removal is required after the hydro-scarification process, which could not have been anticipated or accounted for by normal modifications to the scarification process, such removal shall be paid for according to Article 109.04. Any removal required or made below the specified depth for scarification of the bridge deck, which does not result in full depth patching, shall be filled with the overlay material at the time of the overlay placement.

(4) Final Surface Preparation. Final surface preparation shall consist of the operation of mechanical blast cleaning equipment to remove any weak concrete at the surface, including the microfractured concrete surface layer remaining as a result of mechanical scarification. Any areas determined by the Engineer to be inaccessible to mechanical equipment shall be thoroughly blast cleaned with hand-held equipment. When hydro-scarification equipment is used for concrete removal, the deck surface need not be blast cleaned with mechanical equipment unless the spoils from the scarification operation are allowed to dry and re-solidify on the deck surface.

Final surface preparation shall also include the cleaning of all dust, debris, and concrete fines from the deck surface including vertical faces of curbs, previously placed adjacent overlays, barrier walls up to a height of 1 in. (25 mm) above the overlay, depressions, and beneath reinforcement bars. Hand-held high-pressure waterblasting equipment shall be used for this operation.

If mechanical scarification is used to produce the final deck surface texture, surface pull-off testing will be required. After the final surface preparation has been completed and before placement of the overlay, the prepared deck surface will be tested by the Engineer according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”. The Contractor shall provide the test equipment.

c. Start-up Testing. Prior to the first overlay placement, the Engineer will evaluate the blast cleaning method. The start-up area shall be a minimum of

600 sq. ft. (56 sq. m). After the area has been prepared, six random test locations will be determined by the Engineer, and tested according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”.

The average of the six tests shall be a minimum of 175 psi (1,207 kPa) and each individual test shall have a minimum strength of 160 psi (1,103 kPa). If the criteria are not met, the Contractor shall adjust the blast cleaning method. Start-up testing will be repeated until satisfactory results are attained.

Once an acceptable surface preparation method is established, it shall be continued for the balance of the work. The Contractor may, with the permission of the Engineer, change the surface preparation method, in which case, additional start-up testing will be required.

d. Lot Testing. After start-up testing has been completed, the following testing frequency will be used. For each structure, each stage will be divided into lots of not more than 4500 sq. ft. (420 sq. m). Three random test locations will be determined by the Engineer for each lot, and tested according to the Illinois Test procedure 304 “Pull-off Test (Surface Method)”.

   The average of the three tests shall be a minimum of 175 psi (1,207 kPa) and each individual test shall have a minimum strength of 160 psi (1,103 kPa). In the case of a failing individual test or a failing average of three tests, the Engineer will determine the area that requires additional surface preparation by the Contractor. Additional test locations will be determined by the Engineer.

In addition to start-up and lot testing, the Department may require surface pull-off testing of areas inaccessible to mechanical blast cleaning equipment and blast cleaned with hand-held equipment. The Engineer shall determine each test location, and each individual test shall have a minimum strength of 175 psi (1,207 kPa).

Exposed reinforcement bars shall be free of dirt, detrimental scale, paint, oil, and other foreign substances which may reduce bond with the concrete. A tight non-scaling coating of rust is not considered objectionable. Loose, scaling rust shall be removed by rubbing with burlap, wire brushing, blast cleaning or other methods approved by the Engineer. All loose reinforcement bars, as determined by the Engineer, shall be retied at the Contractor's expense.

All dust, concrete fines, debris, including water, resulting from the surface preparation shall be confined and shall be immediately and thoroughly removed from all areas of accumulation. If concrete placement does not follow immediately after the final surface preparation, the area shall be carefully protected with well-anchored white polyethylene sheeting.

(b) Pre-placement Procedure. Prior to placing the overlay, the Engineer will inspect the deck surface. All contaminated areas shall be blast cleaned again at the Contractor's expense.

Before placing the overlay, the finishing machine shall be operated over the full length of bridge segment to be overlaid to check support rails for deflection and confirm the minimum overlay thickness. All necessary adjustments shall be made and another check performed, unless otherwise directed by the Engineer.

(c) Placement Procedure. Concrete placement shall be according to Article 503.07 and the following:

(1) Bonding Methods. The Contractor shall prepare the deck prior to overlay placement by one of the following methods unless restricted as specified on the plans:

a. Grout Method. The deck shall be cleaned to the satisfaction of the Engineer and shall be thoroughly wetted and maintained in a dampened condition for at least 12 hours before placement of the grout is started. Any excess water shall be removed by compressed air or by vacuuming prior to grout placement. Water shall not be applied to the deck surface within one hour before or at any time during placement of the grout. Immediately before placing the overlay mixture, the exposed area shall be thoroughly covered with a thin layer of grout. The grout shall be thoroughly scrubbed into the surface. All vertical as well as horizontal surfaces shall receive a thorough, even coating. The rate of grout placement shall be limited so the brushed grout does not dry out before it is covered with the concrete.
Grout that is allowed to become dry and chalky shall be blast cleaned and replaced at the Contractor's expense. No concrete shall be placed over dry grout.

b. Direct Bond Method. The deck shall be cleaned to the satisfaction of the Engineer and shall be thoroughly wetted and maintained in a dampened condition for at least 12 hours before placement of the overlay. Any excess water shall be removed by compressed air or by vacuuming prior to beginning overlay placement. Water shall not be applied to the deck surface within one hour before or at any time during placement of the overlay.

(2) Overlay Placement. Placement of the concrete shall be according to Article 503.16.

Internal vibration shall be performed along edges, adjacent to bulkheads, and where the overlay thickness exceeds 3 in. (75 mm). Internal vibration along the longitudinal edges of a pour shall be performed with a minimum of 2 hand-held vibrators, one on each edge of the pour. Hand finishing shall be performed along the edges of the pour and shall be done from sidewalks, curbs or work bridges.

A construction dam or bulkhead shall be installed in case of a delay of 30 minutes or more in the concrete placement operation.

All construction joints shall be formed. When required by the Engineer the previously placed overlay shall be sawed full-depth to a straight and vertical edge before fresh concrete is placed. The Engineer will determine the extent of the removal. When longitudinal joints are not shown on the plans, the locations shall be subject to approval by the Engineer and shall not be located in the wheel paths.

The Contractor shall stencil the date of construction (month and year) and the appropriate letters FA when fly ash is used or GGBFS when GGBF slag is used in the mix design, into the overlay before it takes its final set. The stencil shall be located in a conspicuous location, as determined by the Engineer, for each stage of construction. This location shall be outside of the grooving where possible and within 3 ft. (1 m) of an abutment joint. The characters shall be 3 to 4 in. (75 mm to 100 mm) in height, 1/4 in. (5 mm) in depth and face the centerline of the roadway.

(3) Limitations of Operations:

a. Weather limitations. Temperature control for concrete placement shall be according to 1020.14(b). The concrete protection from low air temperatures during the curing period shall be according to Article 1020.13(d). Concrete shall not be placed when rain is expected during the working period. If night placement is required, illumination and placement procedures will be subject to approval of the Engineer. No additional compensation will be allowed if night work is required.

b. Other Limitations. Concrete delivery vehicles driven on the structure shall be limited to a maximum load of 6 cu. yd. (4.6 cu. m).

Truck mixers, concrete pumps, or other heavy equipment will not be permitted on any portion of the deck where the top reinforcing mat has been exposed. Conveyors, buggy ramps and pump piping shall be installed in a way that will not displace undercut reinforcement bars. Air compressors may be operated on the deck only if located directly over a pier and supported off undercut reinforcement bars. Compressors will not be allowed to travel over undercut reinforcement bars.

Concrete removal may proceed during final cleaning and concrete placement on adjacent portions of the deck, provided the removal does not interfere in any way with the cleaning or placement operations.

If water or contaminants from the hydro-scarification flow into the area of final cleaning or concrete placement, hydro-scarification shall be suspended until the concrete has been placed and has cured a minimum of 24 hours. No concrete shall be removed within 6 ft. (1.8 m) of a newly-placed overlay until the concrete has obtained a minimum compressive strength of 3000 psi (20,700 kPa) or flexural strength of 600 psi (4,150 kPa).

(4) Curing Procedure. The surface shall be continuously wet cured for at least 7 days according to Article 1020.13(a)(5) Wetted Cotton Mat Method.

(5) Opening to Traffic. No traffic or construction equipment will be permitted on the overlay until after the specified cure period and the concrete has obtained a minimum compressive strength of 4000 psi (27,500 kPa) or flexural strength of 675 psi (4,650 kPa) unless permitted by the Engineer.

(6) Overlay Testing. The Engineer reserves the right to conduct pull-off tests on the overlay to determine if any areas are not bonded to the underlying concrete, and at a time determined by the Engineer. The overlay will be tested according to the Illinois Test Procedure 305 "Pull-off Test (Overlay Method)", and the Contractor shall provide the test equipment. Each individual test shall have a minimum strength of 150 psi (1,034 kPa). Unacceptable test results will require removal and replacement of the overlay at the Contractor's expense, and the locations will be determined by the Engineer. When removing portions of an overlay, the saw cut shall be a minimum depth of 1 in. (25 mm).

If the overlay is to remain in place, all core holes due to testing shall be filled with a rapid set mortar or concrete. Only enough water to permit placement and consolidation by rodding shall be used, and the material shall be struck-off flush with the adjacent material.

For a rapid set mortar mixture, one part packaged rapid set cement shall be combined with two parts fine aggregate, by volume; or a packaged rapid set mortar shall be used. For a rapid set concrete mixture, a packaged rapid set mortar shall be combined with coarse aggregate according to the manufacturer's instructions; or a packaged rapid set concrete shall be used. Mixing of a rapid set mortar or concrete shall be according to the manufacturer's instructions.

Method of Measurement. The areas of mechanical and/or hydro scarification on the bridge deck will be measured for payment in square yards (square meters). No additional payment will be made for multiple passes of the equipment required to achieve the specified scarification depth.

The concrete overlay will be measured for payment in square yards (square meters).

When Bridge Deck Hydro-Scarification is specified, the additional concrete placed with the overlay, required to fill all depressions below the specified thickness will be measured for payment in cubic yards (cubic meters). The volume will be determined by subtracting the theoretical volume of the overlay from the ticketed volume of overlay delivered minus the volume estimated by the Engineer left in the last truck at the end of the overlay placement. The theoretical cubic yard (cubic meter) quantity for the overlay will be determined by multiplying the plan surface area of the overlay times the specified thickness of the overlay.

Basis of Payment. Concrete scarification of the bridge deck using mechanical scarification equipment will be paid for at the contract unit price per square yard (square meter) for CONCRETE BRIDGE DECK SCARIFICATION of the depth specified. Concrete scarification of the bridge deck using hydro-scarification equipment will be paid for at the contract unit price per square yard (square meter) for BRIDGE DECK HYDRO-SCARIFICATION of the depth specified.

Fly ash or GGBF slag concrete overlay will be paid for at the contract unit price per square yard (square meter) for BRIDGE DECK FLY ASH OR GGBF SLAG CONCRETE OVERLAY, of the thickness specified. When hydro-scarification equipment is used, the additional volume of overlay required to fill all depressions below the specified thickness will be paid for at the Contractor’s actual material cost for the fly ash or GGBF slag concrete per cubic yard (cubic meter)) times an adjustment factor. For volumes 15 percent or less over the theoretical volume of the overlay the adjustment factor will be 1.15. For volumes greater than 15 percent the adjustment factor will be 1.25 for that volume over 15 percent of the theoretical volume of the overlay.

When mechanical scarification equipment is used, additional partial depth patches poured monolithically with the overlay will be paid for at the contract unit price bid per square yard (square meter) for DECK SLAB REPAIR (PARTIAL).

When the Engineer conducts pull-off tests on the overlay and they are acceptable, Contractor expenses incurred due to testing and for filling core holes will be paid according to Article 109.04. Unacceptable pull-off tests will be at the Contractor’s expense.

When specified, the Contractor has the option of choosing the type of overlay. The options will be limited to those specified in the plans and will be paid for at the contract unit price per square yard (square meter) for BRIDGE DECK CONCRETE OVERLAY OPTION, of the thickness specified.

Overlay material placed off the deck in abutment back walls, and/or other locations will not be measured for payment but will be included in the pay item involved.

BRIDGE DECK MICRO SILICA CONCRETE OVERLAY

Effective: May 15, 1995 Revised: November 14, 2005

Description. This work shall consist of the preparation of the existing concrete bridge deck and the construction of a microsilica concrete overlay to the specified thickness. The minimum thickness of the overlay shall be 60 mm (2 1/4 in.).

Materials. Materials shall meet the requirements of the following Articles of Section 1000:

Item	Article/Section
(a) Microsilica	1014
(b) Portland Cement (Notes 1-6)	1020
(c) Grout (Note 7)	
(d) Rapid Set Materials (Note 8)	
(e) Concrete Curing Materials (Note 9)	
(f) Synthetic Fibers (Note 10)	

Note 1: Cement shall be Type I portland cement. Fine aggregate shall be natural sand and the coarse aggregate shall be crushed stone or crushed gravel. The gradation of the coarse aggregate shall be CA 11, CA 13, CA 14 or CA 16.

Note 2: Mix Design Criteria.
Article 1020.04 shall not apply. The microsilica concrete mix design shall meet the following requirements:

Cement Factor	335 kg/cu m (565 lb/cu yd)
Microsilica Solids	20 kg/cu m (33 lb/cu yd)
Water/Cement Ratio	0.37 to 0.41 (including water in the slurry)
Mortar Factor	0.88 to 0.92
Slump	75 to 150 mm (3 to 6 in.)
Air Content	5.0 to 8.0 percent
Compressive Strength (14 days)	27,500 kPa (4000 psi) minimum
Flexural Strength (14 days)	4,650 kPa (675 psi) minimum

Note 3: Admixtures.
Article 1020.05(b) shall apply except as follows:
High-range water reducing admixtures (superplasticizers) shall be added as determined by the Engineer.

Note 4: Fly Ash.
Article 1020.05(c) shall apply except as follows:

Only Class C fly ash may be used to partially replace portland cement. The amount of cement replaced and replacement ratio shall be the same as for bridge decks.

Note 5: Ground Granulated Blast-Furnace Slag.
Grade 100 or 120 ground granulated blast-furnace slag may replace Portland cement. The cement replacement shall not exceed 25 percent by mass (weight) at a minimum replacement ratio of 1:1. Fly ash shall not be used in combination with ground granulated blast furnace slag.

Note 6: Mixing.
The mixing requirements shall be according to Article 1020.11(d), except as follows:

(a) Water-based microsilica slurry:

(1) Truck Mixer:

- Combine simultaneously air entraining admixture, water-reducing admixture and/or retarding admixture, microsilica slurry and 80 percent of the water with cement, fly ash (if used) and aggregates.
- Add remaining water.
- Mix 30-40 revolutions at 12-15 RPM.
- Add high range water-reducing admixture.
- Mix 60-70 revolutions at 12-15 RPM.

(2) Stationary Mixer:

- The microsilica slurry shall be diluted into the water stream or weigh box prior to adding into mixer. Combine simultaneously air entraining admixture, water-reducing admixture and/or retarding admixture, microsilica slurry and 80 percent of the water with cement, fly ash (if used) and aggregates.
- Add remaining water.
- After mixing cycle is completed deposit into truck mixer.
- Add high range water-reducing admixture.
- Mix 60-70 revolutions at 12-15 RPM.

(b) Densified microsilica (bulk):

(1) Truck Mixer:

- Same as (a)1 above except the densified microsilica shall be added with the cement.

(2) Stationary Mixer:

- Same as (a)2 above except the densified microsilica shall be added with the cement.

(c) Densified microsilica (bag):

Bagged microsilica shall be kept dry. No bag or material containing moisture shall be introduced into the concrete mixer.

(1) Truck Mixer:

- Combine air entraining admixture, water-reducing admixture and/or retarding admixture and 80 percent of the water.
- Add cement, fly ash (if used), and aggregates.
- Add remaining water.
- Mix 30-40 revolutions at 12-15 RPM.
- Add microsilica.
- Mix 70-80 revolutions at 12-15 RPM.
- Add high range water-reducing admixture.
- Mix 60-70 revolutions at 12-15 RPM.

(2) Stationary Mixer:

- Combine air entraining admixture, water-reducing admixture and/or retarding admixture and 80% of the water.
- Add cement, fly ash (if used), and aggregates.
- Add remaining water.
- After mixing cycle is completed deposit into truck mixer.
- Add microsilica to truck.
- Mix 70-80 revolutions at 12-15 RPM.
- Add high range water-reducing admixture.
- Mix 60-70 revolutions at 12-15 RPM.

Note 7: Grout. The grout for bonding new concrete to old concrete shall be proportioned by mass (weight) and mixed at the job site, or it may be ready-mixed if agitated while at the job site. The bonding grout shall consist of one part portland cement and two parts sand, mixed with sufficient water to form a slurry. The bonding grout shall have a consistency allowing it to be scrubbed onto the prepared surface with a stiff brush or broom leaving a thin, uniform coating that will not run or puddle in low spots. Grout that cannot be easily and evenly applied or has lost its consistency may be rejected by the Engineer. Grout that is more than two hours old shall not be used.

At the option of the Contractor the grout may be applied by mechanical applicators. If this option is chosen, the sand shall be eliminated from the grout mix.

Note 8: Rapid set materials shall be obtained from the Department’s approved list of Packaged, Dry, Rapid Hardening Cementitious Materials for Concrete Repairs.

Note 9: Cotton mats shall consist of a cotton fill material, minimum 400 g/sq m (11.8 oz/sq yd), covered with unsized cloth or burlap, minimum 200 g/sq m (5.9 oz/sq yd), and be tufted or stitched to maintain stability. Cotton mats shall be free from tears and in good condition.

Note 10: Synthetic fibers shall be Type iii according to ASTM C 1116. The synthetic fiber shall be a monofilament with a minimum length of 13 mm (0.5 in.) and a maximum length of 63 mm (2.5 in.), and shall have an aspect ratio (length divided by the equivalent diameter of the fiber) between 70 and 100. The synthetic fiber shall have a minimum toughness index I_{20} of 4.5 according to Illinois Modified ASTM C 1018. The maximum dosage rate shall not exceed 3.0 kg/cu m (5.0 lb/cu yd).

The synthetic fibers shall be added to the concrete and mixed per the manufacturer's recommendation. The dosage rate shall be 2.4 kg/cu m (4.0 lb/cu yd).

The department will maintain an "Approved List of Synthetic Fibers".

Equipment: The equipment used shall be subject to the approval of the Engineer and shall meet the following requirements:

(a) Surface Preparation Equipment. Surface preparation equipment shall be according to the applicable portions of Section 1100 and the following:

(1) Sawing Equipment. Sawing equipment shall be a concrete saw capable of sawing concrete to the specified depth.

(2) Mechanical Blast Cleaning Equipment. Mechanical blast cleaning may be performed by high-pressure waterblasting or shotblasting. Mechanical blast cleaning equipment shall be capable of removing weak concrete at the surface, including the microfractured concrete surface layer remaining as a result of mechanical scarification, and shall have oil traps.

Mechanical high-pressure waterblasting equipment shall be mounted on a wheeled carriage and shall include multiple nozzles mounted on a rotating assembly. The distance between the nozzles and the deck surface shall be kept constant and the wheels shall maintain contact with the deck surface during operation.

(3) Hand-Held Blast Cleaning Equipment. Blast cleaning using hand-held equipment may be performed by high-pressure waterblasting or abrasive blasting. Hand-held blast cleaning equipment shall have oil traps.

Hand-held high-pressure waterblasting equipment that is used in areas inaccessible to mechanical blast cleaning equipment shall have a minimum pressure of 48 MPa (7,000 psi).

(4) Mechanical Scarifying Equipment. Scarifying equipment shall be a power-operated, mechanical scarifier capable of uniformly scarifying or removing the old concrete surface and new patches to the depths required in a satisfactory manner. Other types of removal devices may be used if their operation is suitable and they can be demonstrated to the satisfaction of the Engineer.

(5) Hydro-Scarification Equipment. The hydro-scarification equipment shall consist of filtering and pumping units operating with a computerized, self-propelled robotic machine with gauges and settings that can be easily verified. The equipment shall use potable water according to Section 1002. Operation of the equipment shall be performed and supervised by qualified personnel certified by the equipment manufacturer. Evidence of certification shall be presented to the Engineer. The equipment shall be capable of removing concrete to the specified depth and be

capable of removing rust and old concrete particles from exposed reinforcement bars. The hydro-scarification equipment shall be calibrated before being used and shall operate at a uniform pressure sufficient to remove the specified depth of concrete in a timely manner.

(6) Vacuum Cleanup Equipment. The equipment shall be equipped with fugitive dust control devices capable of removing wet debris and water all in the same pass. Vacuum equipment shall also be capable of washing the deck with pressurized water prior to the vacuum operation to dislodge all debris and slurry from the deck surface.

(7) Power-Driven Hand Tools. Power-driven hand tools will be permitted including jackhammers lighter than the nominal 20 kg. (45 lb) class. Jackhammers or chipping hammers shall not be operated at an angle in excess of 45 degrees measured from the surface of the slab.

(b) Pull-off Test Equipment. Equipment used to perform pull-off testing shall be either approved by the Engineer, or obtained from one of the following approved sources:

James Equipment
007 Bond Tester
800-426-6500

Germann Instruments, Inc.
BOND-TEST Pull-off System
847-329-9999

SDS Company
DYNA Pull-off Tester
805-238-3229

Pull-off test equipment shall include all miscellaneous equipment and materials to perform the test and clean the equipment, as indicated in the Illinois Test Procedures 304 and 305 “Pull-off Test (Surface or Overlay Method)”. Prior to the start of testing, the Contractor shall submit to the Engineer a technical data sheet and material safety data sheet for the epoxy used to perform the testing. For solvents used to clean the equipment, a material safety data sheet shall be submitted.

(c) Concrete Equipment. Equipment for proportioning and mixing the concrete shall be according to Article1020.03.

(d) Finishing Equipment. Finishing equipment shall be according to Article 503.03.

(e) Mechanical Fogging Equipment. Mechanical fogging equipment shall consist of a mechanically operated, pressurized system using a triple headed nozzle or an equivalent nozzle. The fogging nozzle shall be capable of producing a fine fog mist that will increase the relative humidity of the air just above the fresh concrete surface without accumulating any water on the concrete. The fogging equipment shall be mounted on either the finishing equipment or a separate foot bridge. Controls shall be designed to vary the volume of water flow, be easily accessible and immediately shut off the water when in the off position.

(f) Hand-Held Fogging Equipment. Hand-held fogging equipment shall use a triple headed nozzle or an equivalent nozzle. The fogging nozzle shall be capable of producing a fine fog mist that will increase the relative humidity of the air just above the fresh concrete surface without accumulating any water on the concrete.

Construction Requirements: Sidewalks, curbs, drains, reinforcement and/or existing transverse and longitudinal joints which are to remain in place shall be protected from damage during scarification and cleaning operations. All damage caused by the Contractor shall be corrected, at the Contractor's expense, to the satisfaction of the Engineer.

The Contractor shall control the runoff water generated by the various construction activities in such a manner as to minimize, to the maximum extent practicable, the discharge of construction debris into adjacent waters, and shall properly dispose of the solids generated according to Article 202.03. Runoff water will not be allowed to constitute a hazard on adjacent or underlying roadways, waterways, drainage areas or railroads nor be allowed to erode existing slopes.

(a) Deck Preparation:

(1) Bridge Deck Scarification. The scarification work shall consist of removing the designated concrete deck surface using mechanical or hydro-scarifying equipment as specified. The areas designated shall be scarified uniformly to the depth as specified on the plans. In areas of the deck not accessible to the scarifying equipment, power-driven hand tools will be permitted. Power driven hand tools shall be used for removal around areas to remain in place.

A trial section on the existing deck surface will be designated by the Engineer to demonstrate that the equipment, personnel and methods of operation are capable of producing results satisfactory to the Engineer. The trial section will consist of approximately 3 sq m (30 sq ft).

Once the settings for the equipment are established, they shall not be changed without the permission of the Engineer. The removal shall be verified, as necessary, at least every 5 m (16 ft) along the cutting path. If sound concrete is being removed below the desired depth, the equipment shall be reset or recalibrated.

If the use of hydro-scarification equipment is specified, the Contractor may use mechanical scarification equipment to remove an initial depth of concrete provided that the last 6 mm (1/4 in.) of removal is accomplished with hydro-scarification equipment. If the Contractor's use of mechanical scarifying equipment results in exposing, snagging, or dislodging the top mat of reinforcing steel, the scarifying shall be stopped immediately and the remaining removal shall be accomplished using the hydro-scarification equipment. All damage to the existing reinforcement resulting from the Contractor's operation shall be repaired or replaced at the Contractor's expense as directed by the Engineer. Replacement shall include the removal of any additional concrete required to position or splice the new reinforcing steel. Undercutting of exposed reinforcement bars shall only be as required to replace or repair damaged or corroded reinforcement. Repairs to existing reinforcement shall be according to the Special Provision for "Deck Slab Repair".

After hydro-scarification the deck shall be vacuum cleaned in a timely manner before the water and debris are allowed to dry and re-solidify to the deck. The uses of alternative cleaning and debris removal methods to minimize driving heavy vacuum equipment over exposed deck reinforcement may be used subject to the approval of the Engineer.

(2) Deck Patching. After bridge deck scarification, all designated patching, except as note below, shall be completed according to the Special Provision for "Deck Slab Repair". All full depth patching shall be completed prior to final surface preparation. When mechanical scarification is specified, partial depth patches may be filled with overlay material at the time of overlay placement.

All patches placed prior to overlay placement shall be struck off and then roughened with a suitable stiff bristled broom or wire brush to provide a rough texture designed to promote bonding of the overlay. Hand finishing of the patch surface shall be kept to a minimum to prevent overworking of the surface.

After scarification, the deck shall be thoroughly cleaned of broken concrete and other debris. The Engineer will sound the scarified deck and all remaining unsound areas will be marked for additional removal and/or repairs as applicable. If the bottom mat of reinforcement is exposed, that area shall be defined as a full depth repair.

In areas where hydro-scarification is specified, no separate payment for partial depth patching will be made regardless of whether it was detailed in the plans or not. Just prior to performing hydro-scarification, the deck shall be sounded, with unsound areas marked on the deck to assist the hydro-scarification process in performing the partial depth removal simultaneously with the hydro-scarification operation. If in the opinion of the Engineer additional removal is required after the hydro-scarification process, which could not have been anticipated or accounted for by normal modifications to the scarification process, such removal shall be paid for according to Article 109.04. Any removal required or made below the specified depth for scarification of the bridge deck, which does not result in full depth patching, shall be filled with the overlay material at the time of the overlay placement.

(3) Final Surface Preparation. Final surface preparation shall consist of the operation of mechanical blast cleaning equipment to remove any weak concrete at the surface, including the microfractured concrete surface layer remaining as a result of mechanical scarification. Any areas determined by the Engineer to be inaccessible to mechanical equipment shall be thoroughly blast cleaned with hand-held equipment. When hydro-scarification equipment is used for concrete removal, the deck surface need not be blast cleaned with mechanical equipment unless the spoils from the scarification operation are allowed to dry and re-solidify on the deck surface.

Final surface preparation shall also include the cleaning of all dust, debris, and concrete fines from the deck surface including vertical faces of curbs, previously placed adjacent overlays, barrier walls up to a height of 25 mm (1 in.) above the overlay, depressions, and beneath reinforcement bars. Hand-held high-pressure waterblasting equipment shall be used for this operation.

If mechanical scarification is used to produce the final deck surface texture, surface pull-off testing will be required. After the final surface preparation has been completed and before placement of the overlay, the prepared deck surface will be tested by the Engineer according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”. The Contractor shall provide the test equipment.

a. Start-up Testing. Prior to the first overlay placement, the Engineer will evaluate the blast cleaning method. The start-up area shall be a minimum of 56 sq m (600 sq ft). After the area has been prepared, six random test locations will be determined by the Engineer, and tested according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”.

   The average of the six tests shall be a minimum of 1,207 kPa (175 psi) and each individual test shall have a minimum strength of 1,103 kPa (160 psi). If the criteria are not met, the Contractor shall adjust the blast cleaning method. Start-up testing will be repeated until satisfactory results are attained.

   Once an acceptable surface preparation method is established, it shall be continued for the balance of the work. The Contractor may, with the permission of the Engineer, change the surface preparation method, in which case, additional start-up testing will be required.

b. Lot Testing. After start-up testing has been completed, the following testing frequency will be used. For each structure, each stage will be divided into lots of not more than 420 sq m (4500 sq ft). Three random test locations will be determined by the Engineer for each lot, and tested according to the Illinois Test procedure 304 “Pull-off Test (Surface Method)”.

   The average of the three tests shall be a minimum of 1,207 kPa (175 psi) and each individual test shall have a minimum strength of 1,103 kPa (160 psi). In the case of a failing individual test or a failing average of three tests, the Engineer will determine the area that requires additional surface preparation by the Contractor. Additional test locations will be determined by the Engineer.

In addition to start-up and lot testing, the Department may require surface pull-off testing of areas inaccessible to mechanical blast cleaning equipment and blast cleaned with hand-held equipment. The Engineer shall determine each test location, and each individual test shall have a minimum strength of 1,207 kPa (175 psi).

Exposed reinforcement bars shall be free of dirt, detrimental scale, paint, oil, and other foreign substances which may reduce bond with the concrete. A tight non-scaling coating of rust is not considered objectionable. Loose, scaling rust shall be removed by rubbing with burlap, wire brushing, blast cleaning or other methods approved by the Engineer. All loose reinforcement bars, as determined by the Engineer, shall be retied at the Contractor's expense.

All dust, concrete fines, debris, including water, resulting from the surface preparation shall be confined and shall be immediately and thoroughly removed from all areas of accumulation. If concrete placement does not follow immediately after the final surface preparation, the area shall be carefully protected with well-anchored white polyethylene sheeting.

(b) Pre-placement Procedure. Prior to placing the overlay, the Engineer will inspect the deck surface. All contaminated areas shall be blast cleaned again at the Contractor's expense.

Before placing the overlay, the finishing machine shall be operated over the full length of bridge segment to be overlaid to check support rails for deflection and confirm the minimum overlay thickness. All necessary adjustments shall be made and another check performed, unless otherwise directed by the Engineer.

(c) Placement Procedure:

(1) Bonding Methods. The Contractor shall prepare the deck prior to overlay placement by one of the following methods unless restricted as specified on the plans:

a. Grout Method. The deck shall be cleaned to the satisfaction of the Engineer and shall be thoroughly wetted and maintained in a dampened condition for at least 12 hours before placement of the grout is started. Any excess water shall be removed by compressed air or by vacuuming prior to grout placement. Water shall not be applied to the deck surface within one hour before or at any time during placement of the grout. Immediately before placing the overlay mixture, the exposed area shall be thoroughly covered with a thin layer of grout. The grout shall be thoroughly scrubbed into the surface. All vertical as well as horizontal surfaces shall receive a thorough, even coating. The rate of grout placement shall be limited so the brushed grout does not dry out before it is covered with the concrete.

Grout that is allowed to become dry and chalky shall be blast cleaned and replaced at the Contractor's expense. No concrete shall be placed over dry grout.

b. Direct Bond Method. The deck shall be cleaned to the satisfaction of the Engineer and shall be thoroughly wetted and maintained in a dampened condition for at least 12 hours before placement of the overlay. Any excess water shall be removed by compressed air or by vacuuming prior to beginning overlay placement. Water shall not be applied to the deck surface within one hour before or at any time during placement of the overlay.

(2) Overlay Placement. For the overlay pour, fogging equipment shall be in operation unless the evaporation rate is less than 0.5 kg/sq m/hr. (0.1 lb/sq ft/hr.) and the Engineer gives permission to turn off the equipment. The evaporation rate shall be determined according to the figure in the Portland Cement Association’s publication

"Design and Control of Concrete Mixtures" (refer to the section on plastic shrinkage cracking).

The fogging equipment shall be adjusted to adequately cover the entire width of the pour.

Hand-held fogging equipment shall be allowed only when a vibratory screed is used. The fog mist shall not be used to apply water to a specific location to aid finishing.

Placement of the concrete shall be a continuous operation throughout the pour. The overlay shall be placed as close to its final position as possible and then mechanically consolidated and screeded to final grade. All finishing and texturing shall be according to Article 503.17 except that the use of vibrating screeds will be allowed for pour widths of 3.6 m (12 feet) or less without length restrictions.

Internal vibration shall be performed along edges, adjacent to bulkheads, and where the overlay thickness exceeds 75 mm (3 in.). Internal vibration along the longitudinal edges of a pour shall be performed with a minimum of 2 hand-held vibrators, one on each edge of the pour. Hand finishing shall be performed along the edges of the pour and shall be done from sidewalks, curbs or work bridges.

A construction dam or bulkhead shall be installed in case of a delay of 30 minutes or more in the concrete placement operation. If there is a delay of more than ten minutes during overlay placement, wet burlap shall be used to protect the concrete until operations resume.

Concrete placement operations shall be coordinated to limit the distance between the point of concrete placement and concrete covered with cotton mats for curing. The distance shall not exceed 10.5 m (35 ft). For overlay pour widths greater than 15 m (50 ft), the distance shall not exceed 7.5 m (25 ft).

All construction joints shall be formed. When required by the Engineer the previously placed overlay shall be sawed full-depth to a straight and vertical edge before fresh concrete is placed. The Engineer will determine the extent of the removal. When longitudinal joints are not shown on the plans, the locations shall be subject to approval by the Engineer and shall not be located in the wheel paths.

The Contractor shall stencil the date of construction (month and year) and the appropriate letters MS, or MSFA when fly ash is used in the mix design, into the overlay before it takes its final set. The stencil shall be located in a conspicuous location, as determined by the Engineer, for each stage of construction. This location shall be outside of the grooving where possible and within 1 m (3 ft) of an abutment joint. The characters shall be 75 mm to 100 mm (3 to 4 in.) in height, 5 mm (1/4 in.) in depth and face the centerline of the roadway.

(3) Limitations of Operations:

a. Weather limitations. Concrete shall not be placed unless the deck temperature is above 10°C (50°F) and the air temperature is predicted to be above 10°C (50°F) for at least 12 hours after placement. The concrete shall be maintained at a minimum of 10°C (50°F) during the curing period according to Article 1020.13. The temperature of the concrete mixture as placed shall not be less than 10°C (50°F) nor more than 32°C (90°F). If night placement is required, illumination and placement procedures will be subject to approval of the Engineer. No additional compensation will be allowed if night work is required.

b. Other Limitations. Concrete delivery trucks shall be limited to a maximum load of 4.6 cu m (6 cu yd).

Truck mixers, concrete pumps, or other heavy equipment will not be permitted on any portion of the deck where the top reinforcing mat has been exposed. Conveyors, buggy ramps and pump piping shall be installed in a way that will not displace undercut reinforcement bars. Air compressors may be operated on the deck only if located directly over a pier and supported off undercut reinforcement bars. Compressors will not be allowed to travel over undercut reinforcement bars.

Concrete removal may proceed during final cleaning and concrete placement on adjacent portions of the deck, provided the removal does not interfere in any way with the cleaning or placement operations.

If water or contaminants from the hydro-scarification flow into the area of final cleaning or concrete placement, hydro-scarification shall be suspended until the concrete has been placed and has cured a minimum of 24 hours. No concrete shall be removed within 1.8 m (6 ft) of a newly-placed overlay until the concrete has obtained a minimum compressive strength of 20,700 kPa (3000 psi) or flexural strength of 4,150 kPa (600 psi).

(4) Curing Procedure. The surface shall be continuously wet cured for at least 7 days according to Article 1020.13(a)(5) Wetted Cotton Mat Method.

(5) Opening to Traffic. No traffic or construction equipment will be permitted on the overlay until after the specified cure period and the concrete has obtained a minimum compressive strength of 27,500 kPa (4000 psi) or flexural strength of 4,650 kPa (675 psi) unless permitted by the Engineer.

(6) Overlay Testing. The Engineer reserves the right to conduct pull-off tests on the overlay to determine if any areas are not bonded to the underlying concrete, and at a time determined by the Engineer. The overlay will be tested according to the Illinois Test Procedure 305 "Pull-off Test (Overlay Method)", and the Contractor shall provide the test equipment. Each individual test shall have a minimum strength of 1,034 kPa (150 psi). Unacceptable test results will require removal and replacement of the overlay at the

Contractor's expense, and the locations will be determined by the Engineer. When removing portions of an overlay, the saw cut shall be a minimum depth of 25 mm (1 in.).

If the overlay is to remain in place, all core holes due to testing shall be filled with a rapid set mortar or concrete. Only enough water to permit placement and consolidation by rodding shall be used, and the material shall be struck-off flush with the adjacent material.

For a rapid set mortar mixture, one part packaged rapid set cement shall be combined with two parts fine aggregate, by volume; or a packaged rapid set mortar shall be used. For a rapid set concrete mixture, a packaged rapid set mortar shall be combined with coarse aggregate according to the manufacturer's instructions; or a packaged rapid set concrete shall be used. Mixing of a rapid set mortar or concrete shall be according to the manufacturer's instructions.

Method of Measurement. The areas of mechanical and/or hydro scarification on the bridge deck will be measured for payment in square meters (square yards). No additional payment will be made for multiple passes of the equipment required to achieve the specified scarification depth.

The concrete overlay will be measured for payment in square meters (square yards).

When Bridge Deck Hydro-Scarification is specified, the additional concrete placed with the overlay, required to fill all depressions below the specified thickness will be measured for payment in cubic meters (cubic yards). The volume will be determined by subtracting the theoretical volume of the overlay from the ticketed volume of overlay delivered minus the volume estimated by the Engineer left in the last truck at the end of the overlay placement. The theoretical cubic meter (cubic yard) quantity for the overlay will be determined by multiplying the plan surface area of the overlay times the specified thickness of the overlay.

Basis of Payment. Concrete scarification of the bridge deck using mechanical scarification equipment will be paid for at the contract unit price per square meter (square yard) for CONCRETE BRIDGE DECK SCARIFICATION of the depth specified. Concrete scarification of the bridge deck using hydro-scarification equipment will be paid for at the contract unit price per square meter (square yard) for BRIDGE DECK HYDRO-SCARIFICATION of the depth specified.

Microsilica concrete overlay will be paid for at the contract unit price per square meter (square yard) for BRIDGE DECK MICROSILICA CONCRETE OVERLAY, of the thickness specified. When hydro-scarification equipment is used, the additional volume of overlay required to fill all depressions below the specified thickness will be paid for at the Contractor's actual material cost for the microsilica concrete per cubic meter (cubic yard) plus 15 percent.

When mechanical scarification equipment is used, additional partial depth patches poured monolithically with the overlay will be paid for at the contract unit price bid per square meter (square yard) for DECK SLAB REPAIR (PARTIAL).

When the Engineer conducts pull-off tests on the overlay and they are acceptable, Contractor expenses incurred due to testing and for filling core holes will be paid according to Article 109.04. Unacceptable pull-off tests will be at the Contractor's expense.

When specified, the Contractor has the option of choosing the type of overlay. The options will be limited to those specified in the plans and will be paid for at the contract unit price per square meter (square yard) for BRIDGE DECK CONCRETE OVERLAY OPTION, of the thickness specified.

Overlay material placed off the deck in abutment backwalls, and/or other locations will not be measured for payment but will be included in the pay item involved.

BRIDGE DECK MICROSILICA CONCRETE O VERLAY

Description. This work shall consist of the preparation of the existing concrete bridge deck and the construction of a microsilica concrete overlay to the specified thickness. The minimum thickness of the overlay shall be 60 mm (2 1/4 in.).

Materials. Materials shall meet the requirements of the following Articles of Section 1000:

Item	Article/Section
(a) Microsilica	1014
(b) Portland Cement (Notes 1-6)	1020
(c) Grout (Note 7)	
(d) Rapid Set Materials (Note 8)	
(e) Concrete Curing Materials (Note 9)	
(f) Synthetic Fibers (Note 10)	

Note 1: Cement shall be Type I Portland cement. Fine aggregate shall be natural sand and the coarse aggregate shall be crushed stone or crushed gravel. The gradation of the coarse aggregate shall be CA 13, CA 14 or CA 16.

Note 2: Mix Design Criteria.

Article 1020.04 shall not apply. The microsilica concrete mix design shall meet the following requirements:

Cement Factor	335 kg/cu m (565 lb/cu yd)
Microsilica Solids	20 kg/cu m (33 lb/cu yd)
Water/Cement Ratio	0.37 to 0.41 (including water in the slurry)
Mortar Factor	0.88 to 0.92
Slump	75 to 150 mm (3 to 6 in.)
Air Content	5.0 to 8.0 percent
Compressive Strength (14 days)	27,500 kPa (4000 psi) minimum
Flexural Strength (14 days)	4,650 kPa (675 psi) minimum

Note 3: Admixtures.
Article 1020.05(b) shall apply except as follows:
High-range water reducing admixtures (superplasticizers) shall be added as determined by the Engineer.

Note 4: Fly Ash.

Fly Ash will not be permitted as a cement replacement in this contract.

Note 5: Ground Granulated Blast-Furnace Slag.
Grade 100 or 120 ground granulated blast-furnace slag may replace Portland cement. The cement replacement shall not exceed 25 percent by mass (weight) at a minimum replacement ratio of 1:1.

Note 6: Mixing.
The mixing requirements shall be according to Article 1020.11(d), except as follows:

(a) Water-based microsilica slurry:

(1) Truck Mixer:

- Combine simultaneously air entraining admixture, water-reducing admixture and/or retarding admixture, microsilica slurry and 80 percent of the water with cement, fly ash or GGBFS cement (if used) and aggregates.
- Add remaining water.
- Mix 30-40 revolutions at 12-15 RPM.
- Add high range water-reducing admixture.
- Mix 60-70 revolutions at 12-15 RPM.

(2) Stationary Mixer:

- The microsilica slurry shall be diluted into the water stream or weigh box prior to adding into mixer. Combine simultaneously air entraining admixture, water-reducing admixture and/or retarding admixture, microsilica slurry and 80 percent of the water with cement, fly ash or GGBFS cement (if used) and aggregates.
- Add remaining water.
- After mixing cycle is completed deposit into truck mixer.
- Add high range water-reducing admixture.
- Mix 60-70 revolutions at 12-15 RPM.

(b) Densified microsilica (bulk):

(1) Truck Mixer:

- Same as (a)1 above except the densified microsilica shall be added with the cement.

(2) Stationary Mixer:

- Same as (a) 2 above except the densified microsilica shall be added with the cement.

(c) Densified microsilica (bag):

Bagged microsilica shall be kept dry. No bag or material containing moisture shall be introduced into the concrete mixer.

(1) Truck Mixer:
- Combine air entraining admixture, water-reducing admixture and/or retarding admixture and 80 percent of the water.
- Add cement, fly ash or GGBFS cement (if used), and aggregates.
- Add remaining water.
- Mix 30-40 revolutions at 12-15 RPM.
- Add microsilica.
- Mix 70-80 revolutions at 12-15 RPM.
- Add high range water-reducing admixture.
- Mix 60-70 revolutions at 12-15 RPM.

(2) Stationary Mixer:
- Combine air entraining admixture, water-reducing admixture and/or retarding admixture and 80% of the water.
- Add cement, fly ash or GGBFS cement (if used), and aggregates.
- Add remaining water.
- After mixing cycle is completed deposit into truck mixer.
- Add microsilica to truck.
- Mix 70-80 revolutions at 12-15 RPM.
- Add high range water-reducing admixture.
- Mix 60-70 revolutions at 12-15 RPM.

Note 7: Grout. The grout for bonding new concrete to old concrete shall be proportioned by mass (weight) and mixed at the job site, or it may be ready-mixed if agitated while at the job site. The bonding grout shall consist of one part Portland cement and two parts sand, mixed with sufficient water to form a slurry. The bonding grout shall have a consistency allowing it to be scrubbed onto the prepared surface with a stiff brush or broom leaving a thin, uniform coating that will not run or puddle in low spots. Grout that cannot be easily and evenly applied or has lost its consistency may be rejected by the Engineer. Grout that is more than two hours old shall not be used.

At the option of the Contractor the grout may be applied by mechanical applicators. If this option is chosen, the sand shall be eliminated from the grout mix.

Note 8: Rapid set materials shall be obtained from the Department's approved list of Packaged, Dry, Rapid Hardening Cementitious Materials for Concrete Repairs.

Note 9: Cotton mats shall consist of a cotton fill material, minimum 400 g/sq m (11.8 oz/sq yd), covered with unsized cloth or burlap, minimum 200 g/sq m (5.9 oz/sq yd), and be tufted or stitched to maintain stability. Cotton mats shall be free from tears and in good condition.

Note 10: Synthetic fibers shall be Type III according to ASTM C 1116. The synthetic fiber shall be a monofilament with a minimum length of 13 mm (0.5 in.) and a maximum length of 63 mm (2.5 in.), and shall have a maximum aspect ratio (length divided by the equivalent diameter of the fiber) of 100. The synthetic fiber shall

have a minimum toughness index I_{20} of 4.5 according to Illinois Modified ASTM C 1018. The maximum dosage rate shall not exceed 1.8 kg/cu m (3.0 lb/cu yd). Synthetic fibers, when required, shall be added to the load after all other mix design components (with the exception of any jobsite added super plasticizer) have been batched and thoroughly mixed. If the fibers are packaged in bags, the bags shall be opened first and then discarded. Fiber only shall be added to the load in a manner that promotes consistent and effective distribution throughout the load. A minimum of 80 revolutions shall be completed at mixing speed after the addition of fiber, although additional mixing may be required to provide complete and even distribution of the fiber throughout the load.
The actual dosage rate of the fibers in the mix shall be determined in the field based on a trial batch, but shall not exceed the maximum dosage rate mentioned above.
The department will maintain an “Approved List of Synthetic Fibers”.

<u>Equipment</u>: The equipment used shall be subject to the approval of the Engineer and shall meet the following requirements:

(a) Surface Preparation Equipment. Surface preparation equipment shall be according to the applicable portions of Section 1100 and the following:

(1) Sawing Equipment. Sawing equipment shall be a concrete saw capable of sawing concrete to the specified depth.

(2) Mechanical Blast Cleaning Equipment. Mechanical blast cleaning may be performed by high-pressure waterblasting or shotblasting. Mechanical blast cleaning equipment shall be capable of removing weak concrete at the surface, including the microfractured concrete surface layer remaining as a result of mechanical scarification, and shall have oil traps.

Mechanical high-pressure waterblasting equipment shall be mounted on a wheeled carriage and shall include multiple nozzles mounted on a rotating assembly. The distance between the nozzles and the deck surface shall be kept constant and the wheels shall maintain contact with the deck surface during operation.

(3) Hand-Held Blast Cleaning Equipment. Blast cleaning using hand-held equipment may be performed by high-pressure waterblasting or abrasive blasting. Hand-held blast cleaning equipment shall have oil traps.

Hand-held high-pressure waterblasting equipment that is used in areas inaccessible to mechanical blast cleaning equipment shall have a minimum pressure of 48 MPa (7,000 psi).

(4) Mechanical Scarifying Equipment. Scarifying equipment shall be a power-operated, mechanical scarifier capable of uniformly scarifying or removing the old concrete surface and new patches to the depths required in a satisfactory manner. Other types of removal devices may be used if their operation is suitable and they can be demonstrated to the satisfaction of the Engineer.

(5) Hydro-Scarification Equipment. The hydro-scarification equipment shall consist of filtering and pumping units operating with a remote-controlled robotic device. The equipment shall use potable water according to Section 1002. Operation of the equipment shall be performed and supervised by qualified personnel certified by the equipment manufacturer. Evidence of certification shall be presented to the Engineer. The equipment shall be capable of removing concrete to the specified depth and be capable of removing rust and old concrete particles from exposed reinforcement bars. The hydro-scarification equipment shall be calibrated before being used and shall operate at a uniform pressure sufficient to remove the specified depth of concrete in a timely manner.

(6) Vacuum Cleanup Equipment. The equipment shall be equipped with fugitive duct control devices capable of removing wet debris and water all in the same pass. Vacuum equipment shall also be capable of washing the deck with pressurized water prior to the vacuum operation to dislodge all debris and slurry from the deck surface.

(7) Power-Driven Hand Tools. Power-driven hand tools will be permitted including jackhammers lighter than the nominal 20 kg (45 lb) class. Jackhammers or chipping hammers shall not be operated at an angle in excess of 45 degrees measured from the surface of the slab.

(b) Pull-off Test Equipment. Equipment used to perform pull-off testing shall be either approved by the Engineer, or obtained from one of the following approved sources:

James Equipment
007 Bond Tester
800-426-6500

Germann Instruments, Inc.
BOND-TEST Pull-off System
847-329-9999

SDS Company
DYNA Pull-off Tester
805-238-3229

Pull-off test equipment shall include all miscellaneous equipment and materials to perform the test and clean the equipment, as indicated in the Illinois Test Procedures304 and 305 “Pull-off Test (Surface or Overlay Method)”. Prior to the start of testing, the Contractor shall submit to the Engineer a technical data sheet and material safety data sheet for the epoxy used to perform the testing. For solvents used to clean the equipment, a material safety data sheet shall be submitted.

(c) Concrete Equipment. Equipment for proportioning and mixing the concrete shall be according to Article1020.03.

(d) Finishing Equipment. Finishing equipment shall be according to Article 503.03.

(e) Mechanical Fogging Equipment. Mechanical fogging equipment shall consist of a mechanically operated, pressurized system using a triple headed nozzle or an equivalent nozzle. The fogging nozzle shall be capable of producing a fine fog mist that will increase the relative humidity of the air just above the fresh concrete surface without accumulating any water on the concrete. The fogging equipment shall be mounted on either the finishing equipment or a separate foot bridge. Controls shall be designed to vary the volume of water flow, be easily accessible and immediately shut off the water when in the off position.

(f) Hand-Held Fogging Equipment. Hand-held fogging equipment shall use a triple headed nozzle or an equivalent nozzle. The fogging nozzle shall be capable of producing a fine fog mist that will increase the relative humidity of the air just above the fresh concrete surface without accumulating any water on the concrete.

Construction Requirements: Sidewalks, curbs, drains, reinforcement and/or existing transverse and longitudinal joints which are to remain in place shall be protected from damage during scarification and cleaning operations. All damage caused by the Contractor shall be corrected, at the Contractor's expense, to the satisfaction of the Engineer.

The Contractor shall control the runoff water generated by the various construction activities in such a manner as to minimize, to the maximum extent practicable, the discharge of construction debris into adjacent waters, and shall properly dispose of the solids generated according to Article 202.03. Runoff water will not be allowed to constitute a hazard on adjacent or underlying roadways, waterways, drainage areas or railroads nor be allowed to erode existing slopes.

(a) Deck Preparation:

(1) Bridge Deck Scarification. The scarification work shall consist of removing the designated concrete deck surface using mechanical or hydro-scarifying equipment as specified. The areas designated shall be scarified uniformly to the depth as specified on the plans. In areas of the deck not accessible to the scarifying equipment, power-driven hand tools will be permitted. Power driven hand tools shall be used for removal around areas to remain in place.

A trial section on the existing deck surface will be designated by the Engineer to demonstrate that the equipment, personnel and methods of operation are capable of producing results satisfactory to the Engineer. The trial section will consist of approximately 3 sq m (30 sq ft).

Once the settings for the equipment are established, they shall not be changed without the permission of the Engineer. The removal shall be verified, as necessary, at least every 5 m (16 ft) along the cutting path. If concrete is being removed below the desired depth, the equipment shall be reset or recalibrated.

If the use of hydro-scarification equipment is specified, the Contractor may use mechanical scarification equipment to remove an initial depth of concrete provided that the last 13 mm (½ in.) of removal is accomplished with hydro-scarification equipment. If the Contractor's use of mechanical scarifying equipment results in exposing, snagging, or dislodging the top mat of reinforcing steel, the scarifying shall be stopped immediately and the remaining removal shall be accomplished using the hydro-scarification equipment. All damage to the existing reinforcement resulting from the Contractor's operation shall be repaired or replaced at the Contractor's expense as directed by the Engineer. Replacement shall include the removal of any additional concrete required to position or splice the new reinforcing steel. Undercutting of exposed reinforcement bars shall only be as required to replace or repair damaged or corroded reinforcement. Repairs to existing reinforcement shall be according to the Special Provision for "Deck Slab Repair".

After hydro-scarification, the deck shall be vacuum cleaned in a timely manner before the water and debris are allowed to dry and re-solidify to the deck. The uses of alternative cleaning and debris removal methods to minimize driving heavy vacuum equipment over exposed deck reinforcement may be subject to the approval of the Engineer.

(2) Deck Patching. After bridge deck scarification, all designated patching, except as note below, shall be completed according to the Special Provision for "Deck Slab Repair". All full depth patching shall be completed prior to final surface preparation. When mechanical scarification is specified, partial depth patches may be filled with overlay material at the time of overlay placement.

All patches placed prior to overlay placement shall be struck off and then roughened with a suitable stiff bristled broom or wire brush to provide a rough texture designed to promote bonding of the overlay. Hand finishing of the patch surface shall be kept to a minimum to prevent overworking of the surface.

After scarification, the deck shall be thoroughly cleaned of broken concrete and other debris. The Engineer will sound the scarified deck and all remaining unsound areas will be marked for additional removal and/or repairs as applicable. If the bottom mat of reinforcement is exposed, that area shall be defined as a full depth repair.

In areas where hydro-scarification is specified, no separate payment for partial depth patching will be made regardless of whether it was detailed in the plans or not. Just prior to performing hydro-scarification, the deck shall be sounded, with unsound areas marked on the deck to assist the hydro-scarification process in performing the partial depth removal simultaneously with the hydro-scarification operation. If in the opinion of the Engineer additional removal is required after the hydro-scarification process, which could have been anticipated or accounted for by normal modifications to the scarification process, such removal shall be paid for according to Article 109.04. Any removal required or made below the specified depth for scarification of the bridge deck, which does not result in full depth patching, shall be filled with the overlay material at the time of the overlay placement.

(3) Final Surface Preparation. Final surface preparation shall consist of the operation of mechanical blast cleaning equipment to remove any weak concrete at the surface, including the microfractured concrete surface layer remaining as a result of mechanical scarification. Any areas determined by the Engineer to be inaccessible to mechanical equipment shall be thoroughly blast cleaned with hand-held equipment. When hydro-scarification equipment is used for concrete removal, the

deck surface need not be blast cleaned with mechanical equipment unless the spoils from the scarification operation are allowed to dry and re-solidify on the deck surface.

Final surface preparation shall also include the cleaning of all dust, debris, and concrete fines from the deck surface including vertical faces of curbs, previously placed adjacent overlays, barrier walls up to a height of 25 mm (1 in.) above the overlay, depressions, and beneath reinforcement bars. Hand-held high-pressure waterblasting equipment shall be used for this operation.

If mechanical scarification is used to produce the final deck surface texture, surface pull-off testing will be required. After the final surface preparation has been completed and before placement of the overlay, the prepared deck surface will be tested by the Engineer according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method).” The Contractor shall provide the test equipment.

a. Start-up Testing. Prior to the first overlay placement, the Engineer will evaluate the blast cleaning method. The start-up area shall be a minimum of 56 sq m (600 sq ft). After the area has been prepared, six random test locations will be determined by the Engineer, and tested according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”.

   The average of the six tests shall be a minimum of 1,207 kPa (175 psi) and each individual test shall have a minimum strength of 1,103 kPa (160 psi). If the criteria are not met, the Contractor shall adjust the blast cleaning method. Startup testing will be repeated until satisfactory results are attained.

   Once an acceptable surface preparation method is established, it shall be continued for the balance of the work. The Contractor may, with the permission of the Engineer, change the surface preparation method, in which case, additional start-up testing will be required.

b. Lot Testing. After start-up testing has been completed, the following testing frequency will be used. For each structure, each stage will be divided into lots of not more than 420 sq m (4500 sq ft). Three random test locations will be determined by the Engineer for each lot, and tested according to the Illinois Test Procedure 304 “Pull-off Test (Surface Method)”.

   The average of the three tests shall be a minimum of 1,207 kPa (175 psi) and each individual test shall have a minimum strength of 1,103 kPa (160 psi). In the case of a failing individual test or a failing average of three tests, the Engineer will determine the area that requires additional surface preparation by the Contractor. Additional test locations will be determined by the Engineer.

In addition to start-up and lot testing, the Department may require surface pull-off testing of areas inaccessible to mechanical blast cleaning equipment and blast cleaned with hand-held equipment. The Engineer shall determine each test location, and each individual test shall have a minimum strength of 1,207 kPa (175 psi).

Exposed reinforcement bars shall be free of dirt, detrimental scale, paint, oil, and other foreign substances which may reduce bond with the concrete. A tight non-scaling coating of rust is not considered objectionable. Loose, scaling rust shall be removed by rubbing with burlap, wire brushing, blast cleaning or other methods approved by the Engineer. All loose reinforcement bars, as determined by the Engineer, shall be retied at the Contractor's expense.

All dust, concrete fines, debris, including water, resulting from the surface preparation shall be confined and shall be immediately and thoroughly removed from all areas of accumulation. If concrete placement does not follow immediately after the final surface preparation, the area shall be carefully protected with well-anchored white polyethylene sheeting.

(b) Pre-placement Procedure. Prior to placing the overlay, the Engineer will inspect the deck surface. All contaminated areas shall be blast cleaned again at the Contractor's expense.

Before placing the overlay, the finishing machine shall be operated over the full length of bridge segment to be overlaid to check support rails for deflection and confirm the minimum overlay thickness. All necessary adjustments shall be made and another check performed, unless otherwise directed by the Engineer.

(c) Placement Procedure:

(1) Bonding Methods. The Contractor shall prepare the deck prior to overlay placement by one of the following methods unless restricted as specified on the plans:

a. Grout Method. The deck shall be cleaned to the satisfaction of the Engineer and shall be thoroughly wetted and maintained in a dampened condition for at least 12 hours before placement of the grout is started. Any excess water shall be removed by compressed air or by vacuuming prior to grout placement. Water shall not be applied to the deck surface within one hour before or at any time during placement of the grout. Immediately before placing the overlay mixture, the exposed area shall be thoroughly covered with a thin layer of grout. The grout shall be thoroughly scrubbed into the surface. All vertical as well as horizontal surfaces shall receive a thorough, even coating. The rate of grout placement shall be limited so the brushed grout does not dry out before it is covered with the concrete.

Grout that is allowed to become dry and chalky shall be blast cleaned and replaced at the Contractor's expense. No concrete shall be placed over dry grout.

b. Direct Bond Method. The deck shall be cleaned to the satisfaction of the Engineer and shall be thoroughly wetted and maintained in a dampened condition for at least 12 hours before placement of the overlay. Any excess water shall be removed by compressed air or by vacuuming prior to beginning overlay placement. Water shall not be applied to the deck surface within one hour before or at any time during placement of the overlay.

(2) Overlay Placement. For the overlay pour, fogging equipment shall be in operation unless the evaporation rate is less than 0.5 kg/sq m/hr. (0.1 lb/sq ft/hr.) and the Engineer gives permission to turn off the equipment. The evaporation rate shall be determined according to the figure in the Portland Cement Association's publication; "Design and Control of Concrete Mixtures" (refer to the section on plastic shrinkage cracking).

The fogging equipment shall be adjusted to adequately cover the entire width of the pour.

Hand-held fogging equipment shall be allowed only when a vibratory screed is used. The fog mist shall not be used to apply water to a specific location to aid finishing.

Placement of the concrete shall be a continuous operation throughout the pour. The overlay shall be placed as close to its final position as possible and then mechanically consolidated and screeded to final grade. All finishing and texturing shall be according to Article 503.17 except that the use of vibrating screeds will be allowed for pour widths of 3.6 m (12 feet) or less without length restrictions.

Internal vibration shall be performed along edges, adjacent to bulkheads, and where the overlay thickness exceeds 75 mm (3 in.). Internal vibration along the longitudinal edges of a pour shall be performed with a minimum of 2 hand-held vibrators, one on each edge of the pour. Hand finishing shall be performed along the edges of the pour and shall be done from sidewalks, curbs or work bridges.
A construction dam or bulkhead shall be installed in case of a delay of 30 minutes or more in the concrete placement operation. If there is a delay of more than ten minutes during overlay placement, wet burlap shall be used to protect the concrete until operations resume.

Concrete placement operations shall be coordinated to limit the distance between the point of concrete placement and concrete covered with cotton mats for curing.

The distance shall not exceed 10.5 m (35 ft). For overlay pour widths greater than 15 m (50 ft), the distance shall not exceed 7.5 m (25 ft).

All construction joints shall be formed. When required by the Engineer the previously placed overlay shall be sawed full-depth to a straight and vertical edge before fresh concrete is placed. The Engineer will determine the extent of the removal. When longitudinal joints are not shown on the plans, the locations shall be subject to approval by the Engineer and shall not be located in the wheel paths.

The Contractor shall stencil the date of construction (month and year) and the appropriate letters MS, or MSFA when fly ash is used in the mix design, into the overlay before it takes its final set. The stencil shall be located in a conspicuous location, as determined by the Engineer, for each stage of construction. This location shall be outside of the grooving where possible and within 1 m (3 ft) of an abutment joint. The characters shall be 75 mm to 100 mm (3 to 4 in.) in height, 5 mm (1/4 in.) in depth and face the centerline of the roadway.

(3) Limitations of Operations:

a. Weather limitations. Concrete shall not be placed unless the deck temperature is above 10°C (50°F) and the air temperature is predicted to be above 10°C (50°F) for at least 12 hours after placement. The concrete shall be maintained at a minimum of 10°C (50°F) during the curing period according to Article 1020.13. The temperature of the concrete mixture as placed shall not be less than 10°C (50°F) nor more than 32°C (90°F). If night placement is required, illumination and placement procedures will be subject to approval of the Engineer. No additional compensation will be allowed if night work is required.

b. Other Limitations. Concrete delivery trucks shall be limited to a maximum load of 4.6 cu m (6 cu yd).
Truck mixers, concrete pumps, or other heavy equipment will not be permitted on any portion of the deck where the top reinforcing mat has been exposed.
Conveyors, buggy ramps and pump piping shall be installed in a way that will not displace undercut reinforcement bars. Air compressors may be operated on the deck only if located directly over a pier and supported off undercut reinforcement bars. Compressors will not be allowed to travel over undercut reinforcement bars.
Concrete removal may proceed during final cleaning and concrete placement on adjacent portions of the deck, provided the removal does not interfere in any way with the cleaning or placement operations.

If water or contaminants from the hydro-scarification flow into the area of final cleaning or concrete placement, hydro-scarification shall be suspended until the concrete has been placed and has cured a minimum of 24 hours. No concrete shall be removed within 1.8 m (6 ft) of a newly-placed overlay until the concrete has obtained a minimum compressive strength of 20,700 kPa (3000 psi) or flexural strength of 4,150 kPa (600 psi).

(4) Curing Procedure. The surface shall be continuously wet cured for at least 7 days according to Article 1020.13(a)(5) Wetted Cotton Mat Method.

(5) Opening to Traffic. No traffic or construction equipment will be permitted on the overlay until after the specified cure period and the concrete has obtained a minimum compressive strength of 27,500 kPa (4000 psi) or flexural strength of 4,650 kPa (675 psi) unless permitted by the Engineer.

(6) Overlay Testing. The Engineer reserves the right to conduct pull-off tests on the overlay to determine if any areas are not bonded to the underlying concrete, and at a time determined by the Engineer. The overlay will be tested according to the

Illinois Test Procedure 305 “Pull-off Test (Overlay Method)”, and the Contractor shall provide the test equipment. Each individual test shall have a minimum strength of 1,034 kPa (150 psi). Unacceptable test results will require removal and replacement of the overlay at the Contractor’s expense, and the locations will be determined by the Engineer. When removing portions of an overlay, the saw cut shall be a minimum depth of 25 mm (1 in.).

If the overlay is to remain in place, all core holes due to testing shall be filled with a rapid set mortar or concrete. Only enough water to permit placement and consolidation by rodding shall be used, and the material shall be struck-off flush with the adjacent material.

For a rapid set mortar mixture, one part packaged rapid set cement shall be combined with two parts fine aggregate, by volume; or a packaged rapid set mortar shall be used. For a rapid set concrete mixture, a packaged rapid set mortar shall be combined with coarse aggregate according to the manufacturer’s instructions; or a packaged rapid set concrete shall be used. Mixing of a rapid set mortar or concrete shall be according to the manufacturer’s instructions.

Method of Measurement. The areas of mechanical and/or hydro scarification on the bridge deck will be measured for payment in square meters (square yards). No additional payment will be made for multiple passes of the equipment required to achieve the specified scarification depth.

The concrete overlay will be measured for payment in square meters (square yards).

When Bridge Deck Hydro-Scarification is specified, the additional concrete placed with the overlay, required to fill all depressions below the specified thickness will be measured for payment in cubic meters (cubic yards). The volume will be determined by subtracting the theoretical volume of the overlay from the ticketed volume of overlay delivered minus the volume estimated by the Engineer left in the last truck at the end of the overlay placement. The theoretical cubic meter (cubic yard) quantity for the overlay will be determined by multiplying the plan surface area of the overlay times the specified thickness of the overlay.

Basis of Payment. Concrete scarification of the bridge deck using mechanical scarification equipment will be paid for at the contract unit price per square meter (square yard) for CONCRETE BRIDGE DECK SCARIFICATION of the thickness specified. Concrete scarification of the bridge deck using hydro scarification equipment will be paid for at the contract unit price per square meter (square yard) for BRIDGE DECK HYDROSCARIFICATION of the thickness specified.

Microsilica concrete overlay will be paid for at the contract unit price per square meter (square yard) for BRIDGE DECK MICROSILICA CONCRETE OVERLAY, of the thickness specified. When hydro-scarification equipment is used, the additional volume of overlay required to fill all depressions below the specified thickness will be paid for at the Contractor’s actual material cost for the microsilica concrete per cubic meter (cubic yard) plus 15 percent.

When mechanical scarification equipment is used, additional partial depth patches poured monolithically with the overlay will be paid for at the contract unit price bid per square meter (square yard) for DECK SLAB REPAIR (PARTIAL).

When the Engineer conducts pull-off tests on the overlay and they are acceptable, Contractor expenses incurred due to testing and for filling core holes will be paid according to Article
109.04. Unacceptable pull-off tests will be at the Contractor's expense.

When specified, the Contractor has the option of choosing the type of overlay. The options will be limited to those specified in the plans and will be paid for at the contract unit price per square meter (square yard) for BRIDGE DECK CONCRETE OVERLAY OPTION, of the thickness specified.

Overlay material placed off the deck in abutment backwalls, and/or other locations will not be measured for payment but will be included in the pay item inv