0-6590-P2

Training Manual

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TxDOT Project 0-6590: Material Selection for Concrete Overlays

AUGUST 2011

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Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.	

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Chapter 1: Overview of Concrete Overlays

1.1 Introduction

The purpose of this product is to summarize the activities that the research team has accomplished on Project 6590: Material Selection for Concrete Overlays – Task 6: Development of a Training Manual. This manual is intended to educate TxDOT personnel for training design engineers, construction personnel, and inspectors. All the information provided can be referenced to the 0-6590 project report.

This chapter briefly covers purposes and usage of different types of concrete overlays.

1.2 Overview

The term "concrete overlay" is used when a layer of portland cement concrete (herein referred to as concrete) is used to resurface an existing pavement as a rehabilitation method. The main purpose of constructing concrete overlays is to optimize/extend the use of the remaining life of the existing pavement by placing an additional layer of concrete above it. By choosing the concrete overlay option, one can expedite construction, reduce cost, increase structural integrity, improve riding quality, and protect structure against deleterious environmental effects.

Concrete overlays are categorized into two types: <u>bonded</u> and <u>unbonded</u> overlay. In bonded overlays, there are ultra-thin and thin whitetoppings and bonded concrete overlay (BCO). These concrete overlays require bonding between the concrete overlay and the existing pavement. In unbonded overlays, there are conventional whitetopping, and unbonded concrete overlay (UBCO). Whitetoppings can be bonded or unbonded depending on their thickness. One other type, partially bonded concrete overlay, is not discussed in this report since it is not used for highway applications in Texas.

1.2.1 Whitetopping

The term "whitetopping" indicates a concrete overlay that is used to resurface an existing asphalt pavement. Whitetoppings are subcategorized by the thickness and the bond conditions.

1.2.1.1 Purposes and Uses

The purposes of whitetopping are to rehabilitate deteriorating asphalt pavements, to increase load capacity and improve ride quality. Since whitetoppings do not develop typical distresses that are found in asphalt pavements, it is a good alternative to placing an asphalt overlay. Whitetoppings are classified as the following:

- Ultra-thin Whitetopping (UTW): This type of application typically consists of a 2 to 4-in.-thick concrete overlay and is used when the existing pavement is considered to be in fair or better condition with minor surface distresses (shoving, rutting, alligator cracking, etc.). The overlay relies on existing pavement to carry much of the load and good bond will promote monolithic behavior. Monolithic behavior reduces flexural stresses in the overly, which can lead to early cracking and failure. UTWs are generally used in light traffic applications.
- Thin Whitetopping (TWT): Identical to UTW, but in this application the overlay is thicker (typically around 5 to 8 in.) and is used when the existing pavement is considered to be more deteriorated than for UTW requirements. The overlay relies on existing pavement to carry

some of the load by monolithic behavior through a good bond between overlay and substrate. TWTs are generally used when moderate traffic is present.

- Conventional Whitetopping (CWT): This concrete overlay is typically 9 in. or thicker and is used when the existing pavement is in severely deteriorated condition. CWT design assumes unbonded condition, so the existing pavement is only expected to serve as a subbase. The new overlay will carry the entire traffic load. CWTs are generally used when heavy traffic is of concern.

1.2.1.2 Performance Factors

The following factors determine the performance of whitetoppings:

- Effectiveness of bond: For whitetoppings that rely on existing pavement to carry load through bonding, properly achieved bond will promote monolithic behavior. This behavior is crucial in ensuring that the stiffness of the rehabilitated pavement (overlay and existing pavement) will carry the traffic load as one structure.
- Existing pavement condition: Since UTWs and TWTs rely on the existing pavement to assist in carrying the traffic load; the condition of the existing pavement affects the performance of the rehabilitated pavement. Proper repairs or upgrades should be made to the substrate to provide adequate support as required by design.
- Proper joint spacing: If joints are made, well designed joint spacing helps to reduce curling stresses and bending stresses due to traffic loads. This is especially true for UTW and TWT because of their thinness.

1.2.1.3 Common Modes of Failure

The following failure modes are commonly seen in whitetoppings:

- Loss of bond: The bond between the overlay and the existing pavement can be lost due to lack of quality control in surface preparation or placement.
- Rapid transition zone failure: Accelerated deterioration in the transition zones can occur where asphalt and the concrete overlay meet. Thicker concrete overlay sections are recommended in these areas [1].

1.2.2 Bonded Concrete Overlay

A “bonded concrete overlay (abbreviated “BCO”) is a relatively thin concrete that is used to resurface an existing concrete pavement. This type of overlay is typically 2 to 8 in.-thick and its performance depends on good bond to the existing pavement.

1.2.2.1 Purposes and Uses

The purpose of BCO is to rehabilitate deteriorating concrete pavements to increase load capacity and ride quality. BCO is recommended when the existing pavement is considered to be in fair or better condition with minor surface distresses and less than a few punchouts per lane mile.

1.2.2.2 Performance Factors

The following factors determine the performance of BCOs:

- Effectiveness of bond: Proper bond will provide monolithic behavior, ensuring that the stiffness of the rehabilitated pavement (overlay and existing pavement) will carry the traffic load as one structure.
- Existing pavement condition: Since BCOs rely on the existing pavement to assist in carrying the traffic load; the condition of the existing pavement affects the performance of the rehabilitated pavement. Proper repairs or upgrades should be made to provide adequate support as required by design.
- Proper joint spacing: If joints are made, well designed joint spacing helps to reduce curling stresses and bending stresses due to traffic and environmental loads. It is crucial that the transverse joints in the BCOs match those in the existing pavement to promote monolithic behavior.

1.2.2.3 Common Modes of Failure

The following failure modes are commonly seen in BCOs:

- Loss of bond: The bond between the overlay and the existing pavement can be lost due to lack of quality control in surface preparation or placement during construction.
- Delamination due to difference in Coefficient of Thermal Expansion (CTE): If BCO has a CTE that is same or more than the CTE of the existing pavement; then the overlay will expand or contract more than the existing pavement. This results in shear and normal stresses forming at the bond line, and these induced stresses can cause the overlay to crack and delaminate.
- Higher stresses at boundaries: Boundary conditions in BCOs at the edges of the overlay and along cracks are higher than in the bonded areas away from them. The effect is highest at the very edge and diminishes rapidly to the standard uniformly distributed stresses. This due to curling and warping stresses in the top of the overlay as temperatures and moisture conditions change more rapidly there than in the rest of the slab depth.

1.2.3 Unbonded Concrete Overlay

The term "unbonded concrete overlay (UBCO)" is used to categorize relatively thick concrete overlays that are used to resurface the existing concrete pavement. The thickness of this type of overlays is typically greater than 7 in. and is designed to perform without bonding to the existing pavement.

1.2.3.1 Purposes and Uses

The purpose of UBCO is to rehabilitate deteriorating concrete pavements, improving load capacity and ride quality. UBCO is used when the existing pavement is severely deteriorated with major surface distresses. A separation layer (typically, 1-in thick asphalt layer) is used to maintain separation between concrete overlay and existing pavement.

1.2.3.2 Performance Factors

The following factors determine the performance of UBCOs:

- Effectiveness of the separation layer: An effective separation layer will act as a shear plane that will prevent cracks from reflecting up from the existing pavement into the overlay. In addition, the separation layer prevents bonding between the new and the old layer allowing them to move independently.
- Effective drainage: A well-constructed drainage system will prevent the building up of pore pressure from the traffic loads. The system serves to prolong the life of the overlay by reducing pumping, asphalt stripping of the separation layer, faulting, and cracking.

1.2.3.3 Common Modes of Failure

The following failure modes are commonly seen in UBCOs:

- Failure to consider at-grade and overhead structures: The elevation of the pavement after an UBCO placement will significantly increase. Therefore, at-grade and overhead structures should be raised, or existing pavement should be removed and replaced near these structures [2].
- Inadequate separation layer: The separation layer prevents reflective cracks from occurring. If the new overlay is not structurally separated from the deteriorated existing pavement, the movement of two structures will be dependent, which will induce heavy reflective stress to the overlay from underneath.
- Poor drainage: The higher elevation of the pavement necessitates a change in the drainage grade lines. Additional right-of-way may be required to provide the proper slopes for the ditches [3].

Chapter 2: Factors that Affect Concrete Overlay Performance

Performance of concrete overlay depends on the following factors:

- Materials compatibility.
- Materials selection.
- Environmental considerations.
- Surface Preparation.
- Construction practice

2.1 MATERIALS COMPATIBILITY (BCOS ONLY)

When constructing a successful BCO, creating a monolithic pavement is very important. Designed concrete should have coefficient of thermal expansion (CTE) and modulus of elasticity (MOE) similar to or lower than that of existing pavement, but no more than 5.5 in/in/ºF, to minimize stress at bond interface. CTE is determined mainly by the coarse aggregate (CA), therefore, CTE of CA should be equal or less than that of existing pavement.

2.2 MATERIALS SELECTION

This section discusses general recommended materials selection for concrete overlays. Materials selected will determine the performance and careful selection is required.

2.2.1 Cement

The most commonly used cement types are Type I, Type I/II, and Type III. Type I is usually preferred over Type III because this Type I of cement develops less heat of hydration, avoiding many of the problems associated with high temperature development [4, 5].

When high early strength is desired, a Type III or more finely ground Type I cement is used. However, the use of these cements will result in an increased heat of hydration and caution should be taken to reduce thermal cracking. Other characteristics to consider when selecting cement are long-term mechanical properties, toughness, volume stability, and long life in severe environments [4, 6]. Strength gain and set time may be regulated with admixtures and mixture proportioning [7, 8].

To prevent alkali-silica reaction (ASR), low alkali cement (total alkalis Na_2O equivalent<0.6%) should be used for any type of cement coming in contact with ASR-prone aggregates. When siliceous aggregates are used, alkalis from cement react to form expansive gel causing deleterious effects. Cement should contain low alkali content and supplementary cementing materials (SCM) substitutions to prevent from ASR from occurring.

2.2.1.1 Cementitious Content

Cementitious content for typical concrete pavement mixture designs can be used for unbonded overlays. However, for bonded overlays, cementitious content should be increased to have enough paste available at the interface to form an efficient bond. A chosen water-to-cementitious materials (w/cm) ratio must provide enough water to create adequate amount of paste but no more than enough to prevent deleterious effects such as shrinkage.

2.2.2 Aggregates

To construct an efficient concrete overlay, the aggregate should be adequately strong, physically stable, and chemically stable. The aggregates make up between 65 and 75% of the total concrete volume; therefore, their properties have a definite influence on those of the concrete.

Available aggregates should be evaluated carefully to determine which best meet early age and long term performance requirements. Performance requirements may justify purchase of more expensive (high-strength, crushed) aggregates, or careful aggregate blending [10]. Aggregates that conform to Item 421 of TxDOT Standard Specifications should be used, but extensive laboratory testing on trial mixtures or demonstrated field performance is required to ensure selection of suitable aggregates.

To prevent ASR, non-reactive aggregates should be selected. Many durability problems result from the reaction between the silica in the aggregates (e.g., siliceous river gravel) and alkalis contained in the cement [11].

Unsaturated absorptive aggregates have a higher moisture demand and can contribute to debonding during curing. These aggregates will absorb available moisture, hindering the curing procedure and affecting shrinkage [4, 10, 12].

2.2.2.1 Coarse Aggregate (CA)

The maximum CA size is a function of the overlay thickness. It is recommended that the largest practical maximum CA size is used in order to minimize paste requirements, reduce shrinkage, minimize costs, and improve mechanical interlock properties at joints and cracks [4, 9]. Maximum CA sizes of 0.75 to 1 in. have been commonly used, but a reduction in size may be necessary for thinner overlays. For non-reinforced pavement structures, a maximum aggregate size of one-third of the slab thickness is recommended [4, 5, 11]. The lowest allowable maximum aggregate size specified should be 0.5 in.

For BCOs only, the compatibility of materials between the old concrete and the new concrete is fundamental for the success of the bond. The coefficient of thermal expansion (CTE) of concrete overlay should be less or at least similar to that of existing pavement [10, 13, 35]. This is because higher slab stresses and wider joint openings can occur when aggregates with higher CTE are used [8]. Since the CTE of the overlay is governed by the coarse aggregate properties, the CTE of the coarse aggregates used in the overlay should be less or equal to that of the existing pavement. Significant differences should be avoided in order to reduce the differential movement between overlay and substrate. In other words, it is recommended that the coarse aggregate in the BCO should have a thermal coefficient no higher than that of the coarse aggregate in existing pavement. For instance, it is advisable to utilize a limestone aggregate for BCO if existing concrete has siliceous river gravel as coarse aggregate, because of limestone’s lower CTE, but the opposite arrangement will produce a BCO prone to delamination. Also, the modulus of elasticity (MOE) for BCOs should be lower than for the existing pavement [11].

2.2.2.2 Fine Aggregate (FA)

FA must be sound and nonreactive. It is necessary that FA be sufficiently resistant to tire wear (polishing) to prevent loss of skid resistance. The polish resistance may be improved by using durable and angular fine aggregates [4, 6, 10].

2.2.2.3 Gradation

Using uniformly and densely graded aggregates is recommended to reduce shrinkage because it reduces required paste. This is helpful in thin concrete overlays, because the risk of debonding due to shrinkage and curling potential is decreased [10]. Both the top size and gradation of the aggregate will also affect aggregate interlock at the joint, which is another important consideration, because thin concrete overlay joints are typically not dowelled [8].

2.2.3 Fly Ash

Cement may be partially replaced with fly ash, which can lead to higher ultimate concrete strengths and lower permeability [7]. Moreover, replacing cement with fly ash can reduce cost, increase workability, and increase protection against deleterious environments. Due to the lower specific gravity of fly ash, as compared to cement, replacement of cement with fly ash increases the volume of cementitious paste in the mixture. This increased volume of paste provides an improved coating of fibers and aggregate in the mixture, leading to improved workability and fiber distribution [4]. However, higher fly ash replacement lowers the early strengths. This may lead to delay in construction and opening to traffic.

2.2.4 Admixtures

Typical admixtures used in concrete overlays include air entrainment, high range water reducers, and retarders. When combinations of these admixtures are used, their combined effects should be observed. Care must be taken to avoid any admixtures that cause unnecessary reduction in the rate of strength gain. Trial batches should be made to determine the interaction between the admixtures. For BCO applications, preliminary bond tests should be conducted with similar concretes, both with and without the chemical admixtures, to ensure that comparable bond strengths are obtained at early ages [5].

2.2.5 Fibers

There is still a lack of studies and experiences using fibers in concrete overlay application. One quantifiable test to measure the benefit of using fibers available is average residual strength (ARS) test (Sec 3.2.5). However, no direct correlation between ARS test and the field performance has been found.

Based on this research project, fiber incorporation may provide reduced shrinkage and/or increased toughness of concrete [14]. But, not enough information exists on how the actual performance of the overlay will be affected. The effect of fibers in concrete on compressive strength generally varies from a negligible increase or decrease to strength gains around 20% [15, 16, 21]. Also, fibers can be beneficial to reduce crack development, to slow crack growth, and to delay debonding propagation while providing residual strength in pavements that have already cracked [17]. Fibers are usually used in thinner overlays because of their high cost.

Fibers can bridge cracks in concrete and restrain them from opening thus increasing the load ability of the concrete overlay [18]. Fiber-reinforced concrete pavements should have a longer service life and require less maintenance than non-reinforced concrete pavements [19].

However, some past experiences have shown that negative effects can be expected from fiber reinforced concrete overlays. The most prevalent effect is the cost. Addition of fibers will tremendously increase the project cost, and, sometimes, it is difficult to calculate cost-to-benefits ratio of using fibers.

Another problem is the difficulty in handling fibers during construction [18]. Fiber balling is a phenomenon that occurs when there is a lack of effort to adequately disperse the fibers in concrete, resulting in balls of bunched fibers in the concrete overlay. Fiber balling not only reduces benefits from using the fibers, but also creates weak spots in concrete overlays.

Proper handling of fibers is required in concrete overlays. Increase in fiber dosage can lead to significant decreases in compressive and flexural strength. Steel fibers can corrode and weaken the surface of concrete overlays. Without proper dispersion of fibers, the crack bridging benefits cannot be expected.

Polypropylene microfibers are produced either as cylindrical monofilaments or fine fibrils with a rectangular cross section. Polypropylene microfibers can be in monofilament, multifilament, or fibrillated form (Figure 2.1).

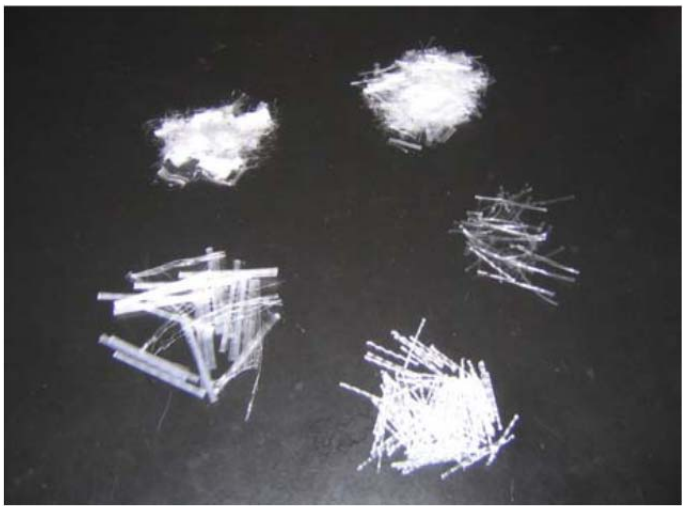


Figure 2.1: Different forms of polypropylene fibers

Microfibers are effective in controlling plastic shrinkage and settlement cracking. The fibrillation process greatly enhances the bonding between the concrete and the polypropylene fibers and can provide residual strength in pavement that has already cracked [6].

Polypropylene macrofibers are coarse fibers that allow greater surface area contact within the concrete, resulting in increased interfacial bonding and flexural toughness. Polypropylene macrofibers can be used as secondary reinforcement and can provide greater post-crack strength and concrete slab capacity. Additional benefits include improved impact, abrasion, and shatter resistance.

Polyester fibers are available only in monofilament form. They commonly have relatively low fiber content and are used to control plastic shrinkage-induced cracking. Synthetic fibers do not absorb water and therefore do not affect the mixing requirements.

Steel fibers are primarily made of carbon steel, although stainless steel fibers are also manufactured. Perhaps the biggest advantage of steel fibers is their high tensile strength and their ability to bridge joints and cracks to provide tighter aggregate interlock, resulting in increased load-carrying capacity. Steel fiber reinforced pavements exhibit excellent toughness and pre- and post-crack capacity [14].

The aspect ratio is an important parameter influencing the bond between the concrete and the fiber, with longer fibers providing greater bond strength and toughness, often at the expense of workability. Steel fibers may also have certain geometric features to enhance pullout or anchorage within the concrete mixture. These features may include crimped or hooked ends or surface deformations and irregularities (Figure 2.4).

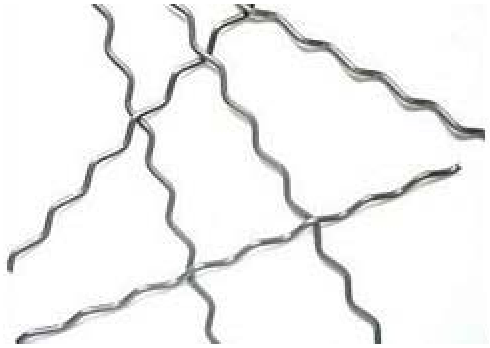


Figure 2.2: Deformed steel fibers

Blended fiber systems combine macrofibers with microfibers or steel fibers. The microfibers in these systems provide resistance to plastic shrinkage and settlement cracking, while the macrofibers or steel fibers provide long-term secondary reinforcement. Blended systems provide higher levels of fatigue resistance, greater flexural toughness, and improved durability. Additional benefits include improved impact, abrasion, and shatter resistance.

2.2.6 Reinforcement Bars or Wire Mesh

When placing reinforcement bars or wire mesh for concrete overlay application, they should be placed at the bottom of the concrete overlay (near the surface) to restrict the movement of concrete at the bottom. An effective bond will be achieved with less movement near the interface.

2.2.7 Separation Layer Materials for UBCOs

A separation layer allows the existing pavement and the new concrete overlay to act independently. It also prevents distresses from reflecting into concrete overlay. Typically, 1 to 2-in.-thick asphalt layer has been widely used for the purpose and has been proven effective. Materials such as polyethylene, roofing paper, and curing compound do not work. Most failures in unbonded concrete overlays are due to the use of inadequate separation layers or insufficient overlay thickness.

Thin separation layers (such as sheathings) must be avoided because they are more likely to permit reflective cracking from the existing pavement. Thicker separation layers can prevent reflective cracks from occurring [34]. Figure 2.3 shows how a smooth slip plane can prevent reflective cracks from occurring.

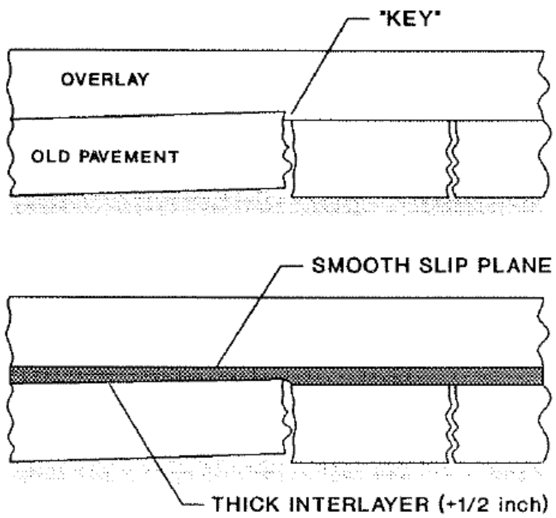


Figure 2.3: Purpose of interlayer

2.3 ENVIRONMENTAL CONSIDERATIONS

Weather conditions prevailing during concrete overlay construction can be critical to the performance; environmental variables that play a key role in the behavior of the concrete overlay are temperature, moisture surrounding the concrete. Hot and dry climates pose the most problematic setting for concrete overlay placement, because these conditions favor the loss of moisture from fresh concrete. Excessive water evaporation from the concrete can cause plastic shrinkage cracking, which reduces the integrity of the concrete surface and reduces its durability.

A combination of high wind velocity, high air temperature, low relative humidity, and high concrete temperature is the most harmful for paving conditions, because it results in high water evaporation. Placing during low temperature months, i.e., December and January, can minimize climatic stresses and cracking [27].

Caution must be taken in hot, dry, and/or windy climates to avoid excessive evaporation of water from concrete and produce plastic shrinkage cracking. Weather stations should be used to monitor the weather condition, and the ACI 503R nomograph should be used to decide the severity of the environment condition. The following adverse conditions must be monitored in construction [4, 28]:

- Surface of the existing pavement should not exceed 125 °F immediately before placement.
- Temperature differential in the 24 hours after the placement must be less than 25 °F.
- A condition where water evaporation rates exceeding 0.2 lb/ft.^{2}/hr based on the ACI 503R nomograph.

Any of these adverse conditions during the placement of concrete should be avoided unless the following steps are taken:

- Cooling the aggregate or concrete.
- Special curing methods (refer to section 2.5.7).
- Use of fly ash as cement replacement to lower the heat of hydration.

ConcreteWorks can be used to simulate temperatures to predict behavior of concrete under certain environmental conditions.

2.4 SURFACE PREPARATION

Surface preparation encompasses the operations conducted on the existing pavement surface to enhance it in such a way that the new concrete layer can behave as designers intended. The level of surface preparation will determine to a significant extent the longevity of a concrete overlay. Surface preparation is crucial for any type of concrete overlays [23].

2.5.2.1 For BCOs

It is not an overstatement to say that the longevity of a BCO is mainly determined by the effectiveness of bond at the interface. This statement is truer the thinner BCOs because thin BCOs rely on the existing pavement to carry the traffic load; thus good bond is the most important factor.

Three typical means of surface preparation for BCOs are shotblasting, milling, and sand blasting. The most efficient method is by means of shotblasting equipment, such as the Skidabrader machine. Unlike cold milling, shotblasting can achieve adequate depth without causing microcracking. It can remove concrete matrix leaving the CA intact undamaged.

Sandblasting is suitable for small and hard to reach areas. It is not recommended for large areas because of its uneven removal of the surface. Surface preparation procedures are listed in Table 2.1.

Table 2.1: Surface preparation procedure [11]

Removal method	Principle behavior	Depth action (mm)	Important advantages	Important disadvantages
Shotblasting	Blasting with steel shot.	No (12)	No microcracking, dust.	Not selective.
Milling (scari-fying)	Longitudinal tracks are intro-duced by rotating metal lamellas.	Yes (75)	Suitable for large volume work, good bond if followed by water flushing.	Microcracking is likely, reinforcement may be damaged, dust development, noisy, not selective.
Sandblasting	Blasting with sands.	No	No microcracking.	Not selective, leaves considerable sand.
Scabbling	Pneumatically driven bits impact the surface.	No (6)	No microcracking, no dust.	Not selective.
Grinding (planning)	Grinding with rotating lamella.	No (12)	Removes uneven parts.	Dust development, not selective.
Flame-cleaning	Thermal lance	No	Effective against pollutions and painting,	The reinforcement may be damaged, smoke

Removal method	Principle behavior	Depth action (mm)	Important advantages	Important disadvantages
			useful in industrial and nuclear facilities.	and gas development, safety considerations limit use, not selective.
Pneumatic (jack) hammers (chipping), hand-held or boom-mounted	Compressed-air-operated chipping	Yes	Simple and flexible use, large ones are effective.	Microcracking, damages reinforcement, poor working environment, slow production rate, not selective.
Explosive blasting	Controlled blasting using small, densely spaced blasting charges.	Yes	Effective for large removal volumes.	Difficult to limit to solely damaged concrete, safety and environmental regulations limit use, not selective.
Water-jetting (hydro demolition)	High pressure water jet from a unit with a movable nozzle	Yes	Effective (especially on horizontal surfaces), selective, does not damage reinforcement or concrete, improved working environment.	Water handling, removal in frost degrees, costs for establishment.

Depth of scarification and type of aggregate of the existing concrete may dictate the type of surface preparation to use. Cost is also a factor to take into consideration. Typically shotblasting is the most inexpensive option and produces better prepared surface [24].

The scarification depth and texture should be specified for each project, depending on economic considerations as well as the material properties, both of the existing pavement and the new overlay. For instance, if the existing pavement paste is relatively soft and the coarse aggregate is especially hard, a light shotblasting will be sufficiently strong to remove the paste to reach the specified depth, leaving the aggregate intact, resulting in a good surface texture.

Typically, the depth of surface removal is about 0.25 in after the coarse aggregate is exposed [35]. It can also be specified in terms of a standardized texture test method, such as the sand patch test or Circular Track Meter (CTM). Typical texture readings from this test are between 0.050 in. and 0.099 in [35].

2.5.2.2 For Whitetopping/Unbonded Concrete Overlay (UBCO)

If surface distortions on the existing asphalt pavement are excessive (greater than 2 in.), either milling or a leveling course may be necessary to provide proper grading. The milling process should be controlled by a string line to prevent concrete quantity overruns [9]. Typically, milling is used to scarify the existing pavement to roughen up the surface.

For UBCO placements, the existing pavement acts as base, and a separation layer is placed on top to separate the UBCO and the existing pavement to prevent cracks from reflecting through. An effective separation layer is the key to the longevity of UBCOs. Since the existing pavement serves only as base, no special preparation is needed. Usually, a thin layer of asphalt is used to act as a separation layer, so if there are any asphalt patches on the existing pavement there is no need to remove them.

White pigmented curing can be used to cool the existing pavement prior to pouring. This curing compound reflects heat and prevents heat build-up in the black surface, reducing shrinkage cracking in the concrete and potential paving problems due to a soft surface [8, 19]. Water fogging is another method that can reduce the asphalt temperature. Figure 2.4 shows a way to cool down the prepared surface by spraying with water. It is good practice to water fog if the asphalt surface heat makes it uncomfortable to touch with an open palm [29]. It has been found that mix water in the fresh concrete overlay was absorbed into the dry substrate, reducing the amount of water available to fully hydrate the cement paste at the bonding interface [30].

Figure 2.4: Cooling down the prepared surface before placement

2.5.3 Surface Cleaning

Surface cleaning refers to the removal of dust and debris after the surface preparation is complete and prior to the placement of the concrete overlays, to ensure that no foreign elements interfere with the achievement of bonding between both layers. Any kind of loose/foreign materials present at the interface will act as a bond breaker and can cause extensive delamination.

After the surface preparation operations are finalized and the reinforcing steel is in place, the last cleaning of the surface is done by air blasting just before concrete placement. It should be noted that air blasting and water blasting should be used only as supplementary cleaning procedures for loose material and debris elimination from the surface after milling, shotblasting, or sandblasting, because these methods are not capable of removing paint stripes, tire marks, or grout matrix. Air blasting is to be used just before overlaying to thoroughly remove debris from milling or shotblasting operations. It is important not to leave a large time lag between the final surface cleaning and paving in order to prevent the contaminants from resettling. Figure 2.5 shows hydro cleaning as a way to clean the prepared surface.

Figure 2.5: Cleaning the surface with hydrocleaning equipment

If trucks or equipment need to drive on top of prepared surface, tarps should be placed to prevent any foreign materials falling on the surface [23]. The ultimate goal in surface preparation is to achieve a well textured and clean surface to receive the concrete overlay.

2.5 Construction Methods

There are a numerous steps for concrete overlay construction that differs from typical pavement constructions.

2.5.5 Placement

The following are general considerations for placement of concrete overlays:

- To prevent water loss in concrete due to absorption by the existing pavement, the prepared surface ahead of the paving machine should be dampened with water to achieve SSD condition [11, 13, 31].
- Tracking of dirt or debris ahead of paving machine should be prevented.
- Bonding agents should not be used unless under special circumstances. With a properly prepared surface in SSD condition, a bonding agent, such as epoxy, is not required. If bonding agents are used improperly, they may act as bond breakers.
- For BCOs, reinforcements can be directly placed on top of existing pavement. Laboratory studies have shown that reinforcement placed at the interface develops the same bond as reinforcement placed in the middle of the overlay. Placement of the reinforcement at the interface also eliminates the risk of concrete honey combing and poor consolidation beneath the steel [4].
- The grading machine must be adjusted to achieve the required thickness of the concrete overlay.

- The steel fibers at the surface of the pavement can become entangled with burlap and can be pulled out along with other fibers and coarse aggregates. An un-weighted carpet drag can be a substitution to provide a satisfactory interim surface finish on the pavement [18, 19].
- Finishing of the new concrete overlay surface should follow the same practices used to finish any concrete pavement [4].

2.5.6 Jointing

To reduce the edge and corner stresses, longitudinal joints should not be placed in the wheel path. Heavy loads concentrated near the edge of the thin panels should not exceed their load capacity [32, 33]. The following are recommendations for jointing:

- The timing of joint sawing is critical. Sawing too early can cause excess raveling, and sawing too late can result in shrinkage stress causing uncontrolled random cracking.
- ACPA recommends that joint spacing be about 12 to 15 times the slab thickness.
- Joint spacing has a significant effect on the rate of corner cracking. Short joint spacing, common on thin concrete overlays, reduces load-related stresses, because the slabs are not long enough to develop as much bending moment [8]. The joint location is also important to avoid concentrated loads. For example, 4-ft. by 4-ft. panels on a 12-ft.-wide lane would put truck tires on the edge of the panels, and significant distress would occur if the thin concrete overlays became de-bonded from the existing pavement [9]. Figure 2.6 is a good example of failed joints in wheel paths.

Figure 2.6: Failed joints in wheel path

2.5.7 Curing [11]

The importance of proper curing can never be understated. Proper curing procedures are essential in preventing excessive moisture loss at early ages that can result in plastic shrinkage and loss in tensile strength capacity at the surface. Curing should begin as soon after placement and finishing as possible to minimize loss of bleed water. Figure 2.7 shows the curing crew following the paving machine closely. For concrete overlays, It is recommended that a double application of the curing compound be used [5, 26].

Figure 2.7: Prompt curing following the paver

Types of curing procedure include the following:

- Curing compound: For textured or tined surface the spray application should be applied from two directions to ensure that the entire surface is coated.
- Membrane curing: Various liquid sealing compounds, e.g. bituminous and paraffinic emulsions, coal tar cut backs, pigmented and non-pigmented resin suspensions, or suspensions of wax or non-liquid protective coating such as sheet plastics or water proof paper, are used to restrict evaporation of water.
- Curing blankets: A covering of sacks, mats, cotton bats, burlap, straw, or other suitable paper is placed over the surface to reduce evaporation and to reduce the temperature reduction at the surface. When used to reduce evaporation the blankets are generally wetted.
- Monomolecular film (MMF): MMFs are compounds that form a thin monomolecular film to reduce moisture loss from the concrete surface prior to curing. Another curing method should be used after the evaporation retardant is sprayed on. Research has shown, however, that the use of MMF followed by application of curing compound does not consistently provide less evaporation than curing compound alone.

2.6 Guidelines Development

Guidelines have been developed to help engineers successfully control the mentioned factors to produce quality concrete overlays: materials selection guideline and construction method guideline. Materials selection guideline provides selection criteria and a flowchart to assist in selecting proper materials in step-by-step method. Construction method guideline provides a construction process walkthrough.

Chapter 3: Guidelines for Materials Selection

The following set of guidelines was developed to assist readers through the recommended process for selecting proper materials for proportioning durable overlays.

3.1 Introduction

It is important to keep in mind that materials selected should satisfy both the performance-based and prescriptive-based acceptance criteria. A set of flowcharts for materials selection has been developed to help guide the reader through the selection process.

3.2 Performance Based Acceptance Criteria

Candidate materials selected for concrete overlays must meet certain recommended performance limits, which were obtained from 0-6590 project and literature review.

3.2.1 Compressive Strength

The compressive strength test (ASTM C39) measures the compressive strength of concrete. The test is intended to determine if concrete has achieved designed strength to resist compressive load induced by traffic. Overlay concrete mixtures must meet minimum average compressive strengths of 3500 psi at 7 days or 4400 psi at 28 days. These limits are found in ITEM 360 in TxDOT Standard Specifications 2004.

For BCOs only, the maximum average must be controlled, so that the overlay's resulting modulus of elasticity (MOE), which is directly proportional to its compressive strength, is less than the MOE of the existing pavement. The MOE in the concrete overlay should always be equal or lower than the MOE in the existing pavement, because higher in moduli in the BCO. And the highest thermal stresses and strains will be introduced at the top one or two inches of depth from surface of the overlay. This is so, because only the top surface is directly exposed to the elements and concrete cannot efficiently conduct heat through the rest of the slab.

In order to increase the compressive strength, the following can be performed:

- Decrease the w/cm of the concrete mixture.
- Decrease fly ash replacement.
- Use coarse aggregate with higher strength.

The following may lower the compressive strength:

- Increase the w/cm of the concrete mixture.
- Increased fly ash replacement.
- Fiber addition (only minimal decrease in the strength).

3.2.2 Flexural Strength

The flexural strength test (ASTM C78) measures the flexural strength of concrete. The test is intended to determine if concrete has achieved designed strength to resist flexural (bending) load induced by traffic. A minimum average flexural strength of 570 psi at 7 days or 680 psi at 28 days is recommended. These limits are found in ITEM 360 in TxDOT Standard Specifications 2004.

The flexural strength for a given mix design using the same aggregates is proportional to the compressive strength, so the same factors that raise or lower the compressive strength (Section 3.2.1 above) simultaneously raise or lower the flexural strength, too.

3.2.3 Coefficient of Thermal Expansion and Modulus of Elasticity

For BCOs only, designers must consider the coefficient of thermal expansion (CTE), ASTM E228, of both the overlay concrete and the substrate concrete. The CTE test measures the degree of concrete expansion and contraction due to thermal change. The CTE compatibility between concrete overlay and the existing pavement is very important to promote a monolithic pavement.

Change in CTE of concrete is attributed mostly to the coarse aggregate (CA). Candidate CAs must make concrete having a CTE that is equal to or lower than the CTE of the existing pavement. For example, it is advisable to utilize a limestone aggregate for the BCO concrete if the existing concrete has siliceous river gravel as CA, because of the lower CTE in limestone, but the opposite arrangement will make up for an overlay prone to delamination.

Based on Project 0-6590, CTE of concrete was not affected by addition of fibers. Double the TxDOT and manufacturer recommended dosage of fibers were added to concrete specimens, but no significant changes in CTE were observed. Detailed information can be found in the final project report.

Also, it should be noted that the modulus of elasticity (MOE), based on ASTM C469, of the concrete overlay must be equal or lower than the MOE of the existing pavement. The MOE test measures the elasticity of concrete, and the MOE compatibility between concrete overlay the existing pavement is very important to reduce stress on the concrete overlay.

The basic premise for achieving equal or lower CTE and MOE is to lower stresses at the interface, because the increased stress at the interface will increase the possibility of debonding.

In order to lower MOE, the following can be performed:

- Increase fly ash replacement.
- Increase the w/cm (lowers strength and MOE, too).
- Add fibers.

The following may increase MOE:

- Decreased fly ash replacement.
- Increased cement content, lower w/cm.

3.2.4 Tensile Bond Strength

The bond strength test (ASTM C1583) measures the bond strength at the interface between concrete overlay and the existing pavement. It determines whether adequate bond strength is achieved at the interface that will promote a monolithic pavement.

The minimum bond strength should be greater than 200 psi. This limit comes from AASHTO and is based on numerous past studies in which it was found that a bond strength greater than 200 psi resulted in satisfactory concrete overlay performance. Maximizing bond strength will promote monolithic movement of the new concrete overlay and the existing pavement.

In order to raise bond strength, the following practice is recommended:

- Prepare the surface properly (refer to section 4.2).

- Use of CA with low CTE and MOE.
- Decrease w/cm.
- Decrease fly ash replacement.
- Add fibers – blending different types of fibers may be helpful.

The following may lower bond strength:
- Lack of proper surface preparation.
- Use of CA with high CTE and MOE.
- Increase w/cm.
- Increased fly ash replacement.

After the concrete overlay placement, the following practice will help to ensure that the minimum bond strength is achieved:

- Until minimum specified strength is achieved, vehicles (including construction vehicles) should not be allowed on the concrete overlay.
- Longer curing time is required when fly ash is used, because it slows the early strength gain.
- Bond strength tests (ASTM C1583) must be performed in order to make sure that the minimum strength is achieved.

3.2.5 Average Residual Strength

One of the possible benefits of incorporating fibers into concrete is their ability to bridge and carry load after concrete cracks. The distributed fibers act as tension load carrying elements and their averaged quantifiable strength is called average residual strength (ARS). The ARS test (ASTM C1399) is a modified four-point bending test with a steel plate. A beam is supported by the steel plate and loaded until first crack occurs. The steel plate is then removed and load is reapplied. The applied bending load post-crack measures the bending resistance of the beam with the contribution of fibers bridging the crack. The current TxDOT recommendation for ARS is equal to or greater than 115 psi.

To accurately and precisely perform ARS tests, fibers should be well dispersed to increase consistency and the average ARS maximum. Better fiber dispersion can be achieved by introducing the fibers gradually and early in the mixer.

In order to raise ARS, the following practice is recommended:
- Use steel or structural synthetic fibers.
- Increase fiber dosage (until at least the minimum workability is achieved).
- Increase fiber dispersion.
- Use fibers with deformed shape.

The following may lower ARS:
- Using normal synthetic fibers.
- Minimal fiber dosage.
- Lack of proper fiber dispersion.

3.2.6 Drying Shrinkage

The drying shrinkage test (ASTM C157) measures the degree of shrinkage of concrete. Drying shrinkage should be minimized especially for concrete overlays. The cracks formed on concrete due to shrinkage will become nucleation sites for debonding. The goal in placing and curing concrete is to always minimize shrinkage as much as possible, because it reduces crack formation.

In order to lower shrinkage, the following practice is recommended:

- Increase fly ash replacement.
- Decrease w/cm.

The following may heighten shrinkage:

- Increased w/cm.
- Decreased fly ash replacement.

3.2.7 Workability

The slump test (ASTM C143), although a measure of consistency, is generally specified as the default test for determining workability of concrete. Criteria for workability in concrete overlays depend on the project and whether the "slip-form" or "formed" method is used for the construction. Currently, TxDOT specifies the following:

- Minimum: 1.5 in. (slip-formed) or 4 in. (formed).
- Maximum: 3 in. (slip-formed) or 6.5 in. (formed).

Trial batches should be made to achieve project specific slump limits. Slump can be reduced by following materials or adjustments: Addition of fibers, high fine aggregate content, using angular aggregates, lowering w/cm. Slump can be increased by following materials or adjustments: Addition of fly ash, low fine aggregate content, using water reducing agents, increasing w/cm.

3.3 PRESCRIPTIVE BASED ACCEPTANCE CRITERIA

Candidate materials selected for concrete overlays should meet certain recommended design guidelines, which were obtained from 0-6590 project and literature review.

3.3.1 Cement Type

Type I/II is adequate for normal concrete overlays and has produced satisfactory results in the research. Literature suggests that Type I can be considered for normal concrete overlays. For expedited concrete overlays, Type III or more finely ground Type I is recommended. They are ideal for expedited construction because higher early strength can be achieved in less time. However, heat of hydration is increased and can cause thermal cracking.

3.3.2 Cement Content

A range of 6 – 7 sks/yd^3 (564 – 658 lb/yd^3) of cement was tested and produced acceptable results for the research. From the literature, up to 7.5 sks/yd^3 (705 lb/yd^3) of cement have been recommended for BCOs. Although this much cement is not normally recommended, increasing typical paving mixtures' cement contents will help ensure that the available paste is sufficient in quality and quantity to achieve adequate bond at the interface. And extra paste also eliminates the need for a bonding agent, adequately coats all aggregates, and increases workability. However, too much cement content should be avoided to reduce shrinkage and the potential for alkali-silica reaction (ASR). Goals of reducing paste demand may be achieved by using uniformly graded aggregates.

Increasing the cement content alone decreases the w/cm, which can lead to the following benefits:

- Higher compressive strength at early age.
- Higher flexural strength at early age.
- Higher bond strength.

The following are the drawback when cement content is increased:

- Higher shrinkage.
- Higher MOE.

3.3.3 Fly Ash Replacement

Fly ash can be used in a concrete mixture to improve workability, finishing, and durability. Fly ash also reduces amount of water required and the heat of hydration, which means less shrinkage and cracking. Moreover, using fly ash lowers the cost of concrete.

However, the main drawback is that as larger amounts of cement are replaced by fly ash, initial strength gain is significantly retarded. This means that the heavily substituted concrete overlay pavements need a longer time to cure until traffic loads can be allowed, and in colder weather the delay may not be practical. So, lack of anticipation of this issue could potentially delay the construction and the opening to traffic.

Fly ash should replace portland cement in proportions that are calculated to ensure that enough is used to maximize its benefits, while minimizing additional time required to gain adequate strength. To accomplish this, environmental conditions must be taken into account. When the temperature is relatively low, fly ash will be slower to react and, therefore, slow down the initial strength gain. For this reason it is recommended that the amount of fly ash replacement should be adjusted to accommodate the seasons of the year and the time of the day (morning is cooler than afternoon).

Based on the research in Project 0-6590, up to 25% fly ash replacement provided adequate strength (compressive, flexural, and bond strength). As the replacement amount reached 50%, the strengths were much lower. However, if a longer curing period is allowed, higher replacement rate can be utilized. Currently, Item 421 in TxDOT Standard Specifications 2004 allows 20% - 35% replacement. Within the range, depending on the environmental conditions, lower or higher replacement rates can be used.

Increasing the fly ash replacement can lead to the following benefits:

- Higher workability.
- Lower MOE.
- Lower drying shrinkage.

The following are the drawbacks from increased fly ash replacement:

- Lower short-term compressive strength.
- Lower short-term flexural strength.

- Lower bond strength.

3.3.4 Water-to-Cementitious Material Ratio

For Project 0-6590, a water-to-cementitious material ratio (w/cm) of 0.40 was used assuming normal placement conditions. This ratio provided enough workability without sacrificing other performance limits. The literature recommends w/cm of 0.40 – 0.45 for normal placement conditions, and as low as 0.35 for expedited placement conditions.

The idea of a minimum limit is that lowering the w/cm can lead to forming a less than ideal amount of paste that can hinder coating of the aggregates and of the interface to develop adequate bond strength, as well as reducing workability. Also, low w/cm is generally associated with high modulus of elasticity. Modulus of elasticity of the new concrete overlay must be either equal or lower than the modulus of the existing pavement. The maximum limit is set, because too much water can increase the chance of shrinkage due to evaporation rate, and it can reduce the strength of the overlay matrix and its bond to the substrate.

3.3.5 Aggregates

Aggregates that conform to Item 421 in the TxDOT Standard Specifications should be used, but laboratory testing on trial mixtures or demonstrated field performance is required to ensure selection of suitable aggregates.

3.3.5.1 Coarse Aggregate

Since the CTE of concrete depends mostly upon the CTE of the CA, the candidate CA in the overlay must have a CTE that is equal or smaller than the CTE of the CA in the existing pavement. The basic premise of achieving lower CTE is to lower stresses at the interface because the increased stress at the interface will increase the possibility of debonding.

Example: It is advisable to utilize a limestone CA for the BCO concrete, if the existing concrete has siliceous river gravel as its CA, because of the limestone’s lower thermal coefficient.

Moreover, the maximum nominal size of CA should be less than one-third the thickness of the concrete overlay (not to exceed 1 to 1.5 in.). The minimum allowable maximum nominal size should be 0.5 in. Finally, uniform gradation reduces paste requirement, thus reducing shrinkage.

3.3.5.2 Fine Aggregate

Literature recommends selecting FA that is from natural siliceous deposits, is non-reactive, has low absorption and an acid insoluble residue (AI) greater than 60%. Some blended sands may be suitable, and TxDOT currently allows for any sands to be used for concrete pavements if the minimum AI is 60% or above. But the use of blended sands was not addressed in this project. TxDOT Project 0-6255: Manufactured Sand in Pavements is researching this issue.

3.3.6 Aggregate Ratio

Research results from this project investigated performance trends for varying the weight ratio of fine aggregate to overall aggregate (FA/(FA+CA)) in typical usage ranges between 0.35

and 0.45. Similarly, inconclusive results were found for performance trends when varying the weight ratio of aggregate to cement (a/c) in typical usage ranges from 4.7 to 6.0.

Generally, increasing the a/c ratio will effectively reduce the paste content and lower workability, while decreasing the ratio will increase the paste content, thereby improving the workability. Also, maximizing a/c can help to reduce shrinkage. Within the explored ratio ranges, all of the concrete mixtures were satisfactory for use as overlays, so this aggregates ratio study never really approached any limit of acceptability for performance. Based on literature, it is preferred to maximize coarse aggregate and minimize fine aggregate to reduce shrinkage, increase workability, and reduce amount of cement paste required.

3.3.7 Admixture Selection and Dosage

The dosage for HRWR and MRWR (mid-range water reducer) varies with the amount of cement and the type of aggregate. (This is especially true for fine aggregate, if manufactured sand blending is required. Varying sand types, however, was not investigated in this research project.) The dosage should be adjusted through trial batches, and the interaction between admixtures should be considered. For example, too much HRWR can cause the mixture to get sticky and will make finishing more difficult. A MRWR might be a better choice for this case, since it requires more MRWR to accomplish the same results, but this increases the paste volume in the stiffer paving mixture, which may improve the workability with less stickiness.

3.3.8 Fibers

There is still a lack of studies and experiences using fibers in concrete overlay application. One quantifiable test to measure the benefit of using fibers available is average residual strength (ARS) test (Sec 3.2.5). However, no direct correlation between ARS test and the field performance has been found. Based on this research project, fibers may help to reduce shrinkage, increase toughness, and improve bond strength. But, not enough information exists on how the actual performance of the overlay will be affected.

Two ways to quantify the effects caused by using fibers are ARS and workability as measured by slump. Increase in fiber dosage will increase ARS and decrease workability and vice versa. Workability also depends on concrete mixture design, and almost always there is a workability requirement. When fibers are used, it is recommended that a relationship between ARS and workability be established. This relationship will provide the permissible fiber dosage that will maximize ARS while meeting the minimum workability requirement. The following steps will assist in creating this relationship plot.

How to find a permissible fiber dosage to achieve maximum ARS while satisfying minimum workability requirement:

- Step 1: Determine the slump requirement range for a given project. TxDOT currently specifies minimums for paving concrete at 1.5 in. (slip-formed) or 4 in. (formed). Current maximums for paving concrete are 3 in. (slip-formed) or 6.5 in. (formed).
- Step 2: Develop a plot with fiber dosage on the X-axis and slump and ARS in the left and right Y-axes. Draw two horizontal lines starting at the minimum and maximum required slump range (labeled “slump requirement limit”).
- Step 3: Once the concrete mixture design (including every admixture that is going to be used) is established for a given project, perform a slump test and make ARS specimens for each batch made with a set incremental fiber dosage (at minimum increments of zero, low,

medium, and high points). As dosage increases, slump decreases in a trend that eventually crosses the lower "slump requirement limit." Create a best fit curve.

- Step 4: Perform ARS tests on the specimens made in Step 3. As dosage increases, ARS increases nonlinearly. Then, superimpose the values on the plot and create a best fit curve.
- Step 5: Draw two vertical lines at the points where the "slump requirement limit" and the slump line or curve intersect. The points at which the two vertical lines meet on the X-axis define the permissible fiber dosage range.
- Step 6: Draw a horizontal line where ARS is 115 psi. This is the current TxDOT recommendation for the minimum ARS. Depending on where the minimum ARS line intersects, the permissible dosage range may change.

Using the above method, a permissible fiber dosage for any fiber and any concrete mixture design can be developed and the resulting maximum ARS can be obtained. Figure 6.1 shows an example plot with each step labeled. There are relationship plots developed with real test data for Project 0-6590 in the final project report.

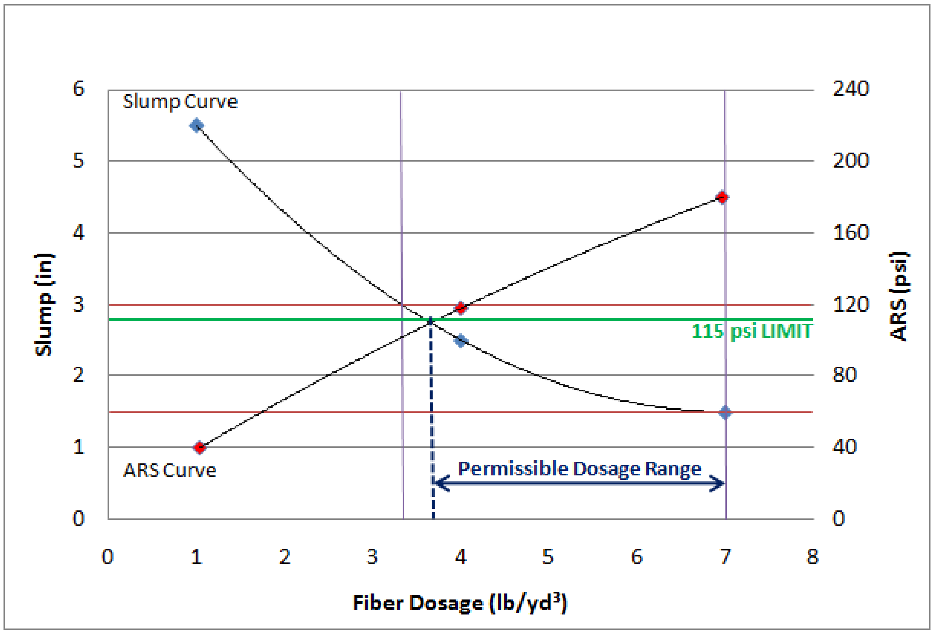


Figure 3.1: An example of ARS and workability relationship plot

3.3.8.1 Fiber Type

Steel fibers are primarily made of carbon steel, although stainless steel fibers are also manufactured. Perhaps the biggest advantage of steel fibers is their high tensile strength and their ability to bridge joints and cracks to provide tighter aggregate interlock, resulting in increased load-carrying capacity. Steel fiber reinforced pavements exhibit excellent toughness.

The most used synthetic fibers are typically made of polypropylene. Although polyester fibers are being produced, they are not as widely used. Synthetic fibers can be either "normal" or "structural." Normal synthetic fibers are much weaker than structural synthetic fibers and can only assist in shrinkage reduction. Structural synthetic fibers are typically rigid and relatively much stronger in tension. Normal synthetic fibers are quite useful to reduce plastic shrinkage in concrete in early age. Structural synthetic fibers are useful for both shrinkage reduction and toughening because of their strength.

3.3.8.2 Fiber Dosage

Addition of fibers impacts ARS and workability. The severity of these changes will be dependent on fiber dosage. Based on Project 0-6590, CTE of concrete was not affected by addition of fibers. Double the TxDOT and manufacture recommended dosage of fibers were added to concrete specimens, but no significant changes in CTE were observed. Detailed information can be found in the final project report.

Increasing the fiber dosage may lead to the following:

- Lower workability.
- Slightly lower compressive strength.
- Slightly lower flexural strength.
- Higher ARS.

Decreasing the fiber dosage may lead to the following:

- Higher workability.
- Lower ARS.

3.3.9 Reinforcement Bars

Although using reinforcement bars (typically, No. 4 or 5) is a time consuming process in concrete overlay construction, it is one of the best methods to reduce shrinkage at the interface and, thus, increase bond strength. The reinforcement bars provide abundant tensile strength to the concrete and, consequently, reduce interface shear stresses that can lead to reduction in bond strength. It provides more reliable interface strengthening than fibers or wire mesh.

3.4 PROJECT SELECTION FLOWCHART [11]

The following conceptual flowchart has been developed for the project selection process, which is a series of activities conducive to a successful concrete overlay. Project Selection is the first stage to evaluate the viable concrete overlay rehabilitation alternatives and selecting the most adequate, from both the technical and economical standpoints. For this purpose, it is necessary to conduct a thorough assessment of the existing pavement conditions and to estimate the cost of the rehabilitation to verify its feasibility, comparing it with the costs of alternative restoration procedures. The importance of the adequate timing of a concrete overlay rehabilitation relative to the current pavement condition is emphasized.

3.4.1 Need for rehabilitation

The four major factors influencing the loss of serviceability of a pavement structure are existing condition, traffic, time, and environment. These factors interact to trigger the need for the pavement rehabilitation. Sometimes the trigger may be a single element, but most of the time is the interaction of factors that signals that the pavement needs rehabilitation. The effects of these factors can be categorized as existing condition, loads, age, and traffic increases.

3.4.1.1 Existing Condition

Depending on what the condition is on an existing pavement, the need for rehabilitation can be determined. Obviously, if there are no major deteriorations, rehabilitation is not needed. The severity of the deterioration on the existing pavement may be the first sign to consider if rehabilitation is needed.

3.4.1.2 Loads

Every pavement is subjected to loads, which can produce stresses that may cause damage. Stresses occur in a pavement even before it has opened to traffic, as a result of the environment and the restraint inherent to the position of the pavement relative to other elements, such as the underlying substrate, adjacent structures, and its own reinforcement. The environment causes contraction and expansion of the materials that compose the pavement; in most cases, they contract or expand at different rates because of their different thermal properties. The environment also makes the materials lose or gain moisture, which in turn causes changes in their composition and volume. These changes are known as environmental loads. Once the pavement opens to vehicle operations, it is subjected to traffic loads. The effects of loads add up as the pavement ages. As a consequence of normal and excessive loads, cumulative traffic, and environmental effects, pavements experience damage, which accumulated effects translate into failure.

Therefore, it is a fact that at some stage of its life, the pavement will show the effects of damage in the form of distresses. An unacceptable level of distress will be the criterion to determine that the pavement has reached a condition of failure.

3.4.1.3 Age

Pavements are designed to last for a limited period of time, which is determined by the design life. It will not be economically feasible or physically possible to design a pavement structure that will last forever. Pavement structures are typically designed for periods ranging from 10 years to 40 years. Based upon traffic estimates for the design life, the pavement thickness is determined. Thus, as the facility's service life comes to an end, it is expected that the amount of traffic loads imposed onto the structure will be similar to the number of load applications the pavement was originally designed to withstand. On the other hand, it is known that the properties of materials that constitute pavements change with time. These changes may be beneficial to performance; however, in most cases, the overall influence of age is detrimental to pavement serviceability.

3.4.1.4 Traffic Increases

Oftentimes, the predicted amount of traffic during the design stage is surpassed well in advance of the end of the pavement design life. An obvious reason for this kind of discrepancy is the inherent difficulty of the traffic prediction task. Also, with growth in population and land development, the usage of the road in question may change from its originally intended purpose to satisfy more ambitious transportation goals, becoming a more heavily traveled road and perhaps connecting to new highways or becoming part of a major corridor that was impossible to predict at the time of design.

3.4.2 Decision to Rehabilitation

Pavement engineers will seek ways to preserve the integrity of the roadway by means of rehabilitation before considering building a new structure, because rehabilitation means utilizing the existing structure to its fullest possible extent, therefore making better use of the existing infrastructure and optimizing the use of the resources. In a few words, it is the best economical solution unless the structure is in an extremely deteriorated condition.

Because the success of the rehabilitation is dependent on economic as well as technical considerations, at this point the agency must decide whether to embark on a rehabilitation project on the basis of the availability of funds for such an endeavor

3.4.3 Type of Rehabilitation

The solution as to how to approach the rehabilitation is not singular. A concrete overlay is just one of the several rehabilitation alternatives, and it is applicable only under certain conditions. If the conditions are not met, the concrete overlay may deliver poor performance and may not fulfill the purpose of its implementation. A concrete overlay is an optimal solution only in certain cases. That is why the other alternatives should be evaluated before a decision is made.

3.4.3.1 Overlay versus Non-Overlay

When the resources are available, the next decision that the designer faces is whether to use an overlay or to use a rehabilitation method other than an overlay. A feasible alternative is one that addresses the cause of the problem motivating the rehabilitation; therefore, the pavement condition must be investigated before making the decision. The reason for the rehabilitation may be the structural or the functional condition of the pavement. Structural condition refers to whether or not the pavement is fit to support current and future traffic loads over the desired design period. The functional condition encompasses those pavement characteristics related to the way the road serves the user in terms of safety and comfort, such as skid resistance, roughness, appearance, and hydroplaning.

The evaluation of the structural condition involves studying the distress patterns of the pavement, which will provide information about the impact of past traffic loadings. This is assessed by means of a visual condition survey. The visual inspection is normally conducted by personnel with training in distress type identification and with experience on their causative mechanisms. Photographic equipment and audio tape recorders can be advantageously utilized in recording and extracting the data. Historical information on patching, slab replacement, and other repairs are other valuable sources for structural condition assessment. Finally, destructive and non-destructive testing (NDT) methods are extremely helpful in determining the structural integrity of the pavement. Among the NDT procedures, the most common is deflection testing. Destructive testing implies the extraction of samples from the pavement for their laboratory evaluation. All these techniques will be discussed in detail in subsequent chapters. The evaluation of the functional condition requires the measurement of roughness and skid resistance and an assessment of the present serviceability.

A key element to consider is that an overlay can provide structural improvements that are not achievable by non-overlay methods. Non-overlay methods can correct only functional deficiencies; hence, only structurally sound pavements are candidates for rehabilitation without overlay.

There are numerous non-overlay methods available; their applicability depends on the condition they attempt to remedy. Most of them can be used in conjunction with each other or with other techniques. In fact, some of these might be utilized as part of the pavement repairs prior to the placement of a concrete overlay. The discussion of non-overlay methods is beyond the scope of this study.

3.4.3.2 Type of Overlay

Once an overlay has been selected over non-overlay methods, depending on the evaluation of the pavement condition, the next resolution involves the type of overlay to apply.

3.4.3.3 Concrete Overlay versus Asphalt overlay

In general, overlays can be classified as asphalt or concrete overlays. Asphalt overlays are known as flexible and concrete overlays are referred to as rigid overlays. The decision as whether to utilize an asphalt overlay or a concrete overlay depends on the pavement condition as well as economic considerations. Some of the factors to take into account when deciding the overlay type are as follows:

- Thin asphalt overlays are not able to remedy structural deficiencies.
- Asphalt overlays represent a smaller initial investment.
- Concrete overlays, in general, will last longer and require less maintenance.
- Considering life-cycle costs, concrete overlays may be more cost-effective.

Thus, conducting a life-cycle cost analysis is advisable in deciding between asphalt and concrete overlays.

3.4.3.4 Bonded and Unbonded Concrete Overlays

There are two types of concrete overlays: bonded or unbonded, as defined in Chapter 1, in which the differences between these overlays were addressed, as well as the advantages and limitations of both types. Depending on the thickness, whitetoppings are considered either bonded or unbonded. To make the decision between bonded and unbonded overlays, it is necessary to define structural and functional failures

3.4.3.5 Structural Failure versus Functional Failure

Unbonded concrete overlays (UBCOs and conventional whitetoppings), as presented in Chapter 1, are used to rehabilitate severely deteriorated asphalt or concrete pavements, with only a minimal amount of repairs performed on the distresses prior to placing the overlay. As mentioned earlier, the bonded overlay and the existing pavement behave as a single structural entity whereas both layers remain independent in an unbonded concrete overlay. This difference is normally accomplished by the placement of a thin asphalt layer between these strata, which ensures that the distresses of the existing pavement will not be reflected in the new overlay.

An unbonded overlay is more cost-effective than a bonded overlay only if the existing pavement is severely deteriorated, because of the unbonded overlay’s reduced need for pre-overlay repairs, as opposed to that of a bonded overlay.

Thus, the main factor influencing the choice between a bonded and an unbounded concrete overlay is the current stage of deterioration of the pavement in question —that is, the type of failure motivating the decision to rehabilitate. The types of failure are related to the structural and functional conditions of the pavement, as defined above. A structural failure occurs when a pavement reaches an established level of distress, such as spalling or punchouts. As the main characteristics of functionality in a pavement are safety and comfort for the user, a functional failure refers to that stage at which the pavement has become unsafe or uncomfortable. In terms of serviceability, using the Present Serviceability Index (PSI), Figure 3.2 shows the typical occurrence of structural and functional failure in the lifespan of the pavement, where P_0 and P_t are the initial and terminal serviceability, respectively.

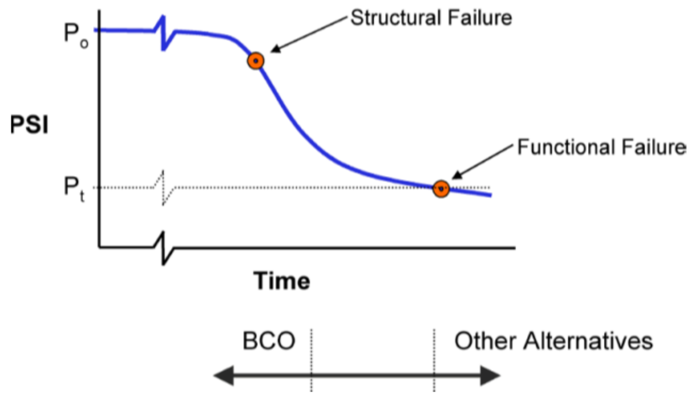


Figure 3.2: Manifestation of structural and functional failure along the PSI curve

After a structural failure has occurred, a bonded overlay is a feasible rehabilitation alternative. However, when a functional failure has appeared, a bonded overlay is no longer a feasible restoration option, because at that stage, the cost of repairing the extensive damage makes it not cost effective as compared with other rehabilitation alternatives such as an unbonded concrete overlay. An important drawback of a bonded overlay is that it reflects the distresses of the existing pavement. If the damage to the original pavement is extensive, the cost of repairs will outweigh the benefits of a bonded overlay, which may not be the optimal solution in that case. Therefore, there is a limit in the pavement's deterioration condition in which a bonded overlay can be successfully applied. This limit is after the pavement has reached the stage of structural failure and before it shows functional failures, as is shown at the bottom of Figure 3.2. If the pavement condition gets close to the appearance of functional failure, a bonded overlay may not be ideal.

There is a stage beyond structural failure but before functional failure, which is illustrated in Figure 4.2, at which it is unclear whether a bonded overlay is applicable. To determine the point at which it is no longer feasible to construct a bonded overlay according to the current conditions of the structure, there are several criteria that the designer should evaluate. These criteria require field testing such as riding quality, deflections, and condition surveys.

3.4.3.6 Riding Quality

Riding quality, expressed in terms of PSI, is an indicator of how damaged the pavement is. It is measured by means of a profilometer. The higher the PSI of the pavement, the higher probability there is for a successful application of a bonded overlay. If the PSI is 2.5 or lower, the likelihood of the occurrence of functional failures is high; therefore, at this PSI level, a bonded overlay is not advised and other rehabilitation alternatives should be pursued. PSI measurements within 2.5 and 3 indicate that a bonded overlay is feasible, but only if there is minimum delay in placing it; otherwise the deterioration rate of the pavement will likely make the bonded overlay unsuccessful. For PSI values from 3 to 3.5, there are good conditions for a bonded overlay, and for values above 3.5, the conditions for it are excellent.

3.4.3.7 Failures

The evaluation should not be based solely on the previous criterion. In fact, many authors recommend evaluating the pavement condition more from a structural standpoint rather than using serviceability criteria, as expressed in the following:

Evaluating the true condition of the existing pavement is one of the most critical factors in selecting the best overlay option. This evaluation should reflect how the existing pavement will affect the behavior and performance of the overlaid pavement. Such an evaluation should be based on structural or behavioral considerations rather than serviceability considerations.

Addressing this concern, the ideal observable and quantifiable behavioral characteristic is the appearance of failures. The data are collected by condition surveys involving the use of visual inspection to record the type and severity of distress.

A study developed by the Center for Transportation Research (CTR) analyzed the history of failures of approximately 25 CRCP sections in Texas and found that whenever the annual failure rate for a particular pavement was below three failures per mile per year, it was economical to use a bonded overlay, but when the rate surpassed three, an unbonded overlay was the best decision. The study plotted charts similar to that in Figure 3.3 for the pavements investigated. The charts illustrated the development of failures per mile with age for each section. The chart shown in Figure 3.3 is only conceptual, but the actual plots with the projects' data are documented. Of course, every pavement has a different annual failure rate, and the shape of the curve varies from project to project, but the value of three failures per mile per year was found to be a breakpoint for selecting between bonded and unbonded overlays. The reason is that once this rate is reached, the cost of repairs is considered excessive for a bonded overlay. As stated before, an unbonded overlay requires minimum repair of the existing pavement.

To arrive at this conclusion, an economic analysis was performed. The distress quantities were gathered during condition surveys conducted between 1974 and 1978 on CRCPs in Texas, where defects included punchouts and patches. Average cost of repairs as well as user delay costs because patching had to be estimated.

Originally, the breakpoint was defined in the study as the point at which it is better to rehabilitate the pavement than to continue with the routine maintenance activities. This was designated as the point of economic failure: when the current value of maintenance costs and the corresponding user costs occurring over a period of time exceed the cost of the rehabilitation strategy that would last for the same length of time. In other words, the economic analysis entails comparing the current value of a rehabilitation strategy to the current value of continued maintenance. When the latter exceeds the former, the point of economic failure has been reached.

The point of economic failure can also be interpreted as the breakpoint between bonded and unbonded concrete overlays, and this interpretation is assumed in this report as the failure criterion, illustrated in Figure 3.3, for choosing between both types of rehabilitation.

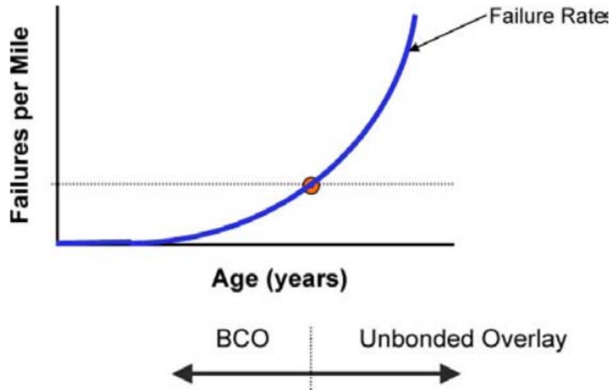


Figure 3.3: Performance curve based on rate of failures per mile per year as criterion for bonded or unbonded overlays

3.4.3.8 Deflections

An invaluable tool in assessing the structural capacity of the pavement is the measurement of deflections. Deflection measurements are normally made by means of several types of non-destructive testing devices, among which the most common is the Falling Weight Deflectometer (FWD). In the past, other frequently used devices were the Benkelman beam, Dynaflect, and Road Rater, but presently most agencies use FWD.

The criterion that follows is based on stress calculations and deflection measurements taken at the cracks and at the mid-span of pavement slabs. Load transfer is reduced at the cracks, where the transverse stress becomes the critical stress. When the overlay is placed, among other benefits, it reinstates the load transfer capability of the structure. Nonetheless, if the stresses at the bottom of the overlay are still high, cracks will appear in the overlay, the structure will deteriorate, and the original cracks will reflect in the overlay.

For the overlay rehabilitation to be cost-effective the stresses at the bottom of the overlay must be below the maximum transverse stress at the bottom of the existing pavement; otherwise the overlay will crack.

The ratio of deflections at cracks to deflections at mid-span for existing pavements was plotted versus the ratio of maximum tensile stress in the overlay to the maximum transverse stress in the existing pavement. For the stress computations, low and high moduli of elasticity concrete were assumed, as well as three different thicknesses for the existing pavement, 8, 10, and 12 in. An existing pavement stiffness of 4,500 ksi was utilized for the low-modulus concrete, and 6,000 ksi was used for the high-modulus concrete. Their ratios of stresses and deflections are shown in Figures 3.4 and 3.5, respectively. From these plots, it was concluded that when a low-modulus concrete overlay is used, a bonded overlay is feasible when the deflection ratio is less than 1.7 for 8- and 10-in. pavements, and less than 1.85 for 12-in.-thick concrete (Figure 3.4). Similarly, for a high modulus concrete overlay, the placement of a bonded overlay is advisable if the deflection ratio is less than 1.25 for 8 and 10-in. pavements and less than 1.40 for 12-in. thick pavement (Figure 3.5). These limits are found by the intersection of a stress ratio of 1 with the respective curves.

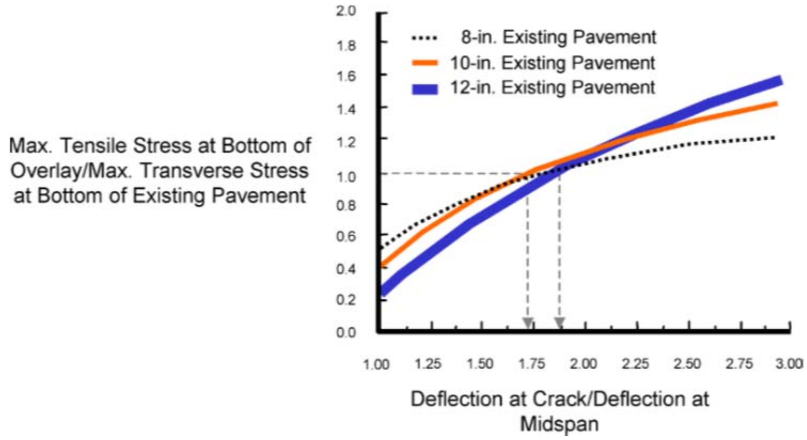


Figure 3.4: Stress ratio versus deflection ratio for low-modulus overlay concrete as criterion for bonded overlay selection

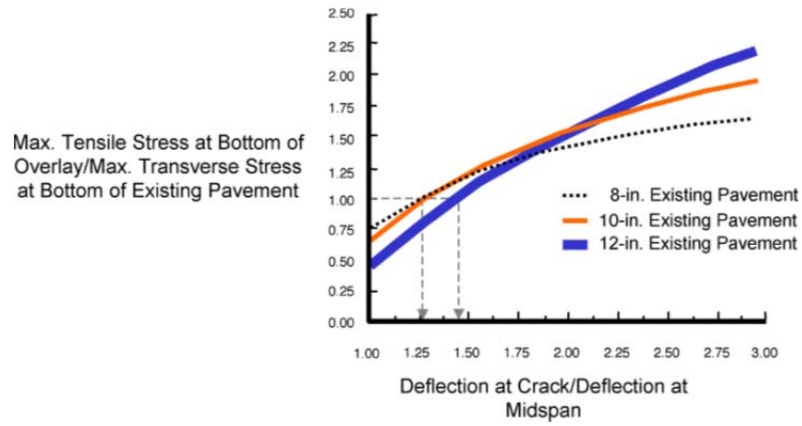


Figure 3.5: Stress ratio versus deflection ratio for high-modulus overlay concrete as criterion for bonded overlay selection

3.4.3.9 Timing

If a bonded overlay is an appropriate rehabilitation strategy at the project selection stage, it should be noted that it might not be an adequate solution if a considerable amount of time goes by before the bonded overlay is actually constructed. If the deterioration rate during the time elapsed between the project selection stage and the construction stage takes the pavement to a condition of functional failure, by the time the bonded overlay is ready to be built, it may be much more expensive to conduct extensive repairs in the existing pavement. Hence, it is important to place the overlay with minimum delay after the design is ready.

3.4.4. Flowchart

The following flowchart (Figures 3.6 and 3.7) summarizes in a simplified way the methodology proposed for the project selection stage.

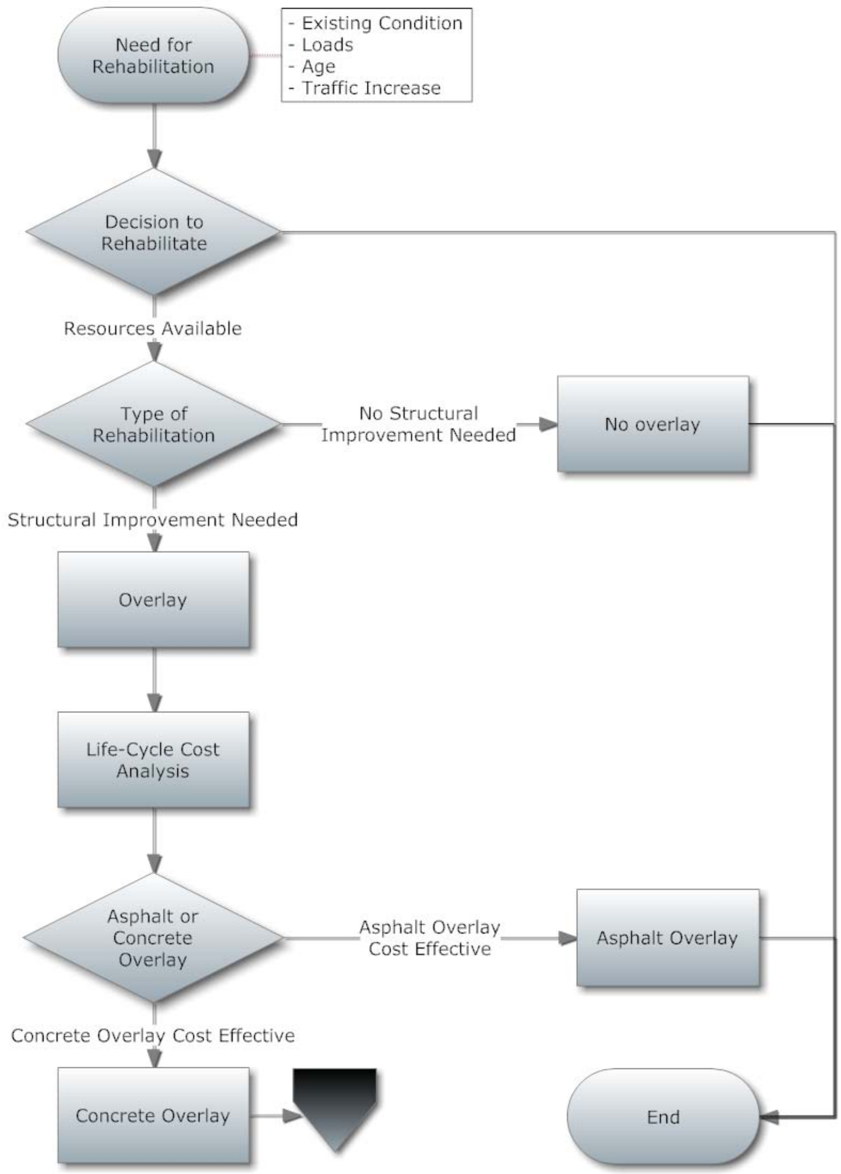


Figure 3.6: A conceptual flowchart of the project selection stage

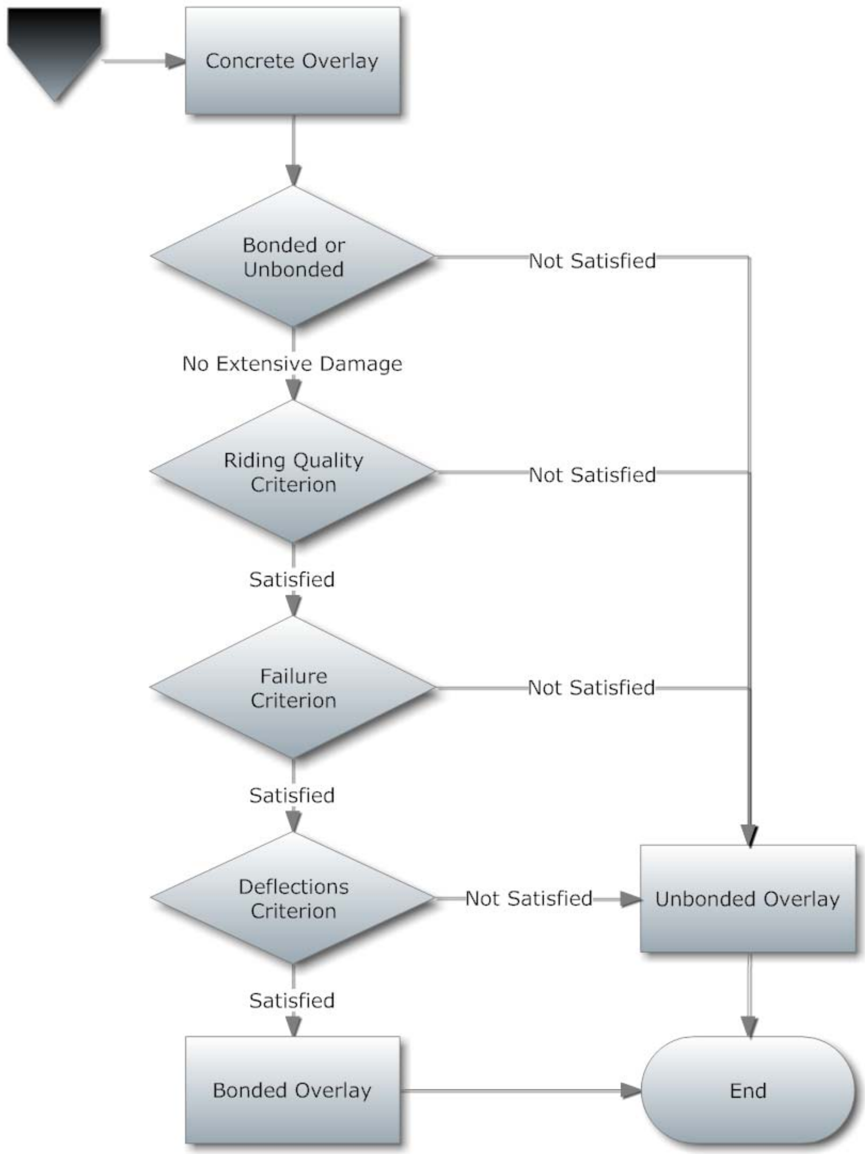


Figure 3.7: Continued conceptual flowchart of the project selection stage

3.5 MATERIALS SELECTION FLOWCHART

The following flowcharts (Figures 3.8 - 11) have been developed by combining laboratory research results and the literature recommendations. It is intended to assist in the project selection and materials selection processes for concrete overlay constructions through a step-by-step procedure. The steps should be used as a checklist, and the flowchart users must refer to the guideline (Chapter 3) for in-depth understanding the appropriate materials choices.

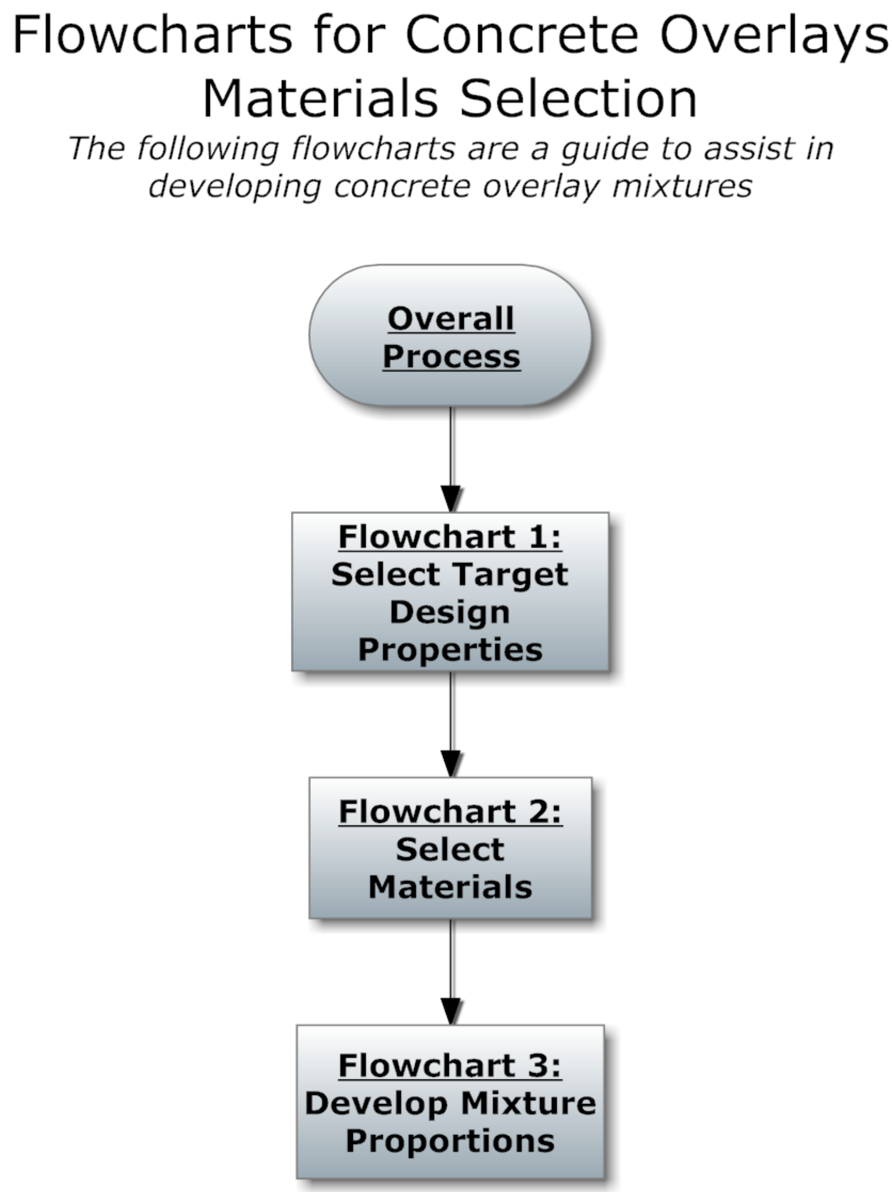
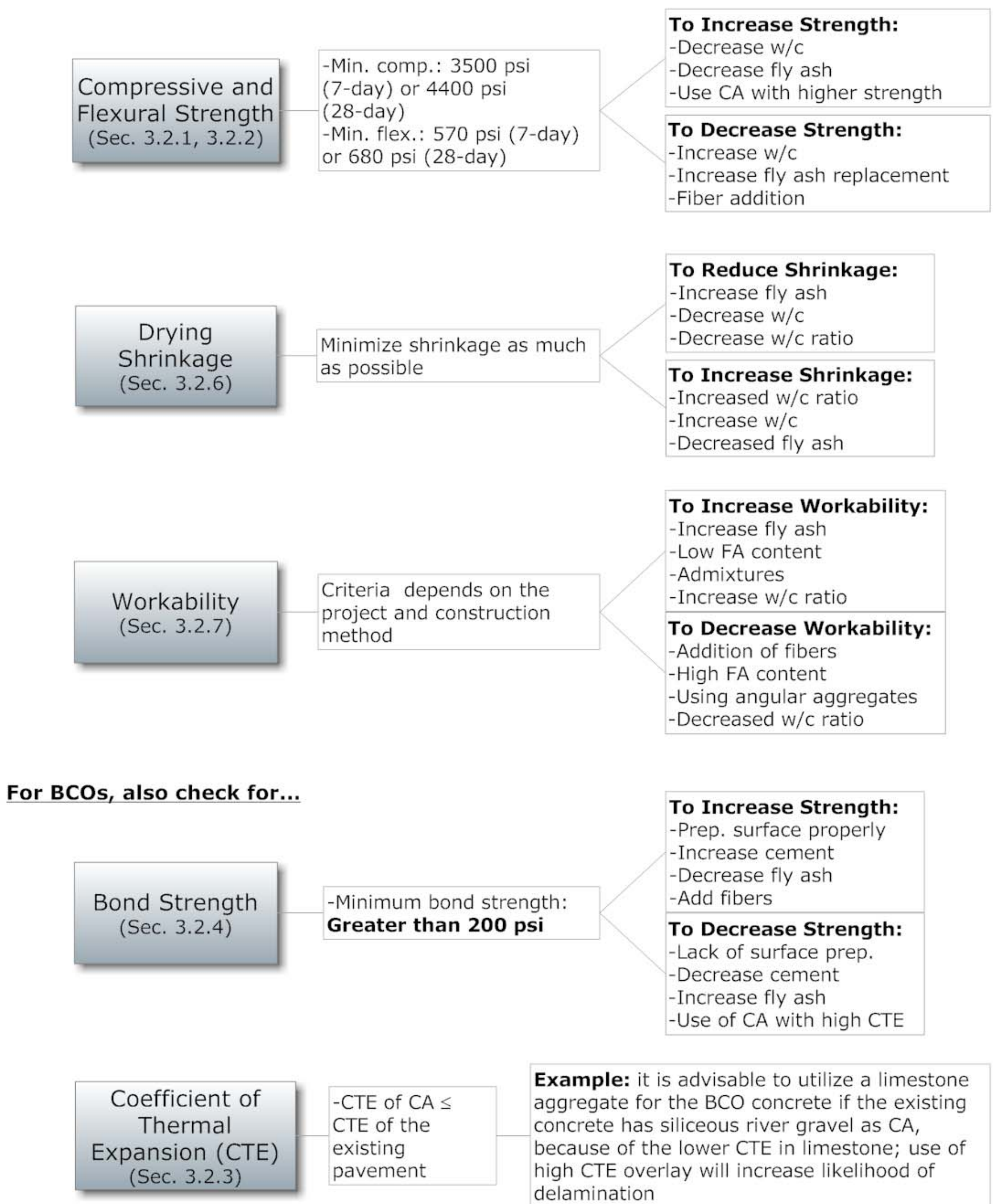


Figure 3.8: Concrete overlays materials selection flowchart

Flowchart 1: Target Design Properties

This flowchart provides a checklist for recommended target design properties for concrete overlay application (see corresponding sections in the 0-6590 training manual for further information)



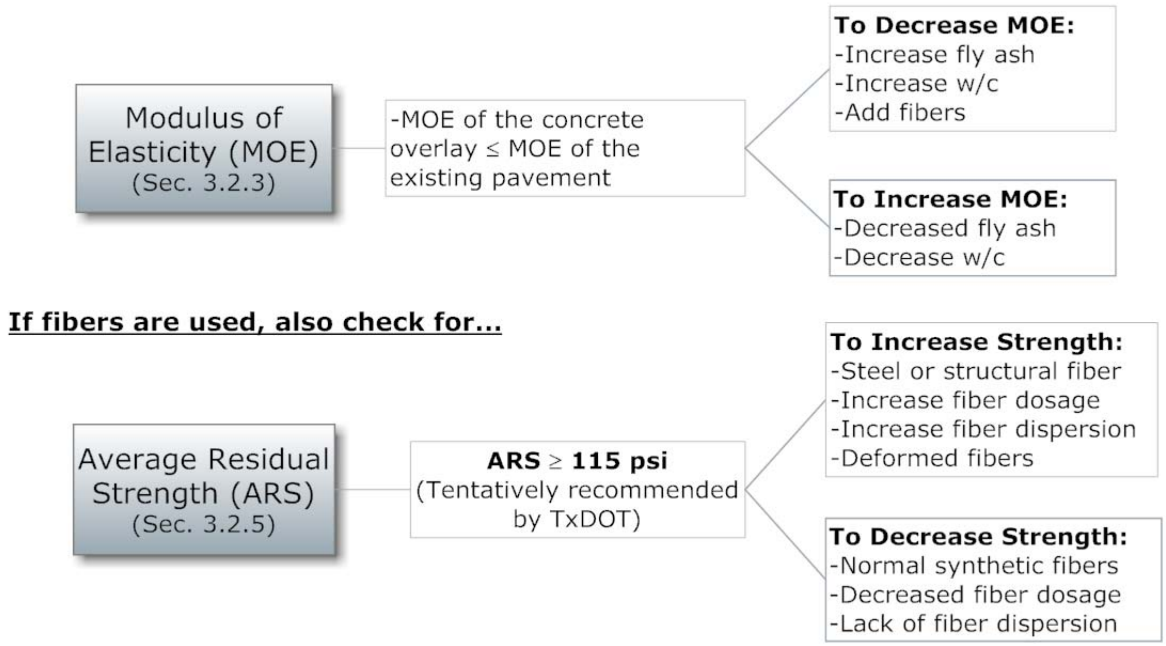
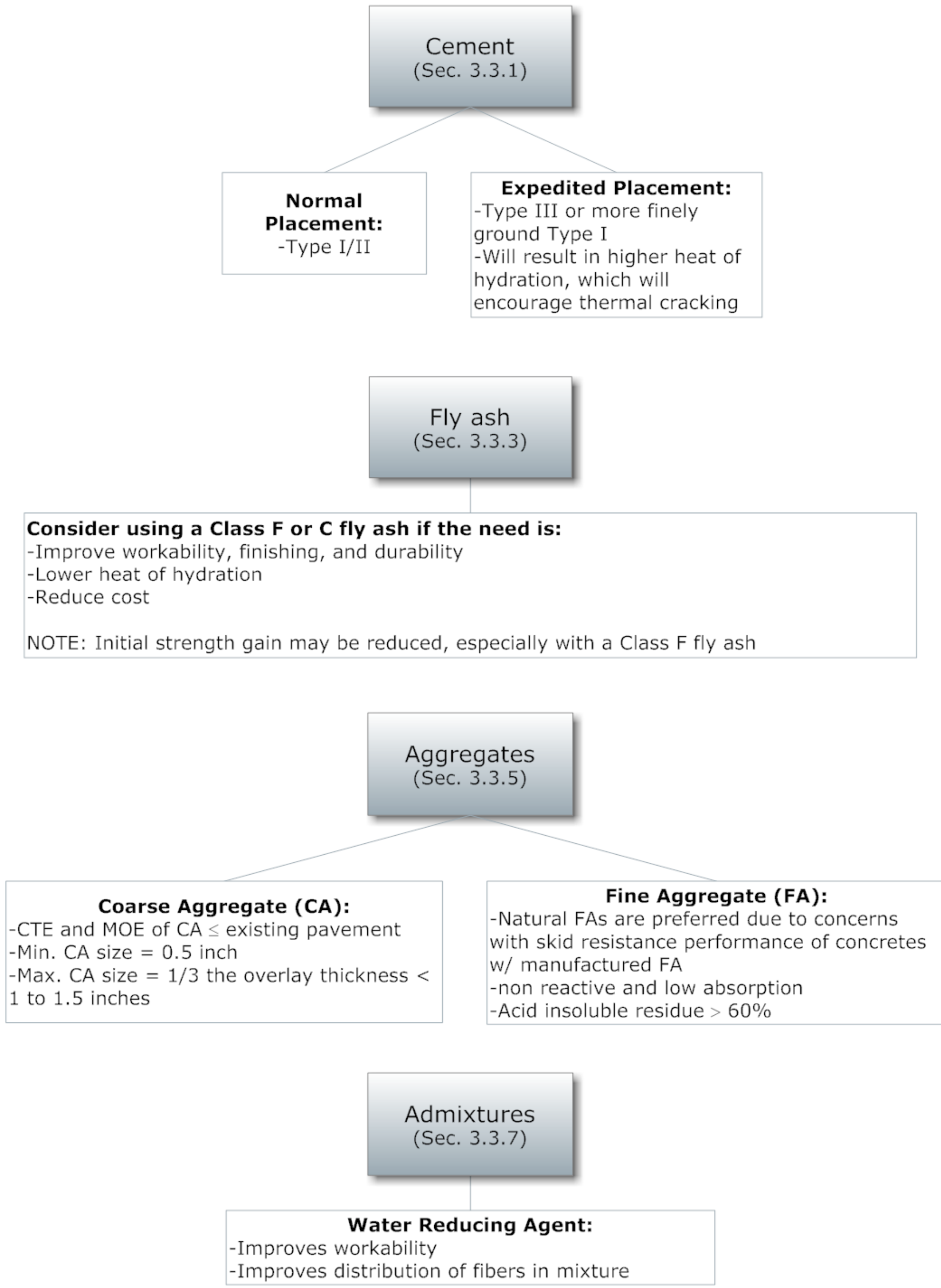


Figure 3.9: Flowchart 1

Flowchart 2: Materials Selection

This flowchart provides a checklist for selecting recommended materials for concrete overlay application (see corresponding section in the 0-6590 training manual for further information)



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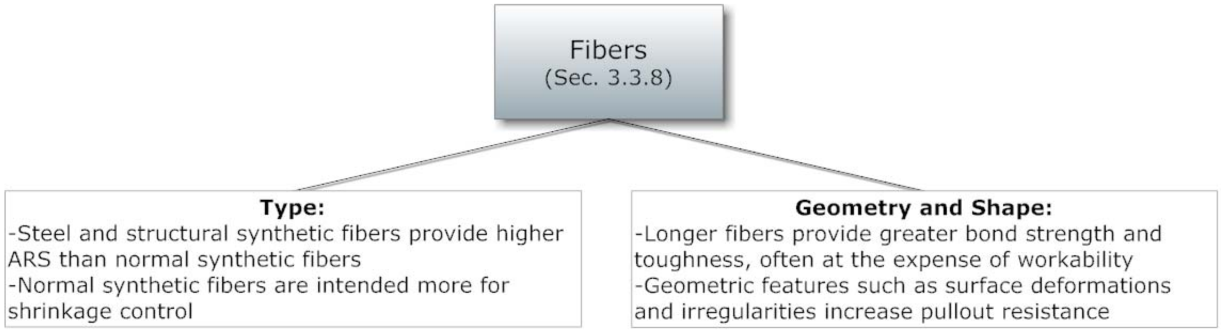

Figure 3.10: Flowchart 2

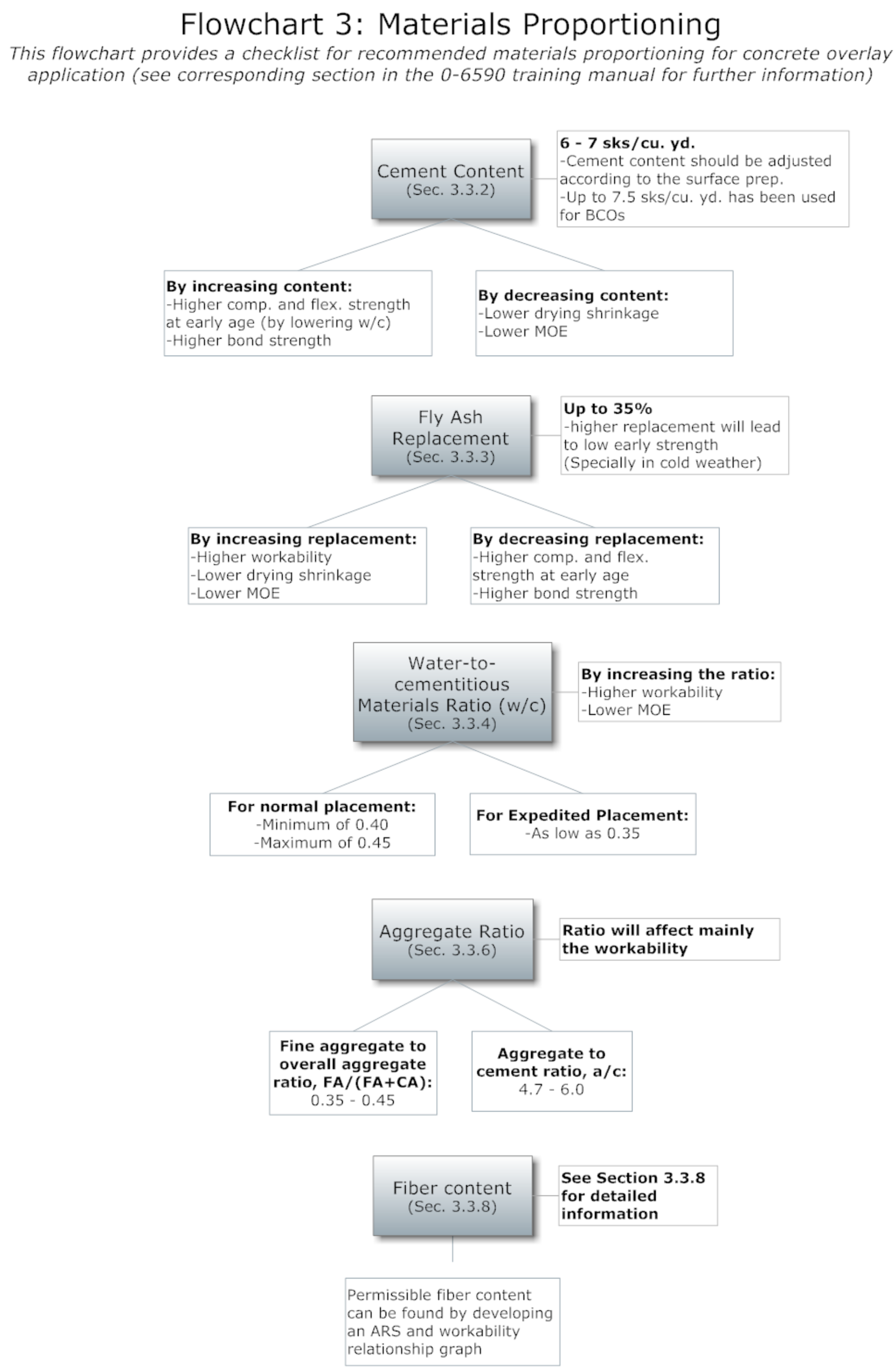

Figure 3.11: Flowchart 3

Chapter 4: Guidelines for Construction Procedures

In many aspects, it is not an overstatement to say that construction quality determines the quality of the concrete overlay. Selecting the right materials is important, but in many ways exercising proper construction methods is more important.

4.1 Introduction

This guideline explains *recommended* methods for each step of concrete overlay construction. The information is mainly derived from the literature review found in Chapter 2 has been reorganized. The following items are discussed:

- Surface Preparation.
- Concrete Overlay Placement.
- Finishing and Curing
- Quality Assurance/Quality Control (QA/QC)

4.2 Surface Preparation

The following steps to achieve a well prepared surface are crucial in promoting successful interface bond between the concrete overlay and existing pavement. Overlays are classified into types that are either "bonded" or "unbonded" and their success depends upon different surface preparation methods.

4.2.1 Bonded Overlays

Bonded overlays are concrete overlays that must form a lasting bond with the existing pavement. Included in this category are bonded concrete overlays, ultrathin whitetoppings, and thin whitetoppings. The main goal of surface preparation for bonded overlays is to provide a good bonding surface because the bond will result in monolithic behavior from the concrete overlay with the existing pavement. The concrete overlay relies on a clean, rough and sound surface to achieve maximum bond strength between the existing pavement the overlay. Once the overlay has been placed, the new slab thickness is adequate to support the current and future design traffic loadings. There are five sequential steps for surface preparation:

- Surface Repair.
- Bituminous and Foreign Material Removal.
- Surface Texturing.
- Surface Cleaning.
- Wetting the Surface before Placement.

4.2.1.1 Surface Repair

Typically, bonded overlays are chosen for existing pavement with minor deterioration that require minimum repair. Bonded overlays are usually relatively thin (2 – 8 in.) and rely on the existing pavement to carry most of the traffic load. Therefore, the existing pavement should be in decent condition with lateral cracking, but without requiring extensive repair for spalls and punchouts.

It is recommended that structural failures (e.g. punchouts) must be repaired. Localized areas of structural weakness need to be partial or full depth repaired. It is recommended to perform spot-repairs to any severely deteriorated areas. Working cracks must be repaired or sawed out, removed or replaced, since they will reflect through the new concrete overlay. Severe edge failures and any longitudinal cracks must be patched. Localized areas of weakness can be strengthened through patching or can be removed. For existing asphalt pavements, milling can be used to remove rutting to achieve a plane surface. Figures 4.1 and 4.2 show typical distresses found in existing pavements and possible repairs for candidate bonded concrete overlays.

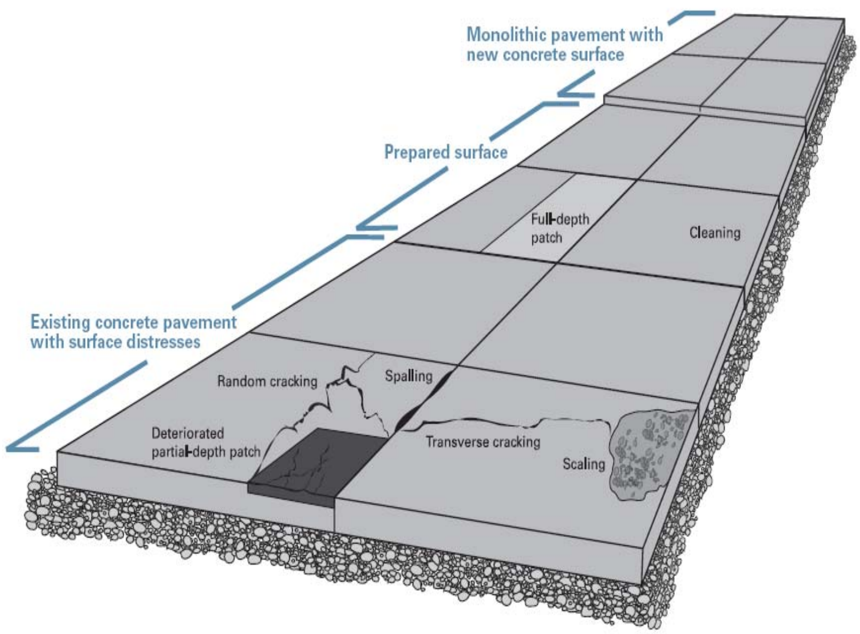

Figure 4.1: Notable distress on existing pavement and possible repairs for BCOs [4]

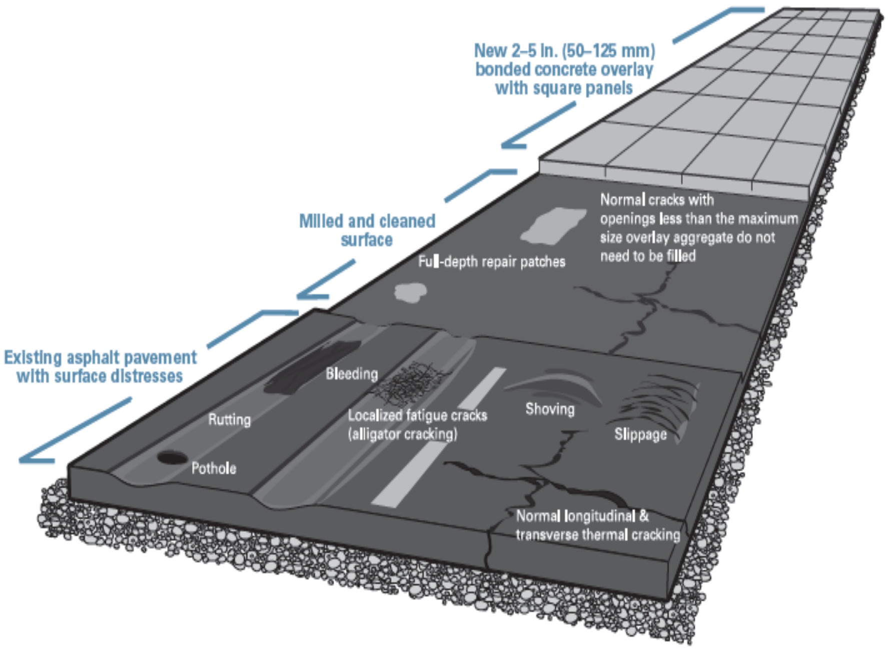

Figure 4.2: Notable distress on existing pavement and possible repairs for bonded whitetoppings [4]

4.2.1.2 Bituminous and Foreign Material Removal

Since efficient bond is the most important factor to promote monolithic movement of the two layers, any undesirable materials that present on the surface and that may hinder the bond must be removed. If the existing pavement is a concrete pavement, any bituminous patching material found on the pavement surface must be removed prior to the overlay placement. Cold milling can be used for any large areas, while jackhammers can be used to remove smaller areas filled with incompatible patching materials. Sandblasting can be used in areas where the shotblasting equipment could not operate, including areas of distress and the pavement edges. Also, paint stripes and existing joint sealing compounds should be removed because, although these areas are small, they can act as origination sites for delamination.

4.2.1.3 Surface Texturing

A well and consistently textured surface is critical in providing aggregate interlock that promotes monolithic bonding. The need is to remove enough of the surface of the existing pavement to expose some of the coarse aggregate profile. It is recommended that minimum texture depth should be 0.25 in. after coarse aggregate is exposed [35]. The circular track meter (CTM) can be used to accurately measure mean profile depth (MPD) and can be correlated to mean texture depth (MTD) to calculate the average textured depth of the prepared surface and, also, consistency of the texture can also be found. Based on Project 0-6590, MPD obtained was 0.80 and the resulting MTD was 0.033 in. Although the literature recommended that the typical MTD should be around 0.050 in. to 0.099 in. [35], the bond strengths achieved in the project were adequate. Detailed information can be found in the final project report.

There are a number of most often used texturing operations: Milling, shotblasting, and sandblasting, high pressure washing.

- Milling: Milling is ideal when the existing pavement is asphalt or asphalt overlaid. However, milling is not recommended for removing the top surface of the original concrete in pavements, because it tends to damage the coarse aggregate instead of exposing them, and it causes microcracking in the concrete substrate's surface. A stringent grade must be maintained during milling operations in surface preparation. Figure 4.3 shows a milled surface of an existing asphalt pavement.
- Shotblasting: It is most often used for cleaning and surface texturing concrete pavements. Shotblasting is intended to cleanly expose the coarse aggregate and provide a roughened surface texture to increase the bond of the overlay. Figure 7.4 shows a shotblasted surface of an existing concrete pavement.
- Sandblasting: Sandblasting is ideal for small and hard to reach areas.
- High pressure washing: Water pressure of 30,000 psi is applied to texture the surface. It is quite effective in removing mortar, but leaving the coarse aggregate sound. Also, there is no dust. However, the water needs to be properly disposed since it contains contaminants.

Figure 4.3: Milled existing asphalt pavement

Figure 4.4: A shot blasted existing concrete pavement

Shotblasted or sandblasted fines should not be piled along the side of the road because they can be blown by wind or tracked back onto the surface contaminating it. Shotblasting/sandblasting should be performed near the paving operation, typically on the same day as paving. The cold milling and shot blasting combination proved to be a better method of preparing the existing pavement than either milling or shot blasting alone.

4.2.1.4 Surface Cleaning

Immediately prior to placing concrete, the prepared and textured surface should be thoroughly cleaned of all dust and loose particles by vacuum, air blowing, and/or by hydro blasting. Any contamination may cause debonding and delamination will occur. During cleaning the surface should be dry, and thoroughly cleaned of all vegetation, dirt, mud, and other objectionable materials. Figure 4.5 shows a worker using an air hose to clean the surface and spread any pooled water just ahead of the paver.

Figure 4.5: Use of an air hose to clean the surface and spread pooled water just ahead of the paver

Appropriate measures must be taken to prevent any contamination to the cleaned surface if trucks or other equipment will be driving on it. Trucks used for transporting concrete will be permitted to drive on the pavement being overlaid and deposit concrete directly in front of the concrete spreader, provided no loose foreign material oil or dirt is dripped or tracked onto the surface.

4.2.1.5 Wetting the Surface before Placement

The goal is to achieve saturated surface dry (SSD) condition on the cleaned surface in order to lower the surface temperature and prevent moisture loss from the fresh overlay to the existing pavement. The surface should be adequately wetted (but free of puddle water) *immediately before* the placement. Pooling of water must be avoided since the excessive water may introduce weakened planes at the interface and hinder bond strength. Figure 4.6 shows a surface that has been wetted but beginning to dry.

Figure 4.6: Wetted surface and dried surface

If the existing pavement is asphalt, spraying water on the asphalt surface ahead of the paver keeps the surface cooler, but should be kept to a minimum and allowed to dry to a SSD before the concrete overlay is placed in order to promote a good bond. The surface temperature shall be less than 100 °F at the time of placement. This may require night placement, water fogging or other approved means of obtaining a cooler surface, however there shall be no pooled water or other contamination to prevent bonding to the asphalt surface.

4.2.2 Unbonded Overlays

Unbonded overlays are concrete overlays that are intentionally not bonded to the existing pavement, such as unbonded concrete overlays and thick whitetoppings. The main goal of surface preparation for unbonded overlays is to isolate the concrete overlay from the existing pavement. In this strategy the existing pavement only serves as a subbase. Once the overlay has been placed, only the new concrete overlay supports the current and future design traffic loadings, as well as the environmental stresses. There are three sequential steps for surface preparation prior to unbonded overlays:

- Surface Repair.
- Separation Layer Placement (for UBCOs).
- Wetting the Surface Before Placement.

4.2.2.1 Surface Repair

Typically, unbonded overlays are chosen for existing pavement with major deterioration. The condition of the existing pavement is typically poor enough that design only relies on it for providing a uniform strength platform for the new concrete overlay. However, some effort should be made to ensure that there is no reflective cracking from severely deteriorated areas. If there are questionable areas, they can be repaired, altered, and/or removed and replaced. Full-depth repairs are required only where structural integrity is lost in isolated spots. A flat uniform surface must be achieved without any ruts for existing asphalt pavements. This can be done by milling. Unbonded overlays are usually relatively much thicker (greater than 7 in.) and carry the entire traffic load. Figure 4.7 and 4.8 show typical distresses found in existing pavements and possible repairs for candidate bonded concrete overlays.

4.2.2.2 Separation layer placement (for UBCOs)

Separation layer is <u>essential</u> to isolate the unbonded concrete overlay from the existing concrete pavement, to minimize reflective cracking, and to provide a smooth and level surface. Typically, an. asphalt layer is placed about 1-in thick. The layer acts as a bond breaker. For whitetoppings that are intended to be unbonded, no separation layer is required. However, the substrate surface should be level and provide a uniform strength platform. Figure 4.9 shows construction of an UBCO.

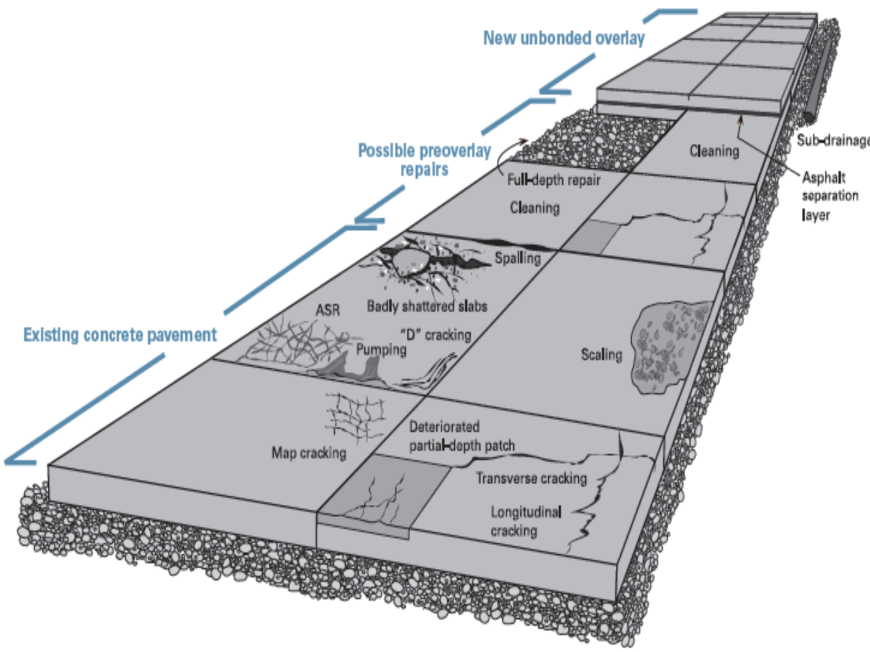

Figure 4.7: Notable distress on existing pavement and possible repairs for UBCOs [4]

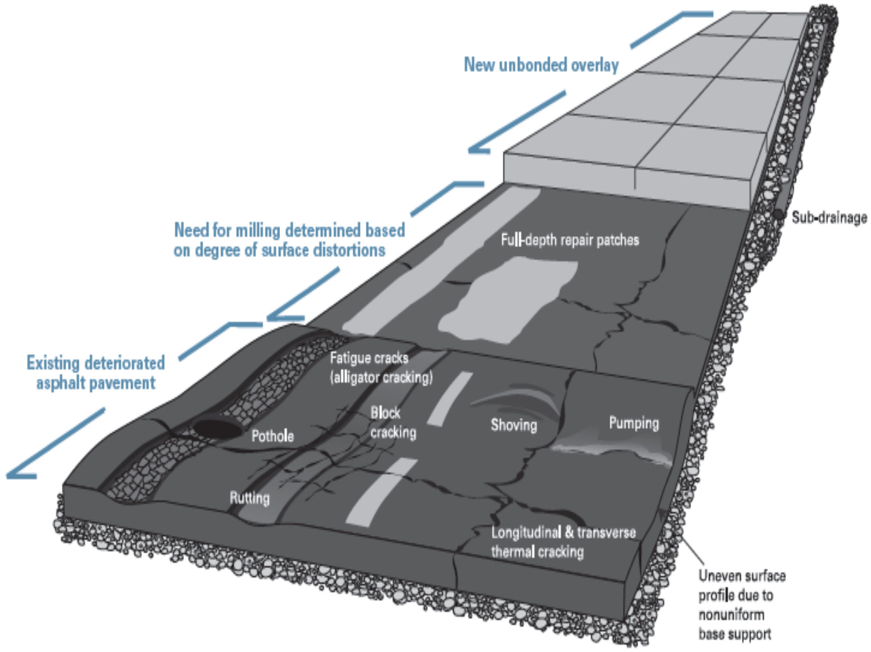

Figure 4.8: Notable distress on existing pavement and possible repairs for thick whitetoppings [4]

Figure 4.9: Existing pavement, 2-in. thick asphalt separation layer, and concrete overlay placement

White pigmented curing compound may be applied to the asphalt interlayer to further deter bonding and reflect heat so that large temperature differences do not develop between the bond-breaking interlayer and the concrete overlay.

4.2.2.3 Wetting the Surface before Placement

The goal is to lower the surface temperature of the substrate or bond breaking interlayer. The surface should be at SSD condition *immediately before* the placement. If the existing pavement is asphalt, spraying water on the asphalt surface ahead of the paver keeps the surface cooler, but should be kept to a minimum and be sprayed off with clean (oil-free), dry compressed air or allowed to dry to a saturated surface condition (SSD) just before the concrete overlay is placed.

4.3 Concrete Overlay Placement

The following procedures are recommended for proper concrete overlay placement:

- Plan For and Monitor Environmental Considerations.
- Bonding Agent Application (if required).
- Consistent Concrete Placement.
- Reinforcement Placements.
- Dowel Placements.

4.3.1 Environmental Considerations

The environmental considerations must follow Item 360 in TxDOT specification. Weather conditions prevailing during concrete overlay construction can be critical to the overlay's performance. Environmental variables that play a key role in the behavior of the concrete overlay are ambient temperatures and moisture or humidity, and wind speed at the specific placement site. Rising winds can almost immediately turn acceptable evaporation rates into unacceptable ones. Hot and dry climates, particularly under windy conditions, pose the most problematic setting for concrete overlay placement, because these conditions exacerbate the loss of moisture from the fresh concrete. Excessive water evaporation from the concrete causes plastic shrinkage cracking, which reduces the integrity of the concrete surface and reduces its durability.

A combination of high wind velocity, high air temperature, low relative humidity, and high concrete temperature is the most harmful for paving conditions, because it results in a high rate of water evaporation. Placing in minimal winds, during low temperature months, i.e., December and January, can minimize climatic stresses and cracking.

Caution must be taken in hot, dry, and/or windy climates that can cause excessive evaporation of water from concrete and produce plastic shrinkage cracking. Weather stations should be used to monitor the weather condition, and the ACI 503R nomograph should be used to decide the severity of the environment condition. The following adverse conditions must be monitored in construction [4, 28]:

- Surface of the existing pavement should not exceed 125 °F immediately before placement.
- The predicted temperature differential within 24 hours after the placement must be less than 25 °F.
- A condition where water evaporation rates exceeding 0.2 lb/ft.^{2}/hr based on the ACI 503R nomograph.

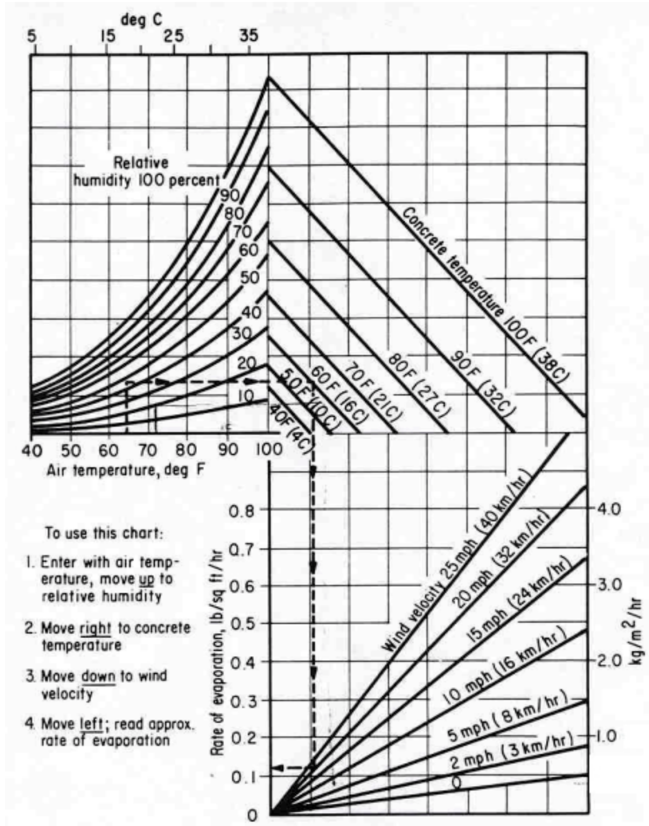

Figure 4.10: ACI evaporation nomograph

Contractors and inspectors must be prepared for an established plan of action when any of the adverse conditions mentioned above occurs during the placement of concrete. Future weather conditions can be forecasted using ConcreteWorks. If adverse environmental conditions occur or are predicted during placement of concrete, the placement should be avoided unless the following conditions can be achieved [4, 28]:

- Cooling the aggregate with cool water or the freshly batched concrete (with ice or liquid nitrogen).
- Cooling the prepared surface of the existing pavement with water.
- Special curing methods (refer to section 2.5.7).
- Use of fly ash as cement replacement to lower the heat of hydration.

4.3.2 Bonding Agent Application (If Required)

Using bonding agent to promote bond at the interface is not recommended or encouraged. Placing bonding agent is cumbersome and, if not done right, bonding agents may act as a bond breaker causing more problems. If, for some reason, lack of bond strength is predicted, bonding agents, e.g., portland cement grouts, latex modified portland cement grout, and epoxy resins, are sometimes used to improve bond. However, bonding agents cannot compensate for bad substrate surface preparation and may act as a bond breaker when used inappropriately; therefore it is not recommended to use bonding agents, unless under special circumstances. The use of bonding agents leads to two interfaces and thus to the creation of two possible planes of weakness instead of one. In addition, grout often has a high water-cement ratio leading to low strength and the risk of a cohesive failure within the bonding agent itself. Bond strength of the concrete overlay does not vary significantly whether with or without a bonding agent [20].

If the surface happens to be wet, a concrete grout will assure better bond strength. Nevertheless, it would be much safer, if the construction can wait until the surface is dry and SSD condition is achieved just before the pour. Typically water-to-cement ratio of the grout is around 0.62 to 0.70 by weight [22], or approximately seven gallons of water per sack of cement. Grout slurry should be applied as a thin, even coat onto the cleaned SSD concrete surface just ahead of the paver. Figure 4.11 shows that immediately before paving, a grout can be uniformly broomed over the full width of the prepared surface.

Figure 4.11: Grout, as a bonding agent, being placed evenly just ahead of paver

When the substrate has been treated only by a less expensive surface cleaning procedure that develops minimal substrate surface texture insufficient to guarantee an adequate bond, epoxy resin bonding systems have been reported to provide extremely high bonding strengths in the laboratory (higher than 5000 psi) [25].

4.3.3 Consistent Concrete Placement

The placement guideline must follow Item 360 in TxDOT specification. Air content and slump should be measured at regular intervals for consistency. Also, consistency in the thickness of the overlay must be checked against the designed thickness regularly. The minimum overlay thickness requirement must be met for successful performance. Transition zones from in-service existing pavement to the newly placed overlay should have thicker layers because higher stress has been reported at the transition zones.

4.3.4 Reinforcement Placement

In one unbonded overlay project [18] steel fibers were added in with the aggregates via a conveyor belt. Since fiber balling is one of the biggest problems, several attempts to reduce or eliminate the fiber balls and uncoated fibers were made at the mixing plant. Introducing the fibers into the mixture sooner, increasing the mixing time slightly, and reducing the batch size were all approaches taken to eliminate this problem. While some slight improvement was noticed following these alterations, some fiber balls and uncoated fibers were still observed throughout the overlay. The moral of the story is that all fibers must be added to the concrete mixture and mixed according to their respective manufacturer's recommendations.

4.3.5 Dowel Placement

Sufficient coverage of concrete over the dowel bars are needed to prevent spalling over the dowel bars. Thin overlays do not provide enough cover over dowel bars and can cause early spalling. Dowel bars must not be placed in thin overlays.

4.4 Finishing and Curing

Finishing and curing must follow procedures from Item 360 in TxDOT specification. Unlike the methods used for typical pavement constructions, finishing and curing methods for concrete overlays require more attention to the specified details. Thinner applications of fresh concrete dry out to critical levels in much less time, so plastic shrinkage is much more likely in drying conditions.

4.4.1 Unweighted Carpet Dragging

The use of a burlap drag is not recommended for finishing fiber-reinforced concrete overlays, because it can result in a poor finish due to the fibers becoming entangled in the burlap, leading to other fibers and coarse aggregate being pulled from the surface of the pavement. An unweighted carpet drag is an alternative option to provide an acceptable finish. Figure 4.12 shows a finished surface with carpet dragged surface texture.

Figure 4.12: Carpet dragged surface texture

4.4.2 Tining

After the completion of the hand finishing, transverse tining should be performed in a smooth and timely manner. The curing compound should be sprayed on the concrete surface immediately following the tining procedure.

4.4.3 Curing

Curing prevents moisture loss and thereby reduces early age shrinkage, leading to higher tensile strength at the onset of normal drying shrinkage. Simultaneously, other advantages are gained: reduced risk of cracking, higher strength, improved durability, and better wear resistance [11]. Curing compound should be applied promptly following paving operation. Figure 4.13 shows curing compound being promptly applied following paving operation.

Figure 4.13: Curing compound being promptly applied following paving operation

Typically, curing compound is applied at a much higher rate for overlays than the curing compound application rate for standard pavement placement. Thinner overlays require higher rates of application and sooner after finishing the overlay surface. Curing compound should be applied at 1.5 – 2 times the normal application rate [5, 26]. If blankets are used for fast tracking, they should be light in color and should not take the place of a curing compound. The temperature under the blanket must not exceed 160° F. Blankets should not be removed until the temperature under the blanket is within 40° F of the ambient temperature.

4.4.4 Jointing

Jointing should follow procedures from Item 360 in the TxDOT specification. The timing of joint sawing is critical. Sawing too early can cause excess raveling, and sawing too late can result in shrinkage stresses, causing uncontrolled random cracking. Early entry saws should be used before internal concrete stresses could build and cause cracking. No cracking should be observed prior to or following the sawing operation. Narrow joints, 1/8-in. wide by 1-in. deep, produced from these saws should minimize incompressible materials entering the joints; therefore no joint sealant is necessary. A maturity curve can be used to predict the right timing for the sawing operation. When the concrete is predicted to have attained adequate strength, according to the maturity curve, the early entry sawing can be allowed to begin. Figure 4.14 shows an early entry sawing at work.

Figure 4.14: Early entry sawing

For BCOs, depending on the type of design, joints in the overlay must match the joint orientations in the existing concrete pavement. Transverse expansion joints and longitudinal lane joints should be cut or placed to match the underlying joint configuration. In order to properly locate the saw cuts in the concrete overlay, the location of all transverse expansion joints and longitudinal lane joints in the existing pavement should be identified by a reliable method. The contractor must receive approval from the engineer for the procedure to be used to mark and relocate existing joints.

Joint spacing has a significant effect on the rate of corner cracking. Short joint spacing, common on thin concrete overlays, reduces load-related stresses, because the slabs are not long enough to develop as much bending moment. ACPA recommends that joint spacing be about 12 to 15 times the slab thickness.

To reduce the edge and corner stresses, longitudinal joints should not be placed in the wheel path. Heavy loads concentrated near the edge of the thin panels should not exceed their load capacity. For example, 4-ft. by 4-ft. panels on a 12-ft.-wide lane would put truck tires on the edge of the panels, and significant distress would occur, if the thin concrete overlays became de-bonded from the existing pavement. The joints are not to be sealed but shall be cleaned of all deleterious material after sawing. Figure 2.4 shows a good example of failed joints in wheel paths.

4.5 Quality Assurance/Quality Control (QA/QC)

A comprehensive QA/QC program is a last step in concrete overlay construction. It must follow the procedures from Item 360 in TxDOT specification. It is required to ensure that owners have a cost-effective and serviceable concrete overlay pavement with a uniform, durable, safe, and low maintenance riding surface for the public. The program should include some or all of the following items:

- Bond strength testing: Pull-off tests (ASTM C1583) should be performed to determine if adequate bond strength has been achieved. This test should be included in special specifications in every bonded overlay project.
- Strength evaluations of overlay concrete such as compressive (ASTM C39 - 10), flexural (ASTM C78 - 10), and/or maturity testing (ASTM C1074 - 11): Compressive and flexural

tests must be performed on field specimens to see if required strengths are met. The intent of maturity testing is to predict in-situ concrete strength in lieu of many cylinders, because cylinders are not always considered representative of actual in-place strength. In-place strength is felt to be higher because of the increased heat generated by a larger volume of concrete. Increased heat means a higher rate of hydration and hence, higher strengths. When time is of the essence, maturity testing can save time and money, while minimizing the inconvenience to the traveling public. It is important to note that a few proving cylinders must still be made and tested to prove predictions of strength have actually been achieved before strength-critical operations are allowed.

- Condition survey by visual monitoring of signs of distress: Visual distress surveys should be performed yearly for at least 5 years to determine development of cracking and any spalling. If the overlay is still performing well after 5 years, the surveys should be continued at appropriate intervals.
- Condition survey by locating area of delamination: By performing sounding tests (such as, chain dragging or bar dropping) locations and area limits of delaminations can be found. A solid sound indicates a non-delaminated area, while a hollow sound indicates a delaminated area.
- FWD testing: Nondestructive testing of pavements using FWD is excellent for in-service pavements. The data from these tests can be analyzed to obtain the effective stiffness of each pavement layer. This information is used to determine where pavement layers are weak, and hence evaluate the likely causes of pavement distresses. The FWD data can also be incorporated into an analytical (mechanistic) pavement design approach for assessment of remedial measures.

Chapter 5: Conclusions

Constructing concrete overlays differs from constructing a typical pavement. Concrete overlays require special attention in selecting appropriate materials that will promote compatibility between the new concrete overlay and existing pavement. In addition, condition and surface preparation of the existing pavement determines the effectiveness of the concrete overlay. Basically, a new concrete overlay must be designed and constructed, so that it is either bonded to the substrate to behave as one monolithic slab, or it is completely separated from the supporting substrate with a bond-breaking layer.

To guide readers in the design and construction of effective concrete overlays, guidelines have been developed for materials selection (Chapter 3) and construction procedures (Chapter 4). The guidelines are provided to assist TxDOT and their contractors in the selection of appropriate materials with their recommended usage levels and to assist in specifying and exercising proper construction practices to produce successful concrete overlays. These guidelines combine the best information from what was learned in the literature review, site surveys, and laboratory experiments. For more detailed information on Project 0-6590: Materials Selection for Concrete Overlays, please refer to the final project report.

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