NCHRP 14-48: Guidance for the Construction of Sand Seals and Ultra-thin Bonded Wearing Courses

Final Report-Part I

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ABSTRACT

This report presents the results of NCHRP Project 14-48. The objective of this project is to develop construction guidance for sand seals and ultrathin bonded wearing courses (UTBWC). These proposed construction guidance documents are developed from information gathered by the research team from literature review, existing construction specifications, a survey questionnaire sent to all 50 states, and the expertise of the research team. The resulting proposed construction guidance documents are intended to be used in part or in total by agencies wishing to construct sand seals (Part II of this report) and UTBWC (Part III of this report). A separate standalone guide for quality assurance for each of the two treatments is also developed and can be found in Part IV of this report (Sand Seal) and Part V of this report (UTBWC). While quality assurance is generally part of a construction guidance document, these treatments are presented separately here to facilitate adoption as a standard practice.

1.0 INTRODUCTION

1.1 Background

Pavement preservation maintains and improves the functional condition of an existing roadway system. Pavement preservation is not expected to increase the structural capacity of the pavement, but by restoring the surface of the pavement, it generally leads to improved pavement performance and a longer service life. There are many different types of treatments that preserve flexible pavements (Braham, 2017). A sampling of these treatments, how they may be used, and what distresses they address are:

- Crack fill (liquid only)
    - Application of liquid asphalt, asphalt emulsion, polymers, other modified asphalt products to seal cracks
    - Place on non-working cracks, less than 1/8in in the spring, summer, and fall
    - Addresses cracking (cracks can be block, longitudinal, thermal, edge, reflective, or transverse)
- Crack seal (liquid only, may have fine aggregate if a mastic)
    - Application of asphalt binder, asphalt emulsion, polymers, other modified asphalt products to seal cracks
    - Fine aggregate may be added to make a mastic crack seal
    - Place on working cracks, greater than 1/8in in the spring and fall
    - Addresses cracking (cracks can be block, longitudinal, thermal, edge, reflective, or transverse)
- Fog seal (liquid only)
    - Application of a light spray application of diluted asphalt emulsion
    - Addresses minor surface cracks, oxidation, and raveling
- Rejuvenated fog seal (liquid only)
    - Application of a light spray application of diluted asphalt emulsion
    - Addresses minor surface cracks, oxidation, and raveling
    - Restores oxidized components of the asphalt binder
- Sand seal (sprayed liquid plus fine aggregate)
    - Application of asphalt emulsion, followed by fine aggregate
    - Can be used in extremely unique situations, not a function of existing pavement or traffic level (i.e. shoulders or bike routes, will be discussed in more detail later in the report)
    - Addresses minor cracking (less than ¼in), raveling, oxidation
    - Restores surface friction and seals pavement surface
- Chip seal (sprayed liquid plus chip aggregate)
    - Application of asphalt binder or asphalt emulsion, followed by aggregate chips
    - Addresses minor cracking (less than ¼in), raveling, oxidation
    - Restores surface friction and seals pavement surface
- Scrub seal (sprayed and broomed liquid plus chip aggregate)

    - Application of asphalt emulsion, with a broom structure to force asphalt emulsion down into cracks, followed by aggregate chips
    - Addresses cracking (cracks can be fatigue, longitudinal, or transverse), loss of friction, raveling, severe oxidation
    - Restores surface friction and seals pavement surface
- Slurry seal (mixed liquid and fine aggregate)
    - Application of asphalt emulsion, fine aggregate, and other additives
    - Uses a physical asphalt emulsion break
    - Addresses loss of friction, oxidation, raveling, bleeding
    - Restores surface friction, provides new traveling surface
    - Note – slurry seal and micro surfacing can be combined referred to as slurry surfacing
- Micro surfacing (mixed liquid and fine aggregate)
    - Application of asphalt emulsion, fine aggregate, and other additives
    - Uses a chemical asphalt emulsion break
    - Addresses loss of friction, oxidation, raveling, bleeding, uneven surface profile, non-working rutting
    - Restores surface friction, provides new traveling surface, fills ruts
    - Note – slurry seal and micro surfacing can be combined referred to as slurry surfacing
- Cape seal (application of a chip or scrub seal plus either slurry seal or micro surfacing)
    - Combines the benefits of the chip/scrub seal on the pavement surface with the benefits of slurry surfacing as the riding surface
    - Addresses minor cracking (chip seal) or cracking (scrub seal)
    - Restores surface friction, provides new traveling surface
- Thin lift asphalt mixture (mixed liquid and aggregate)
    - Application of asphalt binder and aggregate at less than 1.0in thickness
    - Addresses low-severity cracking, raveling, friction loss, and oxidation
    - Restores surface friction, provides new traveling surface
- Ultrathin bonded wearing course (sprayed liquid plus mixed liquid and aggregate)
    - Application of asphalt emulsion plus asphalt binder and aggregate at less than 1.0in thickness
    - Addresses low-severity cracking, raveling, friction loss, oxidation, and moisture spray
    - Restores surface friction, provides new traveling surface, seals pavement surface

Schuler et al. (2018) developed guide specifications for chip seals, micro surfacing, and fog seals for NCHRP 14-37, while Braham et al. (2022) developed guide specifications for slurry seals, scrub seals, and tack coats for NCHRP 14-44. The intent of NCHRP 14-48 is to develop construction guidance for sand seals and ultrathin bonded wearing courses (UTBWC). These treatments will be discussed in more detail below.

Both sand seals and UTBWC are frequently used as preservation treatments for flexible pavements. Sand seals are generally used to enrich a dry, weathered, or oxidized surface, to prevent moisture from penetrating into the pavement structure, and to improve skid resistance (Yamada, 1999). Sand seals are applied by spraying emulsified asphalt onto the pavement surface and then applying a fine aggregate. In terms of performance, cost, and life extension, a sand seal falls between a fog seal and a chip seal but provides more macrotexture than a fog seal and is usually smoother than a chip seal. Without the sand, the asphalt surface would be too slippery and unsafe (Braun, 2016). Various types of emulsified asphalt can be used, including rapid setting, medium setting, and slow setting. There are three gradations available, with Type I having the finest gradation and Type III coarse (AASHTO, 2022d). In terms of design, emulsified application rates are generally 0.91 to 1.36 L/m^2 (0.20 to 0.30 gal/yd^2) while the aggregate application rates are generally 6.51 to 13.6 kg/m^2 (12 to 25 lb/yd^2) (AASHTO, 2022e). Figure 1 shows sand seals being placed in the field.

Figure 1 A sand seal being placed (Yamada, 1999)

While sand seals are a combination of emulsified asphalt and fine aggregate cover, UTBWC is a combination of polymer modified emulsified asphalt and open graded, hot mix asphalt. Ultra-thin bonded overlays seal the existing pavement surface, mitigates light cracking, bleeding, polished aggregate, and raveling, and prevents further oxidation of the pavement (Braun, 2018). The emulsified asphalt, usually a CRS-1P but can also be an anionic polymer-modified emulsified asphalt (AASHTO, 2022a), creates a strong bond between the existing pavement surface and the newly placed overlay that does not delaminate or bleed when applied correctly. In addition, the gap graded aggregate structure allows water to flow through the surface and out the side of the pavement layer by way of lateral drainage on the shoulder. At the same time, the strong aggregate skeleton resists rutting in the overlay. In general, the thickness of the asphalt concrete layer is twice the size of the maximum aggregate size in the mixture so the aggregate is really seated and not meant to densify. The most common aggregate sizes are 12.5 mm (1/2 in), 9.5 mm (3/8 in), and 4.75 mm (No. 4 sieve) (AASHTO, 2022b). The larger aggregate sizes are usually recommended for higher volume traffic (Braham, 2017). Figure 2 shows UTBWC being placed in the field.

Figure 2 Emulsified asphalt being sprayed (left) and asphalt concrete being placed (right) in an UTBWC application (photos by Braham)

Although a great deal of information is available on the design, materials, and construction practices of sand seals and UTBWCs, there have been no nationally accepted guides for their construction. This project will develop the construction guidance for these two treatments.

1.2 Objective

The objective of this research is to develop recommended guidance for the construction of sand seals and UTBWCs as used in preservation treatments. The two guide specifications have been prepared in AASHTO format.

1.3 Report Organization

Chapter 2 of this report is a review of the state of the art and the practice of constructing sand seals and UTBWC. This chapter has three sections, which include a section on sand seals, a section on UTBWC, and a section on the summary of the results of a survey sent to all of the state representatives on the AASHTO Committee on Materials and Pavements (COMP) to identify the state of the practice nationally.

Chapter 3 includes a summary of how the research team developed the deliverables, including the final guidance for the construction of two treatments and the quality assurance guides. Chapter 4 contains all of the references cited in the review of the state of the art and practice as well as a list of the current state specifications referenced in this report. Appendix A includes the survey sent to all the 50 states and the responses to each question from each state.

2.0 REVIEW OF EXISTING PRACTICES

This chapter presents a review of literature on sand seals, UTBWC, and the results of the literature review and those from the on-line survey sent to the 50 state transportation departments via the AASHTO COMP representatives for each state. A summary of the major findings for each is also included at the end of each section. Note, this literature review is a combination of the research team's preliminary literature review, plus additional information gathered revolving around the areas that needed additional attention.

2.1 Literature review

2.1.1 General approach

Using the existing knowledge and resources as a starting point, the project team pursued a two-pronged approach to uncover any missing information that still may be available:

- Literature review
- Online survey of the state DOTs

The objective of the literature review is to identify recent developments in the area of guide specifications for sand seals and UTBWC to accomplish the following:

- The literature search utilized the TRB Transportation Research Innovation Documentation database (TRID), FHWA information resources, online libraries (plus online searches using key words), state and regional transportation agencies, industry organizations, academic institutions, military departments, and other related information sources.
- The search also included international sources with a particular emphasis on information available from Europe, New Zealand, Australia, and South Africa, where much work has been done in the pavement preservation arena.

2.1.2 Sand seal

2.1.2.1 History

The history of sand seals can be traced back to the early 20th century, when asphalt emulsion was first used as a binder for paving materials. The use of sand as a sealant material was introduced in the 1930s, when researchers discovered that sand could be used to fill small cracks and voids in the pavement surface, which helped to prevent further damage and extend the life of the pavement systems (Gransberg, 2005). In the 1950s and 1960s, sand seals became increasingly popular as a pavement preservation technique, particularly in California and other western states in the United States. During this time, researchers and engineers refined the design and construction techniques for sand seals, including the selection of appropriate asphalt emulsion and sand materials, as well as the application rates and methods (AI, MS-16, 2009).

In terms of performance, cost, and life extension, a sand seal falls between a fog seal and a chip seal but provides more macrotexture than a fog seal and is usually smoother than a chip seal. Sand seals are better than fog seals when skid resistance is an issue. Sand seals are more cost-effective for use on oxidized pavement than chip seals, while chip seals are more effective for use on cracked pavement than sand seals. Sand seals could be more effective to fix bleeding pavements than chip seals (Mouaket, et. al. 1992).

Sand seals could be effective to fixing rough pavement surfaces, such as for a bicycle path (Li et. al., 2016). Pavement surface macrotexture - Mean Profile Depth (MPD) of a sand seal is smoother than a chip seal. To address concerns raised by bicyclists regarding the roughness of a chip seal placed on SR 1 in San Luis Obispo County, California, Caltrans sponsored a study to use various surface treatments to increase the smoothness of the pavement at various locations (Li et al., 2013). A set of test sections were built on SR 198 in Mono County (Mon-198). Macrotexture was measured in terms of mean profile depth (MPD). Sand seals had smaller MPD than 5/16in chip seals. The sand seals also had smaller bicycle vibration than chip seals.

2.1.2.2 Description

A sand seal is a pavement preservation treatment used to extend the life of an asphalt pavement. It involves the application of a thin layer of emulsified asphalt to the surface of the pavement, immediately followed by the application of a layer of fine sand or aggregate. The sand is rolled and embedded in the asphalt emulsion to provide a skid-resistant surface and to fill in small cracks or voids in the pavement. The seal may be applied in multiple lifts depending on traffic demands and existing road surface conditions (AASHTO, 2022d). Therefore, a sand seal is essentially the same as a chip seal except finer aggregate are used as cover (FHWA, 1996). Sand seals are generally used to enrich a dry, weathered, or oxidized surface, to prevent moisture from penetrating into the pavement structure, and to improve skid resistance (Yamada, 1999). The sand seals are used to improve micro-texture and provide better surface friction, renew old asphalt surfaces, seal small cracks and surface voids, address raveling or roughness of chip seals (Jahren et. al., 2016; Li et. al., 2017), and maintain and delineate shoulders in high volume roads.

2.1.2.3 Materials

The materials used in a sand seal may include emulsified asphalt (both conventional and polymer-modified emulsified asphalt) and fine aggregates.

Emulsified Asphalts

Based on AASHTO M 344, emulsified asphalt for sand seals shall meet the requirements of rapid-setting (RS), medium-setting (MS), or cationic slow-setting (CSS) type emulsified asphalt in AASHTO M140 or AASHTO M208 (AASHTO, 2022a). A number of different grades of asphalt emulsion can be used in sand seals. The common emulsions used are RS-1, RS-2, CRS-1 and CRS-2 (McAsphalt, 2023). Washington DOT allowed to use CSS-1 (Washington DOT, 2003). The hardness of the emulsified asphalt residue is determined by the owner agency utilizing regional climatic and traffic conditions. In addition, the proper emulsion to be used has to be determined by running compatibility tests between the emulsion and the aggregate to be used.

Aggregates

The type of cover aggregate used in sand seals must meet certain requirements of shape, size, cleanliness. Sand seal aggregate shall consist of fine granular material, composed of hard, durable particles, uniform in quality, and free from deleterious materials. The gradation requirements are specified in Table 1 as three aggregate sizes: No. 8, No. 4 and 3/8 in. The sand equivalent test results should be minimum 45 for all aggregate types (AASHTO, 2022d).

Table 1 Sand Seal Aggregate Types (AASHTO, 2022d)

Sieve Size (see T 11 or T 27)	Passing, %		
	Type I	Type II	Type III
$^3/_8$ in.	100	100	100
No. 4	100	90–100	70–90
No. 8	90–100	65–90	45–70
No. 16	65–90	45–70	28–50
No. 30	40–65	30–50	19–34
No. 50	25–42	18–30	12–25
No. 100	15–30	10–21	7–18
No. 200	10–20	5–15	5–15

2.1.2.4 Design practices

Most of the time, a sand seal is intended to be an economical and simple preservation alternative for low volume roads where high-quality materials may not be available. Therefore, the design method is semi-empirical.

Sand seal by itself is recommended for low volume roads of less than 750 ADT (AASHTO, 2022e). To use sand seals on compacted bases, a prime coat should be applied to the base prior to application of the sand seal. As an initial seal on a road base, more than one sand seal application may be necessary to obtain the expected seal lifespan. For multiple-layer application of sand seals, the road should remain open to traffic for 4 to 8 weeks between successive applications (AASHTO, 2022e).

Several factors will influence the selection of emulsified asphalt spray rates and cover aggregate application rates. These factors include traffic and substrate surface conditions. Emulsified asphalt application rate shall be in the range of 0.20 to 0.30 gal/yd^2(0.91 to 1.36 L/m^2). Cover aggregate shall be spread in the range of 12 to 25 lb/yd^2(6.51 to 13.6 kg/m^2). The Contractor uses lab tests to design specific material quantities to meet existing field conditions (AASHTO, 2022e). The Contractor should determine the gradation of the sand for project. Type I and Type II sand seal gradations will use less emulsified asphalt applications rates and less cover aggregate application rates, while Type III sand seal gradation should use higher emulsified asphalt application rates and higher cover aggregate application rates. Variation in material quantities shall be made without adjustment to contract unit price.

Emulsified asphalt and aggregate used in the design shall meet AASHTO M344 unless otherwise specified by the Owner Agency.

The type and quantity of traffic will have a large effect on the amount of asphalt emulsion to be used as well as the emulsion type (McAsphalt, 2023).

2.1.2.5 Construction practices

Best construction practices for sand seals should be followed to ensure the good quality of sand seal products. The following are the key steps during the construction of sand seals. Note that there are several references to chip seals in this section due to the similarities between chip seals and sand seals.

Preconstruction Meeting

The Agency should arrange for a preconstruction meeting to include the project manager, project engineer, inspector, material tester, representatives of the prime contractor, each sub-contractor, material suppliers, and others as necessary. Besides the administrative and operational considerations, the key items of discussion for the sand seals meeting should include design, sampling, specifications, safety procedures, stockpiling, staging area, traffic control, public notification, quality control plan, project inspection, acceptance, temporary and permanent pavement markings, and payment. In addition, the meeting can include Just-In-Time training (JITT) among the Agency, Contractor, inspectors, and other stakeholders prior to the construction.

Stockpiling Materials

Contractors set up one or more staging areas for the stockpiling or storage of materials, including aggregates, emulsified asphalt for sand seals, and equipment. An important challenge is to minimize or prevent segregation in the aggregate stockpile. It is recommended to use techniques such as one-dump high and benching to build proper stockpiles, as discussed in the chip seal best practices (AASHTO, 2021).

Surface Preparation

Prior to starting a sand seal treatment application, crack filling, isolated patching, and other required repairs should be completed. The entire surface planned for sand seal system treatment application should be cleaned of all vegetation, loose material, dust, dirt, and any other incompressible materials. Sweeping with a high-efficiency vacuum sweeper is the best method to clean the pavement surface, including cracks. Cracks wider than a ¼ in. should be filled and sealed preferably 3 months prior to sand seal construction. Sand seals can’t prevent these cracks from reflecting through if they are not sealed. Water or a high-efficiency vacuum sweeper can also be used to clean the pavement surface and cracks smaller than ¼ in. If water is used, cracks should be allowed to dry thoroughly before applying the emulsified asphalt. Any crack sealing or patching should be completed at least 30 days prior to application of sand seals.

Manhole covers and other utility structures should be covered with heavy paper or roofing felt and should be removed after the sand seal treatments are completed. Thermoplastic markings and other raised markings should be removed or abraded so that sand seal treatment can bond to the pavement.

Equipment

To ensure a high-quality sand seal product, the equipment used for the project should be calibrated and well-functioning. Most sand seal projects will implement the following equipment:

- Asphalt distributor – truck or trailer-mounted insulated tank ranging in capacity from 800 to 5,500 gallons. Most distributors are equipped with a heating system that will maintain the emulsified asphalt at the proper spraying temperature and have a system of spray bars with nozzles that apply the emulsion to the roadway surface.
- Aggregate spreader – the aggregate spreader is to apply a uniform aggregate cover at a specified rate over the freshly sprayed emulsion. Aggregate spreaders should be self-propelled and have a continuous feed feature.
- Rollers – Pneumatic rollers are recommended for all sand seal work and operate on rubber, air-inflated tires. The functions of the roller are to orient the aggregate and embed the aggregate into the binder.
- Sweepers – there are three different types of sweeping equipment typically used in sand seal construction: rotary (or kick) brooms, pick-up sweepers, and vacuum sweepers.

Test Strip

Similar as chip seal construction (Shuler et al., 2018), it is generally recommended a test strip of 500 to 1,000 ft in length be constructed and inspected, allowing the Agency and Contractor to ensure that sand seal equipment is properly calibrated, application rates are appropriate, and that any workmanship issues are resolved before full-scale sand seal production.

Traffic Control

A traffic control plan should be developed for each sand seal project to ensure the safety of the traveling public and the employees performing the work. Traffic control should be in place before work forces and equipment enter the work zone. Traffic control includes construction signs, construction cones, barricades, flag personnel, and pilot cars to direct traffic clear of the working area. A pilot vehicle should be utilized to control the speed of motorists near the project, generally less than 25 mph as discussed in chip seal manuals (Hicks et al., 2019).

Notification

If required by the contract, Contractors notify all residents, businesses, and agencies by an approved, written notice detailing streets, limits of work, and the days and hours of planned work. If required by the contract, Contractor post all work areas with approved no parking signs. Guidelines for this are provided in the *Chip Seal Best Practices* (Gransberg and James, 2005).

Sand Seal Application

Suitable weather conditions are crucial for sand seal applications. It is important to pay attention to details such as temperature, humidity, wind, and the possibility of rain. Sand seal applications should not be started if rain is imminent, air temperature should be a minimum of 50°F and rising, humidity should be 60% or less, and a slight breeze is advantageous. A maximum temperature should also be specified for the sand seal. Ambient air temperatures greater than 110°F can cause the emulsified asphalt to form a “skin” on the surface and a false setting issue (AASHTO, 2021). A false setting is where an asphalt emulsion appears to have fully broken, when there is actually a hidden layer of unbroken emulsion not visible underneath the skin of broken emulsion. Finally, the types of emulsified asphalt used in sand seal require exposure to daylight to break and cure effectively.

The sand seal application includes applying the emulsified asphalt at the designed rate, applying the fine aggregate at the designed rate, rolling the aggregate to embed it into the binder, and sweeping any loose aggregate.

Application Rates and Residual Asphalt Contents

The application rate that the distributor sprays should be based on the emulsified asphalt application rate that was calculated in the sand seal design and adjusted as field conditions change. The spray pattern should be inspected right after takeoff to ensure the nozzles are spraying properly and uniformly. If any streaking, ridging, puddling, or flowing of emulsified asphalt off the roadway surface is observed, the spraying operation should be stopped immediately. The problems with streaking and ridging could be wrong set up or malfunctions of spraying nozzles. The puddling and flowing of emulsified asphalt could be wrong application rates used. Therefore, the Contractor should fix the setup of the equipment and use proper application rates. These problems need to be fixed before the project can be resumed.

Application rates may vary during the project due to changes in the existing pavement surface conditions. The existing surface texture has a direct effect on the application rates of the sand seal system. The more surface cracks, the more emulsified asphalt needs to be placed to satisfy the surface demand. Proper application rates for emulsified asphalt and aggregate applications are crucial to ensure the longevity and durability of sand seals.

To ensure aggregate embedment, the aggregate should be applied as soon as possible. Visual checks should be conducted early in the spreading process to ensure that the aggregate spread is uniform across the entire width of sand distributor.

Longitudinal and Transverse Joints

Longitudinal joints can be constructed as butt joints, which should be straight on tangent sections and uniformly follow the traffic lane on curve sections. Longitudinal joints should be smooth, particularly on roadways with high-speed traffic. Transitions at the transverse joints must be smooth to avoid creating a bump in the surface. The joints must be butted to avoid these bumps. Starting transverse joints on roofing felt can reduce these problems.

Opening to Traffic

Sand seals must build sufficient cohesion to resist abrasion due to traffic. If a sand seal surface is reopened to traffic too early, it will ravel off quickly, particularly in high-stress areas. Temporary pavement markings should be used before the permanent markings are placed.

2.1.2.6 Quality assurance (QC, agency acceptance, independence assurance)

Quality assurance (QA) is defined as all planned and systematic actions taken by the Agency and Contractor to provide the necessary confidence that the procured material and workmanship will satisfy the quality requirements of the contract. Based on AASHTO R10, QA includes quality control (QC), agency acceptance (AA), and independent assurance (IA). Since a sand seal has many similar operations to a chip seal, the AASHTO TSP-2 ETF *QA Guide for Chip Seals* (AASHTO, 2020) was used as a starting template for sand seals.

QC is the system used by the Contractor to monitor, assess, and adjust production and placement processes to ensure that the material and workmanship meet the specified quality. QC is the responsibility of the Contractor.

AA is the system used by the Agency/Engineer to measure the degree of compliance of the quality of materials and workmanship within the contract requirements. Acceptance is the responsibility of the Agency/Engineer and will be conducted in accordance with the specifications.

IA is an unbiased and independent system used to assess all sampling, testing, and inspection procedures used for QA. IA is the responsibility of the Agency/Engineer and is conducted in accordance with the specifications.

Quality Control

The sand seal Contractors establish, implement, and maintain a QC program to control all equipment, materials, production, workmanship, and associated processes during construction. The Contractor's QC program should include preconstruction activities, including sand seal material selection, application rate design, site preparation, material handling and transportation, and stockpiling. The program should also include procedures required for sampling, testing, inspection, monitoring, documentation, and corrective action during transport, stockpiling, placement, and finishing operations.

The written Quality Control Plan details the Contractor's QC program that meets the requirements of these specifications. The QC plan must be contract-specific and signed by the Contractor. Sand seal construction should not proceed without agency acceptance of the QC plan and without QC personnel present on the job. Failure to comply with this provision will result in shutdown of the operation until such time as the Contractor's operations are in compliance.

The laboratory which recommends the application rates must be accredited and the Contractor must provide the name of the lab formulating the design. The laboratory that performs the QC for production can be either qualified or agency approved. The Contractor must provide the name of an agency-approved lab for all tests within the relevant scope of testing. Testing, sampling equipment, and measuring devices should meet the requirements of the Agency's specified standards and test methods. The lab must maintain records of the calibration and maintenance of all sampling, testing, and measuring equipment, as well as all documents required by the accreditation (AASHTO Resource Accredited labs or ASTM D3666) or agency program (AASHTO, 2020).

Prior to the commencement of work, the production equipment must be calibrated in the presence of the agency representative utilizing the materials to be used on the project.

QC activities should include monitoring, inspection, sampling, and testing. The Contractor's QC activities should cover all aspects that affect the quality of materials and workmanship of the sand seal operation. The minimum QC activities and frequencies required are listed as follows, or per agency-specific requirements:

- Component materials
- Transportation material handling
- Design by a qualified lab/engineer
- Test strip construction and assessment
- Placement and finishing
- Performance
- Review of material certifications supplied by vendors and suppliers

Tables 2 and 3 show some recommended testing and testing frequency for chip seal aggregates and emulsion, which should be applicable to the sand seal (AASHTO, 2020).

Table 2 An Example of Aggregate QC Requirements (AASHTO, 2020)

Process Control Test	Test Method	Minimum Frequency
Gradation*	AASHTO T 27 AASHTO T 11	Prior to construction for design, then once per day of placement and every change of source.
Unit Weight	AASHTO T 19	Prior to construction for design, then every change of source.
Bulk Specific Gravity	AASHTO T 85	Once prior to construction for design, then every change of source.
Aggregate Absorption	AASHTO T 85	Once prior to construction for design, then every change of source.
L.A. Abrasion**	AASHTO T 96	Once prior to construction for design, then every change of source.
Soundness**	AASHTO T 104	Once prior to construction for design, then every change of source.
Deleterious Material	AASHTO T 112	Once prior to construction, then every change of source.
Application Rate	Truckload Yield Check, Tarp on Roadway	Once at startup each production day.

* Aggregate samples will be taken at the project stockpile site using AASHTO R 90 Method B. Gradation test results should be provided within 24 hours.

**These tests could be run on the aggregate source from the same quarry/pit

Table 3 An Example of Emulsified Asphalt QC Requirements (AASHTO, 2020)

Tests on Emulsified Asphalt*		
Process Control Test	**Test Method**	**Minimum Frequency**
Viscosity	AASHTO T 59 or T 382	Once per 200 tons of material placed.
Temperature	N/A	Once delivery tanker.
Particle Charge	AASHTO T 59	Prior to loading emulsion distributor
Demulsibility	AASHTO T 59	Once per 200 tons of material placed.
Sieve	AASHTO T 59	Once per 200 tons of material placed.
Storage Stability	AASHTO T 59	Once per 200 tons of material placed.
Residue**	AASHTO R 78-16	Once per 200 tons of material placed.
Application Rate	Computer Printout, Volumetric Measurement, Plate on Roadway	Once at startup each production day, then each 500 tons of aggregate placed.
Tests on Residue		
Process Control Test	**Test Method**	**Minimum Frequency**
Solubility	AASHTO T 44	Once per 200 tons of material placed.
Penetration	AASHTO T 49	Once per 200 tons of material placed.
Ductility	AASHTO T 51	Once per 500 tons of material placed.
Ash Content	AASHTO T 111	Once per 200 tons of material placed.
Elastic Recovery	AASHTO T 301	Once per 500 tons of material placed.
MSCR, Jnr, % Recovery	AASHTO T 350	Once per 500 tons of material placed.

* A material certification from the supplier will be provided with each delivery tanker. Emulsified asphalt samples will be taken at the point of delivery from the delivery tanker using AASHTO R 66.
**Determined by either AASHTO T 59 or agency-approved method.

Agency Acceptance

As the owner of the final sand seal, the Agency must ensure the Contractor has constructed the project in accordance with the specifications. The Agency should conduct acceptance sampling, testing, and inspections consistent with AASHTO R 10 (AASHTO, 2006). They may also conduct verification testing should the QC results be sued for acceptance.

Recommended acceptance activities include the following (AASHTO, 2020):

a. Assure the Contractor has followed the approved QC plan.
b. Materials – monitor all contractor QC testing.
c. Agency to sample and test:
    i. Aggregate – Gradation, moisture content, and deleterious materials, once per day or at the discretion of the Agency.
    ii. Emulsified asphalt – Once per project or at the discretion of the Agency.

(Note: Actual frequency and lot size will be per each agency's frequency guide schedule for verification, sampling, and testing.)

d. Traffic control conforms to plans and specifications and complies with the *Manual on Uniform Traffic Control Devices* (FHWA, 2009).
e. Surface preparation – Monitor and approve sweeping methods, verify surface is clean and dry, assure inlets and manhole covers are protected.
f. Calibration – Witness the calibration of the emulsified asphalt distributor and aggregate spreader.
g. Emulsified asphalt distributor – Verify equipment has been calibrated and is in proper operating condition. Monitor for an even application of material.
h. Aggregate spreader – Verify equipment has been calibrated and is in proper operating condition. Monitor for an even application of material. Ensure spreader is the proper distance from the asphalt distributor.
i. Pneumatic rollers – Verify equipment is in proper operating condition and rollers are positioned in echelon so the entire width of the pavement lane is covered. Roll minimum three complete passes over the aggregate, with one pass defined as the roller moving over the chips in either direction.
j. Sweepers – Verify equipment is in proper operating condition. Ensure loose material is removed without damaging fresh sand seal.
k. Application rates – Monitor and verify correct application rates of emulsified asphalt and cover fine aggregate.
l. Production inspection – to be completed after final sweeping to check for unacceptable conditions, such as:
    i. Bleeding/flushing
    ii. Raveling/stone loss
    iii. Crushed/broken aggregate
    iv. Excessive longitudinal joint overlap
    v. Transverse joint overlap
m. Product acceptance

Independent Assurance Program (IA)

The IA program should follow the FHWA Tech Brief: Independent Assurance Programs, FHWA-HIF-12-001 2011 (FHWA, 2011) and should be the responsibility of the Agency or Owner. The IA Program consists of activities that are an unbiased and independent evaluation of all the observations, sampling and testing procedures and equipment used in the acceptance program. The IA Program should be staffed by qualified agency personnel or an accredited laboratory not involved with acceptance testing. This ensures the sampling and testing is performed correctly and the testing equipment used in the program is operating correctly and remains calibrated. It also involves a separate and distinct schedule of sampling, testing, and observation and the results of the IA testing shall not be used for material acceptance.

2.1.2.7 Measurement and payment

The contract should specify the payment method for the sand seal treatment placement. Methods vary among agencies but usually fall into the following categories: 1) unit area, 2) ton or gallon of emulsified asphalt and ton of dry aggregate, and 3) unit area for placement, plus part of Method 2. Generally, one of the three methods will be used.

The advantages of payment by the unit area for a completed sand seal is simplicity when the area is easily defined. However, this method has some disadvantages, such as the Contractor may reduce the amount of emulsified asphalt, to the minimum requirements. This may lead to aggregate loss, vehicle damage, or early failure of the project (AASHTO, 2020). Therefore, more detailed recommendations are necessary for the proposed construction guidance, such as using quantities of emulsified asphalt, and area of dry aggregates.

2.1.2.8 Typical sand seal specifications

Specifications for sand seals are available from both state and local agencies. These specifications include materials and design practices, as well as construction guides. It is apparent that there are several key differences between agencies in their specifications of materials, design, equipment, construction methods, and quality assurance. These differences are likely attributed to differences in materials, design practices, traffic, and climate.

Table 4 Selected DOT Specifications for Sand Seals

Agency	**Materials Used**	**Design Practices**	**Key Equipment**	**Construction Methods and Procedures**	**Sweeping practices, quality assurance, and payment**
Alaska DOT&PF	Emulsified asphalt. GSB 88. Cut-back asphalt. GSB 78. Sand should be dry, clean, angular, dust-free. Minimum Mohs hardness of 10.	Asphalt material: 0.1-0.15 gal/yd^2. Apply sand 0.65-0.8 lb/ yd^2.	Asphalt distributor, sand distributor with min 3,000 pounds of sand.	1000 ft test strip. Existing surface at least 6 month old. Dry for 4 hours. Minimum 50 ^{0}F. Apply sand immediately after asphalt is applied.	The asphalt surface to be treated shall be free of all dirt, sand, weeds, grass and excessive oil and/or grease. Use power broom or power blower. Crack sealing.

Agency	Materials Used	Design Practices	Key Equipment	Construction Methods and Procedures	Sweeping practices, quality assurance, and payment
	Gradation: No. 16: 90-100 No. 40: 0-20 No.100: 0-2				Sand seal to be paid by yd^2. Sand and removal of excess sand are subsidiary.
Indiana DOT	Fine aggregates, Emulsion	Emulsified asphalt application rate: 0.10-0.25 gal/ yd^2. Aggregates: 10-25 lbs/ yd^2.			
Iowa	Emulsified asphalt, CRS-2P, CRS-2, HFRS-2 Cut back asphalt MC-800 or MC-3000, For dust control: CSS-1, CSS-1H, or SS-1H. Aggregate is washed and crushed hard durable gravel, stone, or mixture with LA abrasion less than 40%. Gradation: 3/8 in: 100 No.8: 60-90 No.30: 40 No.200: 0-1.5	Binder application rate: 0.15 gal/ yd^2. Sand: 18 lbs/ yd^2.	Aggregate spreader; Hopper: Minimum 5 tons. Bitumen distributors. Brooms. Rollers.	Do not apply seal coats after September 15 unless temperatures 60°F and rising. Do not spread until the distributor has been tested to ensure a uniform distribution of bitumen. Minimize longitudinal overlap of adjacent bitumen applications. Five passes of a roller are required for cover aggregate; one pass is required for sand applied as cover	After final rolling operation, use a sweeper with a dust suppressant system to pick up loose aggregate. Complete clean up as directed by the Engineer, but not more than 21 days after application. For rural-type pavements, the Engineer may determine that sweeping is not necessary.
South Dakota DOT	SS-1h or CSS-1h	flush seals within 10 days after the			

Agency	Materials Used	Design Practices	Key Equipment	Construction Methods and Procedures	Sweeping practices, quality assurance, and payment
		completion of asphalt paving. Emulsified asphalt: 0.05 gal/ yd^2. Sand: 8 lbs/ yd^2.			
Texas DOT		The use of such technology is up to the individual district. The districts have alternative sealing and texturing practices. The most similar method is "scrub seal". Use a broom to force emulsion into cracks and follow with a fine aggregate / sand prior to rolling.		Use to seal very small cracks and add surface texture. Most likely this would be used in very rural areas with large mileage to cover.	
Washington DOT	CRS-1, CSS-1 Aggregates should 3/8 inch or smaller.	Tightening surface texture and reducing raveling.	Pneumatic roller is desirable.		
AASHTO	CRS, CHFRS, HRRS, RS. Fine granular material, hard, durable, uniform, and free from deleterious materials.	Low volume roads < 750 ADT. Apply on asphalt concrete, on compacted bases, and possible multiple-layer applications.			

Agency	Materials Used	Design Practices	Key Equipment	Construction Methods and Procedures	Sweeping practices, quality assurance, and payment
	Three types of sand seals: No. 8, No. 4 and 3/8 in.	Emulsified asphalt: 0.2-0.3 gal/ yd^2. Aggregate: 12-25 lb/ yd^2.			

2.1.2.9 Summary of findings for sand seals based on literature review

The literature review has identified some of the challenges moving forward with sand seal construction guide specifications, from the perspectives of both contractors and agencies. The following are the major findings or challenges based on the literature:

- AASHTO has a standard material specification and a standard sand seal design, but there is no national standard on construction.
- Mentioned in AASHTO MP 34-18, sand seals can have multiple layer application. However, it is not advised to place multiple layers in a short period of time – need enough time for previous layer to be fully cured.
- The purposes and project selection of sand seals are different from state to state. Sand seals are not just applied on regular, HMA surface, but also placed on chip seals (Caltrans) – can smooth surface for bicycle. Some agencies add sand to make fog seals last longer, or restore friction (from bleeding or polished aggregate)
- There is a major difference between fog seal with sanding and sand seals. For the latter, will follow the sand seal design. Others put fog seal and then put on sand, especially for slippery surfaces. For a fog seal with sanding, the goal is not to have the sand stay long-term, it is a short-term fix. The timing is also different.
- Payment items vary from state to state.
- The types of binders used by agencies are very different. Some use Rapid Setting, while others use Slow Setting.
- The application rates of binder and aggregates are very different from state to state.
- The construction procedures of sand seals are similar from state to state, but the detailed requirements on weather, testing, and rolling etc., are different.
- A better construction guide is needed to avoid common distresses of sand seals. Raveling and bleeding are common distresses for sand seals.

The findings from the literature helped develop the sand seal construction guide and quality assurance guide. Resources are available to meet the above challenges and support the national construction guide and quality assurance guide development.

2.1.3 Ultra Thin Bonded Wearing Course (UTBWC)

2.1.3.1 History

Ultra-Thin Bonded Wearing Course, or UTBWC, is a pavement process that utilizes a self-priming paver that applies an ultra-thin gap-graded asphalt mixture (typically polymer modified) wearing course over a polymer-rich asphalt. UTBWC was originally developed by SCREG Routes in 1998 utilizing the concept based off a micro surfacing machine frame with the first patent filed in 1989. The concept of UTBWC was introduced into the United States after an FHWA tour in Europe to visit various projects (AASHTO, 1991). There were two projects that were highlighted during this study. The first was an ultrathin hot mix layer placed in Loire Atlantique, which included a gap graded hot mix placed over a polymer-modified asphalt emulsion. The overlay was trade named COLRUG while the tack coat was trade named EMULCOL, both of which were marketed by Colas. Based on a preliminary review of the literature, it is not clear whether the emulsion was placed on the same machine as the hot mix. The second project was actually an extension of a chip seal, where a polymer-modified asphalt emulsion was placed on the same machine as pre-coated chips. This process was termed NovaChip™. This treatment was a proprietary product of SCREG Routes Group.

During this same time, through a series of two papers in Transportation Research Record (Serfass et al., 1991; Bellanger et al., 1992). Serfass et al. introduced the NovaChip™ as an "ultrathin surfacing" that was used as a friction course. However, mid-way through the report they started using the term NovaChip™, which is the patented name that saw wide-spread use in the United States in the late 1990s and early 2000s as a hot mix placed over polymer modified asphalt emulsion on a single machine. Serfass et al. described the overall concept, the materials, the design, the equipment, the application method, the in-place characteristics, and the overall behavior of NovaChip™. A key part of the treatment was the single-pass machine, and the paper included a schematic of the machine (see Figure 3), which is extremely similar to the UTBWC machine we see today. A schematic of UTBWC is shown in Figure 4 and shows how the emulsion membrane "wicks" up into the gap-graded aggregate gradation.

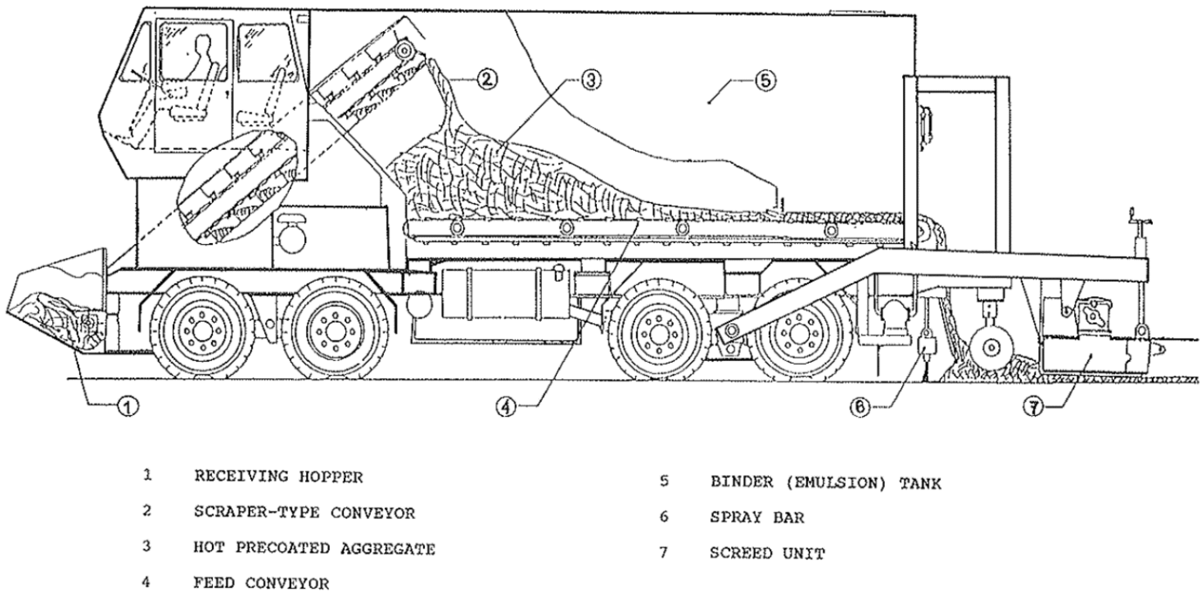

Figure 3 A schematic of the NovaChip machine (Serfass et al., 1991)

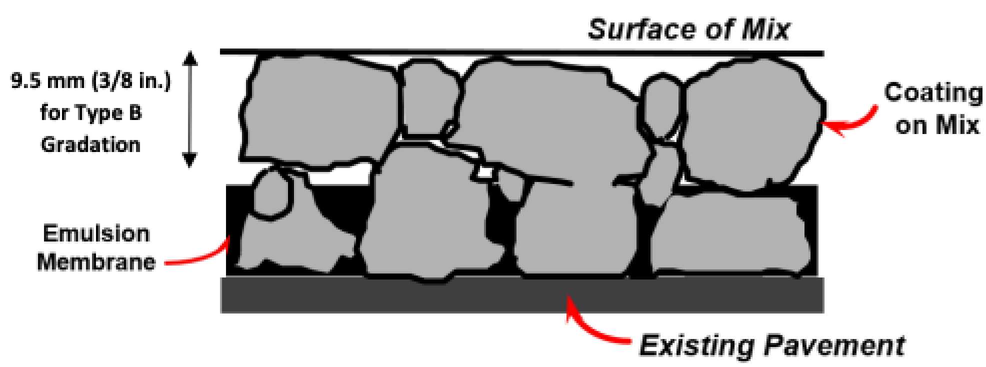

Figure 4 UTBWC Schematic (Braun, 2018)

Bellanger et al. (1992) compared three different treatments for pavement thin layers: chip seals, very thin surface layers, and ultrathin hot-mix asphalt layers. The ultrathin hot-mix asphalt layer leverages the spray paver and is thus most closely related to UTBWC. The authors promote the macrotexture, skid resistance, tire-pavement contact noise reduction, impermeability, and longitudinal evenness of the UTBWC in the paper. Therefore, it appears that the NovaChip™ that was used extensively in the United States in the late 1990s and early 2000s was a blend of the two treatments from France and has its roots in chip seal theory.

One of the first state studies that explored the use of NovaChip™ came from Texas. Estakhri and Button (1993) published a construction report for NovaChip™. Over two jobs (US 281 and SH46) the research team defined the existing roadway and traffic conditions, described the specifications and job materials for each job, and recorded construction notes for both jobs. Finally, they evaluated some early ride quality and functional characteristics on each job. This report was summarized in a TRR paper as well (Estakhri and Button, 1994). Estakhri and Button continued the evaluation of the NovaChip™ sections after three years of being placed (1995). They stated that NovaChip™ showed promise as a preventative maintenance treatment or surface rehabilitation technique.

During a similar timeframe, Oklahoma DOT published a construction report for NovaChip™ (Brewer and Williams, 1995). In this study, ODOT compared Novachip to a traditional open graded friction course (OGFC) and a permeable friction course. Brewer found that NovaChip™ and OGFC performed in a similar manner but NovaChip™ required specialized equipment. A couple of years later, NCAT reported on the construction and performance of NovaChip™ (Kandhal and Lockett, 1997). They found, among other things, that NovaChip™ was a strong alternative to chip seals, micro surfacing, and traditional open-graded friction course. Figure 5 shows the NovaChip™ paving machine.

Figure 5 The NovaChip™ paving machine used in Alabama (Kandal and Lockett, 1997)

Louisiana also published a report about NovaChip™ in 1997 (Abadie, 1997) that placed NovaChip™ on LA 308. One benefit of this report is that the special provision for the project was included in the report, which gives a glimpse into the actual process that was followed 25 years ago. Another nice feature to this study is that a follow up six years later provided an evaluation of the treatment (Cooper and Mohammad, 2004). This second study provided a review of the original report, but then went on to state that NovaChip™ provided "satisfactory" performance in regard to IRI, rutting, and cracking (including longitudinal, random, and transverse). In addition, they found that the treatment resulted in a cost savings to Louisiana compared to a traditional overlay.

State research continued in Washington, where NovaChip™ was placed on SR-17 (Uhlmeyer et al., 2003). This report provided a background, material description, and process overview of NovaChip, and then went into the construction and performance of the test section. Similar to Louisiana, there are several beneficial appendices to this report, including a summary of NovaChip™ jobs performed in the

United States to date, programming issues with the project, contracting issues with the project, the mix design, and three test reports. These documents could provide insight with details that may otherwise have been lost to time.

The last state covered in this brief literature review is Minnesota, who published a series of reports in 2007, 2010, 2018, 2019, and 2020. The first report (Ruranika and Geib, 2007) described the performance of UTBWC on a single highway in Minnesota (US-169). Figure 6 shows the road seven years after construction. Ahmed (2010) provided a follow-up of four sections placed on Interstates and other highways in the Twin Cities (I-94, I-35W, I-394, and MNTH-55). While UTBWC showed promised with ride quality index, the majority of minor distresses were from reflective cracking from the existing in-place concrete joints. The final two reports (Braun, 2018; Braun, 2019) discussed the effects of snow, ice, and wind on UTBWC, and explored proper winter maintenance of roads surfaced with UTBWC, which may include extra salt early in the season. These two documents were primarily synthesis of knowledge gained from existing literature and interviews. Finally, the National Road Research Alliance sponsored research that explored surface life enhancements of UTBWC, chip seals, and micro surfacing (Blanchette et al., 2020). Regardless of existing pavement, the research found that UTBWC has a remaining service life (RSL) of 8 to 15 years, chip seals 8 to 10 years, and micro-surfacing 8 to 11 years.

Figure 6 UTBWC Overlay Section at Mile Marker 181.00 NB (Ruranika and Geib, 2007)

In addition to these state reports, there have been several research projects that have explored UTBWC:

- Hanson (2001) – a summary of UTBWC up to 2001
- Bennert et al. (2005) – tire-pavement noise, wet-skid resistance, and ride quality of UTBWC
- Ji et al. (2015) – case study of UTBWC on Indiana SR-11
- Beyene et al. (2016) – the impact of limestone in UTBWC that led to premature loss of skid-resistance

Finally, the Federal Highway Administration (FHWA, 2019) developed a checklist for UTBWC as a part of the "Pavement Preservation Checklist Series." This checklist provided information for preliminary responsibilities, pre-application inspection responsibilities, project inspection responsibilities, opening to traffic, and common problems with solutions.

2.1.3.2 Description

An UTBWC is a pavement preservation treatment used to extend the life of a structurally sound asphalt pavement (low to medium severity distresses such as rutting, bleeding, raveling, polished aggregates, friction loss) or Portland cement concrete pavement (spalling of longitudinal and transverse joints, corner breaks). The construction process involves spraying a heavy layer of polymer-modified asphalt emulsion within inches of the application of the gap-graded asphalt concrete mixture. The UTBWC can be placed as thin as 0.5-inches to 1.5 inches thick. The asphalt emulsion cools quickly and bonds the asphalt mixture to the pavement rapidly. Compaction is the final step of the process where the mat is rolled (statically) just enough to seat the aggregate into the emulsion. UTBWC has been an effective pavement preservation treatment for high volume roadways, airport pavements, residential streets, city streets, and interstates. Some advantages of UWTBC include (Russell et al., 2008; Braham, 2017; Kandhal and Lockett, 2017):

- Long lasting skid resistance because of high quality aggregates,
- Reduced noise,
- Reduced back spray in wet weather which improves visibility and safety,
- Quick construction and quick return to traffic which reduces user delays,
- Thin lift which allows for retained clearances under overpasses, and
- The polymer-modified emulsion seals and preserves both asphalt and concrete pavements while improving the bonding of the gap-graded asphalt mixture which resists raveling and delamination which is a common distress in thin asphalt concrete overlays.

The estimated life extension for an existing pavement in good condition is 8 to 15 years, for a pavement in fair condition it is 5 to 10 years, and for a pavement in poor condition it is 2 to 10 years.

2.1.3.3 Materials

The materials used in UTBWC include asphalt mixtures (modified and unmodified) and polymer modified emulsified asphalt. AASHTO materials specifications for UTBWC are included in AASHTO M 346 (AASHTO, 2022a) and AASHTO R 108 (AASHTO, 2022b). The aggregate, polymer-modified emulsified asphalt, mineral filler, and performance-graded binder will be evaluated in accordance with AASHTO M 346 (AASHTO, 2022c). In addition, while UTBWC is considered an gap-graded mixture, there are many similarities between the construction of gap-graded and open-graded mixtures. Therefore two additional documents were targeted in order to capture all of the salient information. The first document, from the National Asphalt Pavement Association (NAPA) is "Design, Construction, and Maintenance of Open-Graded Asphalt Friction Courses", or IS 115 (Kandhal, 2002). The second document is from South Africa, and is titled "The Design and Use of Porous Asphalt Mixes," as gap-graded mixtures are a type of porous asphalt mix (Sabita, 2011). Finally, content from the survey will also be included in the discussion, and will be referenced by state.

Asphalt Mixtures

The asphalt concrete mixture used for the UTBWC is a gap-graded mixture that includes a large portion (70 to 80%) of a single-sized crushed aggregate that is bound with a mastic composed of manufactured sand, filler (if needed) and asphalt binder. The binder content is a minimum of 4.8% depending on the aggregate gradation, maximum aggregate size, traffic, climate, lift thickness, and other existing peculiarities of the existing pavement. AASHTO R 108-22 is the Standard Practice for Ultrathin Bonded Wearing Course Design. Table 5 provides the aggregate gradation guidelines for a Type C (12.5 mm NMAS), Type B (9.5 mm NMAS), and Type A (4.75 mm NMAS) UTBWC aggregate gradation and typical binder content range for each nominal maximum aggregate size (NMAS). Many agencies have used UTBWC over time and have developed their own specifications or special provisions to meet their specific pavement, traffic, and climatic conditions. For example, while there is no published reference available, Koch Materials Company developed a gradation for a ¾ in (19.0 mm) NMAS, but that was not adopted in AASHTO's standard.

Table 5 UTBWC Aggregate Gradation Guidelines and Binder Content[1] (AASHTO R 108)

Sieve Size	Nominal Maximum Aggregate Size (NMAS) Mixture Designation – Control Point (Percent Passing)		
	Type C: 1/2 in. (12.5 mm)	Type B: 3/8 in. (9.5 mm)	Type C: No. 4 4.75 mm)
¾ in. (19.0 mm)	100.0	–	–
½ in. (12.5 mm)	85 – 100	100	–
3/8 in. (9.5 mm)	55 – 80	85 – 100	100
No. 4 (4.75 mm)	22 – 38	22 – 38	40 – 55
No. 8 (2.36 mm)	19 – 32	19 – 32	20 – 32
No. 16 (1.18 mm)	15 – 24	15 – 24	15 – 24
No. 30 (600 µm)	11 – 18	11 – 18	11 – 18
No. 50 (300 µm)	8 – 14	8 – 14	8 – 14
No. 100 (150 µm)	5 – 10	5 – 10	5 – 10
No. 200 (75 µm)	4.0 – 5.5	4.0 – 5.5	4.0 – 5.5
Binder Content, %	4.6 – 6.1	4.8 – 6.1	5.0 – 6.3
Lift Thickness (in.)	5/8 – 7/8	5/8 – 7/8	½
Typical Yield (lbs/yd^2)	65 – 75	60 – 70	55 – 65

[1]Placement rates are based on 100 lb/yd^2/in. using a mixture specific gravity of 2.500. Mixtures with different specific gravities will require an adjusted equivalent placement rate.

NAPA deviates slightly from AASHTO R 108 and recommends 2-4% P200 in the mix (Kandhal, 2002). Like any mix, dust content is critical. Lower dust opens up the aggregate skeleton and the mixture moves away from a Stone Matrix Asphalt (SMA) type mixture.

In addition to meeting the gradation and binder requirements in Table 5, the gap-graded asphalt mixture must meet the drain down requirement of 0.1% max when tested in accordance with AASHTO T 305. Moisture damage of the gap-graded mixture must meet or exceed a tensile strength ratio (TSR) of 80% when testing in accordance with AASHTO T 283 with the following exceptions (AASHTO, 2022b):

- Condition the loose mixture for 2 hours in accordance with AASHTO R 30, Section 7.1,
- Compact the specimens to 100 gyrations using the Superpave Gyratory Compactor while maintaining the typical dimensions of TSR specimens (150 mm diameter by 95.25 ± 6.35 mm height),
- Extrude the samples as soon as possible without damage to the sample.
- Use AASHTO T 269 to determine the air void content and record the air void content for each specimen, and
- If less than 55% saturation is achieved, the procedure does not need to be repeated unless the difference in tensile strength between duplicate specimens is greater than 25 psi (0.17 MPa)

Aggregates

The quality of the aggregate is important to provide long-lasting, adequate skid resistance and noise reduction. The mineral aggregate shall be 90% crushed on two or more faces for the coarse aggregate. Only manufactured fine aggregate (material passing the #8 sieve) is allowed. The quality requirements for the coarse aggregates are shown in Table 6 while the quality requirements for the fine aggregate are shown in Table 7 or as specified by the owner agency.

Table 6 Coarse Aggregate Quality Requirements (AASHTO M 346)

Test	Method	Limit, %
Flat & Elongated Ratio, 3:1	ASTM D 4791	25 max
Los Angeles Abrasion, % Loss[1]	AASHTO T 96	40 max
Aggregate Wear Index	AASHTO T 210	260 min
Crushed Particles, Two Faced, %	AASHTO T 335	90 min
Deleterious Particles	AASHTO T 112	1.0 max
Water Absorption	AASHTO T 85	3.0 max
Micro-Deval, % Loss	AASHTO T327	18 max
Bulk Specific Gravity	AASHTO T 331	2.50 max
Magnesium Sulfate Soundness, Max Loss, %, 5 cycles Or	AASHTO T 104	20
Sodium Sulfate Soundness, Max Loss, %, 5 cycles	AASHTO T 104	15

[1]The Los Angeles abrasion test is to be run on the parent aggregate, i.e., the limestone, sandstone, etc. from which was derived.

Table 7 Fine Aggregate Quality Requirements (AASHTO M 346)

Test	Method	Requirement
Sand Equivalent	AASHTO T 176	45 min
Uncompacted Void Content, %	AASHTO T 304	40 min
Water Absorption, %	AASHTO T 84	3.0 max

Mineral filler used in the UTBWC mix design can be lime, fly ash, or baghouse fines collected during the mixing process or other approved filler that meets the requirements in AASHTO M 17, M 295, or M 303. There is some guidance available as to the quantity of mineral filler allowed. Kandhal (2002) indicates that approximately 0.4% of the total mix can be mineral filler, with the exact quantity based on a draindown test. Texas indicates that lime can be used as a mineral filler and can be used up to 1.0% by weight of the total dry aggregate, with the exact quantity based on the boil test (Tex-530-C).

However, it is worth noting that NAPA has slightly more stringent requirements for some of the coarse and fine aggregate properties (Kandhal, 2002). These can be found in Table 8.

Table 8 Aggregate Requirements Different than AASHTO M 346 (Kandhal, 2002)

Test	Method	Limit, %
Flat & Elongated Ratio, 3:1 and	ASTM D4791	20 max
Flat & Elongated Ratio, 5:1	ASTM D4791	5 max
Los Angeles Abrasion, % Loss[1]	AASHTO T 96	30 max
Crushed Particles, One Faced, %	AASHTO T 335	100%
Crushed Particles, Two Faced, %	AASHTO T 335	90
Water Absorption	AASHTO T 85	2.0 max
Uncompacted Void Content, %	AASHTO T 304	45 min

[1]The Los Angeles abrasion test is to be run on the parent aggregate, i.e., the limestone, sandstone, etc. from which was derived.

In addition, based primarily on NAPA IS115 titled "Open-Graded Asphalt Friction Courses" (Kandhal, 2002) and Sabita Manual 17 "Porous Asphalt" (Sabita, 2017), a limit was not recommended for carbonate coarse aggregate. By adhering to more stringent aggregate requirements, any carbonate coarse aggregate requirements would be redundant. However, based on the information gathered, Table 9 below in this report shows values that should either be added or values that should be modified in M 346 in order to tighten the restrictions on coarse aggregate to reduce the possibility of premature failure due to coarse aggregate. It is also important to note that mineral filler is discussed specifically in M 346 if the percentage of fines needs to be increased. Mineral filler can consist of lime, fly ash, or baghouse fines. According to NAPA IS115, mineral filler should be added at approximately 0.4% of the asphalt mixture, and should only be added to control the draindown test.

Table 9 Added and adjusted aggregate properties for UTBWC

Test	Method	Limit
Add: Flat & Elongated Ratio, 5:1	ASTM D4791	<5%
Adjust: Flat & Elongated Ratio, 3:1	ASTM D4791	<20% (from <25%)
Adjust: LA Abrasion	AASHTO T 96	<35%
Add: Crushed Particles, One Faced	AASHTO T 335	=100%
Adjust: Magnesium Sulfate Soundness or Sodium Sulfate Soundness	AASHTO T 104	<18% (from <20%) or <12% (from <15%)
Adjust: absorption (coarse and fine)	AASHTO T 85	< 2% (from <3%)
Add: methylene blue (P200 material)	AASHTO T 330	< 10%
Add: P200 (includes mineral filler)	AASHTO T 11	2-4%

Another potential addition to aggregate properties for UTBWC could come from performance tests. If an aggregate is prone to polishing, a test such as the Dynamic Friction Tester (DFT) could be used in order to quantify the friction characteristics. This concept will be explored in more detail over the upcoming months, but any findings will most likely be limited to the report and perhaps a note in the construction guidance.

The asphalt industry is moving toward including more recycled materials in asphalt mixtures. This includes Reclaimed Asphalt Pavement (RAP), Recycled Asphalt Shingles (RAS), rubber, plastics, and bio-binders. However, it is important to keep in mind that UTBWC is a premium overlay material, and should be treated as such. In fact, several states prohibit the use of RAP in UTBWC, including Kansas, Maryland, Missouri, New Hampshire, Texas, Utah, Vermont, Virginia, and Wyoming. In addition, several states prohibit the use of RAS, including Kansas, Maryland, Missouri, Texas, Utah, Vermont, and Virginia. Rubber, on the other hand, has been approved for use in the asphalt binder (the wet-process), in Arizona, California, Massachusetts, New Hampshire, and Texas. In addition, Sabita (2011) indicates that rubber is an acceptable additive in the asphalt binder. No literature was found that allowed the use of rubber as an aggregate (dry-process), which could be attributed to the fact that the dry rubber may swell, thus closing the gap-graded mixture. It should be noted that Koch Materials Company, the company that promoted NovaChip in the 1990s-2000s, explicated stated that there should be no reclaimed materials used in UTBWC (KPS, 2011). While the use of recycled materials is of upmost importance moving forward, both economically and environmentally, it is recognized that the proper place to make these additions and formal statements are in AASHTO M 346.

Asphalt Binder

The binder grade for the UTBWC asphalt mixture should be recommended for the climatic and traffic conditions of the project. The asphalt binder should be evaluated in accordance with AASHTO M 320 or AASHTO M 332. However, it is recommended that the high temperature binder grade is two grades stiffer than normally used. In addition, polymer is recommended for several situations, including hot climates, cold climates with freeze-thaw cycles, medium to high level traffic volume, and air voids greater than 20%. A key reason for polymer modification is that unmodified binders tend to have lower resistance to abrasion versus polymer modified binders (Kandhal, 2002). It is recommended that M 346 be modified to require binder modification for the asphalt binder in the asphalt mixture. The modification can be either polymer modification or asphalt rubber modification. However, the modification is required for cohesion of the asphalt mixture. Again, it is recognized that the proper place to make these additions and formal statements are in AASHTO M 346.

However, while tests beyond the traditional Superpave Binder Grading System are beginning to gain traction, such as the Multiple Stress Creep Recovery (MSCR) in AASHTO M 332, there are more tests and analysis methods that are becoming more common. These tests and analysis methods, such as Delta Tc (Asphalt Institute, 2019), black space, and the Glover Rowe (G-R) parameter (Rowe, 2019). While the introduction of these types of concepts are beyond the scope of the construction guide, they should continue to be examined and explored for potential implementation into AASHTO M 320, AASHTO M 332, or a new AASHTO standard.

Additives

There are two potential additives for the asphalt mixture in UTBWC (Kandhal, 2022). The first additive is cellulose fiber, which is 0.2-0.5% of the total mixture, with a typical addition rate of 0.3%. The exact rate depends on the draindown test results. The cellulose can be either loose or pelletized, and Kandhal provides a good discussion on how to add the cellulose fiber at either a batch or continuous lant. The second potential additive is an anti-strip additive. AASHTO R 108 mentions anti-strip additives but does not require them. However, multiple states have guidelines on when to use anti-strip additives in UTBWC:

- California: if Tensile Strength Ratio (TSR) is less than 70%, an anti-strip additive is required. The additive can be either lime or liquid.
- Connecticut: "When necessary, an anti-stripping agent shall be added to provide resistance to stripping." It is worth noting that there is a minimum 80% value for TSR.
- Illinois: if TSR is less than 85%, an anti-strip additive is required. However, if an anti-strip additive is used, the conditioned tensile strength can not decrease. The additive can be hydrated lime, slaked quicklime, or liquid additive. Dry hydrated lime should be added at a rate of 1.0-1.5% by weight of total dry aggregate, while the slurry should have a dry residual weight equivalent. However, the exact rate up to engineer.
- Kansas: 0.25% of amine based antistripping agent by weight of asphalt binder is required. The anti-strip additive should follow ASTM D2074.
- Pennsylvania: "Visual stripping will require modification or readjustments or both as directed by the Representative"
- Texas: lime mineral filler can be added at a rate of 1.0% by weight of total dry aggregate. However, both lime and liquid antistripping allowed. Add as directed if signs of stripping exist following the Boil Test (Tex-530-C).

- Vermont: if granite or quartzite aggregates used in mixture, an anti-strip additive shall be added at a minimum of 0.5% by percentage of asphalt weight.
- Virginia: anti-strip agent shall be used and the type can be either hydrated lime or a chemical additive. If the TSR is greater than 0.80, it should be added at a rate of 0.30% or more by weight of total asphalt content

Emulsified asphalt

Based on AASHTO M 346-22, the polymer modified emulsified asphalt for UTBWC shall meet the requirements of rapid-setting (RS-1P) or cationic rapid setting (CRS-1P) type emulsified asphalt. An anionic polymer-modified emulsified asphalt (RS-1P) shall meet the requirements of Table 10. The emulsified asphalt classification is determined by the owner agency based on regional climatic and traffic conditions.

Table 10 Anionic Polymer-Modified Emulsified Asphalt Specification (AASHTO M 346)

Tests on Emulsion	Method	Minimum	Maximum
Viscosity, Saybolt Furol @ 122°F (50°C), s	AASHTO T 59	20	100
Storage Stability 24 hr, %	AASHTO T 59	–	1.0
Demulsibility, 35 mL 0.02 N $CaCL_2$, %	AASHTO T 59	40	–
Sieve, %	AASHTO T 59	–	0.05
Evaporation Residue, %	AASHTO T 59	63	–
Tests on Residue from Evaporation			
Penetration @ 77°F (25°C), dmm	AASHTO T 49	80	100
Elastic Recovery @ 77°F (25°C), %	AASHTO T 301	50	–

A cationic polymer-modified emulsified asphalt (CRS-1P) shall meet the requirements of Table 3 in AASSTHO M 316 except as modified in Table 11 below. The emulsified asphalt classification is determined by the owner agency based on regional climatic and traffic conditions.

Table 11 Modified AASHTO M 316 Cationic Polymer-Modified Emulsified Asphalt Specification (AASHTO M 346)

Tests on Emulsion	Method	Minimum	Maximum
Sieve Test, Retained on No. 20 (850 μm) Sieve, %	AASHTO T 59	–	0.05

Note that some state specifications also allow the use of high-viscosity emulsified asphalts (RS-2P and CRS-2P).

Similar to the discussion above for asphalt binders, there has also been a significant amount of research performed around emulsified asphalt and emulsified asphalt residue. For example, there has been significant work exploring emulsion performance grade and surface performance grade for emulsified asphalts (Kim et al., 2017; Epps Martin et al., 2022; AASHTO, 2022f; Anderson, 2023). A key point of discussion around these performance grades for emulsified asphalt is how emulsified asphalt residue is obtained. There is a general consensus that AASHTO R 78 Procedure B obtains a more representative material than the distillation procedure in AASHTO T 59, but work continues in NCHRP 9-63 in order to deliver final recommendations. While the introduction of these types of concepts are beyond the scope of the construction guide, they should continue to be examined and explored for potential implementation into AASHTO T 59, AASHTO M 346, or a new AASHTO standard.

2.1.3.4 Design practices

Design practices for UTBWC are primarily housed in AASHTO R 108 (AASHTO, 2022b). A brief summary of R 108 will be included here, followed by some discussion on how individual states handle certain topics of interest within the design practice. Discussion on the materials can be found in the previous section.

Once the aggregate, asphalt binder, additives, and emulsified asphalt have been selected, there are several additional requirements for UTBWC in R 108. First, the maximum specific gravity is required as part of the design process. Next, the draindown from the loose mixture must be less than 0.10% according to AASHTO T 305. Note that Kandhal (2002) recommends the draindown test be run at both 6.0% and 6.5% asphalt binder content, which is the upper range of the recommended binder content in AASHTO R 108 as part of determining the optimal mix design with multiple trial gradations. Finally, the TSR must be equal to or greater than 80% according to AASHTO T 283. However, in addition to the these tests, there are two other key areas of interest in the area of design for UTBWC: the film thickness and performance tests beyond the draindown test and the TSR.

For the film thickness, the majority of states use the Asphalt Institute MS-2 method (AI, 2014). The surface area of aggregate is estimated by multiplying the total percent passing each sieve size (decimal form) by a surface area factor. This products are summed and the total will is an approximation of the equivalent surface area. Arizona, Arkansas, Connecticut, Maryland, Missouri, and Utah use this method. However, some states have calculations based on the surface area, including California and Maine. For example, Maine estimates the film thickness by multiplying the asphalt content of the mix design by 1,000, and dividing this number by the total surface area of the aggregate blend multiplied by the specific gravity of the asphalt. Other states, such as Illinois (Illinois Test Procedure 406), Kansas (KDOT Construction Manual Section 5.10.4), Pennsylvania, and Vermont have their own methods. Finally, Texas and Virgina require film thickness calculations for UTBWC, but do not provide any specific guidance on how to obtain. Regardless of the method to calculate the film thickness, there is a relatively small range of required film thicknesses. Of the states mention in the film thickness discussion below, the lowest specified minimum film thickness is 9.0 microns (Connecticut, Kansas, and Texas) while the highest specified minimum film thickness is 10.0 microns (Arizona, California, Maine, Maryland, Missouri, and Utah). Two states indicate a range of film thickness from 9-11 microns (Arkansas and Illinois).

In addition to film thickness, the asphalt binder content used for the draindown tests was an open area of knowledge. From IS115, it is recommended that during trail gradations, asphalt binder contents of 6.0% and 6.5% be utilized. However, AASHTO R 108 already requires a maximum draindown of 0.10% through AASHTO T 305 at design asphalt binder content, and the research team believes that this is adequate guidance.

After the discussion of anti-strip agents, the next open area was shot rate. The shot rate is already established in Table 2 of AASHTO R 108, and no additional recommendations were established after the research team reviewed literature.

In terms of performance tests, UTBWC behaves more like a surface treatment than an asphalt mixture in many respects. For example, no states were found exploring the concept of balanced mix design, as UTBWC are not expected to rut. However, there were five tests discussed in literature that could be used as performance indicators for UTBWC. The first test, the Cantabro Abrasion Test (Tex-245-F) can be run on both unaged and aged samples. The aging protocol consists of placing a compacted UTBWC sample in an oven at 85C for five days, and cooling the sample to 25C before testing. Unaged samples should have a maximum max loss of 20-25% and aged samples should have an average loss less than 30%, with on single maximum value required to be less than 50% (Kandhal, 2002). The second test recommended was the draindown test, with a maximum draindown of 0.3%. The third test was permeability. Kandhal (2002) recommended a permeability of greater than 100 m/day. While this recommendation is based on ASTM PS 129, this specific standard has been withdrawn. An alternate could be ASTM D5084, which was used by Kanitpong et al. (2001) to quantify permeability of asphalt mixtures. A second alternative would be the LCS Drainometer (Sabita, 2011). The fourth test was the modified Lottman (AASHTO T 283) for moisture susceptibility. However, Kandhal (2002) recommended five freeze/thaw cycles versus just one, on samples compacted to 50 gyrations on the Superpave Gyratory Compactor, a partial vacuum of 26 inches Hg for 10 minutes to saturate, and keep the specimens submerged in water during freeze cycles. Finally, the fifth potential performance test is a skid resistance test. Sabita (2011) recommends the Sideways-force Coefficient Routine Investigation Machine, or SCRIM, brake force trailer. Table 12 summarizes potential performance tests for UTBWC.

Table 12 Potential performance tests for UTBWC

Test	Method	Limit
Cantabro Abrasion - unaged	TEX-245	<20%
Cantabro Abrasion – aged (85C, 5 days)	TEX-245, AASHTO R 30	<30% average, single value <50%
Permeability	ASTM D5084	>100 m/day
Skid resistance	SCRIM – Sideways force Coefficient Routine Investigation Machine	n/a

While the film thickness and alternate performance tests could enhance the long-term durability of UTWBC, there is not enough information available to make a recommendation for changing any content in R 108 at this point. However, if more data is obtained in the upcoming years, this may change.

2.1.3.5 Construction practices

Best construction practices for UTBWC should be followed to ensure the good quality of UTBWC products. The following are key steps during the construction of UTBWC. Note that there are several references to chip seals and standard hot mix asphalt in this section as UTBWC has components of each of these treatments.

Preconstruction Meeting

The Agency should arrange for a preconstruction meeting to include the project manager, project engineer, inspector, material tester, representatives of prime contractor, each sub-contractor, material suppliers, and others as necessary. Besides the administrative and operational considerations, the key items of discussion for the UTBWC meeting should include design, sampling, specifications, safety procedures, stockpiling, staging area, traffic control, public notification, quality control plan, project inspection, acceptance, temporary and permanent pavement markings, and payment. In addition, the meeting can include Just-In-Time training (JITT) among the Agency, Contractor, inspectors, and other stakeholders prior to the construction.

Production and Hauling

In general, the standard practices for producing and hauling asphalt mixtures can be used for UTBWC. However, because of the unique materials, there are several special considerations (Kandhal, 2002). For example, I mineral fibers or cellulous fibers are utilized, there will need to be a special feed device added to the plant. In addition, dry and wet mixing times will need to be increased in a batch plant. Another special consideration in a batch plant would be the screening capacity based on the single aggregate size of the gradation. The UTBWC should not be stored in surge bins or silos for expended periods of time, as that would increase the potential for draindown. Finally, special attention should be paid to the calibration of the asphalt mixture plant before production because of the one-sized nature of the gap-graded mixture

Along with the special considerations for production, Kandhal (2002) provided special considerations for hauling. With the polymer-modified mix, it is important to apply a heavy and thorough coat of asphalt release agents to the truck beds. In addition, the truck beds should be raised after spraying to drain any puddles. Tarping is required for each load to prevent excessive crusting. In addition, Oregon recommends no more than a 35-mile haul distance to prevent mix crusting, which leads to cold lumps forming and causing pulls on the mat. Finally, there should be enough trucks so that the paver does not stop, as too many paver stops will delay unloading and therefore prematurely cool and mix, potentially creating cold lumps.

Surface Preparation

The UTBWC does not add structural strength to the pavement, thus any structural problems such as alligator cracking or potholes must be repaired before the application of the UTBWC. The UTBWC should not be used as a rut filler (ruts greater than ½ in. deep) or leveling course. The pavement should be prepared as if it were a chip seal project. Pavement cracks and joints greater than ¼ in (6.3 mm) wide should be cleaned (the removal of all incompressible material) and filled prior to the UTBWC. Crack sealant should be placed sufficiently in advance of the UTBWC so that that crack sealant is fully cured and does not bleed through. The entire pavement surface should be cleaned with pressurized water or a vacuum system to ensure the surface is clean of debris. If paving on city streets and residential areas, all manhole covers, grates, catch basins, and other utility structures should be protected and covered with plastic or building felt before application of the UTBWC (Hanson, 2001). Thermoplastic markings and other raised markings should be removed or abraded so that UTBWC treatment can bond to the pavement. The majority of states indicate that the surface of the pavement can be damp when placing UTWBC, but there should not be any standing water. However, a handful of states specifically require a dry surface, including Connecticut, Illinois, Massachusetts, Texas, and Wyoming.

Equipment

To ensure a high-quality UTBWC product, equipment used for the project should be calibrated and well-functioning. Most UTBWC will implement the following equipment:

- Material Transfer Vehicle (MTV) – while an MTV is optional, it is highly recommended based on the unique materials in UTBWC (Kandhal, 2002). Based on the importance of a homogeneous mixture, from both a gradation and thermal perspective, an MTV is recommended in the construction guide.
- Spray Paver – UTBWC uses a specially built paving machine. While there are several manufacturers of spray pavers, two specific manufacturers will be discussed here for the sake of demonstration. A Midland paver contains a receiving hopper, a spray bar before the augers, auger conveyors that transport the gap-graded mixture to the screed, a combination vibratory bar screed for spreading and initial seating and an insulated 3,000 gal (11, 300 L) storage tank for the emulsified asphalt. Conversely, a Vogele machine is similar but uses a 1,057 gal (4,000 L) emulsion tank. Most states require that the asphalt mixture is placed no more than five seconds after the emulsified asphalt is sprayed, regardless of the exact configuration of the spray paver.
- Rollers – A minimum of two steel double drum rollers (at least 9 metric tons) are recommended for all UTBWC projects operating in the static mode. Three rollers may be necessary during night paving on cooler nights. Pneumatic tire rollers are not recommended.

Test Strip

It is generally recommended a test strip of 500 to 1,000 ft in length be constructed and inspected, allowing the Agency and Contractor to ensure that UTBWC equipment is properly calibrated, application rates are appropriate for the polymer modified emulsion, gap-graded asphalt mixture meets the gradation and target binder content, and that any workmanship issues are resolved before full-scale UTBWC production. This range is based on Idaho's recommendation of a 500 foot test section in their specification, California's recommendation of 600 feet in their specification, and FHWA's definition of a "short distance" of a test strip equaling 1000 feet (FHWA, 2023).

Traffic Control

A traffic control plan should be developed for each UTBWC project to ensure the safety of the traveling public and the employees performing the work. Traffic control should be in place before work forces and equipment enter the work zone. Traffic control includes construction signs, construction cones, barricades, flag personnel, and pilot cars to direct traffic clear of the working area. A pilot vehicle may be utilized to control the speed of motorists near the project, generally less than 25 mph (Hamilton and Owns, 2017).

Notification

If required by the contract, Contractors notify all residents, businesses, and agencies by an approved, written notice detailing streets, limits of work, and the days and hours of planned work. If required by the contract, Contractors post all work areas with approved no parking signs. Guidelines for this are provided in the *Chip Seal Best Practices* (Gransberg and James, 2005).

Application Rates

The application rate of the UTBWC depends on the plant production (tons/hour) of the gap-graded asphalt mixture, the number of haul trucks, the spray paver speed, number of rollers, and emulsion trucks to fill the spray paver. Many of the states that indicated they use UTBWC state that the paver should move at approximately 30-90 ft/min, including Arizona, Arkansas, Connecticut, Delaware, Kansas, Maine, Nevada, and Utah. Other states simply set a minimum paver speed of approximately 30-35 ft/min, including Illinois, Hew Hampshire, Vermont, and Wyoming. However, it is worth noting that the majority of state specifications required the asphalt mixture to be placed no more than five seconds after the asphalt emulsion membrane was applied, essentially forcing the equipment to be a spray paver.

Logistics are very important to ensure that the paver does not stop which can cause bumps in the surface which increases the pavement roughness. Table 2 in AASHTO R 108 (AASHTO, 2022b) recommends asphalt emulsion application rates and adjustment factors for surface conditions, as seen in Table 13.

Table 13 Recommended General Emulsified Asphalt Tack Coat Application Rate and Adjustment Factors for Surface Conditions (from AASHTO R 108)

	Mixture Designation		
	½ in. (12.5 mm)	3/8 in. (9.5 mm)	No. 4 (4.75 mm)
General Application Rate, gal/yd^2 (L/m^2)	0.20 (0.91)	0.18 (0.81)	0.14 (0.63)
Recommended Adjustments to Application Rate, gal/yd^2 (L/m^2), by Existing Surface Condition			
PCCP, Smooth or Polished	-0.03 (-0.14)	-0.03 (-0.14)	-0.03 (-0.14)
PCCP, Broomed or Textured	0	0	0
Flushed Asphalt Concrete Surface	-0.02 (-0.09)	-0.03 (-0.14)	-0.03 (-0.14)
Dense, Unaged Asphalt Concrete	0	0	0
Open Textured, Dry, Aged or Oxidized	+0.02 (+0.09)	+0.01 (+0.05)	+0.01 (+0.05)
Milled Asphalt Concrete Surface	+0.02 (+0.09)	+0.01 (+0.05)	+0.01 (+0.05)

[1]A tolerance of ± 0.02 gal/yd^2 (0.09 L/m^2) shall be applied to the final target application rate.

Rolling

It is important to note that this section is called rolling and not compacting. This is because the aggregate in UTBWC is not compacted, it is "seated." Several states take note of this in their UTWBC specifications:

- Connecticut: "compaction process used is meant to seat the PMA mixture into the sprayed polymer modified emulsion rather than to obtain density"
- Minnesota: "Roll in static mode only immediately following the placement of the UTBWC in order to seat the mix"
- Texas: only compaction requirement is permeability for porous friction course asphalt mixture (other asphalt mixture types allowed)
- Utah: "Roll BWC material sufficiently to seat without fracturing mix aggregate"

Therefore, moving forward, the term "seat" will be used instead of "compacting." When seating the aggregate, only conventional steel wheel rollers should be used. Pneumatic tires should not be used. The rollers should stay within 50 ft of the paver, when the asphalt mixture is still hot and workability. The roller should complete 1-2 complete coverages of the mat in static mode. The only time vibratory rolling should be used is at "high joints," either transverse or longitudinal. In general, vibratory mode is discouraged unless a high joint needs to be "knocked down" (Kandhal, 2002). Roller should not stop on the mat. It is important to note that agency specifications and incentives can play a large role in proper rolling of UTBWC (Aschenbrener et al., 2018).

Longitudinal and Transverse Joints

Longitudinal joints can be constructed as butt joints that are well bonded and sealed. Longitudinal joints should be straight on tangent sections and uniformly follow the traffic lane on curve sections. Longitudinal joints should be smooth, particularly on roadways with high-speed traffic. Longitudinal joints may be constructed by placing mix ~1/16 in above previously placed/compacted lane. Edge of screed must follow join exactly (Kandhal, 2002).

Transitions at the transverse joints must be smooth to avoid creating a bump in the surface. The joints must be butted to avoid these bumps. Care must be taken during rolling in order to ensure proper density is achieved at all cold-joints. A potential method of constructing a transverse joint is to start with screen one foot behind joint, and lay screen flat on existing UTBWC mat. The hot asphalt mixture is augured in front of screed, and drug off the new joint when travel begins. The emulsified asphalt should be sprayed immediately after the existing cold joint. The joint can be cross rolled with steel wheel breakdown roller (Kandhal, 2002).

Handwork

Handwork is not recommended for UTBWC. If a certain job requires a large amount of handwork (i.e. tapers, road approaches, inlets, and manholes), UTWBC may not the proper treatment to apply on the roadway (Kandhal, 2002). With the polymer modified asphalt binder and the potential for fibers, handwork produces rough areas, blemished surfaces, and excessive voids. This will lead to inadequate seating followed by the potential of excessive raveling under traffic (Sabita, 2011).

Opening to Traffic

Because the gap-graded mixture being places is thin, the mixture cools quickly, and the roadway can be opened up to traffic in about 15 minutes. The road can be opened to traffic when the mixture temperature drops below 185°F (85C°) (Hanson, 2001) or if cool enough to prevent damage when opened to traffic, especially if softer binder grades are utilized.

2.1.3.6 Quality assurance (QC, agency acceptance, independence assurance)

Quality Assurance (QA) is defined as all those planned and systematic actions taken by the agency and contractor to provide the necessary confidence that the procured material and workmanship will satisfy the quality requirements of the contract. Based on AASHTO R10, QA includes Quality Control (QC), Acceptance and Independent Assurance (IA).

QC is the system used by the Contractor to monitor, assess and adjust production and placement processes to ensure that the material and workmanship will meet the specified quality. QC is the responsibility of the Contractor.

Agency Acceptance is the system used by the Agency/Engineer to measure the degree of compliance of the quality of the materials and workmanship with the Contract requirements. Acceptance is the responsibility of the Agency/Engineer and will be conducted in accordance with the specifications.

IA is an unbiased and independent system used to assess all sampling, testing, and inspection procedures used for QA. IA is the responsibility of the Agency/Engineer and is conducted in accordance with the specifications.

Quality Control

The UTBWC Contractor establish, implement, and maintain a QC program to control all equipment, materials, production, workmanship, and associated processes during construction. Existing state specifications have various examples of potential quality control plans. For example, Maine (Maine UTBWC, 2021) has minimum quality control frequencies for the asphalt mixture and emulsified asphalt, and also has control limits of various materials. These are seen below in Tables 14 and 15.

Table 14 Minimum Quality Control Frequencies (Maine UTBWC, 2021)

Test or Action	Frequency	Test Method
Temperature of mix	6 per day at street and plant	-
Temperature of mat	4 per day	-
Emulsified tack coat application rate & yield*	1 per 10,000 SY (minimum of 2 per day)	-
Gradation	1 per 500 ton	AASHTO T 30
PGAB content	1 per 500 ton	AASHTO T 164 or T 308
Rice Specific Gravity	1 per 500 ton	AASHTO T 209
Coarse Aggregate Angularity	1 per 5000 ton	ASTM D5821
Flat and Elongated Particles	1 Per 5000 ton	ASTM D4791
Fine Aggregate Angularity	1 Per 5000 ton	AASHTO T 304

* Emulsified tack coat application rate and yield shall be verified independent of the rate displayed on the paver

Table 15 Control Limits (Maine UTBWC, 2021)

Property	UCL and LCL
Passing NMAS sieve	Target +/-4.0˅
Passing 4.75 mm and larger sieves	Target +/-4.0
Passing 2.36 mm sieve	Target +/-2.5
Passing 0.075 mm sieve	Target +/-1.0^
PGAB Content*	Target +/-0.25
Theoretical Maximum Specific Gravity	JMF Target +/-0.020

˅ The mixture shall be produced to comply with the control points outlined in Table 1.
* Based on AASHTO T 308
^ The minimum LCL shall be 3.0% and the maximum UCL shall be 7.0%.

Agency Acceptance

As the owner of the final UTBWC, the Agency must ensure the contractor has constructed the project in accordance with the specifications. The Agency should conduct acceptance sampling, testing, and inspections consistent with AASHTO R 10. The Agency may conduct verification testing should the QC results be used for Acceptance. Again, Maine (Maine UTBWC, 2021) provides potential templates for agency acceptance for UTBWC, as seen in Tables 16 and 17.

Table 16 UTBWC Acceptance Criteria (Maine UTBWC, 2021)

Property	Point of Sampling	Test Method
Gradation	Paver Hopper	AASHTO T 30
PGAB Content	Paver Hopper	AASHTO T 308

Table 17 UTBWC Acceptance Limits (Maine UTBWC, 2021)

Property	USL and LSL
Passing NMAS sieve	Target +/-5%*
Passing 4.75 mm and larger sieves	Target +/-5%
Passing 2.36 mm to 1.18 mm sieves	Target +/-3%
Passing 0.60 mm	Target +/-3%
Passing 0.30 mm to 0.15 mm sieve	Target +/-2%
Passing 0.075 mm sieve	Target +/-2%^
PGAB Content	LSL = Target - 0.3% USL = Target + 0.4%

* The mixture shall be produced to comply with the control points outlined in Table 1.
^ The minimum LSL shall be 3.0% and the maximum USL shall be 7.0%.

Note that the previous four tables are shown for demonstration purposes only. The AASHTO construction guides for hot mix asphalt, along with other state specifications for UTBWC, were reviewed and the most appropriate information from each was provided in the final deliverables of this research.

Independent Assurance Program (IA)

The IA program should follow the Tech Brief: Independent Assurance Programs, report number FHWA-HIF-12-001 2011 (FHWA, 2011) and should be the responsibility of the Agency or Owner. The IA Program consists of activities that are an unbiased and independent evaluation of all the observations, sampling and testing procedures and equipment used in the acceptance program. The IA Program is staffed by qualified agency personnel or an accredited laboratory not involved with acceptance testing. It ensures the sampling and testing is performed correctly and the testing equipment used in the program is operating correctly and remains calibrated. It involves a separate and distinct schedule of sampling, testing, and observation. The results of the IA testing should not be used for material acceptance.

2.1.3.7 Measurement and payment

The contract should specify the payment method for the UTBWC. Methods vary among agencies but usually fall into the following categories: 1) unit area, 2) ton or gallon of emulsified asphalt and ton of asphalt mixture, or 3) ton or gallon of emulsified asphalt, ton or gallon of asphalt binder, and ton of aggregate. Generally, one of the three methods will be used.

The advantages of payment by the unit area for a completed UTBWC is simplicity when the area is easily defined. However, this method has some disadvantages, such as the Contractor may reduce the amount of emulsified asphalt or asphalt binder, to the minimum requirements. This may lead to raveling of the asphalt mix, delamination of the asphalt mix, vehicle damage, or early failure of the project. Therefore, more detailed recommendations are necessary for the proposed construction guidance.

2.1.3.8 Typical UTBWC specifications

Specifications for UTBWC are available from primarily state agencies. These specifications include materials and design practices, as well as construction guides. It is apparent that there are several key differences between agencies in their specification of materials, design, equipment, construction methods, and quality assurance. These differences are likely attributed to differences in materials, design practices, traffic, and climate. Table 18 summarizes the twenty-one states that have specifications or special provisions in place for UTBWC.

Table 18 Selected DOT Specifications for UTBWC

Agency	**Materials Used**	**Design Practices**	**Key Equipment**	**Construction Methods and Procedures**	**Quality assurance and payment**
Arizona	• Uncrushed fine virgin aggregate up to 15% total	• Spread rate per inch thickness 100 lb/yd2 • Film thickness >10µm	• Paving equipment must apply at 30-50 ft/min • MTV required	• Static mode compaction only	• Weekly QC meeting required • No separate payment for WMA
Arkansas	• ≤60% carbonate coarse aggregate	• Air voids ≥10%	• Hot mix must be placed within 5 sec of emulsion	• Open to traffic after rolling complete, mat <160°F	• PWL for asphalt binder content • Pay per square yard
California	• Rubber modified hot mix allowed	• TSR ≥ 70	• Roadtext and Vogele	• Windrowing / pick-up	• Important aspects of

Agency	Materials Used	Design Practices	Key Equipment	Construction Methods and Procedures	Quality assurance and payment
			pavers showcased	machines not allowed	paving summarized
Connecticut	• ≥6.7 pH on emulsion if particle charge inconclusive	• ≤0.1% draindown on mixture	• Two infrared thermo-meters required	• 3 rollers minimum	• <0.625 in or >0.875 in PMA material must be removed • MTV pay unit ton
Delaware	• >35mph speed and >8,000 ADT requires non-carbonate aggregate	• Tack rate 0.20 ±0.05 gsy	• Tack applied by metered pressure sprayer	• Two roller passes minimum before 160°F mid-layer	• Pay by square yard of HMA • Pay includes all work
Illinois	• Saybolt (20-100 s) and paddle (40-200 mPa-s) viscosity req'd	• Binder SBR or SBS PG 70-22	• ≥30 ft/min paver speed	• Place only 50°F and rising	• Tack coat paid for by residue asphalt
Kansas	• Do not use RAP or RAS	• 0.25% amine based anti-strip agent by binder content required	• Screed must crown pavement	• Surface should no tear during paving	• Submit QC plan at pre-construction conference
Maine	• >3% latex in asphalt emulsion	• Calculate film thickness by binder content, surface area, surface factor	• Spray paver must be "self priming"	• Emulsion application 0.17-0.25 gsy based on existing surface	• Control and acceptance limits outlined
Maryland	• Aggregate control tolerance ±2% each sieve	• Mix design has emulsion spray rate based on HMA and existing surface	• n/a	• n/a	• HMA asphalt content tolerance ±0.4%
Massachusetts	• Based on existing specifications	• Based on existing design practices	• Calibrate spray paver 1/year re: ASTM D2995	• Control strip 600-1200 tons	• Bond coat by gallon, HMA by square yard
Michigan	• No reclaimed materials	• Draindown test at JMF asphalt content +0.5%	• Heated internal	• Remove paving markings	• Application rate check 3x day

Agency	Materials Used	Design Practices	Key Equipment	Construction Methods and Procedures	Quality assurance and payment
			emulsion storage tank		and mixture from truck
Minnesota	• PG 64-34 only	• TSR run at 7-8% air voids	• Do not allow rollers to sit on mat	• Damp surface allowed	• Minimum one sample per day of HMA
Missouri	• Fine agg. <10 Methylene Blue	• No non-carbonate req. with dolomite coarse agg	• Handwork must be performed w/in 5 min	• Emulsion applicate rate function of mixture type	• Paid at "contract unit price"
Nevada	• Gap-mixed aggregate gradation	• 0.13-0.17 gsy application rate dependent on hot mix	• Sump pump for excess spray bar emulsion	• Should not be placed on wet pavement	• Two pads for emulsion calibration • Payment per ton HMA
New Hampshire	• WMA required	• Foam WMA not allowed	• >44,000 lbs tractor and screed	• Cover all utilities	• WMA ton, emulsion gallon
Pennsylvania	• No fly ash if ≥3 million ESALs • Binder modified pre-emulsion	• Mix accept: binder content, P200, P8, P1/4 in	• Winter paving restrictions	• 45-85 psy mix application, based on agg gradation	• Density testing not required
Texas	• Mineral filler: ag lime, crusher fines, hydrated lime	• Cellulose/ mineral fibers not allowed with rubber binder	• Thermal imaging not req'd when surface >70°F	• With rubber, in-line viscosity measuring at plant req'd	• Aging ratios >3.5 do not meet spec
Utah	• Coarse agg tests include flakiness index	• ≥5.0% asphalt binder content	• MTV required	• >2 week crack seal cure	• Calibrate paver at 13' and 17' width
Vermont	• Emulsion must be CRS-1P	• Anti strip must be used with granite or quartzite agg	• Screed: variable width, ironing-type, heated	• When temp <140°F, traffic can return	• 19 req'd items in quality control plan
Virginia	• Binder chemical additives must be added before	• Film thickness >9µm	• Mix must be placed on emulsion	• 80-85 psy mixture for ¾ in thickness	• Testing req'd every 500 tons of production

Agency	**Materials Used**	**Design Practices**	**Key Equipment**	**Construction Methods and Procedures**	**Quality assurance and payment**
	mixing with aggregate		within 10 seconds		
Wyoming	• Emulsion must be CRS-2P	• Insoluble residue or polish req'd for aggregate	• Rollers reverse direction w/o backlash	• Minimize handwork	• Emulsion and mix by ton

2.1.3.9 Summary of findings for UTBWC based on literature review

The literature review has identified some of the challenges moving forward with UTBWC guide specifications, from the perspectives of both contractors and agencies. The following are the major findings and challenges based on the preliminary literature review that were considered in this project:

- The materials for UTBWC are aggregate, neat and polymer-modified asphalt binder, polymer-modified rapid set emulsified asphalt, and mineral fillers. While existing state specifications have many similarities, there are also some key differences.
- There are generally three, gap-graded asphalt mixtures used in UTBWC: ½ in. (12.5 mm), 3/8 in. (9.5 mm), and No. 4 (4.75 mm). These are often referred to as Type C, Type B, and Type A respectively.
- The application rate of emulsified asphalt is dependent on the asphalt mixture gradation and the existing pavement surface, but literature is not consistent with the actual numbers that should be considered. In addition, it is not clear if the rate should be designed within a range by the contractor, the engineer, or with input from both.
- The surface of the existing road must be clean and the pavement must be structurally sound before placing UTWBC.
- A special paver that includes both traditional HMA paving equipment, an emulsion storage tank, and a spray bar must be used for UTBWC.
- Rolling and compaction should follow thin lift, gap graded quality guidelines.
- Like all paving materials, quality assurance (including quality control, agency acceptance, and independent assurance) continues to increase in importance, but there are diverse methods in approaching this topic between different resources.
- Measurement and payment generally falls into one of three categories: 1) unit area, 2) ton or gallon of emulsified asphalt and ton of asphalt mixture, or 3) ton or gallon of emulsified asphalt, ton or gallon of asphalt binder, and ton of aggregate.

The findings from the literature helped develop the UTBWC construction guide and quality assurance guide. Resources are available to meet the above challenges and support the national construction guide and quality assurance guide development.

2.2 Online survey

2.2.1 General approach

In addition to the literature search, the team developed and distributed an online survey of state DOTs as follows:

- Assess whether or not the state DOTs are actively involved in sand seals and UTBWC and, if so, whether or not they have done any recent work dealing with the development of guidance for the construction specifications for these treatments.
- For those state DOTs that already have guidelines, identify the person(s) through whom additional information in support of the project can be obtained.

The survey was sent to the voting members of the AASHTO Committee on Materials and Pavements (COMP) and copied to the TRB contact at each state DOT and the District of Columbia. The survey questions are included in Appendix A, along with a graphical summary of the responses as well as a detailed breakdown of the responses. The survey was first sent on November 28, 2022. A reminder to complete the questionnaire was sent December 12, 2022. As of April 2, 2023, 42 out of 51 agencies responded (82.4%). Figure 7 shows a summary of agency responses.

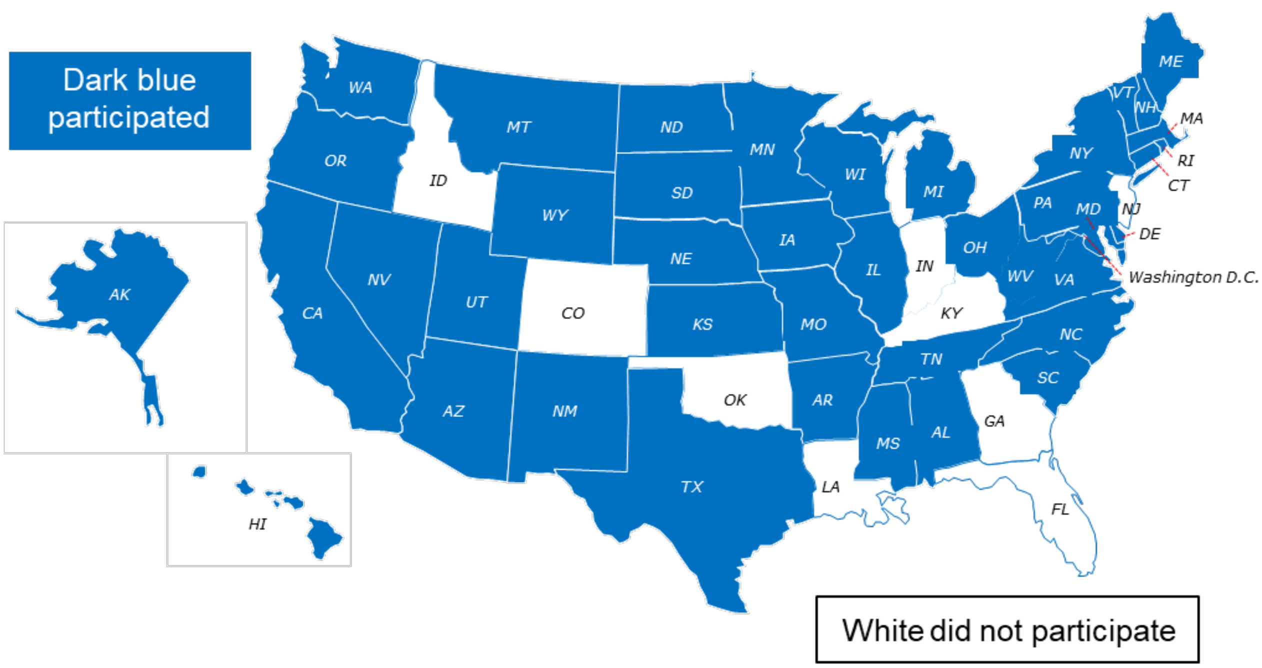

Figure 7 Online Survey Responses for NCHRP 14-48 (map from yourfreetemplates.com)

The following section provides a summary of the results and the major findings/issues what were identified through the course of the literature review.

2.2.2 Summary of findings/major issues

For sand seals, the first interesting finding was that only four agencies regularly use sand seals. This indicates that a sand seal treatment is not commonly used in the United States. However, ten agencies moved forward with answering the remaining questions, so the sample set is not too small. It was not surprising that the majority of agencies placed sand seals on good roads (PCI 85-100), but it was surprising that one agency immediately placed a sand seal after new construction, while a second agency only placed sand seals on the shoulder when micro surfacing was placed in the driving lanes. It was also not surprising that the majority of agencies placed sand seals on roads less than 5,000 AADTT in each direction, but two agencies indicated that they place it on roads up to 100,000 AADTT, which is a high volume roadway. It is encouraging that the majority of agencies indicated that they expect 2-5 years from a sand seal, while a minority expected up to 9 years if placed on the right road at the right time with proper construction.

From a construction standpoint, agencies indicated almost without exception that proper surface preparation, the construction process, workmanship/experience, and quality control contributed to both good short term (less than one year) and longer term (greater than one year) performance for sand seals. There was no clear consensus on what challenges are faced during construction, with about half of the agencies indicating durability, proper application rates, surface preparation, construction equipment, weather conditions, workmanship/experience, and quality control. Of note, it was also indicated that snow plow damage can be an issue with sand seals, as is getting the traffic paint to stick to the surface. There was also no clear consensus of problems with sand seal, but shedding, flushing, and bonding were indicated as problems by 30-40% of the agencies.

From a materials standpoint for sand seals, the agencies were split about 50/50 on whether they use conventional or polymer modified emulsions, with one agency indicating they use both. There was a surprisingly large number of specific restrictions or guidance for aggregate, with specifications revolving around angularity, gradation, and specific aggregate source type. One agency mentioned the aggregate should be coated if used with rubber seals. Finally, the vast majority of agencies (greater than 80%), do not follow a specific procedure for design, do not have a quality assurance field test, and 70% do not have existing construction guide specifications. The agencies that do have specifications use either a method base or end-result specification.

For UTBWC, the first interesting finding is that eighteen agencies regularly use UTBWC, with the majority indicating that they are placed on a satisfactory road (PCI 70-85). One agency indicated that they place UTBWC to seal rigid pavements experiencing alkali-silica reaction (ASR). Half of the agencies placed UTBWC on roads with AADTT from 1,000-5,000 and 50,000-100,000, while the majority placed on roads from 5,000-50,000. The majority of agencies expected UTBWC to last 10-14 years, while just under 50% said 5-9 years if placed on the right road at the right time with proper construction.

For construction of UTBWC, over 65% of agencies felt that asphalt concrete mix design, asphalt emulsion design application rate, existing pavement condition, proper surface preparation, construction process, workmanship/experience, and quality control were important for both short (less than 3 years) and long (greater than 7 years) performance. One agency emphasized that underlying transverse joints reflect quickly and that sealing those reflection cracks in year 3 is important. While there was no strong consensus of challenges of construction, 50% or more reported issues with emulsion application rate, weather conditions, and workmanship/experience. Two agencies explicitly mention that a challenge was a limited number of contractors with access to a spray paver. When considering problems with UTBWC, the majority of agencies did not coalesce around any one problem, but approximately 45% indicated that raveling and cracking were an issue, with seven indicating reflective cracking as the cracking type. However, two agencies did report that during wet-freezing conditions, the UTBWC mat requires the use of additional deicing agents to ensure ice does not form on the surface. One agency said, “we have great performance with ours, I wish we could do more.”

Finally, 100% of states reported that they use polymer modified asphalt binder for UTBWC, where just under 20% used unmodified or rubber modified asphalt binder. The majority of states had a 9.5 mm or 12.5 mm Nominal Maximum Aggregate size for gradation, while over 75% used a gap gradation. For the aggregate itself, over 80% reported specifications around LA Abrasion and crushed faces, with approximately 70% reporting flat and elongated. For the asphalt emulsion, over 90% used polymer modification with two using both conventional and polymer modified. Approximately 50% of agencies used a design procedure and 50% used experience to manage and track construction while 75% did not report a quality assurance field test. However, International Roughness Index and permeability were each reported by one agency. Finally, over 75% of agencies reported a method specification for UTBWC and just over 50% stated they had existing construction guide specifications.

The results of this survey were synthesized with the information found in literature and the specifications reviewed. All of this was then incorporated into the development of the construction guides and quality assurance guides for sand seals and UTBWC.

3.0 DEVELOPING THE PROPOSED CONSTRUCTION GUIDES

3.1 Introduction

The overall objective of this research was to develop recommended guidance for the construction of sand seals and UTBWCs as used in preservation treatments. The iterative process described below was used to accomplish this objective. This process utilized expertise from the perspective of the owner as well as the contractor to produce documents that are immediately implementable.

3.2 Guide Development

The project began with a preliminary review of the pertinent literature and technology including an on-line survey and development the work plan for completing the objective stated above. This resulted in preliminary outlines for the construction guides and quality assurance guide, along with a list of areas that need further exploration. After the areas that needed further exploration were development, the research returned to literature to address those areas, and culminated with the development of the full construction guides and quality assurance guides.

3.2.1 Guide specification preparation

Based on the results of preliminary literature review, Tables 19-20 (sand seals and UTBWC, respectively) show the research team's thinking on the outlines for the two treatments. These outlines were enhanced and bolstered by the survey and follow the AASHTO guidelines for developing Construction guides (AASHTO, 2020).

Special attention is directed to the sections "quality control" and "agency acceptance" in Table 21. Within the past couple of years, these two topics have been placed in quality assurance guides for chip seals, and slurry systems (AASHTO QA Guides, 2020). The quality assurance guides include quality control, agency acceptance, and independent assurance. However, since construction guides from the NCHRP 14-37 report included only sections on quality control and agency acceptance, the project team believes that they should be included here as well. If they are phased out in the final construction guide for inclusion in quality assurance guides, the content developed during this project can be used as a foundation for the content in the quality assurance guides for these two treatments. Finally, Table 22 is an updated outline for proposed agency acceptance for both treatments as well.

Table 19 Outline for Construction Guide Specification for Sand Seals

1. Description
2. Referenced Documents
   - 2.1. AASHTO Standards
   - 2.2. ASTM Standard
   - 2.3. Other Documents
3. Terminology
4. Materials
   - 4.1. Emulsified Asphalt
   - 4.2. Aggregate
   - 4.3. Sand Seal Design
5. Construction
   - 5.1. Weather Limitations
   - 5.2. Preconstruction Meeting
   - 5.3. Road Surface Preparation
     - 5.3.1. Cleaning Pavement
     - 5.3.2. Protecting Accessories
     - 5.3.3. Stripe Removal
   - 5.4. Equipment
     - 5.4.1. Asphalt Distributor
     - 5.4.2. Sand Spreader
     - 5.4.3. Pneumatic Tire Rollers
     - 5.4.4. Brooms
     - 5.4.5. Trucks
   - 5.5. Equipment Calibration
     - 5.5.1. Asphalt Distributor
     - 5.5.2. Sand Spreader
   - 5.6. Test Strip
     - 5.6.1. Verify on Application Rates
     - 5.6.2. Verify Equipment and Workmanship
   - 5.7. Traffic Control
   - 5.8. Application of Emulsified Asphalt
     - 5.8.1. Guide on Field Adjustment
   - 5.9. Application of Sand
     - 5.9.1. Guide on Field Adjustment
   - 5.10. Workmanship
   - 5.11. Longitudinal Joints
   - 5.12. Transverse Paper Joints
   - 5.13. Rolling Operations
   - 5.14. Sweeping
   - 5.15. Protection of Motor Vehicles
   - 5.16. Sequence of Work
   - 5.17. Project Documentation
   - 5.18. Quality Assurance
6. Measurement
   - 6.1. Emulsified Asphalt
   - 6.2. Sand
   - 6.3. Area Treated with Sand Seal
7. Warranty
   - 7.1. Materials
   - 7.2. Equipment
   - 7.3. Work
   - 7.4. Special Warranties
8. Payment
   - 8.1. Payment by Unit Price
   - 8.2. Payment for Completed Sand Seal

Table 20 Outline for the Construction Guide Specification for UTBWC

1. Description
2. Referenced Documents
    - 2.1. AASHTO Standards
    - 2.2. ASTM Standard
    - 2.3. Other Documents
3. Terminology
4. Materials
    - 4.1. Asphalt Binder
    - 4.2. Aggregate
    - 4.3. Asphalt Concrete
    - 4.4. Emulsified Asphalt
    - 4.5. UTBWC Design
5. Construction
    - 5.1. Weather Limitations
    - 5.2. Preconstruction Meeting
    - 5.3. Road Surface Preparation
        - 5.3.1. Cleaning Pavement
        - 5.3.2. Protecting Accessories
        - 5.3.3. Stripe Removal
    - 5.4. Equipment
        - 5.4.1. Paver with Spray Bar
        - 5.4.2. Pneumatic Tire Rollers
        - 5.4.3. Steel Wheel Rollers
        - 5.4.4. Feeder Trucks
    - 5.5. Equipment Calibration
        - 5.5.1. Asphalt Concrete Paver
        - 5.5.2. Emulsified Asphalt Spray Bar
    - 5.6. Test Strip
        - 5.6.1. Verify on Application Rates
        - 5.6.2. Verify Equipment and Workmanship
    - 5.7. Traffic Control
    - 5.8. Application of Asphalt Concrete
        - 5.8.1. Guide on Field Adjustment
    - 5.9. Application of Emulsified Asphalt
        - 5.9.1. Guide on Field Adjustment
    - 5.10. Workmanship
    - 5.11. Longitudinal Joints
    - 5.12. Transverse Paper Joints
    - 5.13. Rolling Operations
    - 5.14. Protection of Motor Vehicles
    - 5.15. Sequence of Work
    - 5.16. Project Documentation
    - 5.17. Quality Assurance
6. Measurement
    - 6.1. Asphalt Concrete
    - 6.2. Emulsified Asphalt
    - 6.3. Area Treated with UTBWC
7. Warranty
    - 7.1. Materials
    - 7.2. Equipment
    - 7.3. Work
    - 7.4. Special Warranties
8. Payment
    - 8.1. Payment by Unit Price
    - 8.2. Payment for Completed UTBWC

Table 21 Outline for Proposed Quality Control (QC) Guides for Both Treatments

1. Description
2. Quality Assurance
3. Quality Control
   - 3.1. General
   - 3.2. Reference Documents
   - 3.3. Definitions
   - 3.4. Personnel
   - 3.5. QC Testing Laboratories and Equipment
   - 3.6. QC Activities
   - 3.7. Contractor's QC Plan
   - 3.8. Records and Documentation
   - 3.9. Compliance with Specifications
4. Agency Acceptance
   - 4.1. General
   - 4.2. Acceptance activities
5. Independent Assurance Program

Table 22 Outline for Proposed Agency Acceptance (AA) Guides for Both Treatments

- Design
  - Methods
  - Project Selection
- Contract Administration
  - Types
  - Management
  - Risks
  - Warranties
- Site Selection
  - General parameters and advice
  - Site selection for specific distresses
  - Road type and surface
  - Traffic specifics
  - Climate
- Material Selection
  - Binder
  - Aggregate
  - Aggregate-Binder Compatibility
- Equipment Practices
  - Binder
  - Aggregate
  - Aggregate and Binder
  - Rollers
  - Sweeping
  - Unique Equipment
- Construction Practices
  - Weather
  - Road Preparation
  - Binder Application
  - Aggregate Application
  - Roller Operations
  - Sweeping/Brooming
  - Traffic Control
  - Construction Practices for High-Volume Traffic
  - Quality Assurance
  - Quality Control
  - Lab Design and Materials Testing
  - Field Testing
- Performance Measures
  - Engineering-Based Qualitative Performance Indicators

Based on the literature review as well as the agency survey reported in Chapter 2, areas that required extra attention are summarized in Table 23. Each of the areas identified in Table 23 are key parts of the construction guides that were developed. A more detailed review of the issues in Table 23 using the literature and survey was performed to obtain additional information or clarification on the items shown in Table 23. All of the additional information was folded into the literature review presented in Chapter 2.

Table 23 Areas that required additional attention

Item	Sand Seal	UTBWC
Materials	• What should be suitable types of emulsified asphalt? • Quality tests required for sand • Any performance tests should be conducted on sand seals?	• Is there a limit for carbonate coarse aggregate? • Can RAP or RAS be used? • What type of polymer modification is possible for HMA, for emulsion? • Are there special considerations for rubber modified HMA?
Mix Design	• What should be the proper application rates for emulsified asphalt and sand, respectively?	• What is the best (balance ease with accuracy) way to measure film thickness? • What asphalt binder content should be used for draindown test? • Should anti-strip be required? • How is emulsion spray rate determined (HMA type, surface, etc)? • What are potential performance tests: cracking/rutting (BMD), tack coat shear strength
Equipment	• It may be challenging to apply the sand uniformly without a proper sand spreading equipment.	• What is the optimal paver speed? • Is there an desired rolling/ compacting procedure? • What are similarities/differences in paving procedures between UTBWC and standard asphalt mixtures? • How do we test what we are getting? Min. number of roller passes, proper rolling, proper temperature → could have regional notes
Surface preparation	• What are the requirements for the surface preparation before a sand seal?	• What are the potential surface moisture condition: dry, damp, or wet?
QA procedures (may need to be separated into separate quality assurance guides)	• Sand seal is similar with chip seals in term of construction procedures. However, it also has its own tests and unique requirement. Should sand seal has its own QA guide?	• Synthesize existing state and federal documents for thin lift hot mix, UTBWC, and other similar treatments
Method of payment	• Should sand seals be paid by area completed or quantities of materials used, or both area and quantity?	• Should asphalt mixture be separate from asphalt emulsion? • Should aggregate be separate from asphalt binder in mixture? • Can we include incentives?
Performance issues	• How to deal with performance issues, such as bleeding, raveling, or delamination?	• Should handwork be allowed? • Cold joint bumps and poor compaction.
Motivation of selection	• When should sand seals be used? Where should sand seals be used? What are the purposes of selecting a sand seal treatment?	• How to differentiate between ultra-thin overlays and standard overlays?

Based on the feedback from the NCHRP panel from the interim report and interim meeting, the synthesis and analysis of existing information from Chapter 2, and information from the additional review of issues from Table 23, detailed construction guide specifications and quality assurance guides for sand seals and UTBWC were prepared.

In addition to the full AASHTO formatted construction guide specifications, a PowerPoint presentation of the construction guide specifications was developed and submitted to the NCHRP for approval to present at AASHTO COMP by the project PI.

Privileged

3.2.2 Presentation

A second presentation was prepared in PowerPoint that describes the research effort, the two construction guide specifications, the two quality assurance guides, and is intended to facilitate adoption by AASHTO. This second presentation was tailored for use by the state DOTs and other organizations, including small and local agencies, actively engaged in pavement preservation so that utilization of the two construction guide specifications is optimized. This presentation was produced to accompany a technical memorandum entitled “Implementation of Research Findings and Products” so that any agency wishing to implement one or both guide specifications will have clear direction on how to do so. The technical memorandum includes, but not be limited to:

a. **Background**: project overview and basics of two treatments;
b. **Findings**: treatment usage, treatment design, types of performance issues, specification types, quality assurance use, etc.;
c. **Implementation**: identifying possible public and private institutions (such as AASHTO COM, AASHTO COMP, ISSA, AEMA, and/or PPRA) that might take leadership in applying the research findings/products;
d. **Barriers to implementation**: discuss barriers affecting potential implementation of the findings/products and recommend possible actions to address these issues;
e. **Advantages to implementation**: review advantages to implementation based on findings and recommended possible actions on how to showcase these advantages; and
f. **Summary and recommendations**: methods of identifying and measuring the impacts associated with implementation of the findings/products. Implementation of these recommendations is not part of the research project and, if warranted, details of these actions will be developed and implemented in future efforts.

This presentation provides a foundation for future webinars and other methods of dissemination of the research in future work beyond this proposal.

4.0 SUMMARY AND RECOMMENDATIONS

4.1 Summary

From a review of literature and a survey of state highway agencies, this project discovered considerable variety regarding specifications for construction of sand seals and UTBWC. This variety ranges from specifications containing very comprehensive descriptions of the materials and methods to be used, to those that significantly lack such descriptions. The research did not uncover any specifications that contained every part of what should be included in a completely comprehensive construction specification for the studied treatments. Therefore, the proposed construction guidance documents developed from this research are intended to help agencies fill gaps in existing construction specifications where gaps exist, or to be utilized as complete construction specifications. In addition, proposed QA guides were developed for each of the two treatments as standalone documents. These can be found in Part III of this report.

The construction guidance documents were designated Section 4XX (Sand Seals) and Section 4YY(Ultrathin Bonded Wearing Course) to conform to the relevant sections of Division 400, Flexible Pavements of the AASHTO Guide Specifications for Highway Construction (2020). At the time of this writing, the section numbers for these treatments had not yet been assigned. The quality assurance guides were titled “Sand Seal Quality Assurance Guide” and “UltraThin Bonded Wearing Course Quality Assurance Guide,” and have followed the format established by previous pavement preservation quality assurance guides, including scrub seals, slurry surfacing, and tack coats for pavement preservation treatments.

4.2 Recommendations for Research

There are several recommendations for research moving forward. First, past time intervals of sand seal/UTBWC pre-construction guide to those post-construction guide should be explored. This will help answer the question as to whether the construction guides make sense economically. Second, moving forward, it is important to develop performance based specifications. This report identified several lab tests to quantify the performance of UTBWC, but these tests need to be expanded on and incorporated into specifications. Third, it is recommended to include pay adjustments if the treatments are not meeting specification. This could include some sort of incentive and disincentive program in order to reward high quality work and penalize low quality work in the field.

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APPENDIX A – ONLINE SURVEY

A.1 Survey form

Survey Questions for

NCHRP Project 14-48: Guidance for the Construction of Sand Seals and Ultra-thin Bonded Wearing Courses

Thank you for participating in the survey on sand seals and Ultra-thin Bonded Wearing Courses (UTBWC) for NCHRP 14-48. Please feel free to contact Andrew Braham (afbraham@uark.edu) if you have any questions.

Sand Seals

1. Please enter your name, state, position, and email (note, none of this information will be shared externally, it will only be used for any potential follow-up questions).
2. Has your agency ever placed a sand seal (per the definition provided in AASHTO MP 34: "An application of emulsified asphalt, followed immediately by an application of a single layer of fine graded cover aggregate, which is then rolled for embedment. The seal may be applied in multiple lifts depending on traffic demands and existing road surface conditions.")?
    a. Yes
    b. No (if no, please skip to Question 17 in the next section)
3. Does your agency regularly use sand seals? If no, please discuss why you do not.
    a. Yes
    b. No
4. What is the pavement's existing surface condition for sand seals to be considered good treatment candidates per ASTM D6433?
    a. PCI 85-100 (good)
    b. PCI 70-85 (satisfactory)
    c. PCI 55-70 (fair)
    d. PCI 40-55 (poor)
    e. Other (please enter below)
5. What traffic levels (AADTT in each direction) are considered appropriate for sand seals? Please check all that apply.
    a. < 500
    b. 500 – 1,000
    c. 1,000 – 5,000
    d. 5,000 – 20,000
    e. 20,000 – 50,000
    f. 50,000 – 100,000
    g. >100,000

6. Assuming the sand seal is placed on the right road at the right time, with proper construction, what is the expected treatment life?
    a. <2 years
    b. 2-5 years
    c. 5-9 years
    d. 10-14 years
    e. >14 years
7. What design or construction factors contribute to good short (less than one year) performance for sand seals (please check all that apply)?
    a. Design traffic volume
    b. Mix design
    c. Existing pavement condition
    d. Proper surface preparation
    e. Construction process
    f. Workmanship/experience
    g. Quality control
    h. Other (please enter below)
8. What design or construction factors contribute to good long term (greater than 3 years) performance for sand seals (please check all that apply)?
    a. Design traffic volume
    b. Mix design
    c. Existing pavement condition
    d. Proper surface preparation
    e. Construction process
    f. Workmanship/experience
    g. Quality control
    h. Other (please enter below)
9. What challenges have you faced with the construction of sand seals (please check all that apply)?
    a. Durability
    b. Good joints
    c. Proper application rates
    d. Surface preparation
    e. Construction equipment
    f. Weather conditions
    g. Workmanship/experience
    h. Quality control
    i. Other (please enter below)

10. Which of these problems, if any, have you had with sand seals once they have been constructed?
    a. Shedding (the raveling/disintegration of the sand seal)
    b. Flushing
    c. Bonding (loss of adhesion of asphalt emulsion residue from aggregate)
    d. Delamination
    e. Excess sand application
    f. Other (please enter below)
11. For sand seals, do you routinely use conventional and/or polymer modified asphalt emulsion?
    a. Conventional emulsions
    b. Polymer modified emulsion
    c. Both
12. For sand seals, do you have any specific restrictions or guidance for the type or source of aggregate used? If yes, please provide the restrictions and/or guidance?
    a. Yes
    b. No
13. For sand seals, do you follow a specific procedure for the design of sand seals? If yes, what procedure do you use?
    a. Yes
    b. No
14. For sand seals, do you have a quality assurance field tests that relates to the performance of this treatment? If yes, what tests? (If you use a test that is not an AASHTO/ASTM procedure, please attach the procedure used. Otherwise, skip and continue the questionnaire.)
    a. Yes
    b. No
15. What type of specification do you use for sand seals
    a. Method specification
    b. Performance based (warranty, limited warrantee, design/build, etc.)
    c. End result specification (focus on final product only)
    d. Other (please enter below)
16. Does your agency have existing construction guide specifications (including information on materials, design practices, construction practices, QC/Acceptance testing, measurement and payment, etc.) for sand seals? If yes, please upload the file here. If no, skip and continue the questionnaire.

Ultra-thin Bonded Wearing Courses (UTBWCs)

17. Has your agency ever placed a UTBWC (per the definition provided in AASHTO MP 44: "A 0.5-1.0 in. (12.5-25.4 mm) thick mix and consist of a polymer-modified emulsified asphalt membrane followed immediately with an ultrathin gap graded asphalt mixture. The ultrathin bonded wearing course shall be placed using an integrated distributor-paver to apply the bonded wearing course.")?
    a. Yes
    b. No (if no, please go to the end and submit)
18. Does your agency regularly use UTBWCs? If no, please discuss why you do not.
    a. Yes
    b. No
19. What is the pavement's existing surface condition for UTBWCs to be considered good treatment candidates per ASTM D6433? Note, if you do not use PCI, please approximate your pavement condition to this scale.
    a. PCI 85-100 (good)
    b. PCI 70-85 (satisfactory)
    c. PCI 55-70 (fair)
    d. PCI 40-55 (poor)
    e. Other (please enter below)
20. What traffic levels (AADTT in each direction) are considered appropriate for UTBWC? Please check all that apply.
    a. < 500
    b. 500 – 1,000
    c. 1,000 – 5,000
    d. 5,000 – 20,000
    e. 20,000 – 50,000
    f. 50,000 – 100,000
    g. >100,000
21. Assuming the UTBWC is placed on the right road at the right time, with proper construction, what is the expected treatment life?
    a. <2 years
    b. 2-5 years
    c. 5-9 years
    d. 10-14 years
    e. >14 years
22. What design or construction factors contribute to good short (less than three years) performance for UTBWCs (please check all that apply)?
    a. Asphalt concrete mix design
    b. Asphalt emulsion design application rate
    c. Existing pavement condition
    d. Proper surface preparation

e. Construction process
f. Workmanship/experience
g. Quality control
h. Other (please enter below)

23. What design or construction factors contribute to good long term (greater than 7 years) performance for UTBWCs (please check all that apply)?
    a. Asphalt concrete mix design
    b. Asphalt emulsion design application rate
    c. Existing pavement condition
    d. Proper surface preparation
    e. Construction process
    f. Workmanship/experience
    g. Quality control
    h. Other (please enter below)
24. What challenges have you faced with the construction of UTBWCs (please check all that apply)?
    a. Durability
    b. Good joints
    a. Asphalt mixture materials
    b. Asphalt mixture application rate (thickness)
    c. Emulsion type selection
    d. Proper application rates of emulsion (quantity and/or even distribution)
    e. Emulsion washout during/after construction
    f. Emulsion break issues
    g. Roadway geometry
    h. Proper surface preparation
    i. Construction process
    j. Specialty paver performance (combined emulsion spray bar with paving machine)
    k. Weather conditions
    l. Workmanship/experience
    m. Quality control
    n. Other (please enter below)
25. Which of these problems, if any, have you had with UTBWCs once they have been constructed (please check all that apply)?
    a. Raveling
    b. Bleeding
    c. Cracking (list type below, i.e. reflective, longitudinal, top down, fatigue, etc.)
    d. Delamination
    e. Improper gradation (closed matrix, poor drainage)
    f. Emulsion washout
    g. Emulsion break issues
    h. Other (please enter below)

26. For UTBWCs, what type of asphalt binder do you use in the asphalt mixture (please check all that apply)?
    a. Unmodified (neat asphalt binder)
    b. Polymer modified asphalt binder
    c. Rubber modified asphalt binder
    d. Other (please enter below)
27. For UTBWCs, what size of nominal maximum aggregate size do you use in the asphalt mixture (please check all that apply)?
    a. 4.75 mm
    b. 9.5 mm
    c. 12.5 mm
    d. 19.0 mm
    e. Other (please enter below)
28. For UTBWCs, what type of gradation do you use in the asphalt mixture (please check all that apply)?
    a. Gap graded
    b. Open graded
    c. Dense graded
    d. SMA
    e. Other (please enter below)
29. For UTBWCs, which types of aggregate quality tests do you specify in design (please check all that apply)?
    a. LA Abrasion
    b. Micro Deval
    c. Crushed faces
    d. Absorption
    e. Soundness: sulfate
    f. Soundness: magnesium
    g. Flat and elongated
    h. Other (please enter below)
30. For UTBWCs, do you routinely use conventional and/or polymer modified asphalt emulsion?
    a. Conventional emulsion
    b. Polymer modified emulsion
    c. Both
31. For UTBWCs: how do you determine the application rates for the asphalt mixture? If you use a design procedure, please provide the procedure used.
    a. Using design procedure
    b. Experience

32. During construction of UTBWC, do you use any specific technology to manage and track uniform placement, compaction, or any other construction parameter? If yes, please describe the technology used.
    a. Yes
    b. No
33. For UTBWCs, do you have a quality assurance field test that relates the performance of this treatment? If you have a quality assurance field test, please provide the procedure used (i.e. standard number).
    a. Yes
    b. No
34. What type of specification do you use for UTBWCs
    a. Method specification
    b. Performance based (warrantee, limited warrantee, design/build, etc.)
    c. End result specification (focus on final product only)
    d. Other (please enter below)
35. Does your agency have existing construction guide specifications (including information on materials, design practices, construction practices, QC/Acceptance testing, measurement and payment, etc.) for UTBWC? If yes, please upload the file here. If no, skip and continue the questionnaire.

A.2 Detailed results

Sand Seal summary tables (Table 1 of 12 – note, the number “1” indicates that the box was checked)

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
2. Has your agency ever placed a sand seal per the definition provided in AASHTO MP 34?									
Yes		1	1		1			1	
No	1			1			1		1
3. Does your agency regularly use sand seals?									
Yes			1						
No		1			1			1	
4.What is the pavement's existing surface condition for sand seals to be considered good treatment candidates per ASTM D6433?									
PCI 85-100 (good)		1	1						
PCI 70-85 (satisfactory)		1	1						
PCI 55-70 (fair)			1					1	
PCI 40-55 (poor)									
Other (please enter below)									
5. What traffic levels (AADTT in each direction) are considered appropriate for sand seals?									
< 500		1						1	
500 - 1,000		1							
1,000 - 5,000		1							
5,000 - 20,000			1						
20,000 - 50,000									
50,000 - 100,000									
>100,000									
6. Assuming the sand seal is placed on the right road at the right time, with proper construction, what is the expected treatment life?									
<2 years									
2-5 years		1	1					1	
5-9 years									
10-14 years									
>14 years									
7. What design or construction factors contribute to good short (less than one year) performance for sand seals (please check all that apply)?									
Design traffic volume			1						
Mix Design									
Existing pavement condition			1						
Proper surface preparation		1	1						
Construction process		1	1					1	
Workmanship/experience		1	1					1	
Quality control		1	1					1	
Other (please enter below)			1						
8. What design or construction factors contribute to good long term (greater than 3 years) performance for sand seals (please check all that apply)?									
Design traffic volume			1						
Mix Design									
Existing pavement condition		1	1						
Proper surface preparation		1	1						
Construction process		1	1					1	
Workmanship/experience		1	1					1	
Quality control		1	1					1	
Other (please enter below)			1						

Sand Seal summary tables (Table 2 of 12 – note, the number "1" indicates that the box was checked)

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
9. What challenges have you faced with the construction of sand seals (please check all that apply)?									
Durability			1						
Good joints			1						
Proper application rates			1					1	
Surface preparation		1	1						
Construction equipment			1						
Weather conditions		1	1					1	
Workmanship/experience			1					1	
Quality control			1					1	
Other (please enter below)			1						
10. Which of these problems, if any, have you had with sand seals once they have been constructed?									
Shedding			1						
Flushing			1					1	
Bonding			1					1	
Delamination									
Excess sand application									
Other (please enter below)		1							
11. For sand seals, do you routinely use conventional and/or polymer modified asphalt emulsion?									
Conventional emulsions		1	1						
Polymer modified emulsion								1	
Both									
12. For sand seals, do you have any specific restrictions or guidance for the type or source of aggregate used?									
Yes		1	1						
No								1	
13. For sand seals, do you follow a specific procedure for the design of sand seals? If yes, what procedure do you use?									
Yes			1						
No		1						1	
14. For sand seals, do you have a quality assurance field tests that relates to the performance of this treatment? If yes, what tests?									
Yes		1	1						
No								1	
15. What type of specification do you use for sand seals									
Method specification									
Performance based									
End result specification		1	1						
Other(s)								1	
16. Does your agency have existing construction guide specifications for sand seals?									
Yes		1							
No			1					1	

Sand Seal summary tables (Table 3 of 12 – note, the number "1" indicates that the box was checked)

	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine
2. Has your agency ever placed a sand seal per the definition provided in AASHTO MP 34?											
Yes							1				
No			1		1			1			1
3. Does your agency regularly use sand seals?											
Yes											
No							1				
4.What is the pavement's existing surface condition for sand seals to be considered good treatment candidates per ASTM D6433?											
PCI 85-100 (good)											
PCI 70-85 (satisfactory)											
PCI 55-70 (fair)							1				
PCI 40-55 (poor)											
Other (please enter below)											
5. What traffic levels (AADTT in each direction) are considered appropriate for sand seals?											
< 500							1				
500 - 1,000							1				
1,000 - 5,000							1				
5,000 - 20,000											
20,000 - 50,000											
50,000 - 100,000											
>100,000											
6. Assuming the sand seal is placed on the right road at the right time, with proper construction, what is the expected treatment life?											
<2 years											
2-5 years							1				
5-9 years							1				
10-14 years											
>14 years											
7. What design or construction factors contribute to good short (less than one year) performance for sand seals (please check all that apply)?											
Design traffic volume							1				
Mix Design							1				
Existing pavement condition							1				
Proper surface preparation							1				
Construction process							1				
Workmanship/experience							1				
Quality control							1				
Other (please enter below)							1				
8. What design or construction factors contribute to good long term (greater than 3 years) performance for sand seals (please check all that apply)?											
Design traffic volume							1				
Mix Design							1				
Existing pavement condition							1				
Proper surface preparation							1				
Construction process							1				
Workmanship/experience							1				
Quality control							1				
Other (please enter below)							1				

Sand Seal summary tables (Table 4 of 12 – note, the number "1" indicates that the box was checked)

	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine
9. What challenges have you faced with the construction of sand seals (please check all that apply)?											
Durability							1				
Good joints											
Proper application rates											
Surface preparation											
Construction equipment											
Weather conditions							1				
Workmanship/experience							1				
Quality control											
Other (please enter below)							1				
10. Which of these problems, if any, have you had with sand seals once they have been constructed?											
Shedding											
Flushing											
Bonding											
Delamination											
Excess sand application											
Other (please enter below)							1				
11. For sand seals, do you routinely use conventional and/or polymer modified asphalt emulsion?											
Conventional emulsions											
Polymer modified emulsion							1				
Both											
12. For sand seals, do you have any specific restrictions or guidance for the type or source of aggregate used?											
Yes							1				
No											
13. For sand seals, do you follow a specific procedure for the design of sand seals? If yes, what procedure do you use?											
Yes											
No							1				
14. For sand seals, do you have a quality assurance field tests that relates to the performance of this treatment? If yes, what tests?											
Yes											
No							1				
15. What type of specification do you use for sand seals											
Method specification							1				
Performance based											
End result specification											
Other(s)											
16. Does your agency have existing construction guide specifications for sand seals?											
Yes							1				
No											

Sand Seal summary tables (Table 5 of 12 – note, the number "1" indicates that the box was checked)

	Maryland	Massachusetts	Michigan	Minnesota	Mississippi	Missouri	Montana	Nebraska	Nevada
2. Has your agency ever placed a sand seal per the definition provided in AASHTO MP 34?									
Yes									
No	1	1	1	1	1	1	1	1	1
3. Does your agency regularly use sand seals?									
Yes									
No				1					
4.What is the pavement's existing surface condition for sand seals to be considered good treatment candidates per ASTM D6433?									
PCI 85-100 (good)									
PCI 70-85 (satisfactory)									
PCI 55-70 (fair)									
PCI 40-55 (poor)									
Other (please enter below)									
5. What traffic levels (AADTT in each direction) are considered appropriate for sand seals?									
< 500									
500 - 1,000									
1,000 - 5,000									
5,000 - 20,000									
20,000 - 50,000									
50,000 - 100,000									
>100,000									
6. Assuming the sand seal is placed on the right road at the right time, with proper construction, what is the expected treatment life?									
<2 years									
2-5 years									
5-9 years									
10-14 years									
>14 years									
7. What design or construction factors contribute to good short (less than one year) performance for sand seals (please check all that apply)?									
Design traffic volume									
Mix Design									
Existing pavement condition									
Proper surface preparation									
Construction process									
Workmanship/experience									
Quality control									
Other (please enter below)									
8. What design or construction factors contribute to good long term (greater than 3 years) performance for sand seals (please check all that apply)?									
Design traffic volume									
Mix Design									
Existing pavement condition									
Proper surface preparation									
Construction process									
Workmanship/experience									
Quality control									
Other (please enter below)									

Sand Seal summary tables (Table 6 of 12 – note, the number “1” indicates that the box was checked)

	Maryland	Massachusetts	Michigan	Minnesota	Mississippi	Missouri	Montana	Nebraska	Nevada
9. What challenges have you faced with the construction of sand seals (please check all that apply)?									
Durability									
Good joints									
Proper application rates									
Surface preparation									
Construction equipment									
Weather conditions									
Workmanship/experience									
Quality control									
Other (please enter below)									
10. Which of these problems, if any, have you had with sand seals once they have been constructed?									
Shedding									
Flushing									
Bonding									
Delamination									
Excess sand application									
Other (please enter below)									
11. For sand seals, do you routinely use conventional and/or polymer modified asphalt emulsion?									
Conventional emulsions									
Polymer modified emulsion									
Both									
12. For sand seals, do you have any specific restrictions or guidance for the type or source of aggregate used?									
Yes									
No									
13. For sand seals, do you follow a specific procedure for the design of sand seals? If yes, what procedure do you use?									
Yes									
No									
14. For sand seals, do you have a quality assurance field tests that relates to the performance of this treatment? If yes, what tests?									
Yes									
No									
15. What type of specification do you use for sand seals									
Method specification									
Performance based									
End result specification									
Other(s)									
16. Does your agency have existing construction guide specifications for sand seals?									
Yes									
No									

Sand Seal summary tables (Table 7 of 12 – note, the number “1” indicates that the box was checked)

	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota
2. Has your agency ever placed a sand seal (per the definition provided in AASHTO MP 34?						
Yes	1		1			1
No				1	1	
3. Does your agency regularly use sand seals?						
Yes						1
No	1		1			
4.What is the pavement's existing surface condition for sand seals to be considered good treatment candidates per ASTM D6433?						
PCI 85-100 (good)	1		1			1
PCI 70-85 (satisfactory)	1					
PCI 55-70 (fair)						
PCI 40-55 (poor)						
Other (please enter below)						
5. What traffic levels (AADTT in each direction) are considered appropriate for sand seals?						
< 500	1		1			1
500 - 1,000	1		1			1
1,000 - 5,000	1					1
5,000 - 20,000						1
20,000 - 50,000						1
50,000 - 100,000						1
>100,000						1
6. Assuming the sand seal is placed on the right road at the right time, with proper construction, what is the expected treatment life?						
<2 years						
2-5 years	1		1			
5-9 years						1
10-14 years						
>14 years						
7. What design or construction factors contribute to good short (less than one year) performance for sand seals (please check all that ap						
Design traffic volume			1			
Mix Design	1					
Existing pavement condition	1		1			
Proper surface preparation	1		1			1
Construction process	1		1			1
Workmanship/experience	1		1			1
Quality control	1		1			1
Other (please enter below)						
8. What design or construction factors contribute to good long term (greater than 3 years) performance for sand seals (please check all t						
Design traffic volume			1			
Mix Design	1					
Existing pavement condition	1		1			
Proper surface preparation	1		1			1
Construction process	1		1			1
Workmanship/experience	1		1			1
Quality control	1		1			1
Other (please enter below)						

Sand Seal summary tables (Table 8 of 12 – note, the number "1" indicates that the box was checked)

	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota
9. What challenges have you faced with the construction of sand seals (please check all that apply)?						
Durability	1					1
Good joints						1
Proper application rates	1					1
Surface preparation	1					1
Construction equipment	1					1
Weather conditions	1					1
Workmanship/experience	1		1			1
Quality control	1					1
Other (please enter below)	1					
10. Which of these problems, if any, have you had with sand seals once they have been constructed?						
Shedding						1
Flushing	1					
Bonding	1					
Delamination						
Excess sand application			1			
Other (please enter below)	1					
11. For sand seals, do you routinely use conventional and/or polymer modified asphalt emulsion?						
Conventional emulsions			1			
Polymer modified emulsion						1
Both	1					
12. For sand seals, do you have any specific restrictions or guidance for the type or source of aggregate used?						
Yes	1					1
No			1			
13. For sand seals, do you follow a specific procedure for the design of sand seals? If yes, what procedure do you use?						
Yes						
No	1		1			1
14. For sand seals, do you have a quality assurance field tests that relates to the performance of this treatment? If yes, what tests?						
Yes						
No	1		1			1
15. What type of specification do you use for sand seals						
Method specification	1					1
Performance based						
End result specification						
Other(s)	1					
16. Does your agency have existing construction guide specifications for sand seals?						
Yes	1					
No			1			1

Sand Seal summary tables (Table 9 of 12 – note, the number "1" indicates that the box was checked)

	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Tennessee
2. Has your agency ever placed a sand seal per the definition provided in AASHTO MP 34?								
Yes			1				1	
No	1			1	1	1		1
3. Does your agency regularly use sand seals?								
Yes							1	
No			1					
4.What is the pavement's existing surface condition for sand seals to be considered good treatment candidates per ASTM D6433?								
PCI 85-100 (good)			1					
PCI 70-85 (satisfactory)			1					
PCI 55-70 (fair)			1					
PCI 40-55 (poor)								
Other (please enter below)							1	
5. What traffic levels (AADTT in each direction) are considered appropriate for sand seals?								
< 500			1				1	
500 - 1,000			1				1	
1,000 - 5,000			1				1	
5,000 - 20,000							1	
20,000 - 50,000							1	
50,000 - 100,000							1	
>100,000							1	
6. Assuming the sand seal is placed on the right road at the right time, with proper construction, what is the expected treatment life?								
<2 years								
2-5 years			1				1	
5-9 years								
10-14 years								
>14 years								
7. What design or construction factors contribute to good short (less than one year) performance for sand seals (please check all that apply)?								
Design traffic volume			1					
Mix Design								
Existing pavement condition			1				1	
Proper surface preparation			1				1	
Construction process			1				1	
Workmanship/experience			1				1	
Quality control								
Other (please enter below)								
8. What design or construction factors contribute to good long term (greater than 3 years) performance for sand seals (please check all that apply)?								
Design traffic volume			1					
Mix Design								
Existing pavement condition			1				1	
Proper surface preparation			1				1	
Construction process			1				1	
Workmanship/experience			1				1	
Quality control								
Other (please enter below)								

Sand Seal summary tables (Table 10 of 12 – note, the number “1” indicates that the box was checked)

	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Tennessee
9. What challenges have you faced with the construction of sand seals (please check all that apply)?								
Durability			1					
Good joints								
Proper application rates			1					
Surface preparation								
Construction equipment								
Weather conditions								
Workmanship/experience								
Quality control								
Other (please enter below)							1	
10. Which of these problems, if any, have you had with sand seals once they have been constructed?								
Shedding			1					
Flushing			1					
Bonding								
Delamination								
Excess sand application								
Other (please enter below)								
11. For sand seals, do you routinely use conventional and/or polymer modified asphalt emulsion?								
Conventional emulsions			1				1	
Polymer modified emulsion								
Both								
12. For sand seals, do you have any specific restrictions or guidance for the type or source of aggregate used?								
Yes							1	
No			1					
13. For sand seals, do you follow a specific procedure for the design of sand seals? If yes, what procedure do you use?								
Yes								
No			1				1	
14. For sand seals, do you have a quality assurance field tests that relates to the performance of this treatment? If yes, what tests?								
Yes								
No			1				1	
15. What type of specification do you use for sand seals								
Method specification			1					
Performance based								
End result specification								
Other(s)							1	
16. Does your agency have existing construction guide specifications for sand seals?								
Yes								
No			1				1	

Sand Seal summary tables (Table 11 of 12 – note, the number "1" indicates that the box was checked)

	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
2. Has your agency ever placed a sand seal per the definition provided in AASHTO MP 34?								
Yes	1							
No		1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1
3. Does your agency regularly use sand seals?								
Yes								
No	1							
4.What is the pavement's existing surface condition for sand seals to be considered good treatment candidates per ASTM D6433?								
PCI 85-100 (good)								
PCI 70-85 (satisfactory)								
PCI 55-70 (fair)								
PCI 40-55 (poor)								
Other (please enter below)	1							
	1							
5. What traffic levels (AADTT in each direction) are considered appropriate for sand seals?								
< 500								
500 - 1,000								
1,000 - 5,000								
5,000 - 20,000								
20,000 - 50,000								
50,000 - 100,000								
>100,000								
6. Assuming the sand seal is placed on the right road at the right time, with proper construction, what is the expected treatment life?								
<2 years								
2-5 years	1							
5-9 years								
10-14 years								
>14 years								
7. What design or construction factors contribute to good short (less than one year) performance for sand seals (please check all tha								
Design traffic volume	1							
Mix Design	1							
Existing pavement condition	1							
Proper surface preparation	1							
Construction process	1							
Workmanship/ experience	1							
Quality control	1							
Other (please enter below)								
8. What design or construction factors contribute to good long term (greater than 3 years) performance for sand seals (please check								
Design traffic volume	1							
Mix Design	1							
Existing pavement condition	1							
Proper surface preparation	1							
Construction process	1							
Workmanship/ experience	1							
Quality control	1							
Other (please enter below)								

Sand Seal summary tables (Table 12 of 12 – note, the number “1” indicates that the box was checked)

	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
9. What challenges have you faced with the construction of sand seals (please check all that apply)?								
Durability	1							
Good joints								
Proper application rates	1							
Surface preparation	1							
Construction equipment	1							
Weather conditions								
Workmanship/ experience	1							
Quality control								
Other (please enter below)								
10. Which of these problems, if any, have you had with sand seals once they have been constructed?								
Shedding	1							
Flushing								
Bonding								
Delamination								
Excess sand application								
Other (please enter below)								
11. For sand seals, do you routinely use conventional and/or polymer modified asphalt emulsion?								
Conventional emulsions								
Polymer modified emulsion	1							
Both								
12. For sand seals, do you have any specific restrictions or guidance for the type or source of aggregate used?								
Yes	1							
No								
13. For sand seals, do you follow a specific procedure for the design of sand seals? If yes, what procedure do you use?								
Yes								
No	1							
14. For sand seals, do you have a quality assurance field tests that relates to the performance of this treatment? If yes, what tests?								
Yes								
No	1							
15. What type of specification do you use for sand seals								
Method specification	1							
Performance based								
End result specification	1							
Other(s)								
16. Does your agency have existing construction guide specifications for sand seals?								
Yes								
No	1							

UTBWC summary tables (Table 1 of 18 – note, the number “1” indicates that the box was checked)

17. Has your agency ever placed a UTBWC per the definition provided in AASHTO MP 44?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
Yes			1	1	1		1	1	
No	1	1							1

18. Does your agency regularly use UTBWCs?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
Yes				1	1		1	1	
No			1						

19. What is the pavement's existing surface condition for UTBWCs to be considered good treatment candidates per ASTM D6433?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
PCI 85-100 (good)				1			1		
PCI 70-85 (satisfactory)			1	1			1		
PCI 55-70 (fair)			1		1			1	
PCI 40-55 (poor)									
Other (please enter below)			1						

20. What traffic levels (AADTT in each direction) are considered appropriate for UTBWC?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
< 500				1					
500 - 1,000				1				1	
1,000 - 5,000				1				1	
5,000 - 20,000				1	1		1		
20,000 - 50,000			1	1	1		1		
50,000 - 100,000			1	1	1		1		
>100,000				1	1		1		

21. Assuming the UTBWC is placed on the right road at the right time, with proper construction, what is the expected treatment life?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
<2 years									
2-5 years									
5-9 years				1	1			1	
10-14 years			1	1	1		1		
>14 years									

22. What design or construction factors contribute to good short (less than three years) performance for UTBWCs (please check all that apply)?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
Asphalt concrete mix design			1		1		1	1	
Asphalt emulsion design application rate			1		1		1	1	
Existing pavement condition			1		1			1	
Proper surface preparation			1		1			1	
Construction process			1	1	1		1	1	
Workmanship/experience			1	1	1		1	1	
Quality control			1	1	1		1	1	
Other (please enter below)					1				

23. What design or construction factors contribute to good long term (greater than 7 years) performance for UTBWCs (please check all that apply)?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
Asphalt concrete mix design			1		1			1	
Asphalt emulsion design application rate			1		1		1	1	
Existing pavement condition			1	1	1		1	1	
Proper surface preparation			1		1		1	1	
Construction process			1	1	1		1	1	
Workmanship/experience			1	1	1			1	
Quality control			1	1	1		1	1	
Other (please enter below)					1				

UTBWC summary tables (Table 2 of 18 – note, the number "1" indicates that the box was checked)

24. What challenges have you faced with the construction of UTBWCs (please check all that apply)?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
Durability									
Good joints					1				
Asphalt mixture materials								1	
Asphalt mixture application rate			1				1		
Emulsion type selection									
Proper application rate of emulsion							1	1	
Emulsion washout							1		
Emulsion break issues							1		
Roadway geometry					1				
Proper surface preparation					1				
Construction process				1			1	1	
Specialty paver performance							1	1	
Weather conditions			1	1	1		1		
Workmanship/experience				1			1	1	
Quality control							1	1	
Other (please enter below)									

25. Which of these problems, if any, have you had with UTBWCs once they have been constructed

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
Raveling							1		
Bleeding							1		
Cracking (list type)								1	
Delamination				1					
Improper gradation				1					
Emulsion washout							1		
Emulsion break issues									
Other (please enter below)			1						

26. For UTBWCs, what type of asphalt binder do you use in the asphalt mixture?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
Unmodified (neat asphalt binder)					1			1	
Polymer modified asphalt binder			1	1	1		1	1	
Rubber modified asphalt binder			1		1				
Other (please enter below)									

27. For UTBWCs, what size of nominal maximum aggregate size do you use in the asphalt mixture?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
4.75 mm								1	
9.5 mm			1	1	1		1		
12.5 mm				1	1				
19.0 mm									
Other (please enter below)									

28. For UTBWCs, what type of gradation do you use in the asphalt mixture (please check all that apply)?

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
Gap graded			1	1	1		1		
Open graded					1				
Dense graded			1		1			1	
SMA									
Other (please enter below)					1				

UTBWC summary tables (Table 3 of 18 – note, the number "1" indicates that the box was checked)

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Dist. of Columbia
29. For UTBWCs, which types of aggregate quality tests do you specify in design (please check all that apply)?									
LA Abrasion			1	1	1		1	1	
Micro Deval				1					
Crushed faces			1	1	1		1		
Absorption			1					1	
Soundness: sulfate							1		
Soundness: magnesium							1		
Flat and elongated				1	1				
Other (please enter below)			1		1		1		
30. For UTBWCs, do you routinely use conventional and/or polymer modified asphalt emulsion?									
Conventional emulsions									
Polymer modified emulsion			1	1	1		1		
Both								1	
31. For UTBWCs: how do you determine the application rates for the asphalt mixture?									
Use design procedure			1	1	1				
Experience							1	1	
32. During construction of UTBWC, do you use any specific technology to manage and track any construction parameter?									
Yes			1		1		1		
No				1				1	
33. For UTBWCs, do you have a quality assurance field test that relates the performance of this treatment?									
Yes				1	1				
No			1				1	1	
34. What type of specification do you use for UTBWCs?									
Method specification			1	1			1	1	
Performance based									
End result specification			1					1	
Other(s)					1				
35. Does your agency have existing construction guide specifications for UTBWC?									
Yes			1	1					
No					1		1	1	

UTBWC summary tables (Table 4 of 18 – note, the number "1" indicates that the box was checked)

	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine
17. Has your agency ever placed a UTBWC per the definition provided in AASHTO MP 44?											
Yes					1		1	1			1
No			1								
18. Does your agency regularly use UTBWCs?											
Yes					1			1			1
No							1				
19. What is the pavement's existing surface condition for UTBWCs to be considered good treatment candidates per ASTM D6433?											
PCI 85-100 (good)								1			
PCI 70-85 (satisfactory)								1			1
PCI 55-70 (fair)											1
PCI 40-55 (poor)											
Other (please enter below)					1						
20. What traffic levels (AADTT in each direction) are considered appropriate for UTBWC?											
< 500					1			1			1
500 - 1,000					1			1			1
1,000 - 5,000					1			1			1
5,000 - 20,000					1			1			1
20,000 - 50,000					1			1			1
50,000 - 100,000					1			1			
>100,000					1						
21. Assuming the UTBWC is placed on the right road at the right time, with proper construction, what is the expected treatment life?											
<2 years											
2-5 years											
5-9 years								1			1
10-14 years					1						
>14 years											
22. What design or construction factors contribute to good short (less than three years) performance for UTBWCs (please check all that apply)?											
Asphalt concrete mix design					1			1			1
Asphalt emulsion design application rate					1			1			
Existing pavement condition					1			1			
Proper surface preparation								1			1
Construction process								1			1
Workmanship/experience					1			1			1
Quality control								1			
Other (please enter below)											
23. What design or construction factors contribute to good long term (greater than 7 years) performance for UTBWCs (please check all that apply)?											
Asphalt concrete mix design					1			1			1
Asphalt emulsion design application rate					1			1			1
Existing pavement condition					1			1			1
Proper surface preparation								1			1
Construction process								1			1
Workmanship/experience					1			1			1
Quality control								1			1
Other (please enter below)											

UTBWC summary tables (Table 5 of 18 – note, the number “1” indicates that the box was checked)

	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine
24. What challenges have you faced with the construction of UTBWCs (please check all that apply)?											
Durability								1			1
Good joints					1			1			
Asphalt mixture materials											1
Asphalt mixture application rate											
Emulsion type selection											
Proper application rate of emulsion					1			1			
Emulsion washout								1			
Emulsion break issues								1			
Roadway geometry											
Proper surface preparation					1			1			
Construction process								1			
Specialty paver performance											
Weather conditions								1			
Workmanship/experience								1			1
Quality control								1			
Other (please enter below)											
25. Which of these problems, if any, have you had with UTBWCs once they have been constructed											
Raveling								1			1
Bleeding											
Cracking (list type)					1			1			1
Delamination								1			
Improper gradation											
Emulsion washout								1			
Emulsion break issues											
Other (please enter below)											
26. For UTBWCs, what type of asphalt binder do you use in the asphalt mixture?											
Unmodified (neat asphalt binder)											1
Polymer modified asphalt binder					1			1			1
Rubber modified asphalt binder											
Other (please enter below)											
27. For UTBWCs, what size of nominal maximum aggregate size do you use in the asphalt mixture?											
4.75 mm											
9.5 mm					1						
12.5 mm					1			1			1
19.0 mm											
Other (please enter below)											
28. For UTBWCs, what type of gradation do you use in the asphalt mixture (please check all that apply)?											
Gap graded					1						1
Open graded								1			
Dense graded											
SMA											
Other (please enter below)											

UTBWC summary tables (Table 6 of 18 – note, the number “1” indicates that the box was checked)

	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine
29. For UTBWCs, which types of aggregate quality tests do you specify in design (please check all that apply)?											
LA Abrasion					1			1			1
Micro Deval								1			1
Crushed faces								1			1
Absorption					1			1			1
Soundness: sulfate					1						
Soundness: magnesium											
Flat and elongated					1			1			1
Other (please enter below)								1			
30. For UTBWCs, do you routinely use conventional and/or polymer modified asphalt emulsion?											
Conventional emulsions											
Polymer modified emulsion					1			1			1
Both											
31. For UTBWCs: how do you determine the application rates for the asphalt mixture?											
Use design procedure					1						
Experience								1			1
32. During construction of UTBWC, do you use any specific technology to manage and track any construction parameter?											
Yes											
No					1			1			1
33. For UTBWCs, do you have a quality assurance field test that relates the performance of this treatment?											
Yes											
No					1			1			1
34. What type of specification do you use for UTBWCs?											
Method specification					1						1
Performance based											
End result specification											
Other(s)								1			
35. Does your agency have existing construction guide specifications for UTBWC?											
Yes					1			1			
No											

UTBWC summary tables (Table 7 of 18 – note, the number “1” indicates that the box was checked)

	Maryland	Massachusetts	Michigan	Minnesota	Mississippi	Missouri	Montana	Nebraska	Nevada
17. Has your agency ever placed a UTBWC per the definition provided in AASHTO MP 44?									
Yes	1	1	1	1		1		1	1
No					1		1		
18. Does your agency regularly use UTBWCs?									
Yes	1	1		1		1			1
No			1					1	
19. What is the pavement's existing surface condition for UTBWCs to be considered good treatment candidates per ASTM D6433?									
PCI 85-100 (good)	1	1	1	1					
PCI 70-85 (satisfactory)	1	1	1	1		1			
PCI 55-70 (fair)			1	1					
PCI 40-55 (poor)									
Other (please enter below)		1						1	1
20. What traffic levels (AADTT in each direction) are considered appropriate for UTBWC?									
< 500			1	1					
500 - 1,000			1	1					
1,000 - 5,000			1	1		1			
5,000 - 20,000	1	1	1	1		1			1
20,000 - 50,000	1	1	1	1		1			1
50,000 - 100,000		1		1					1
>100,000		1		1					1
21. Assuming the UTBWC is placed on the right road at the right time, with proper construction, what is the expected treatment life?									
<2 years									
2-5 years									
5-9 years	1		1					1	
10-14 years	1	1	1	1		1			1
>14 years									1
22. What design or construction factors contribute to good short (less than three years) performance for UTBWCs (please check all that apply)?									
Asphalt concrete mix design	1			1					
Asphalt emulsion design application rate	1	1		1		1		1	
Existing pavement condition	1		1	1					1
Proper surface preparation	1	1	1	1		1			
Construction process	1	1	1	1					1
Workmanship/experience	1	1	1	1					1
Quality control	1	1		1					1
Other (please enter below)		1		1				1	
23. What design or construction factors contribute to good long term (greater than 7 years) performance for UTBWCs (please check all that apply)?									
Asphalt concrete mix design	1			1					
Asphalt emulsion design application rate	1	1		1		1			
Existing pavement condition	1	1	1	1		1		1	1
Proper surface preparation	1	1	1	1		1			1
Construction process	1	1	1	1		1			1
Workmanship/experience	1	1	1	1		1			1
Quality control	1	1		1					1
Other (please enter below)									

UTBWC summary tables (Table 8 of 18 – note, the number “1” indicates that the box was checked)

	Maryland	Massachusetts	Michigan	Minnesota	Mississippi	Missouri	Montana	Nebraska	Nevada
24. What challenges have you faced with the construction of UTBWCs (please check all that apply)?									
Durability				1				1	
Good joints								1	1
Asphalt mixture materials									
Asphalt mixture application rate									
Emulsion type selection									
Proper application rate of emulsion				1		1			1
Emulsion washout									1
Emulsion break issues									
Roadway geometry						1			
Proper surface preparation									1
Construction process									1
Specialty paver performance	1					1			
Weather conditions	1	1							1
Workmanship/experience	1	1				1			1
Quality control		1							1
Other (please enter below)	1		1	1					
25. Which of these problems, if any, have you had with UTBWCs once they have been constructed									
Raveling		1				1			1
Bleeding									
Cracking (list type)						1			1
Delamination									1
Improper gradation									
Emulsion washout									
Emulsion break issues									
Other (please enter below)	1	1	1			1			
26. For UTBWCs, what type of asphalt binder do you use in the asphalt mixture?									
Unmodified (neat asphalt binder)									
Polymer modified asphalt binder	1	1	1	1		1		1	1
Rubber modified asphalt binder		1				1			
Other (please enter below)				1					
27. For UTBWCs, what size of nominal maximum aggregate size do you use in the asphalt mixture?									
4.75 mm				1				1	
9.5 mm	1			1		1			1
12.5 mm	1	1	1			1			
19.0 mm						1			
Other (please enter below)								1	
28. For UTBWCs, what type of gradation do you use in the asphalt mixture (please check all that apply)?									
Gap graded	1	1	1	1		1			1
Open graded			1						
Dense graded								1	
SMA									
Other (please enter below)				1					

UTBWC summary tables (Table 9 of 18 – note, the number "1" indicates that the box was checked)

	Maryland	Massachusetts	Michigan	Minnesota	Mississippi	Missouri	Montana	Nebraska	Nevada
29. For UTBWCs, which types of aggregate quality tests do you specify in design (please check all that apply)?									
LA Abrasion		1	1	1		1			1
Micro Deval			1			1			
Crushed faces		1	1			1		1	1
Absorption		1	1						
Soundness: sulfate		1				1		1	1
Soundness: magnesium		1							
Flat and elongated		1	1	1		1			
Other (please enter below)				1				1	1
30. For UTBWCs, do you routinely use conventional and/or polymer modified asphalt emulsion?									
Conventional emulsions									
Polymer modified emulsion	1	1	1	1		1		1	1
Both									
31. For UTBWCs: how do you determine the application rates for the asphalt mixture?									
Use design procedure	1		1	1		1		1	
Experience		1							1
32. During construction of UTBWC, do you use any specific technology to manage and track any construction parameter?									
Yes	1								1
No		1	1	1		1		1	
33. For UTBWCs, do you have a quality assurance field test that relates the performance of this treatment?									
Yes						1			1
No	1	1		1				1	
34. What type of specification do you use for UTBWCs?									
Method specification	1		1	1		1		1	1
Performance based									
End result specification									
Other(s)		1		1					
35. Does your agency have existing construction guide specifications for UTBWC?									
Yes	1	1		1					1
No						1		1	

UTBWC summary tables (Table 10 of 18 – note, the number "1" indicates that the box was checked)

	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota
17. Has your agency ever placed a UTBWC per the definition provided in AASHTO MP 44?						
Yes	1			1		
No			1		1	1
18. Does your agency regularly use UTBWCs?						
Yes	1					
No				1		
19. What is the pavement's existing surface condition for UTBWCs to be considered good treatment candidates per ASTM D6433?						
PCI 85-100 (good)	1					
PCI 70-85 (satisfactory)	1			1		
PCI 55-70 (fair)						
PCI 40-55 (poor)						
Other (please enter below)						
20. What traffic levels (AADTT in each direction) are considered appropriate for UTBWC?						
< 500				1		
500 - 1,000				1		
1,000 - 5,000				1		
5,000 - 20,000	1			1		
20,000 - 50,000	1					
50,000 - 100,000	1					
>100,000						
21. Assuming the UTBWC is placed on the right road at the right time, with proper construction, what is the expected treatment life?						
<2 years						
2-5 years						
5-9 years				1		
10-14 years	1					
>14 years						
22. What design or construction factors contribute to good short (less than three years) performance for UTBWCs (please check all that						
Asphalt concrete mix design				1		
Asphalt emulsion design application rate				1		
Existing pavement condition	1			1		
Proper surface preparation	1			1		
Construction process	1			1		
Workmanship/experience	1			1		
Quality control	1			1		
Other (please enter below)						
23. What design or construction factors contribute to good long term (greater than 7 years) performance for UTBWCs (please check all t						
Asphalt concrete mix design				1		
Asphalt emulsion design application rate				1		
Existing pavement condition	1			1		
Proper surface preparation	1			1		
Construction process	1			1		
Workmanship/experience	1			1		
Quality control	1			1		
Other (please enter below)						

UTBWC summary tables (Table 11 of 18 – note, the number "1" indicates that the box was checked)

	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota
24. What challenges have you faced with the construction of UTBWCs (please check all that apply)?						
Durability				1		
Good joints	1			1		
Asphalt mixture materials						
Asphalt mixture application rate				1		
Emulsion type selection						
Proper application rate of emulsion				1		
Emulsion washout						
Emulsion break issues				1		
Roadway geometry						
Proper surface preparation				1		
Construction process	1			1		
Specialty paver performance				1		
Weather conditions	1			1		
Workmanship/experience	1			1		
Quality control						
Other (please enter below)						
25. Which of these problems, if any, have you had with UTBWCs once they have been constructed						
Raveling	1					
Bleeding	1			1		
Cracking (list type)				1		
Delamination				1		
Improper gradation				1		
Emulsion washout						
Emulsion break issues						
Other (please enter below)						
26. For UTBWCs, what type of asphalt binder do you use in the asphalt mixture?						
Unmodified (neat asphalt binder)	1					
Polymer modified asphalt binder	1			1		
Rubber modified asphalt binder	1					
Other (please enter below)						
27. For UTBWCs, what size of nominal maximum aggregate size do you use in the asphalt mixture?						
4.75 mm						
9.5 mm				1		
12.5 mm	1			1		
19.0 mm						
Other (please enter below)						
28. For UTBWCs, what type of gradation do you use in the asphalt mixture (please check all that apply)?						
Gap graded	1					
Open graded				1		
Dense graded				1		
SMA				1		
Other (please enter below)						

UTBWC summary tables (Table 12 of 18 – note, the number "1" indicates that the box was checked)

	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota
29. For UTBWCs, which types of aggregate quality tests do you specify in design (please check all that apply)?						
LA Abrasion	1			1		
Micro Deval				1		
Crushed faces	1			1		
Absorption						
Soundness: sulfate						
Soundness: magnesium						
Flat and elongated				1		
Other (please enter below)						
30. For UTBWCs, do you routinely use conventional and/or polymer modified asphalt emulsion?						
Conventional emulsions						
Polymer modified emulsion				1		
Both	1					
31. For UTBWCs: how do you determine the application rates for the asphalt mixture?						
Use design procedure				1		
Experience	1					
32. During construction of UTBWC, do you use any specific technology to manage and track any construction parameter?						
Yes						
No	1			1		
33. For UTBWCs, do you have a quality assurance field test that relates the performance of this treatment?						
Yes				1		
No	1					
34. What type of specification do you use for UTBWCs?						
Method specification	1			1		
Performance based						
End result specification						
Other(s)						
35. Does your agency have existing construction guide specifications for UTBWC?						
Yes	1					
No				1		

UTBWC summary tables (Table 13 of 18 – note, the number "1" indicates that the box was checked)

	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Tennessee
17. Has your agency ever placed a UTBWC per the definition provided in AASHTO MP 44?								
Yes				1	1			1
No	1		1			1	1	
18. Does your agency regularly use UTBWCs?								
Yes								
No				1	1			1
19. What is the pavement's existing surface condition for UTBWCs to be considered good treatment candidates per ASTM D6433?								
PCI 85-100 (good)								
PCI 70-85 (satisfactory)								
PCI 55-70 (fair)					1			
PCI 40-55 (poor)								
Other (please enter below)				1				1
20. What traffic levels (AADTT in each direction) are considered appropriate for UTBWC?								
< 500				1	1			
500 - 1,000				1	1			
1,000 - 5,000				1	1			
5,000 - 20,000				1	1			1
20,000 - 50,000				1				1
50,000 - 100,000				1				
>100,000				1				
21. Assuming the UTBWC is placed on the right road at the right time, with proper construction, what is the expected treatment life?								
<2 years								
2-5 years								
5-9 years				1				1
10-14 years					1			
>14 years								
22. What design or construction factors contribute to good short (less than three years) performance for UTBWCs (please check all that apply)?								
Asphalt concrete mix design								1
Asphalt emulsion design application rate					1			1
Existing pavement condition					1			1
Proper surface preparation					1			1
Construction process					1			1
Workmanship/experience					1			1
Quality control					1			1
Other (please enter below)				1				
23. What design or construction factors contribute to good long term (greater than 7 years) performance for UTBWCs (please check all that apply)?								
Asphalt concrete mix design				1	1			1
Asphalt emulsion design application rate				1	1			1
Existing pavement condition				1	1			1
Proper surface preparation				1	1			1
Construction process				1	1			1
Workmanship/experience				1	1			1
Quality control				1	1			1
Other (please enter below)								

UTBWC summary tables (Table 14 of 18 – note, the number "1" indicates that the box was checked)

	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Tennessee
24. What challenges have you faced with the construction of UTBWCs (please check all that apply)?								
Durability				1				
Good joints				1				
Asphalt mixture materials								
Asphalt mixture application rate				1				
Emulsion type selection								
Proper application rate of emulsion				1				
Emulsion washout								
Emulsion break issues								
Roadway geometry								
Proper surface preparation					1			
Construction process				1				
Specialty paver performance				1	1			
Weather conditions					1			
Workmanship/experience					1			
Quality control				1				
Other (please enter below)				1				1
25. Which of these problems, if any, have you had with UTBWCs once they have been constructed								
Raveling				1	1			1
Bleeding								
Cracking (list type)				1	1			
Delamination				1				
Improper gradation				1				
Emulsion washout								
Emulsion break issues								
Other (please enter below)								
26. For UTBWCs, what type of asphalt binder do you use in the asphalt mixture?								
Unmodified (neat asphalt binder)				1				
Polymer modified asphalt binder				1	1			1
Rubber modified asphalt binder								
Other (please enter below)								
27. For UTBWCs, what size of nominal maximum aggregate size do you use in the asphalt mixture?								
4.75 mm								1
9.5 mm				1	1			
12.5 mm				1				
19.0 mm								
Other (please enter below)				1				
28. For UTBWCs, what type of gradation do you use in the asphalt mixture (please check all that apply)?								
Gap graded				1	1			
Open graded								1
Dense graded								
SMA								
Other (please enter below)								

UTBWC summary tables (Table 15 of 18 – note, the number “1” indicates that the box was checked)

	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Tennessee
29. For UTBWCs, which types of aggregate quality tests do you specify in design (please check all that apply)?								
LA Abrasion				1	1			1
Micro Deval				1				
Crushed faces				1	1			1
Absorption				1				1
Soundness: sulfate				1	1			1
Soundness: magnesium								
Flat and elongated				1	1			1
Other (please enter below)								
30. For UTBWCs, do you routinely use conventional and/or polymer modified asphalt emulsion?								
Conventional emulsions								
Polymer modified emulsion				1	1			1
Both								
31. For UTBWCs: how do you determine the application rates for the asphalt mixture?								
Use design procedure				1				
Experience					1			
32. During construction of UTBWC, do you use any specific technology to manage and track any construction parameter?								
Yes				1				
No					1			
33. For UTBWCs, do you have a quality assurance field test that relates the performance of this treatment?								
Yes								
No				1	1			
34. What type of specification do you use for UTBWCs?								
Method specification				1	1			
Performance based								
End result specification								
Other(s)								
35. Does your agency have existing construction guide specifications for UTBWC?								
Yes				1				
No					1			1

UTBWC summary tables (Table 16 of 18 – note, the number "1" indicates that the box was checked)

	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
17. Has your agency ever placed a UTBWC per the definition provided in AASHTO MP 44?								
Yes	1	1	1	1	1			1
No						1	1	
	1	1	1	1	1	1	1	1
18. Does your agency regularly use UTBWCs?								
Yes	1	1	1	1				1
No					1			
19. What is the pavement's existing surface condition for UTBWCs to be considered good treatment candidates per ASTM D6433?								
PCI 85-100 (good)	1	1	1					
PCI 70-85 (satisfactory)	1	1	1	1	1			1
PCI 55-70 (fair)			1					
PCI 40-55 (poor)								
Other (please enter below)	1							
20. What traffic levels (AADTT in each direction) are considered appropriate for UTBWC?								
< 500								
500 - 1,000				1				
1,000 - 5,000				1				1
5,000 - 20,000		1	1		1			
20,000 - 50,000		1	1					
50,000 - 100,000		1	1					
>100,000		1						
21. Assuming the UTBWC is placed on the right road at the right time, with proper construction, what is the expected treatment life?								
<2 years								
2-5 years			1					
5-9 years								1
10-14 years	1	1		1	1			
>14 years								
22. What design or construction factors contribute to good short (less than three years) performance for UTBWCs (please check all t								
Asphalt concrete mix design	1	1	1		1			1
Asphalt emulsion design application rate	1	1	1	1	1			1
Existing pavement condition	1	1	1	1	1			1
Proper surface preparation	1	1	1	1	1			1
Construction process	1	1	1		1			1
Workmanship/ experience	1	1	1		1			1
Quality control	1	1	1		1			1
Other (please enter below)								
23. What design or construction factors contribute to good long term (greater than 7 years) performance for UTBWCs (please check								
Asphalt concrete mix design	1	1	1		1			1
Asphalt emulsion design application rate	1	1	1		1			1
Existing pavement condition	1	1	1		1			1
Proper surface preparation	1	1	1		1			1
Construction process	1	1	1		1			1
Workmanship/ experience	1	1	1	1	1			1
Quality control	1	1	1	1	1			1
Other (please enter below)								

UTBWC summary tables (Table 17 of 18 – note, the number "1" indicates that the box was checked)

	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
24. What challenges have you faced with the construction of UTBWCs (please check all that apply)?								
Durability			1					
Good joints								
Asphalt mixture materials								
Asphalt mixture application rate		1	1					
Emulsion type selection								
Emulsion application rate		1	1	1	1			1
Emulsion washout				1				
Emulsion break issues				1				
Roadway geometry		1						
Proper surface preparation	1	1	1		1			1
Construction process	1		1		1			1
Specialty paver performance					1			1
Weather conditions			1		1			
Workmanship/ experience	1	1	1					1
Quality control	1	1	1					
Other (please enter below)								
25. Which of these problems, if any, have you had with UTBWCs once they have been constructed								
Raveling			1	1				
Bleeding			1					1
Cracking (list type)			1		1			
Delamination		1						
Improper gradation	1							
Emulsion washout				1				1
Emulsion break issues								
Other (please enter below)	1							
26. For UTBWCs, what type of asphalt binder do you use in the asphalt mixture?								
Unmodified (neat asphalt binder)								
Polymer modified asphalt binder	1	1	1	1	1			1
Rubber modified asphalt binder								
Other (please enter below)								
27. For UTBWCs, what size of nominal maximum aggregate size do you use in the asphalt mixture?								
4.75 mm								
9.5 mm				1				1
12.5 mm		1	1		1			
19.0 mm								
Other (please enter below)	1							
28. For UTBWCs, what type of gradation do you use in the asphalt mixture (please check all that apply)?								
Gap graded	1	1	1	1	1			
Open graded								1
Dense graded								
SMA								
Other (please enter below)								

UTBWC summary tables (Table 18 of 18 – note, the number “1” indicates that the box was checked)

	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
29. For UTBWCs, which types of aggregate quality tests do you specify in design (please check all that apply)?								
LA Abrasion	1	1	1		1			1
Micro Deval	1	1						
Crushed faces	1	1	1		1			1
Absorption					1			
Soundness: sulfate	1	1						
Soundness: magnesium	1							
Flat and elongated	1	1	1	1	1			
Other (please enter below)	1							1
30. For UTBWCs, do you routinely use conventional and/or polymer modified asphalt emulsion?								
Conventional emulsions								
Polymer modified emulsion	1	1	1	1	1			1
Both								
31. For UTBWCs: how do you determine the application rates for the asphalt mixture?								
Use design procedure	1	1						
Experience			1	1	1			
32. During construction of UTBWC, do you use any specific technology to manage and track any construction parameter?								
Yes	1							
No		1	1	1	1			1
33. For UTBWCs, do you have a quality assurance field test that relates the performance of this treatment?								
Yes	1							
No		1	1	1	1			1
34. What type of specification do you use for UTBWCs?								
Method specification	1	1	1	1				
Performance based				1				
End result specification		1			1			1
Other(s)								
35. Does your agency have existing construction guide specifications for UTBWC?								
Yes	1	1		1				
No			1		1			1

A.3 Summary Figures

The graphical results of the survey are shown in the following thirty-three graphs. Note, this section simply shows the results. The analysis can be found in Section 2.2.2. Note, the first question read: "Question 1. Please enter your name, state, position, and email (note, none of this information will be shared externally, it will only be used for any potential follow-up questions)."

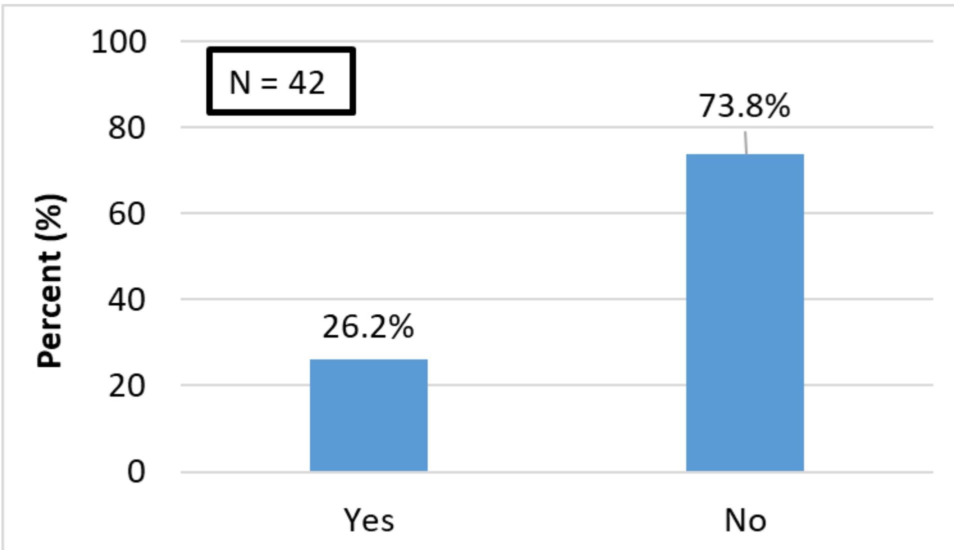
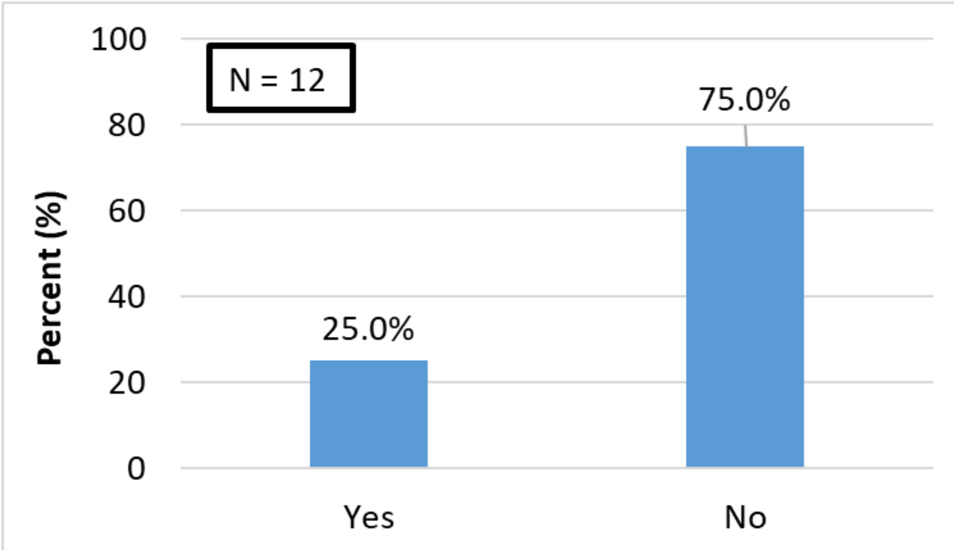


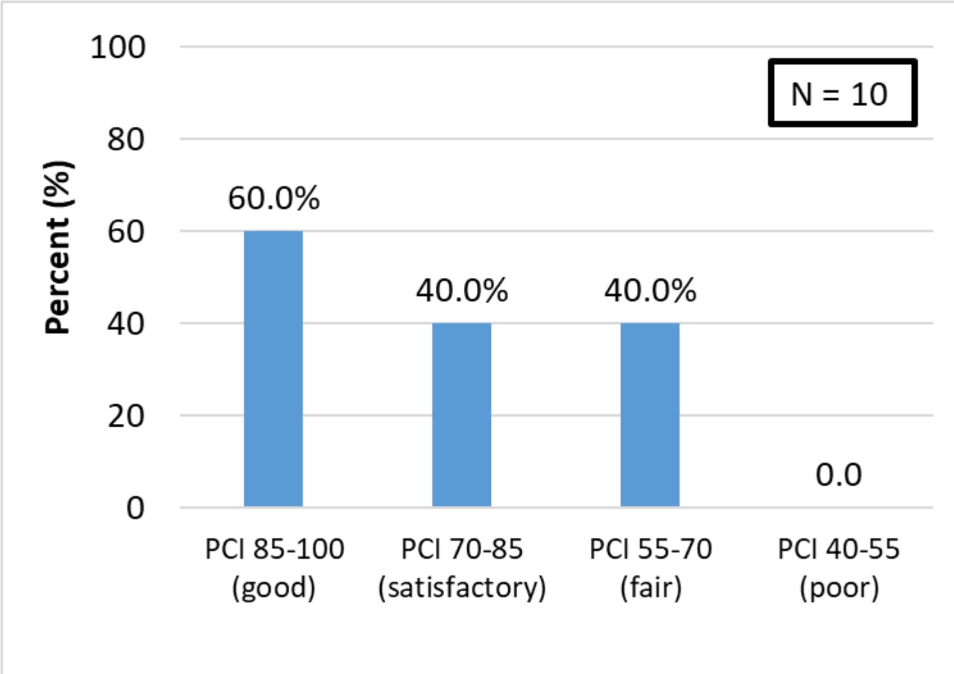
Figure 8 Question 2. Has your agency ever placed a sand seal per the definition provided in AASHTO MP 34?



Comments:

- We used to place with our own forces but stopped due to lack of forces (New Hampshire)
- Occasionally used (Iowa)
- Our agency used sand seal in the past. Other preservation treatments such as slurry seals, micro surfacing, emulsion/hot applied chip seals, and UTBWC are routinely used for pavement preservation (California)
- The use of such technology is up to the individual district. The districts have alternative sealing and texturing practices. However, there are a few districts that may occasionally utilize this. The most similar method we have is "scrub seal". We use a broom to force emulsion into cracks and follow with a fine aggregate/sand prior to rolling. (Texas)
- We have higher volume roadways and the chip seals we use are a better product for our agency. We use ~3/8in aggregate. (Minnesota)
- We use what we call a flush seal. Flush seals are usually applied within 10 days after the completion of paving. (South Dakota)
- We are just starting to more regularly use them. Primarily on one of our major airports and we are now branching out to using them on our highways. (Alaska)
- We've only done test sections. We did see the benefit of a sand seal for our area (Deleware)

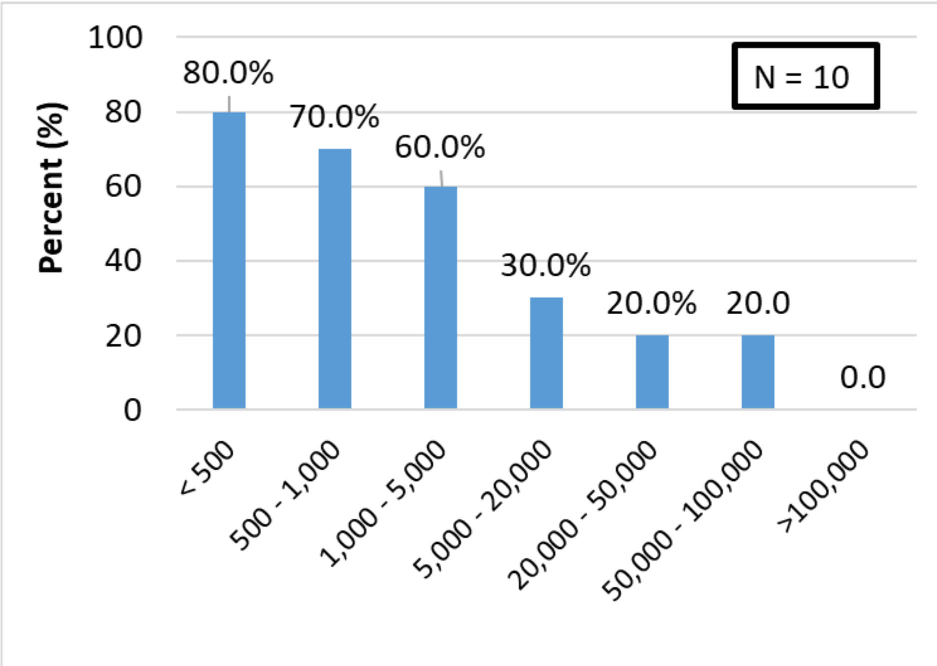
Figure 9 Question 3. Does your agency regularly use sand seals?



Comments:

- This is ultimately up to the district and their preventative maintenance (PM) plan. Our pavement manual does not list this as a typical PM measure; however, it is allowed per a special specification. This would be used for a minimally cracked pavement that was in overall good condition. It would be used to seal very small cracks and add surface texture. Most likely this would be used in very rural areas with large mileage to cover. (Texas)
- New construction. (South Dakota)

Figure 10 Question 4. What is the pavement's existing surface condition for sand seals to be considered good treatment candidates per ASTM D6433?



Comments:

- Sand seals are only placed on shoulders when micro-surfacing the driving lanes, they are not applied on driving lanes or in any other scenario (North Dakota)

Figure 11 Question 5. What traffic levels (AADTT in each direction) are considered appropriate for sand seals?

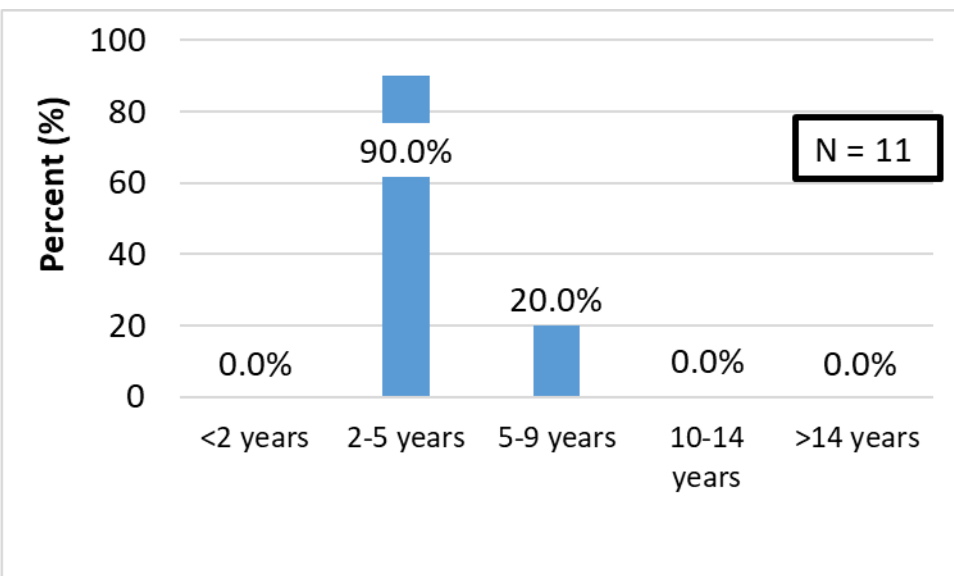
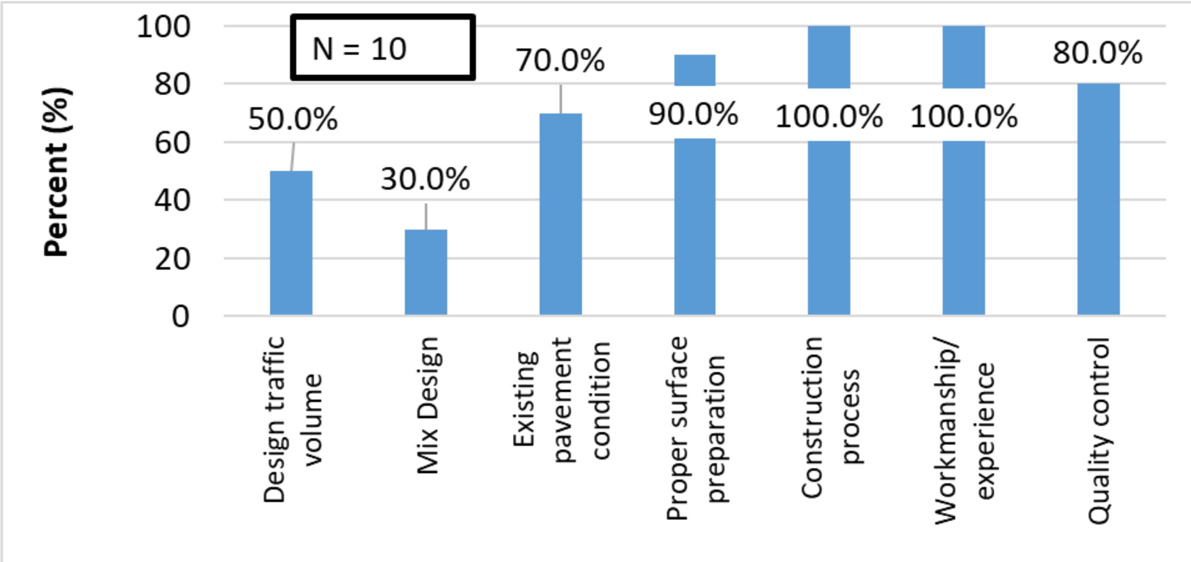


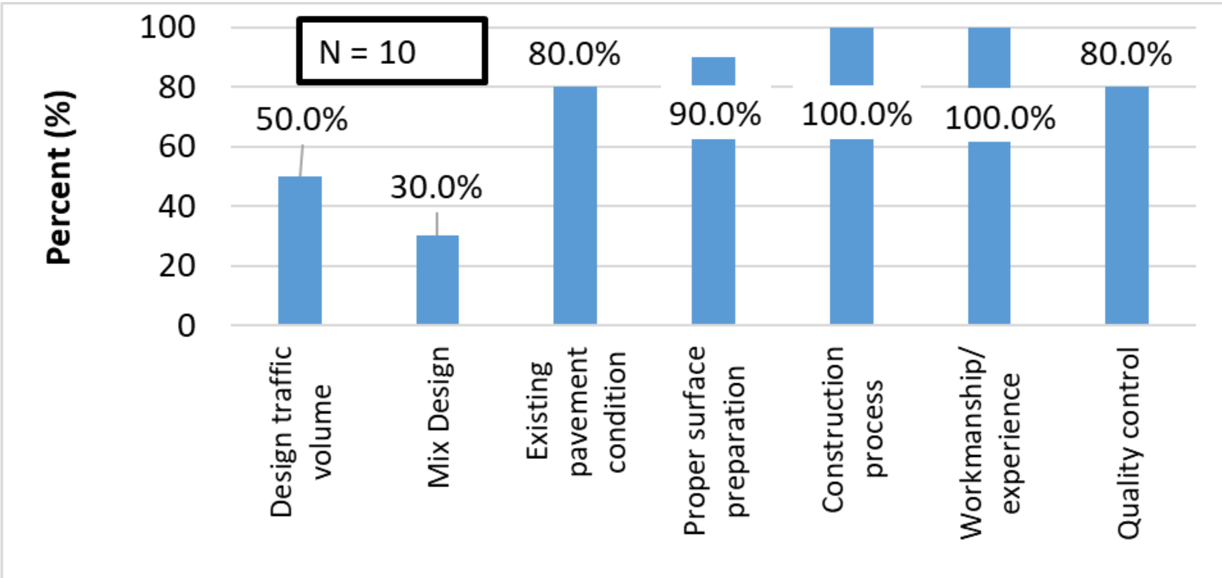
Figure 12 Question 6. Assuming the sand seal is placed on the right road at the right time, with proper construction, what is the expected treatment life?for sand seals?



Comments:

- Not used often enough to say for sure (Iowa)
- Meeting test specification (Arizona)

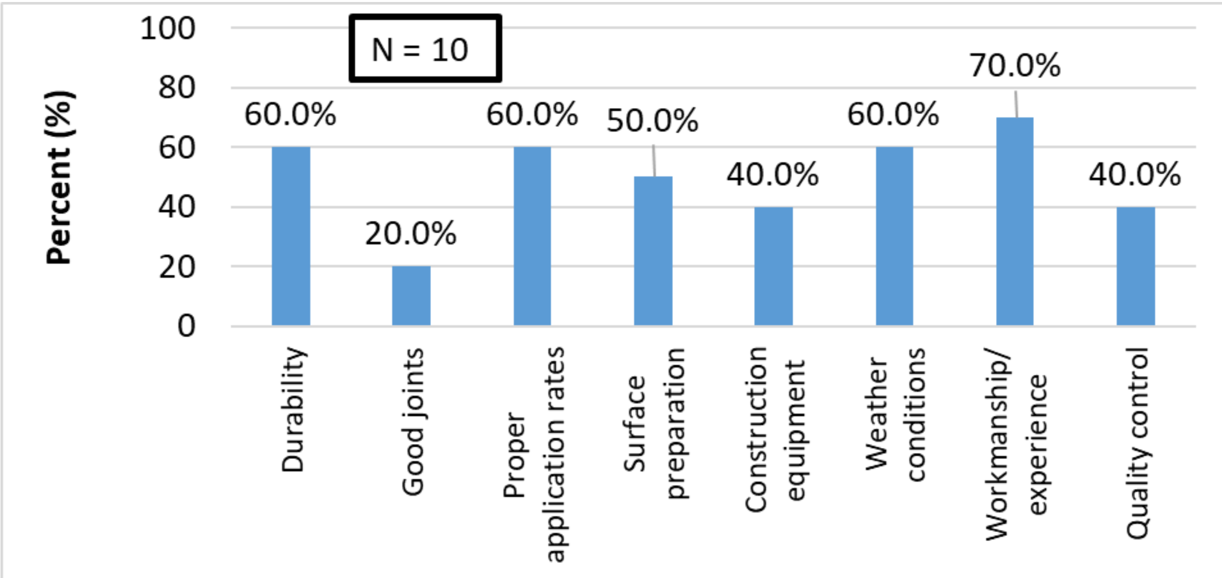
Figure 13 Question 7. What design or construction factors contribute to good short (less than one year) performance for sand seals (please check all that apply)?



Comments:

- Not used often enough to say for sure (Iowa)
- Meeting test specification (Arizona)

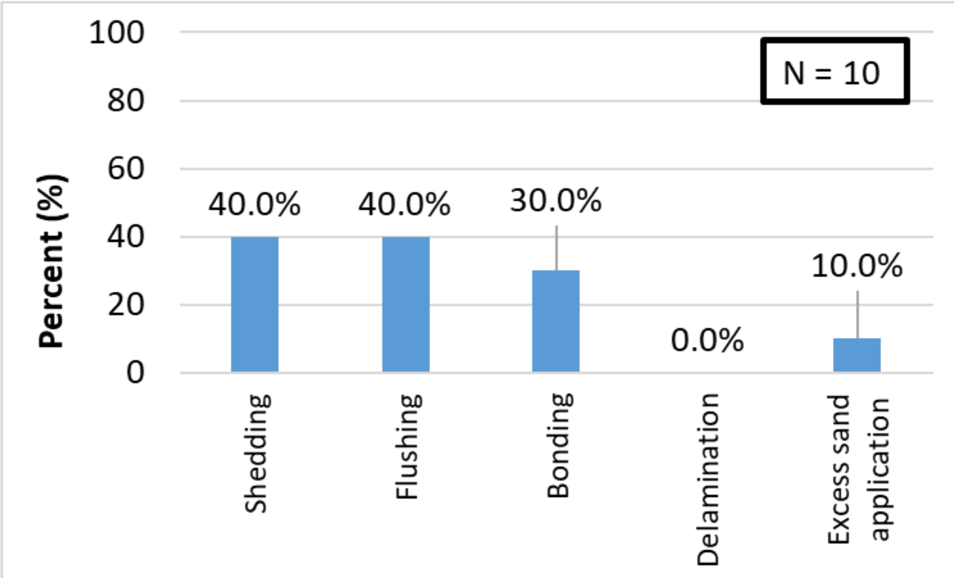
Figure 14 Question 8. What design or construction factors contribute to good long term (greater than 3 years) performance for sand seals (please check all that apply)?



Comments:

- Plow damage (New Hampshire)
- Not used often enough to say for sure (Iowa)
- Meeting specification (Arizona)
- Getting traffic paint to stick (South Dakota)

Figure 15 Question 9. What challenges have you faced with the construction of sand seals (please check all that apply)?



Comments:

- Plow damage (New Hampshire)
- Not used often enough to say for sure (Iowa)
- Traffic was released too early once and some of the emulsion got flung onto vehicles. On another project the crack sealing applied prior to the seal was not recessed (humped) and got pulled out by large aircraft traffic (Alaska)

Figure 16 Question 10. Which of these problems, if any, have you had with sand seals once they have been constructed?

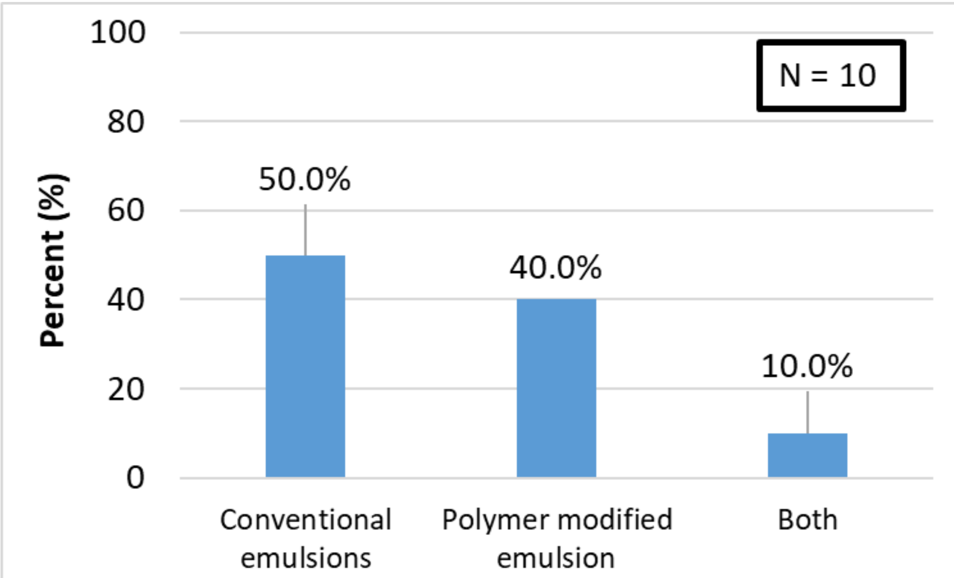
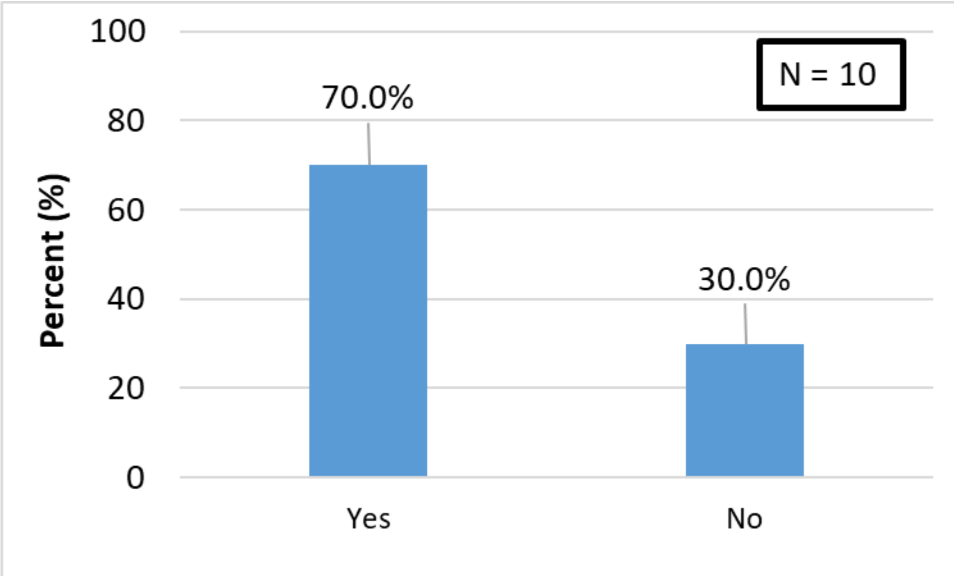


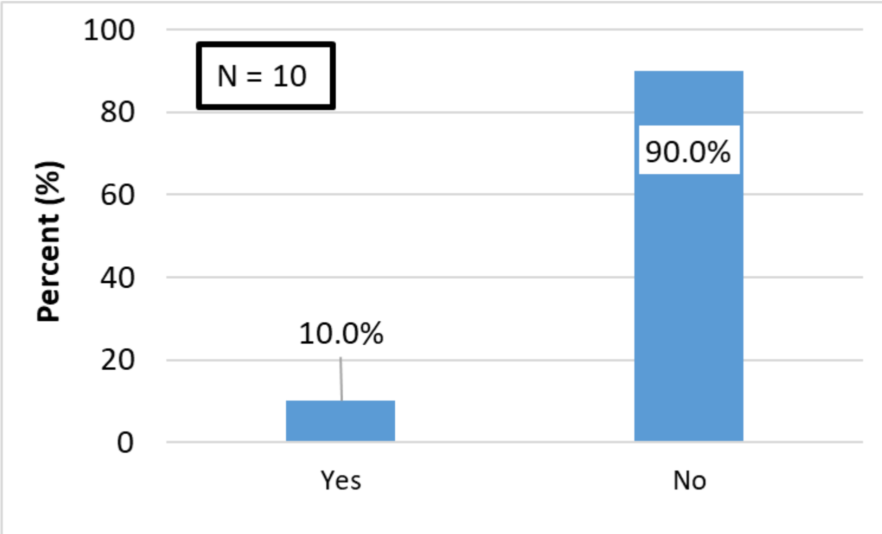
Figure 17 Question 11. For sand seals, do you routinely use conventional and/or polymer modified asphalt emulsion?



Comments:

- 100% of the aggregate shall be 100% crushed ledge. Percent wear not to exceed 35% (AASHTO T-96). Flakiness not to exceed 35 (FLHT 508). Aggregate to be preheated (200 degrees F to 300 degrees F) and precoated (0.4% to 0.8%) with PG 58-28 or PG 64-28 for asphalt rubber seals. There are also gradation requirements. (New Hampshire)
- Source approval, including bed control within the quarry (Iowa)
- Meeting gradation and free of deleterious materials or foreign substances (Arizona)
- Type and gradation requirements in specifications unless otherwise shown on the plans. For final surfaces, unless otherwise shown on the plans, furnish aggregate with a surface aggregate classification of "B" or better. Provide aggregates from sources listed in the Department's Bituminous Rated Source Quality Catalog (BRSQC). Use material not listed or not meeting the requirements of the BRSQC only when tested by the Engineer and approved before use. Allow 30 calendar days for testing of material from such sources. (Texas)
- P3/8in = 100%; P#40 = 0-60%; P#200 = 0-20.0%; plasticity index = 12 max (South Dakota)
- Taconite (Alaska)

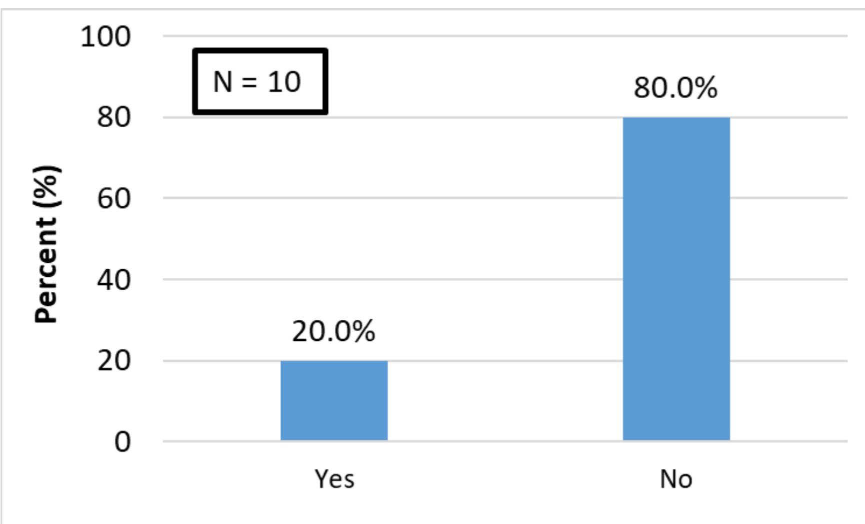
Figure 18 Question 12. For sand seals, do you have any specific restrictions or guidance for the type or source of aggregate used?



Comments:

- Rate of application/applications if more than one (Arizona)

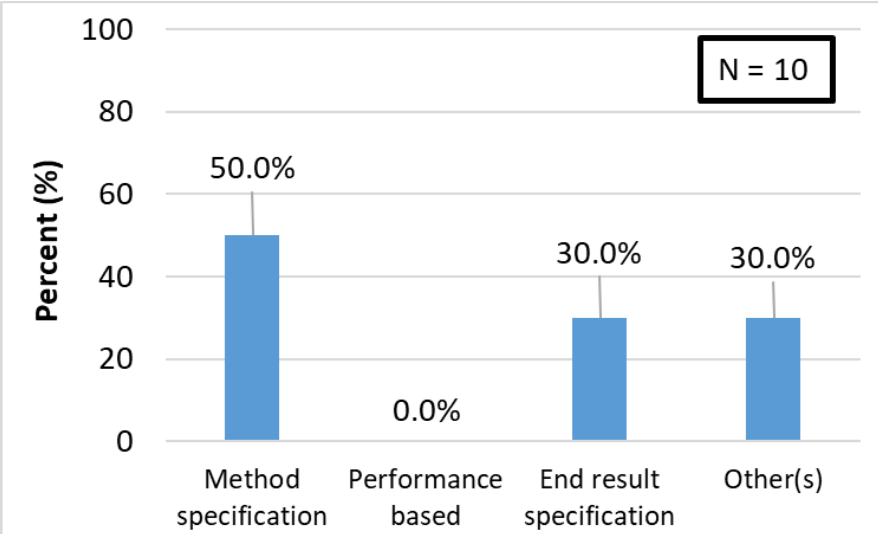
Figure 19 Question 13. For sand seals, do you follow a specific procedure for the design of sand seals? If yes, what procedure do you use?



Comments:

- ASTM E1911 "Standard Test Method for Measuring Surface Frictional Properties Using the Dynamic Friction Tester" (Alaska)

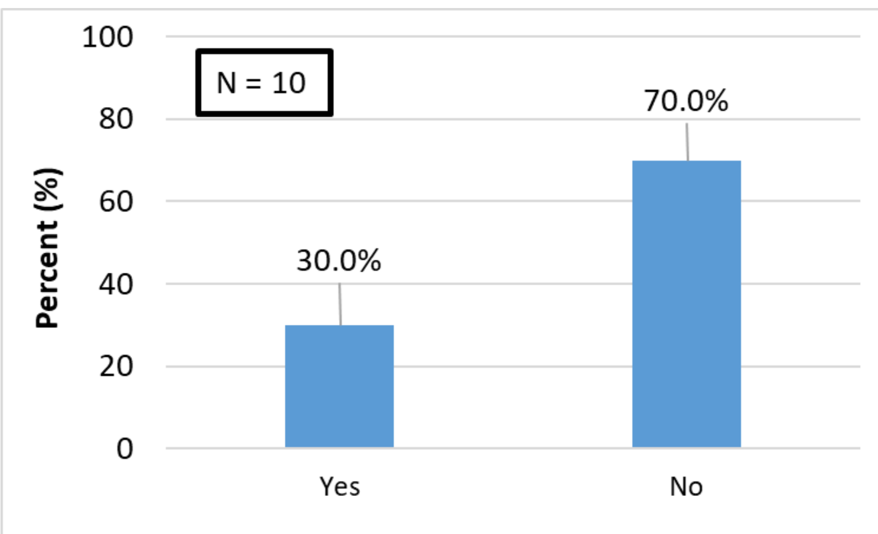
Figure 20 Question 14. For sand seals, do you have a quality assurance field tests that relates to the performance of this treatment? If yes, what tests?



Comments:

- Plan note for emulsion and sand rates, sand has a gradation spec, emulsion is tested (South Dakota)
- Done in house, visual inspection (Deleware)

Figure 21 Question 15. What type of specification do you use for sand seals?



Comments:

- We do not have a statewide sand seal spec. It may/may not have been used in localized areas throughout the state, but I have not seen it. You may find a OTU (one time use) in our historical specs. The scrub seal is the closest that we currently have. (Texas)

Figure 22 Question 16. Does your agency have existing construction guide specifications for sand seals?

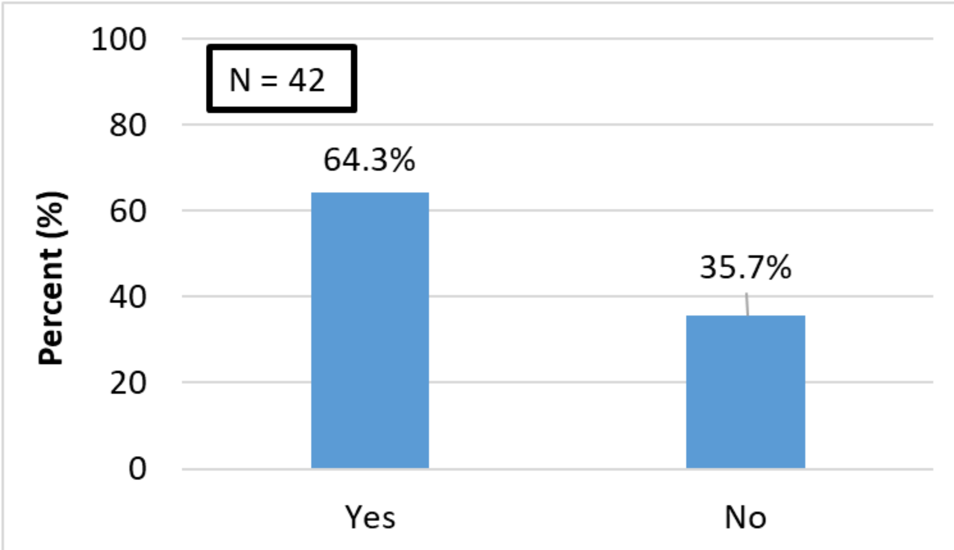
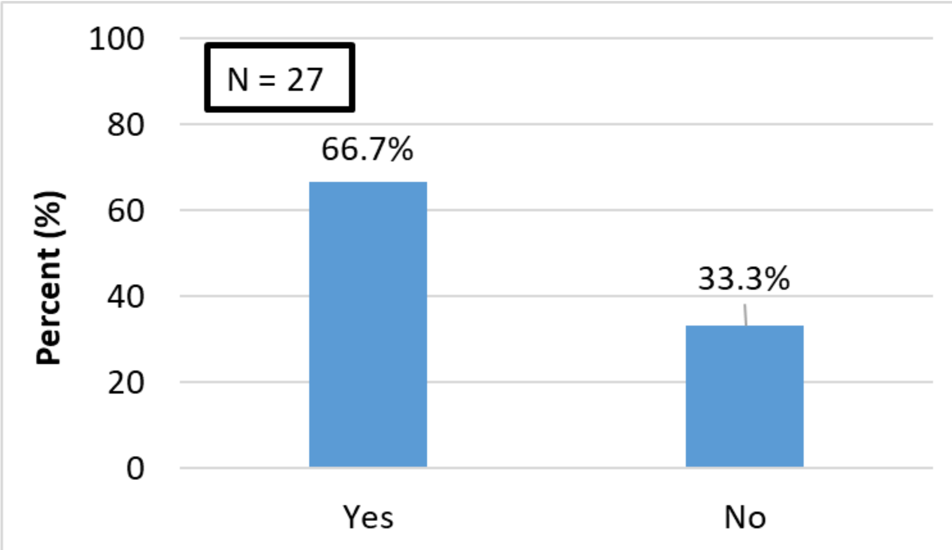


Figure 23 Question 17. Has your agency ever placed an Ultra-Thin Bonded Wearing Course (UTBWC) per the definition provided in AASHTO MP 44?

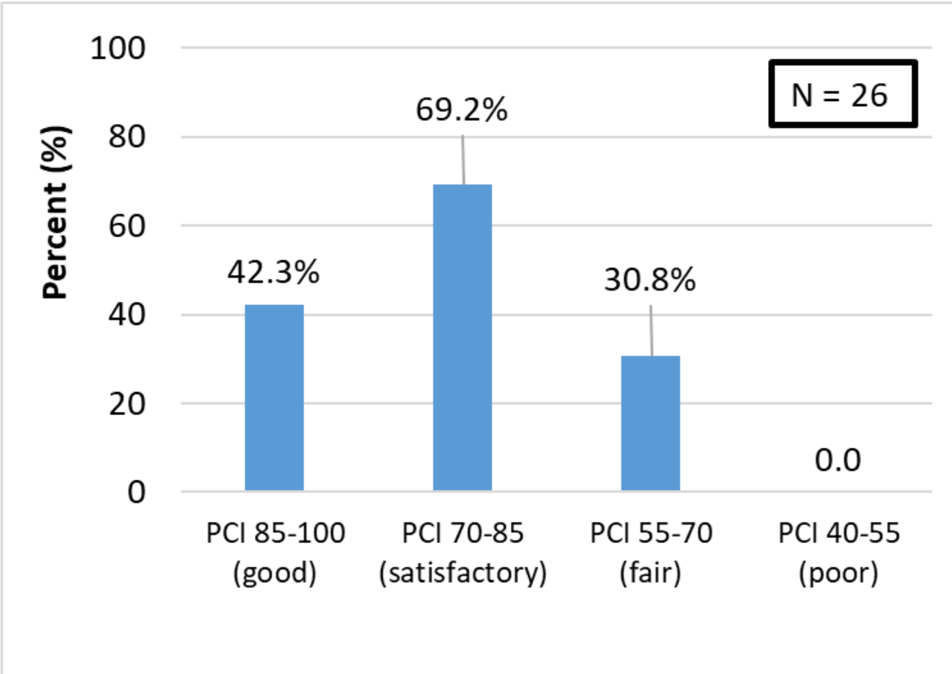
[note from April 9, 2023: MP 44 is now M 346]



Comments:

- Our agency has had 28 UTBWC projects in the last 6 years. Most of our Districts prefer to use SMA or standard WMA for mill and overlay projects. For overlaying concrete pavement, most Districts prefer using 1.5 or 2 inches of 9.5 or 12.5 wearing course on 2.5 inches of 19 mm binder course as specified in our pavement preservation guidelines. For asphalt surfaced pavements, Districts prefer to mill and overlay with 9.5 mm or 12.5 mm SMA or WMA. (Pennsylvania)
- Issues with snow/ice removal in the trial section so no additional projects constructed after that (Iowa)
- Our agency just started to use the UTBWC this year (Arizona)
- We have placed dense grade UTBWC (Nebraska)
- We typically do between 3-5 per year. We call our UTBWC a Paver Placed Surface Seal (PPSS) (Michigan)
- Some regions in our state have no confidence in them to last (New York)
- More expensive than chip seal, don't have contractor experience (Washington)

Figure 24 Question 18. Does your agency regularly use UTBWCs?



Comments:

- Some repairs made to the existing surface then with an overlay of UTBWC (Arizona)
- Our agency does not use PCI (Nevada)
- We have used UTBWC to seal PCC with ASR (Nebraska)
- Distress of candidate pavements should be limited to: 1. Low severity cracking, or raveling; 2. Infrequent corrugations, settlements, heaves or slippage cracks; 3. Medium severity rutting. (Pennsylvania)
- This will depend on the individual district policy, we have 25 districts. Overall, the pavement surface needs to be in good condition. (Texas)
- We are required to have a Condition Rating Survey (CRS) above 5.5 on Interstates and 5.0 off interstate. (Illinois)
- Selection is distress dependent. (Massachusetts)

Figure 25 Question 19. What is the pavement's existing surface condition for UTBWCs to be considered good treatment candidates per ASTM D6433?

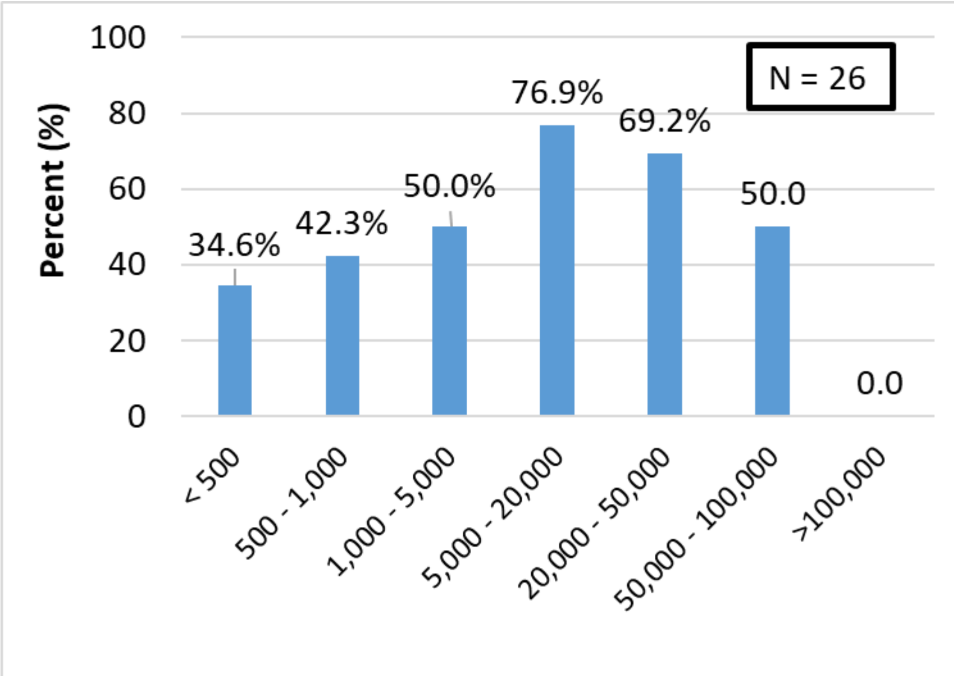


Figure 26 Question 20. What traffic levels (AADTT in each direction) are considered appropriate for UTBWC?

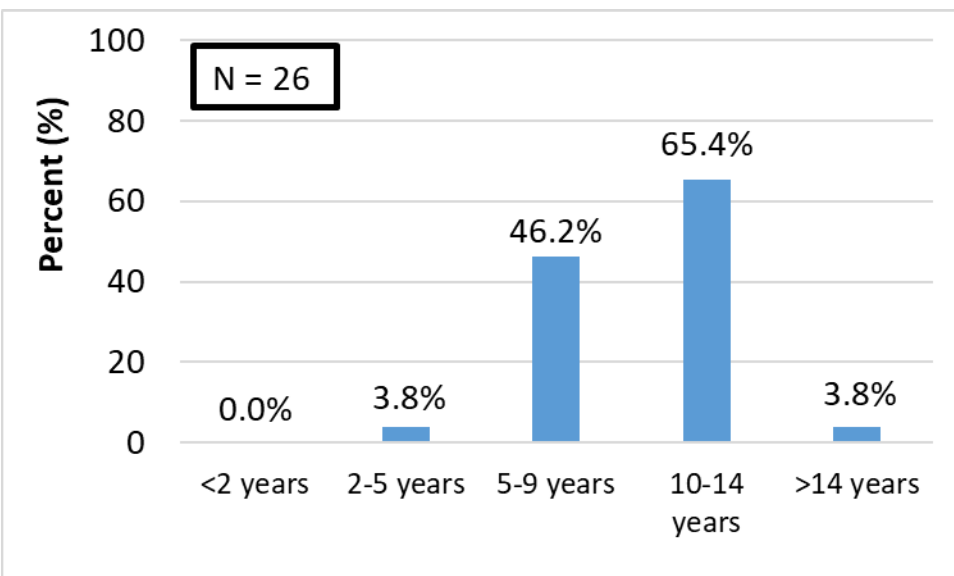
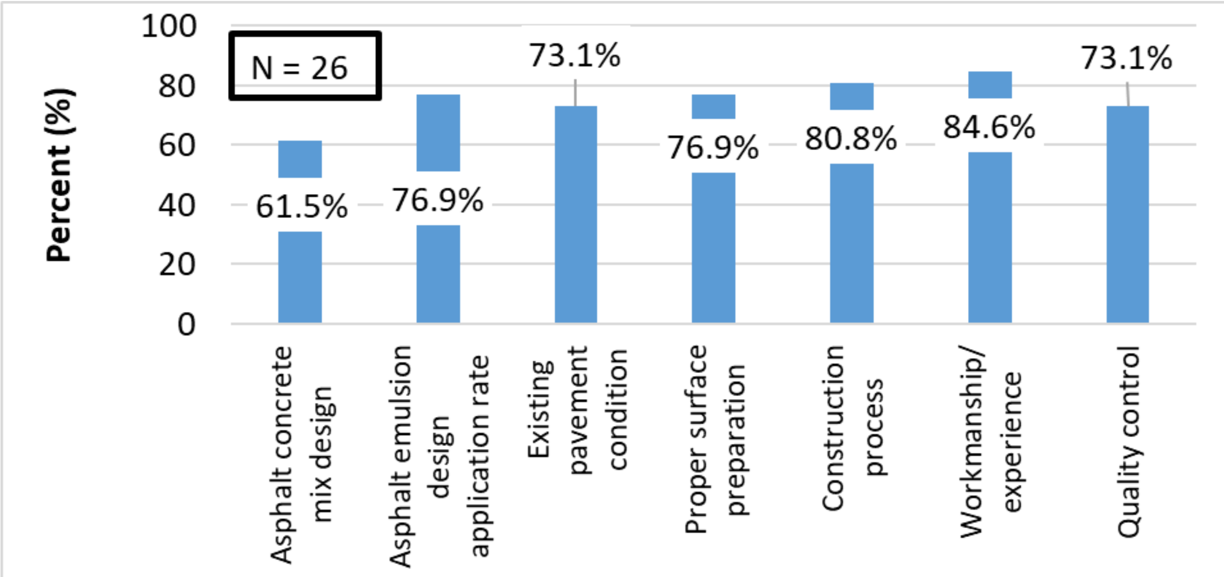


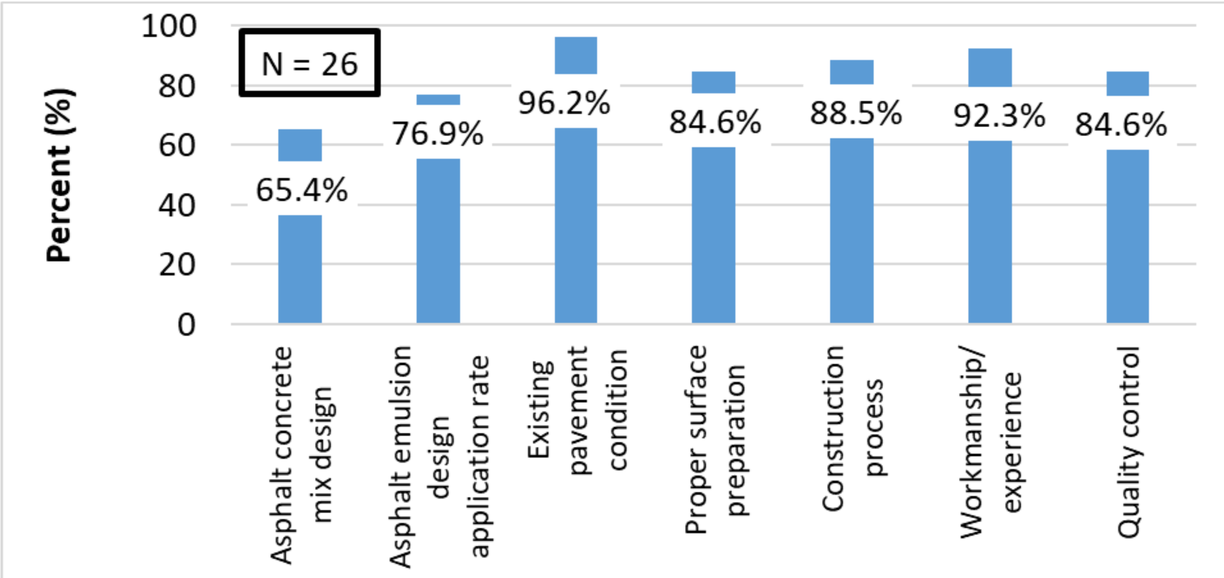
Figure 27 Question 21. Assuming the UTBWC is placed on the right road at the right time, with proper construction, what is the expected treatment life?



Comments:

- Our agency expects a service life of 8-10 years from an UTBWC. UTBWC treatments are not used for sort term applications due to cost. (Pennsylvania)
- Ambient and pavement surface conditions, weather (wet surface vs dry surface), inspection and inspector experience. (California)
- Underlying PCC transverse joints reflect quickly, getting those sealed in Year 3 is important (Nebraska)
- Placing in the appropriate temperature (greater than 50F) (Massachusetts)

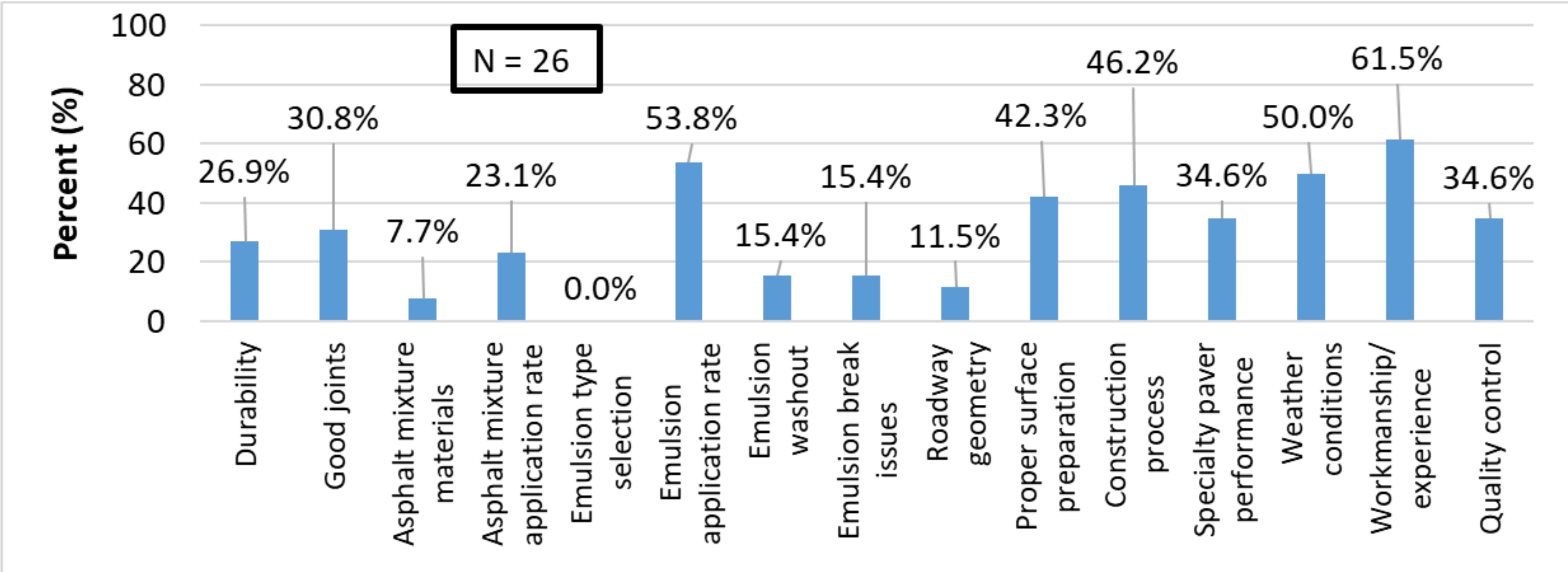
Figure 28 Question 22. What design or construction factors contribute to good short (less than three years) performance for UTBWCs (please check all that apply)?



Comments:

- One of the biggest determinants is the continuity of paving. Stops and starts affect final product and its performance, durability (California)

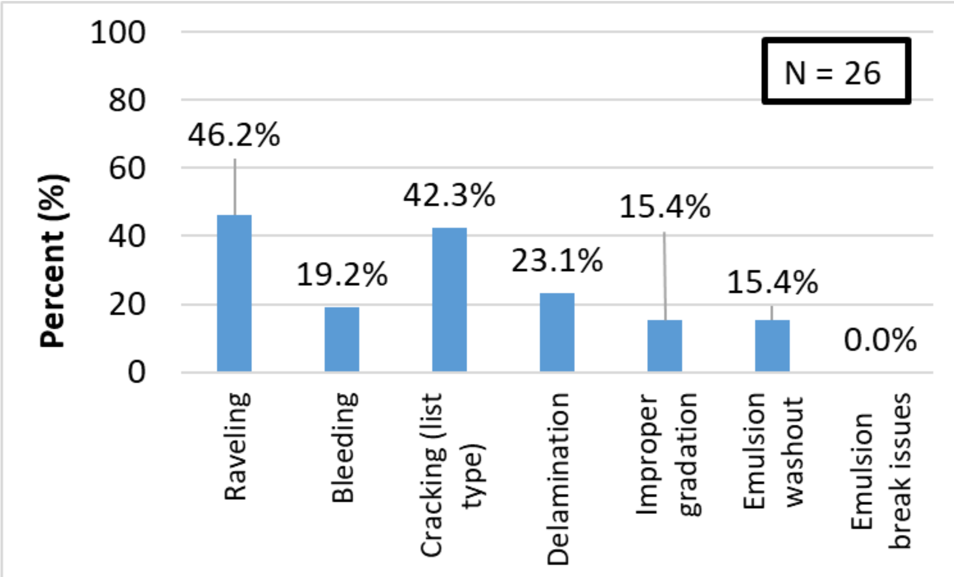
Figure 29 Question 23. What design or construction factors contribute to good long term (greater than 7 years) performance for UTBWCs (please check all that apply)?



Comments:

- Limited number of contractors with access to spray pavers (Maryland, Minnesota)
- Our biggest challenge is getting a decent price on the work. We only have one contractor in the state with a spray-bar equipped paver and have no support from our Asphalt Industry in buying the pavers. This requires the use of contractors from out of state. (Michigan)
- Continuous paver break downs, insufficient trucking, cold material (Pennsylvania)
- Lack of spray pavers/lack of contractors/lost out to thin lift HMA in our program (Tennessee)

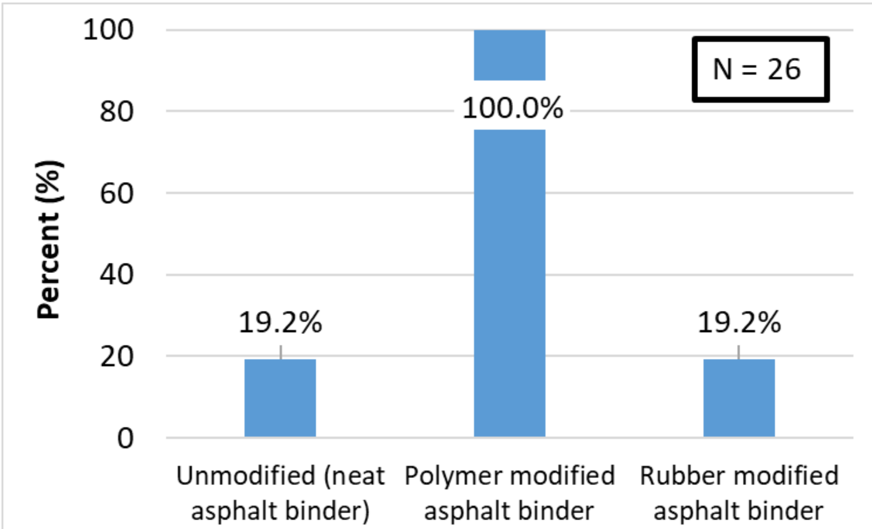
Figure 30 Question 24. What challenges have you faced with the construction of UTBWCs (please check all that apply)?



Comments:

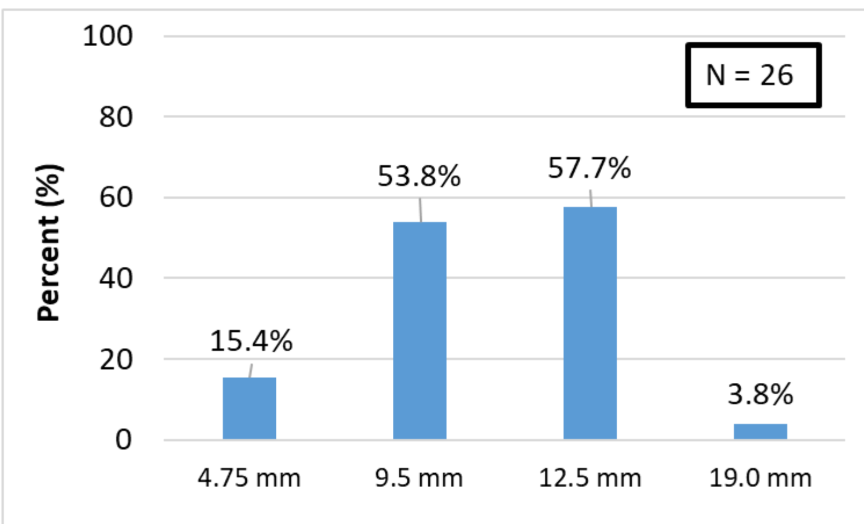
- Cracking type: reflective cracking (Kansas, Washington, New York, Pennsylvania, Missouri, Maine, Illinois – note, project was not good candidate), thermal cracking (Pennsylvania), block cracking after 10 years of life performance (Rhode Island), top down cracking (New York)
- Icing issues after winter precipitation events. (Maryland)
- During wet-freezing conditions, the UTBWC will experience icing issues not experienced by traditional asphalt mixtures. UTBWC mat require the use of additional deicing agents. (Missouri)
- No data due to being new and just starting to use UTBWC (Arizona)
- At one time, we allowed SAC A and SAC B (hard and soft aggregates) material to be used as long as >50% was SAC A. The SAC A tended to crush the SAC B over time and close off the structure. We now have language to ensure SAC B aggregate will not crush when blending. This has not been an issue since. (Texas)
- We have great performance with ours, I wish we could do more (Michigan)
- Cold weather paving led to raveling (Massachusetts)

Figure 31 Question 25. Which of these problems, if any, have you had with UTBWCs once they have been constructed?



Comment: PG 58H-34 (Minnesota)

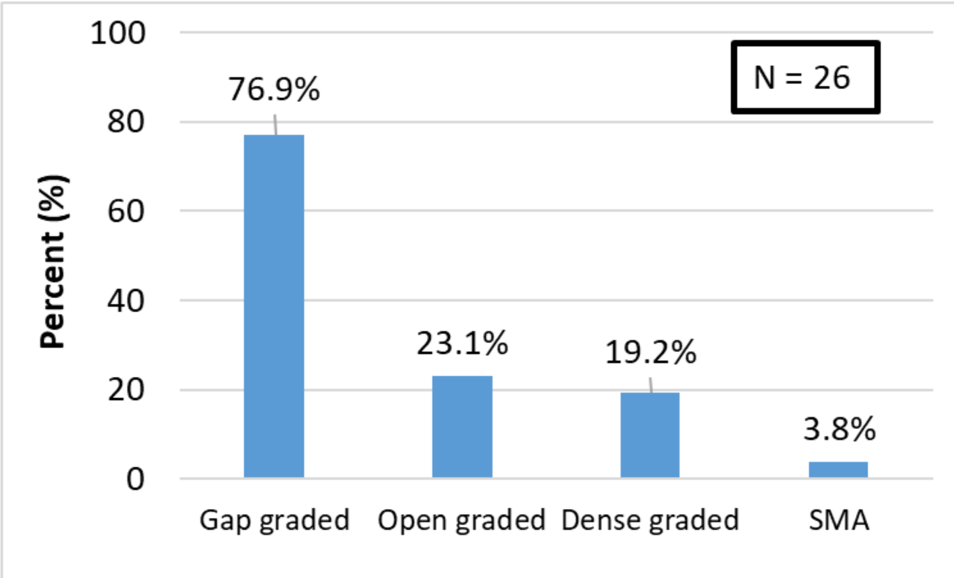
Figure 32 Question 26. For UTBWCs, what type of asphalt binder do you use in the asphalt mixture?



Comments:

- 6.3 mm (Pennsylvania)
- ¼in limestone chips (Nebraska)
- We have multiple grades within our specification. We have 2 grades for thin bonded PFC (OGFC), and 3 grades for thin bonded friction course. (Texas)

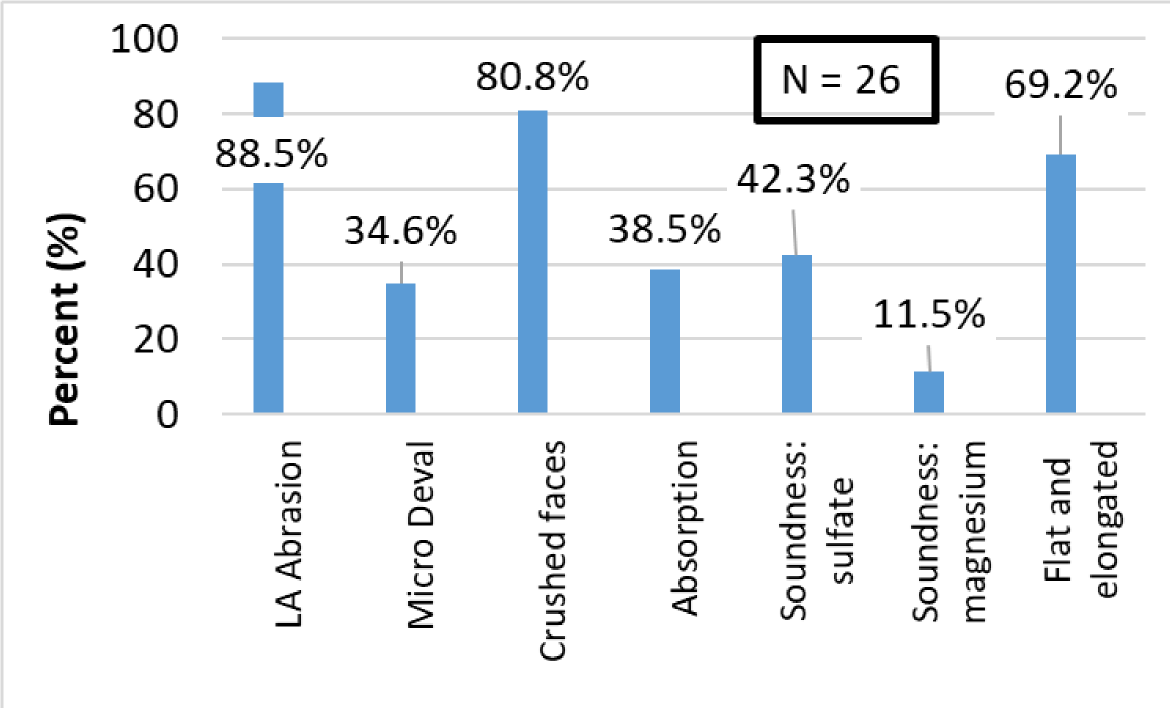
Figure 33 Question 27. For UTBWCs, what size of nominal maximum aggregate size do you use in the asphalt mixture?



Comments:

- Rubberized Hot Mix Asphalt (RHMA), both gap and open graded (California)
- A smaller gap graded gradation is used where icing on the road surface is a concern (Minnesota)

Figure 34 Question 28. For UTBWCs, what type of gradation do you use in the asphalt mixture (please check all that apply)?



Comments:

- Additional tests for coarse aggregate
  - Soundness, AASHTO T 103 (Kansas)
  - Skid resistance level (Pennsylvania)
  - Coarse aggregate angularity (Nebraska)
- Additional tests for fine aggregate
  - Sand equivalent, AASHTO T 176 (Minnesota, Texas, Connecticut, California, Arizona, Pennsylvania)
  - Methylene blue, AASHTO T 330 (Texas, Pennsylvania)
  - Uncompacted void content, AASHTO T 304 (Minnesota, Nebraska, California, Arizona, Pennsylvania)
  - Insoluble Residue in Carbonate Aggregates (Arizona, Wyoming)
  - Moisture content, AASHTO T 255 (California)
  - Film Thickness (Arizona)
  - Liquid limit (Nevada)
  - Plasticity index (Nevada)

Figure 35 Question 29. For UTBWCs, which types of aggregate quality tests do you specify in design (please check all that apply)?

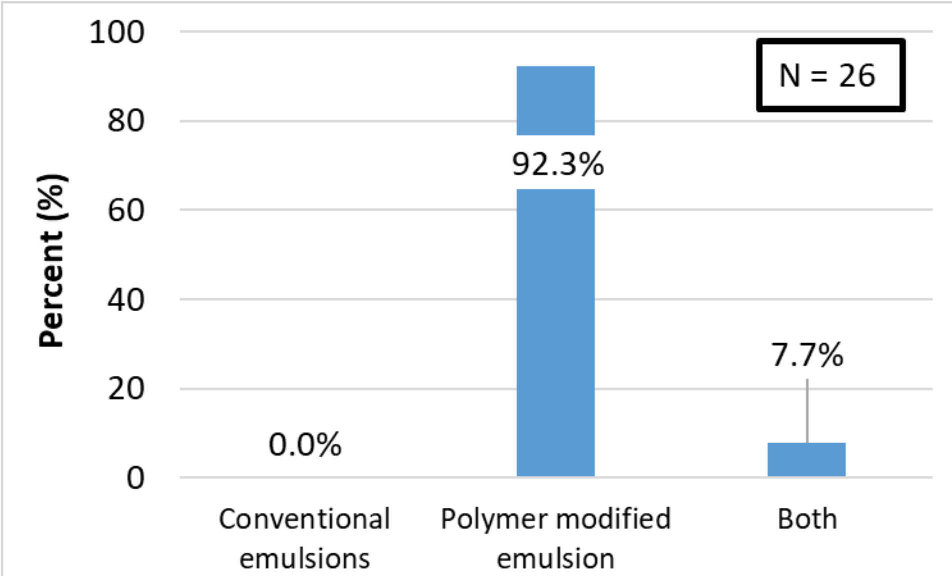
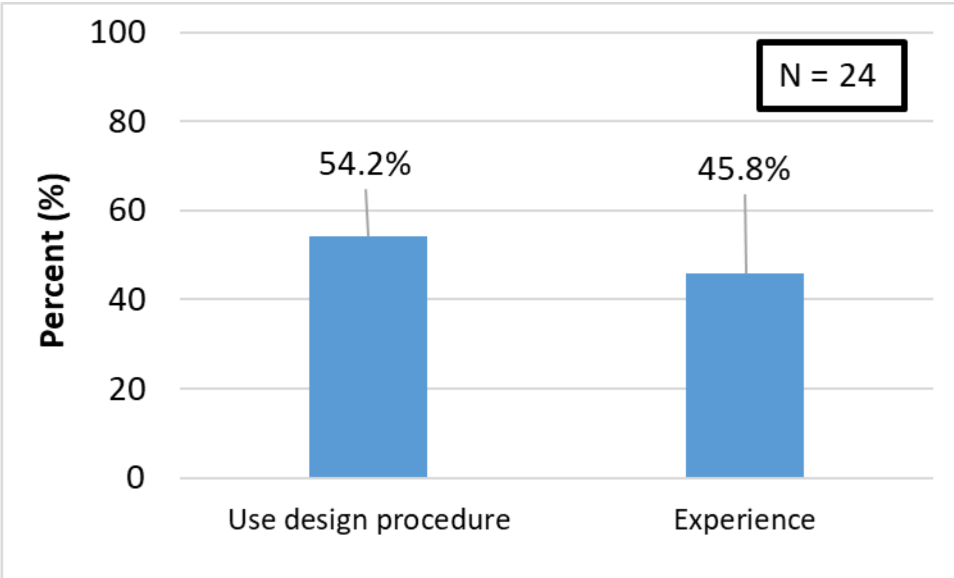


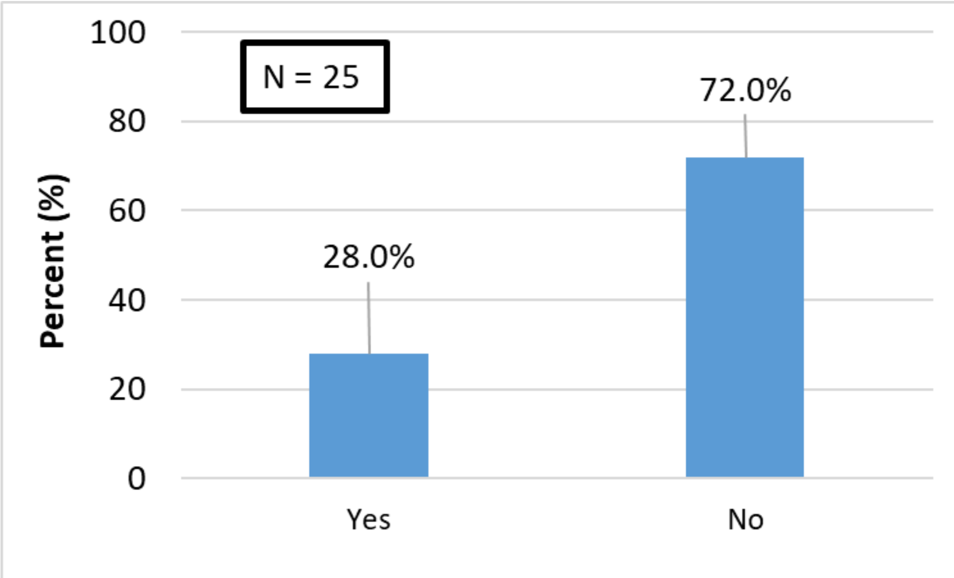
Figure 36 Question 30. For UTBWCs, do you routinely use conventional and/or polymer modified asphalt emulsion?



Comments:

- Application rates are determined by NMAS of the mix. 6.3 mm placed at 45 to 65 lb/yd2. 9.5 mm placed at 55 to 80 lb/yd2. 12.5 mm placed at 60 to 85 lb/yd2 (Pennsylvania)
- Spread rate per inch thickness, 100 lb/yd2 adjusted in the field meeting thickness requirement (Arizona)
- Application rates vary depending on the surface condition (California)
- Emulsion membrane ranges are provided in our specification. Can deviate from these based on conditions if needed. HMA mixture rates should be dictated by a desired yield and mat thickness to meet a desired in place air void (we have a maximum for this mix to ensure proper drainage) (Texas)
- Target 65-75 lbs/yd2 (Minnesota)
- 0.20 gal/yd2 (Michigan, Nebraska)
- Mix design with preliminary testing (New York)
- PCC Pavement: 0.12 to 0.16 g/yd2; Dense, Compacted, New/Existing Asphalt Pavement or Milled Surface: 0.17 to 0.21 g/yd2; Open Textured, Dry, Aged, or Oxidized Asphalt Surface 0.20 to 0.26: g/yd2 (Utah)
- Standard Specifications: Section 413.30.5.4.2 - Application Rate of Membrane (Missouri)

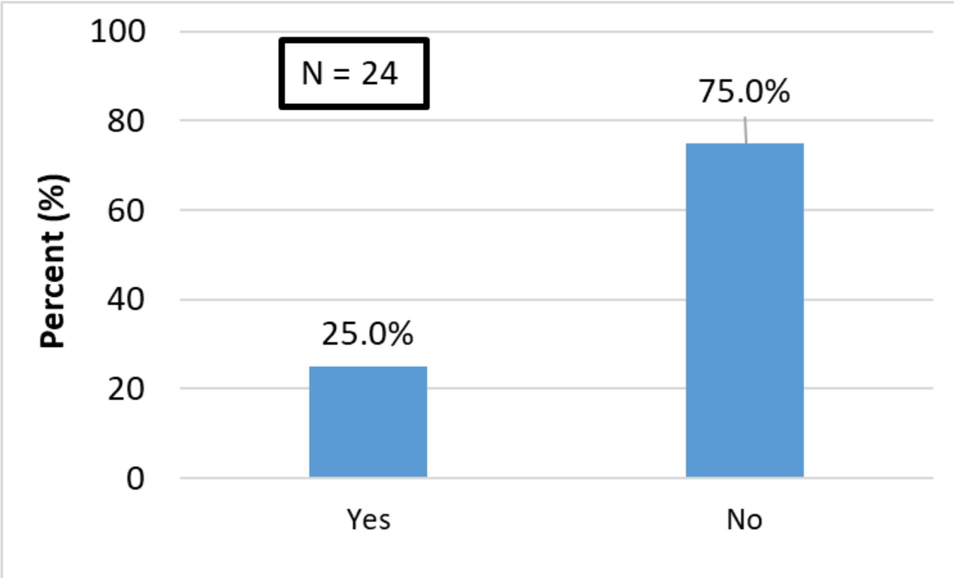
Figure 37 Question 31. For UTBWCs: how do you determine the application rates for the asphalt mixture?



Comments:

- Some projects use a stick rule or asphalt poker and also check the paver monitors for depths (Pennsylvania)
- Self priming paver built for applying UTBWC using material transfer vehicle (Arizona)
- Inspection of spray nozzles and application rate before the start of paving (California)
- Use material transfer vehicle (Nevada)
- Intelligent placement/compaction technologies (e.g., Trimble, Topcon) placed on the spray paver and rollers and used to continuously track/collect real-time GPS information related to equipment speed, material temperature, and numbers of passes made. Data is processed using Veta software by the engineer and compared to the specification requirements for minimum number of passes in the allotted compaction window. Analysis is used to determine an adjustment (10% maximum penalty) to the eligible quantity of UTBWC material to be paid to the contractor. (Connecticut)

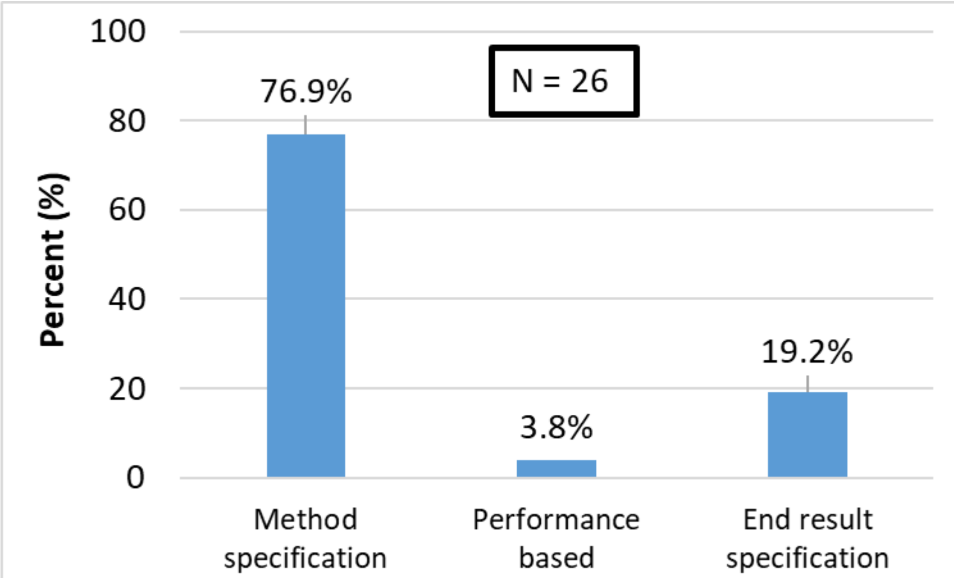
Figure 38 Question 32. During construction of UTBWC, do you use any specific technology to manage and track any construction parameter?



Comments:

- Emulsion and mix tests (California)
- IRI smoothness (Nevada)
- We perform a permeability test to ensure mixtures are not overly dense and still allow water drainage (this only applies to our thin PFC. Our thin friction course does not have this limitation). (Texas)
- QC/QA field lab monitoring (Kansas)
- Standard Specifications: Section 413.30.6 - Quality Control and Section 413.30.7 - Quality Assurance (Missouri)

Figure 39 Question 33. For UTBWCs, do you have a quality assurance field test that relates the performance of this treatment?



Comments:

- QC/QA type specification (Massachusetts, California)
- QC/QA for asphalt content, film thickness, gradation (Kansas)

Figure 40 Question 34. What type of specification do you use for UTBWCs?

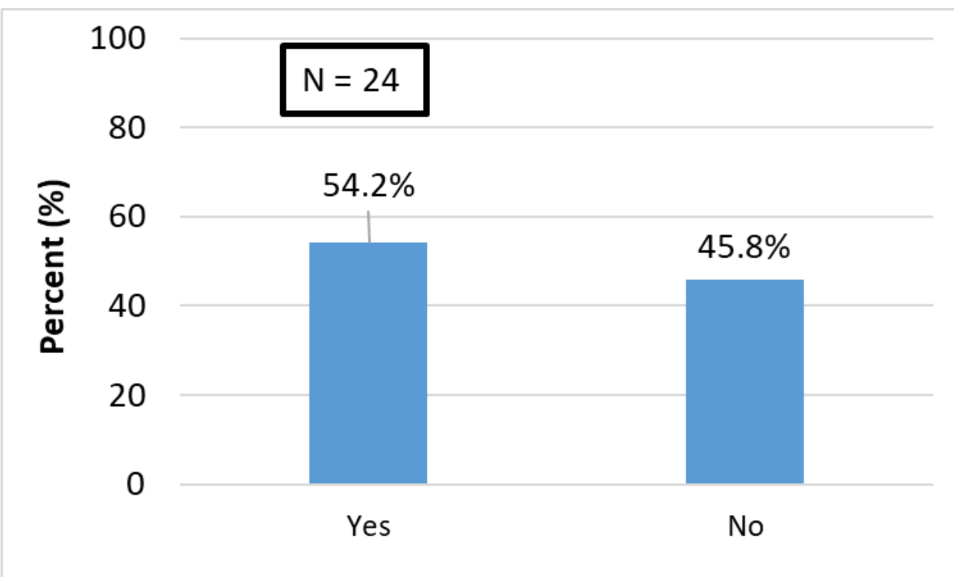


Figure 41 Question 35. Does your agency have existing construction guide specifications for UTBWC?

Part II – Proposed Construction Guide Specification for Sand Seal

Part III – Proposed Construction Guide Specification for UTBWC

Part IV – Proposed Quality Assurance Guide for Sand Seal

Part V – Proposed Quality Assurance Guide for UTBWC